INTERNATIONAL JOURNAL

of

COMPUTERS, COMMUNICATIONS & CONTROL

With Emphasis on the Integration of Three Technologies

IJCCC
A Quarterly Journal

Year: 2008 Volume: III Number: 1 (March)

Agora University Editing House

CCC Publications

Licensed partner: EBSCO Publishing

www.journal.univagora.ro

Publisher & Editorial Office

CCC Publications, Agora University
Piata Tineretului 8, Oradea, jud. Bihor, Romania, Zip Code 410526
Tel: +40 259 427 398, Fax: +40 259 434 925, E-mail: ccc@univagora.ro
Website: www.journal.univagora.ro
ISSN 1841-9836, E-ISSN 1841-9844

International Journal of Computers, Communications and Control (IJCCC) is published from 2006 and has 4 issues/year (March, June, September, December), print & online.

Founders of IJCCC: I. Dziţac, F.G. Filip and M.J. Manolescu (2006)

This publication is subsidized by:

1. Agora University
2. The Romanian Ministry of Education and Research / The National Authority for Scientific Research

CCC Publications, powered by Agora University Publishing House, currently publishes the "International Journal of Computers, Communications & Control" and its scope is to publish scientific literature (journals, books, monographs and conference proceedings) in the field of Computers, Communications and Control.

IJCCC is indexed and abstracted in a number of databases and services including:

1. Directory of Open Access Journals;
2. The Collection of Computer Science Bibliographies;
3. Open J-Gate;
4. FIZ KARLSRUHE's informatics portal;
5. EBSCO;
6. The Index of Information Systems Journals;
7. Urlich's Periodicals Directory,
8. SCIRUS;
9. e-Math for Africa;
10. Google Scholar, Google Academic.

Contents

International Journal of Computers, Communications & Control
Vol. III (2008), No. 1, pp. 6-20

Robust Fuzzy Sliding Mode Controller for Discrete Nonlinear Systems

Hafedh Abid, Mohamed Chtourou, Ahmed Toumi

Abstract: In this work we are interested to discrete robust fuzzy sliding mode control. The discrete SISO nonlinear uncertain system is presented by the Takgi-Sugeno type fuzzy model state. We recall the principle of the sliding mode control theory then we combine the fuzzy systems with the sliding mode control technique to compute at each sampling time the control law. The control law comports two terms: equivalent control law and switching control law which has a high frequency. The uncertainty is replaced by its upper bound. Inverted pendulum and mass spring dumper are used to check performance of the proposed fuzzy robust sliding mode control scheme.

Keywords: Nonlinear systems, Sliding mode, T-S fuzzy systems, Reaching law.

1 Introduction

Many of the industrial plants include nonlinearities or/and uncertainties. To reach the wanted performances, using the classical theories, nonlinearities must be identified to calculate the appropriate controller. The robust control theories is one of the techniques that permits to reach the desired performances in presence of external or/ and internal disturbances. In addition to the stability, the tracking problem must be solved independently of uncertainties. In the literature, many methods have been developed in continuous as well in discrete-time to solve the tracking problem for nonlinear systems. In the last decade many researches combine classical techniques with intelligent one, such as sliding mode with Neuronal systems or sliding mode with fuzzy systems [3][4], to benefit from the advantages of the two control techniques.

The sliding mode control (SMC) was originally developed for variable structure systems in continuous domain. Utkin [12] gives a thorough description of the sliding mode theory in continuous time. Also, Slotine and Li [16] describe in detail continuous sliding mode controllers.

At the end of the twentieth century, the research of discrete time SMC has been attracted more attention, such as [6],[8],[9],[10], as for the implementation of the controller on a digital computer requires a sampling time and the assumption of an infinite switching time does not hold any more.

The fuzzy systems have been combined with classical sliding mode control to provide robust stability to the fuzzy controller. The combination of the two control principles, is called fuzzy sliding mode control (FSMC), it provides an alternative to design a robust controller for nonlinear systems with uncertainties [15],[14]. Our contribution in this work consists in presenting a new robust fuzzy sliding mode controller based on the Takagi-Sugeno fuzzy state model for discrete nonlinear systems. This paper is organised as follow. In Section 2, we recall the discrete Takagi-Sugeno type fuzzy state model for nonlinear systems. Then, we describe the sufficient and necessary reaching conditions of sliding mode control for discrete nonlinear systems in the first part of the third section ten, a fuzzy sliding mode controller for discrete time of nonlinear systems is developed in the second part and tracking robust fuzzy sliding mode control law is described in the third part. The simulation results of two nonlinear systems show performances of the proposed FSMC in Section 4. Conclusions are drawn in the final section.

2 Problem Statement and Fuzzy Systems

2.1 Problem Statement

Consider a class of discrete nonlinear SISO systems described by the following equations:

$$\begin{cases} x_1(k+1) = x_2(k) \\ x_i(k+1) = x_{i+1}(k) \\ x_n(k+1) = f(X(k)) + g(X(k))u(k) \\ y(k) = CX(k) \end{cases} \tag{1}$$

where, C=$[1,0,...,0]$, $X(k) = \begin{bmatrix} x_1(k) & . & . & . & x_n(k) \end{bmatrix}^T \in R^n$ it is the state vector that is assumed to be observable.

We note that $f(X(k))$ and $g(X(k))$ represent two discrete bounded nonlinear functions of the nonlinear SISO systems . They can be obtained from the continuous form by the first order discretized system using Eulers approximation. In order for (1) to be controllable, it is required that $g(X(k)) \neq 0$. If both functions $f(X(k))$ and $g(X(k))$ in (1) are available for feedback, the feedback linearization control can be used to design a well-defined controller, which is usually given in the form:

$$u(k) = \frac{1}{g(X(k))}\left(-K^T E(k) - f(X(k)) + x_{nd}(k+1)\right) \tag{2}$$

where, the state vector $X(k)$and the desired state vector $X_d(k)$ are defined as:

$X(k) = \begin{bmatrix} x_1(k) & . & . & . & x_n(k) \end{bmatrix}^T \in R^n$;$X_d(k) = \begin{bmatrix} x_{1d}(k) & . & . & . & x_{nd}(k) \end{bmatrix}^T \in R^n$

$E(k)$ represents the state tracking error, it is defined as: $E(k) = X(k) - X_d(k)$, the vector $K(k) = \begin{bmatrix} k_n & k_{n-1} & . & . & k_1 \end{bmatrix}^T \in R^n$ will be chosen such that all roots of the following polynomial $h(s) = s^n + k_1 s^{n-1} + ... + k_n$ are situated inside the unit complex disc. In general case, the functions $f(X(k))$ and $g(X(k))$ are badly known nonlinear functions so, the control law (2) cannot be implanted. To overcome this difficulty, many approaches are used such as adaptive control, linearization around operating points, fuzzy control… etc.

2.2 Discrete Takagi-Sugeno type Fuzzy Systems

The advantage of the T-S type fuzzy models is that their description permits the utilization of the state representation, and by consequence to exploit the maximum of the potential relative to this representation. The Takagi-Sugeno (T-S) type fuzzy model can be viewed as a natural expansion of piecewise linear partition for nonlinear systems. The nonlinear system is represented as a collection of the fuzzy IF-THEN rules, where each rule describes the local dynamics by a linear system model. The general fuzzy model is achieved by fuzzy amalgamation of the linear systems models [1][2]. The i^{th} rule of the discrete fuzzy model has the following form:
i^{th} plant rule :

$$IF\ Z_1 is\ \mu_{i1} and...and\ Z_n\ is\ \mu_{in}\ THEN\ X(k+1) = (A_{di} + \Delta A_{di})X(k) + (B_{di} + \Delta B_{di})u(k) \tag{3}$$

where $\{\mu_{ij}\}$ are the fuzzy sets, $A_{di} \in R^{nxn}$ and $B_{di} \in R^{nxm}$ are recpectively the i^{th} state matrix and the input matrix, c is the number of the *IF-THEN* fuzzy rules; $u(k)$ is the input vector, $Z(k) = \begin{bmatrix} Z_1(k) & . & . & . & Z_n(k) \end{bmatrix}$ are the premise variables they represent some measurable system variables, they can be chosen as a state variables. For each rule R_i is attributed a weight $w_i(z(k))$ which depends on the grade of the membership function of the premise variables $z_j(k)$ in fuzzy sets μ_{ij} :

$w_i(Z(k)) = \prod_{j=1}^{n} \mu_{ij}(Z_j(k))\,;\, w_i(Z(k)) \succ 0$;for $i = 1,...,c$; $\sum_{i=1}^{c} w_i(Z(k)) \succ 0.$
where, $\mu_{ij}(Z_j(k))$ is the grade of the membership function of $Z_j(k)$ to the fuzzy set μ_{ij}.
The discrete Takagi-Sugeno type fuzzy model is inferred as follows:

$$X(k+1) = \frac{\sum_{i=1}^{c} w_i(Z(k))\left((A_{di}+\Delta A_{di})X(k) + (B_{di}+\Delta B_{di})u(k)\right)}{\sum_{i=1}^{c} w_i(Z(k))} \tag{4}$$

The normalized weight is defined as which is presented as follow:

$h_i(Z(k)) = \frac{w_i(Z(k))}{\sum_{i=1}^{c} w_i(Z(k))};\ 0 \prec h_i(Z(k)) \prec 1;\ i = 1,...,c; \sum_{i=1}^{c} h_i(Z(k)) = 1.$

The output of the discrete Takagi-Sugeno type fuzzy model for the uncertain nonlinear systems can be inferred as:

$$\begin{cases} X(k+1) = \sum_{i=1}^{c} h_i(Z(k))\left((A_{di}+\Delta A_{di})X(k) + (B_{di}+\Delta B_{di})u(k)\right) \\ y(k) = \sum_{i=1}^{c} h_i(Z(k))C_i X(k) \end{cases} \tag{5}$$

where $C_i = [1, 0, 0, \ldots, 0]$.
It is required that all $B_{di}(k)$ are different from zero to assure the controllability of (5).

3 Sliding mode control law and reaching conditions

Sliding mode control, first appeared in the Soviet literature, it has been widely recognized as a potential approach to uncertain dynamical non-linear systems that are subject to external disturbances and parameter variations [12].

In sliding mode control (SMC), the control action forces the system trajectories to cross a manifold of the state space which is called the sliding surface designated by the designers [12]. The system trajectories are then constrained to the sliding surface for all subsequent time via the use of high speed switching controls. The most significant advantage of the sliding mode is robustness against changes in system parameters or disturbances. The major disadvantage associated to the sliding mode control is the chattering phenomena, because it can excite undesirable high frequency dynamics.

The sliding mode control comports three modes, namely, the reaching mode (RM), sliding mode (SM), and steady-state mode (SS).

Let us describe the discrete sliding mode control however, only a few researches are interested by discrete-time systems. A discrete version of SMC has a big importance when the implementation of the control is realized by numerical components which need a sampling period to compute the appropriate controller. It must be pointed out that the discrete version of SMC cannot be obtained from their continuous counterpart by means of simple equivalence. Among the first which are interested by SMC problem and used an equivalent form of the continuous reaching condition to give a discrete reaching condition are Dote and Hoft [5].

$$[S(k+1) - S(k)]\,S(k) \prec 0 \tag{6}$$

Milosavljevic [6] recommended the concept of the quasi-sliding mode and signalled hat condition (6) is not sufficient for a discrete sliding mode control.

Sarpturk, et al. [7], used the following reaching condition.

$$|S(k+1)| \prec |S(k)| \tag{7}$$

Furuta [8] used the equivalent form of a Lyapunov-type of continuous reaching condition to give the discrete version.

$$V(k+1) - V(k) \prec 0 \quad with\, V(k) = \frac{1}{2}(S(k))^2 \tag{8}$$

Weibing Gao et al. [9] pointed out that all these forms of reaching conditions are incomplete for a satisfactory characterization of a discrete-time sliding mode. He suggests that the state trajectory of a discrete sliding mode control system must have some attributes which form the basis of the discrete sliding mode control, for more information see [9]:

3.1 Discrete fuzzy sliding mode control law

For a discrete SMC the following reaching law has been chosen:

$$S(k+1) = S(k) - qTS(k) - \varepsilon T sgn(S(k)), with 1 - qT \succ 0,\ \varepsilon \succ 0, q \succ 0. \tag{9}$$

The sliding surface is defined as: $S(k) = G^T X(k)$

where G^T is a constant row vector $G^T = [g_1, ..., g_{n-1}, 1]$ such that all the roots of the following polynomial are situated in the left-half open complex plane:

$h(s) = s^{n-1} + g_{n-1}s^{n-2} + ... + g_1$

The sliding Mode control comports two terms which are:equivalent control term and switching control term[3][5][7][12].

$$u_g = u_e + u_s \tag{10}$$

The equivalent control law

In the first part we assume that : $\Delta A_{di} = 0nxn$ and $\Delta B_{di} = [0, ..., 0]^T$.

The switching function is defined as: $S(k) = G^T X(k)$

The ideal quasi sliding mode satisfies: $S(k+1) = S(k) = 0$

We deduct :

$$0 = G^T \sum_{i=1}^{c} h_i(Z(k))(A_{di}(k+1)X(k) + B_{di}\, u_e(k));\ k = 0, 1, ... \tag{11}$$

The equivalent control term is given by:

$$u_e(k) = -\left(\sum_{i=1}^{c} h_i(Z(k))\, G^T B_{di}\right)^{-1}\left[G^T \sum_{i=1}^{c} h_i(Z(k)) A_{di}(k+1)X(k)\right] \tag{12}$$

We assume that condition is hold: $\left(\sum_{i=1}^{c} h_i(Z(k))\, G^T B_{di}\right) \neq 0$

The switching control law

From the reaching law we can write:$S(k+1) - S(k) = -qTS(k) - \varepsilon T sgn(S(k))$

$$S(k+1) - S(k) = G^T \sum_{i=1}^{c} h_i(Z(k))(A_{di}(k+1)X(k) + B_{di}\, u(k)) - G^T X(k) \tag{13}$$

If we compare the two latest equations we deduct the global control law:

$$u_g(k) = -F^{-1}\left[\sum_{i=1}^{c} h_i(Z(k))\left(G^T A_{di}(k+1)\right)X(k) - (1-qT)S(k) + \varepsilon T\,sgn(S(k))\right] \tag{14}$$

where $F = \left(\sum_{i=1}^{c} h_i(Z(k))\,G^T B_{di}\right)$
From equations and we obtain the switching control term:

$$u_s(k) = -\left(\sum_{i=1}^{c} h_i(Z(k))\,G^T B_{di}\right)^{-1}\left[-(1-qT)S(k) + \varepsilon T\,sgn(S(k))\right] \tag{15}$$

3.2 Robust fuzzy sliding mode Control law

Consider the discrete system in the perturbed condition. It will be described by the T-S type fuzzy model . Where ΔA_{di} represents system parameters variation and ΔB_{di} is the external disturbance for each sub-model. We assume the matching conditions are satisfied: $\Delta A_{di} = B_{di}\breve{A}_{di}$ and $\Delta B_{di} = B_{di}\breve{B}_{di}$

where, $\breve{A}_{di}$ is a row vector and $\breve{B}_{di}$ is a scalar . They should be written as:
$\breve{A}_{di} = \begin{bmatrix} -\Delta a_{i1} & -\Delta a_{i2} & . & . & . & -\Delta a_{in} \end{bmatrix}$ $\breve{B}_{di} = -\Delta b_i$.
Then the equation (5) becomes:

$$X(k+1) = \sum_{i=1}^{c} h_i(Z(k))\left(A_{di}X(k) + B_{di}u(k) + \breve{A}_{di}X(k) + \breve{B}_{di}\right) \tag{16}$$

However, the global control law will be expressed as:

$$u_g(k) = -F^{-1}\left[\sum_{i=1}^{c} h_i(Z(k))\left(G^T A_{di}(k+1)\right)X(k) + \Gamma - (1-qT)S(k) + \varepsilon T\,sgn(S(k))\right] \tag{17}$$

where $\Gamma = G^T B_{di}\left(\breve{A}_{di}X(k) + \breve{B}_{di}\right)$

In general case and are unknown, but their upper bound are known, so the last global control law can not be implemented. However, to over com this difficulty we replace respectively the unknown terms and by the following expressions:
$\overline{A_i} = \left(\sqrt{\left(eig\left(\breve{A}_{diup}^T \breve{A}_{diup}\right)\right)}\right)^T$; $\overline{B_i} = \Delta b_{i\max}$.
$\breve{A}_{diup} = \begin{bmatrix} -\Delta a_{i1\max} & -\Delta a_{i2\max} & . & . & . & -\Delta a_{in\max} \end{bmatrix}$ $\breve{B}_{diup} = -\Delta b_{i\max}$

We define a new set of perturbations and control parameters as follow:.

$S_{ig} = G^T B_{di}\overline{A_i}X(k);$ $\qquad F_{ig} = G^T B_{di}\overline{B_i};$

The choice of S_{ig} and F_{ig} is done to ensure that the sign of the incremental $S(k)$ is opposite to the sign of $S(k)$.

The global control law will be expressed as:

$$u_g(k) = -F^{-1}\left[\sum_{i=1}^{c} h_i(Z(k))\left(G^T A_{di}\right)X(k) + Q_i - (1-qT)S(k) + \varepsilon T\,sgn(S(k))\right] \tag{18}$$

where $Q_i = (S_{ig} + F_{ig}) - (S_{ig} + F_{ig})\,sgn(S(k))$

3.3 Tracking robust fuzzy sliding mode Control law

The tracking problem will be transformed into the stability problem. Indeed,$S(k) = 0$ represents an equation whose unique stationary solution is . The tracking problem of the desired vectorX_d comes back to locate inside the quasi-sliding band width the sliding surface for all sampling time. The sliding surface will be expressed as: $S(k) = G^T \widetilde{X}(k)$ where, $\widetilde{X}(k) = X(k) - X_d(k)$

The control law will be expressed as:

$$u_g(k) = -F^{-1}\left[\sum_{i=1}^{c} h_i(Z(k))\left(G^T A_{di}\right)\widetilde{X}(k) + Q_i - (1 - qT)S(k) + \varepsilon T sgn(S(k))\right] \tag{19}$$

4 Illustration

To illustrate the performance of the presented approach, we choose inverted pendulum and Mass spring damper which are widely used in the control literature of nonlinear system.

4.1 Inverted pendulum

The equations of system in continuous form are given by (20) [18]: where, x_1 is the angle in radian of the pendulum from the vertical axis; x_2 is the angular velocity in rad/s; g is the gravity acceleration; m and $2l$ are respectively the mass and the length of the pendulum; M is the mass of the cart and u is the force applied to the cart. The nominal values of the parameters are: g= 9.81m/s2, m = 2 kg, M = 8 kg, $2l$ =1m.

$$\begin{cases} \dot{x}_1(t) = x_2(t) \\ \dot{x}_2(t) = f(x_1,x_2) + g(x_1,x_2)u + d(t) \\ f(x_1,x_2) = \frac{mlx_2^2 \sin x_1 \cos x_1 - (m+M)g \sin x_1}{ml\cos^2 x_1 - \frac{4l}{3}(m+M)}; g(x_1,x_2) = \frac{\cos x_1}{ml\cos^2 x_1 - \frac{4l}{3}(m+M)} \end{cases} \tag{20}$$

The membership functions for $x_i \in]-\pi/2, \pi/2[$are:

$\mu_{1i}(x_i) = 1 - \left|\frac{x_i(k)}{\pi/2}\right|$ and $\mu_{2i}(x_i) = \left|\frac{x_i(k)}{\pi/2}\right|$,

The state matrices and input vectors for sub-systems are:

$$A_{d1} = \begin{bmatrix} 1 & 0.01 \\ 0.1729 & 1 \end{bmatrix}; A_{d2} = \begin{bmatrix} 1 & 0.01 \\ 0.0936 & 1 \end{bmatrix}, B_{d1} = \begin{bmatrix} 0 \\ 0.0018 \end{bmatrix}, B_{d2} = \begin{bmatrix} 0 \\ 0.000052 \end{bmatrix}$$

$$\Delta A_{d1up} = \begin{bmatrix} 0 & 0 \\ 0.05229 & 0 \end{bmatrix}, ; \Delta A_{d2up} = \begin{bmatrix} 0 & 0 \\ 0.028 & 0 \end{bmatrix}, \Delta B_{d1up} = 0.0005;\ \Delta B_{d2up} = 0.00002;$$

We have been chosen: $q = 70; T = 0.01; \varepsilon = 0.1$; G^T= [10 1];

The figure 1 presents the simulation results of the behavior of variable state $x_1(k)$and $S(k)$ of inverted pendulum for nominal system. The initial conditions are given by:$X(0) = [\pi/3; 0]$.

We present by the figures2, 3, 4, 5, 6 and 7 the simulation results of the behavior of the state variables $x_1(k)$,$x_2(k)$, the position and velocity error $e_1(k)$ and $e_2(k)$, the sliding surface and the control law respectively of the inverted pendulum with parameters vary of an uncertain way in time.The initial conditions are given by: $X(0) = [-\pi/60; 0]$; G^T=[15 1], q=80, ε =1.5;

The function sign is replaced by the well known sat function which is defined as:

$$\begin{cases} \text{if } S \prec \frac{1}{\Phi};\ sat = S \\ \text{if } S \succeq \frac{1}{\Phi};\ sat = sgn(S) \end{cases}$$

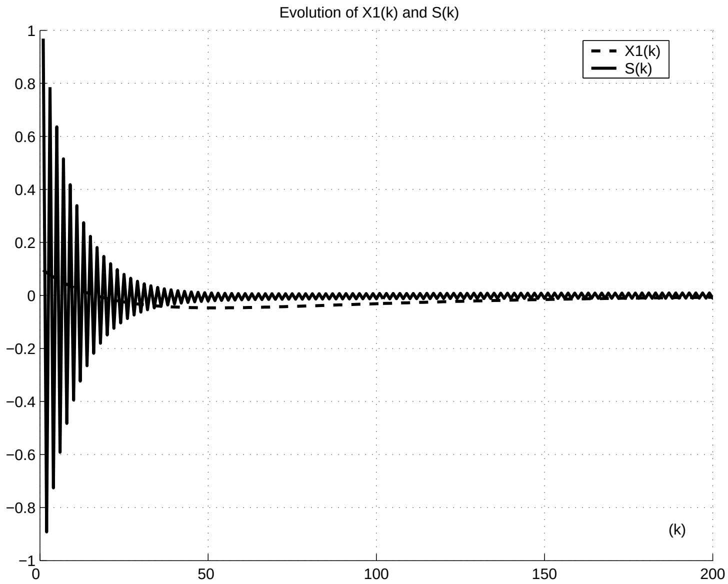


Figure 1: Stabilization of *X1(k)* and the sliding surface *S(k)*

4.2 Mass spring damper

The Mass-spring-damper system is described in continuous time by the following equation [17]: $M_1\ddot{x_1}(t)+c_1x_1(t)+c_2\dot{x_1}(t)+c_3x_1(t)+c_4x_1^2(t)=\left(1+c5\left(\dot{x_1}\right)^3(t)\right)u(t)$

TheT-S fuzzy model is discribe by the following rules:

Rule 1: IFx_1 is M_{11} and x_2 is M_{12} THEN $X(k+1)=A_{d1}X(k)+B_{di1}u(k)$

Rule 2: IF x_1 is M_{21} andx_2 is M_{22} THEN $X(k+1)=A_{d2}X(k)+B_{di2}u(k)$

Rule 3: IF x_1 is M_{31} and x_2 is M_{32} THEN $X(k+1)=A_{d3}X(k)+B_{di3}u(k)$

Rule 4: IF x_1 is M_{41} and x_2 is M_{42} THEN $X(k+1)=A_{d4}X(k)+B_{di4}u(k)$

For nominal values of M_1, c_2, c_3 and c_4, matrices A_i and B_i are given by:

$$A_{d1}=A_{d2}=\begin{bmatrix}1 & 0.01\\ -0.0001 & 0.99\end{bmatrix};A_{d3}=A_{d4}=\begin{bmatrix}1 & 0.01\\ -0.0023 & 0.99\end{bmatrix};$$

$$B_{d1}=B_{d3}=\begin{bmatrix}0\\ 0.0143\end{bmatrix},B_{d2}=B_{d4}=\begin{bmatrix}0\\ 0.0056\end{bmatrix};$$

$$\Delta A_{d1up}=\Delta A_{d2up}=\begin{bmatrix}0 & 0\\ 0 & 0.003\end{bmatrix},\Delta A_{d3up}=\Delta A_{d4up}=\begin{bmatrix}0 & 0\\ 0.0007 & 0.003\end{bmatrix},$$

$\Delta B_{d1up}=\Delta B_{d3up}=0.043;\ \Delta B_{d2up}=\Delta B_{d4up}=0.0017;$

The initial condition and parameters are chosen as:$X(0)=[-\pi/60;0]$; G^T=[15 1], T=0.01; q=70, ε =0.15.

We present by the figures 8and 9 the simulation results of the behavior of the state variables $x_1(k)$,$x_2(k)$, of the mass spring damper with parameters vary of an uncertain way in time.

We present by the figures 10, 11, 12 and 13 the simulation results of the behavior of the position and velocity error $e_1(k)$ and $e_2(k)$, the sliding surface and the control law respectively of the mass spring damper with parameters vary of an uncertain way in time.

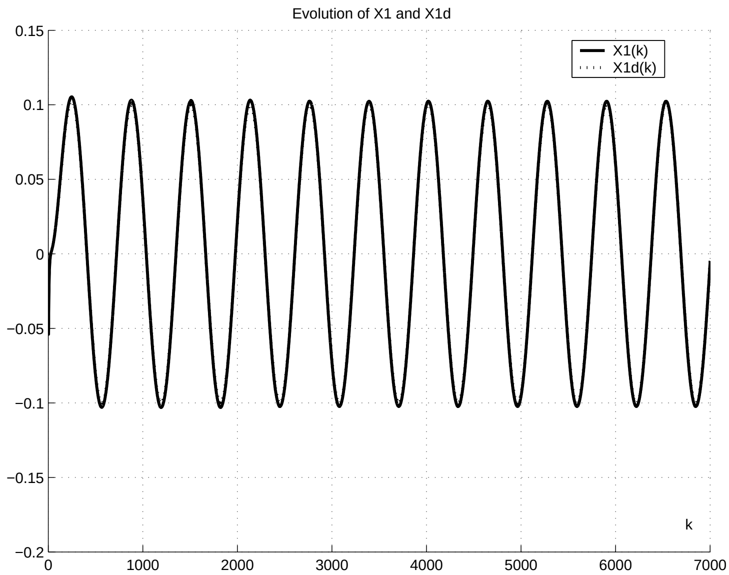


Figure 2: Evolution of *x1* and *x1d*

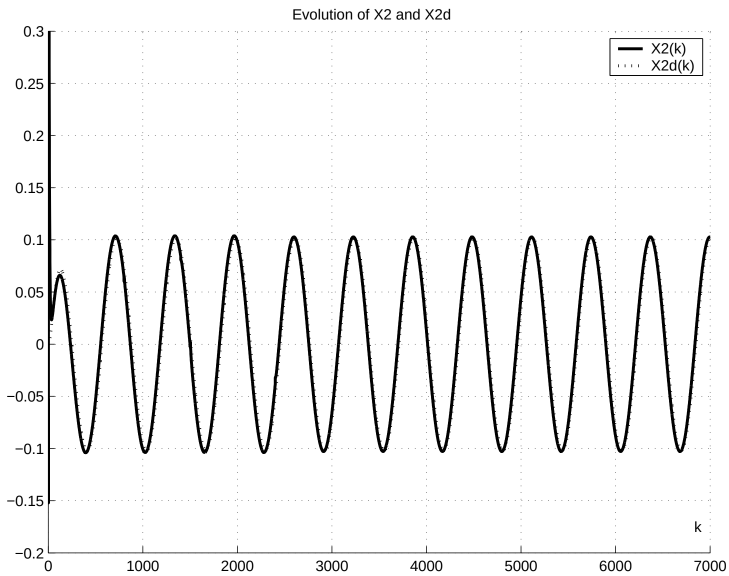


Figure 3: Evolution of *x2* and *x2d*

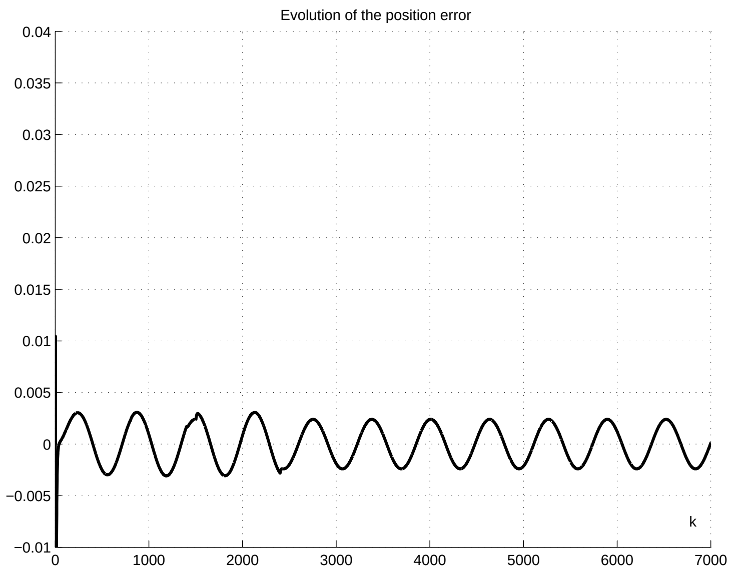


Figure 4: Evolution of the position error

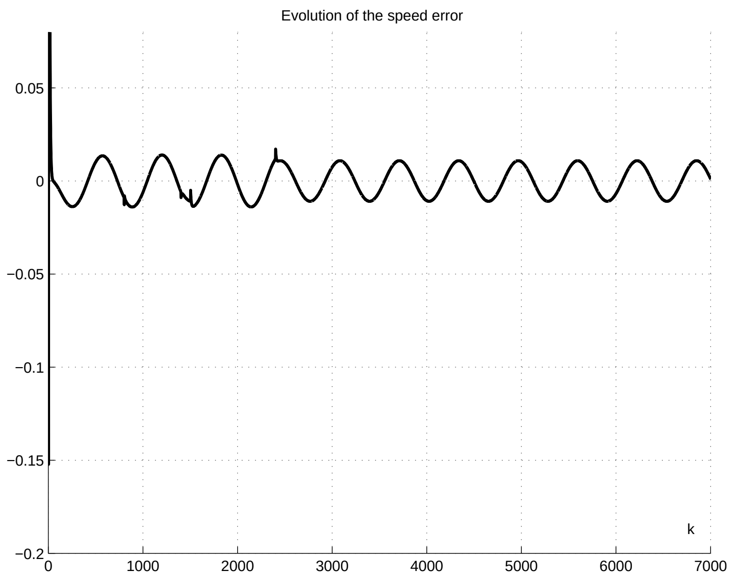


Figure 5: Evolution of the speed error

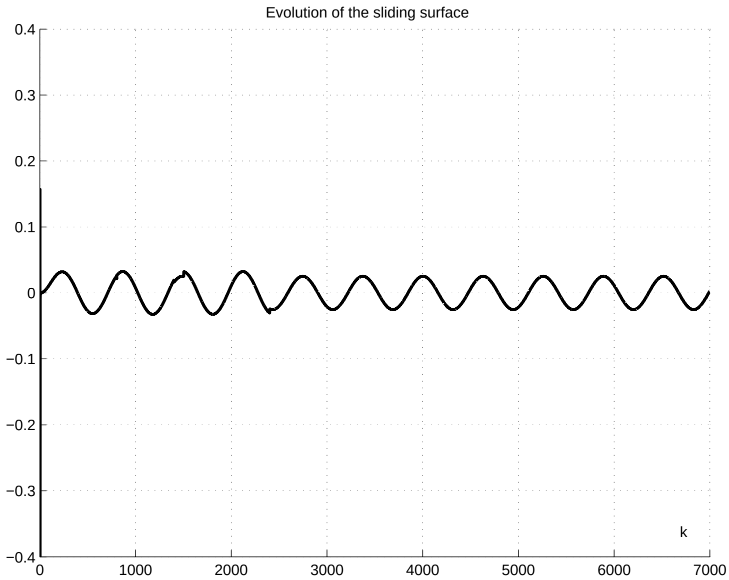


Figure 6: Evolution of the sliding surface

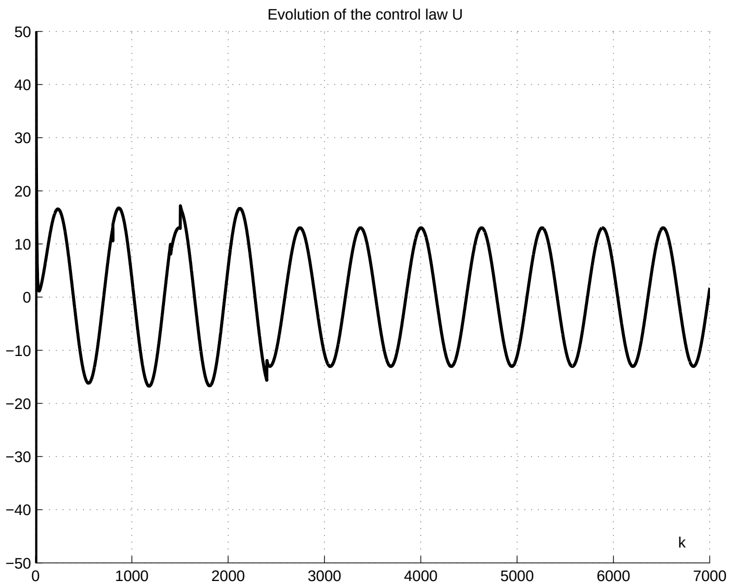


Figure 7: Evolution of the control law

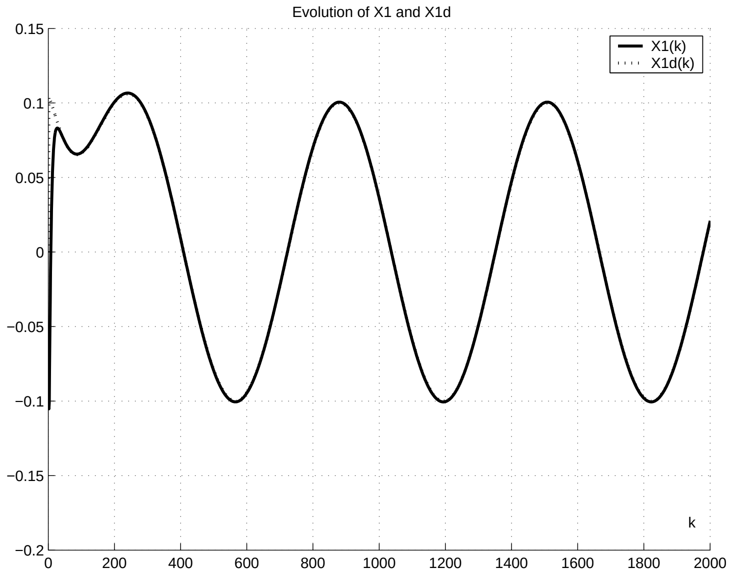


Figure 8: Evolution of *x1* and *x1d*.

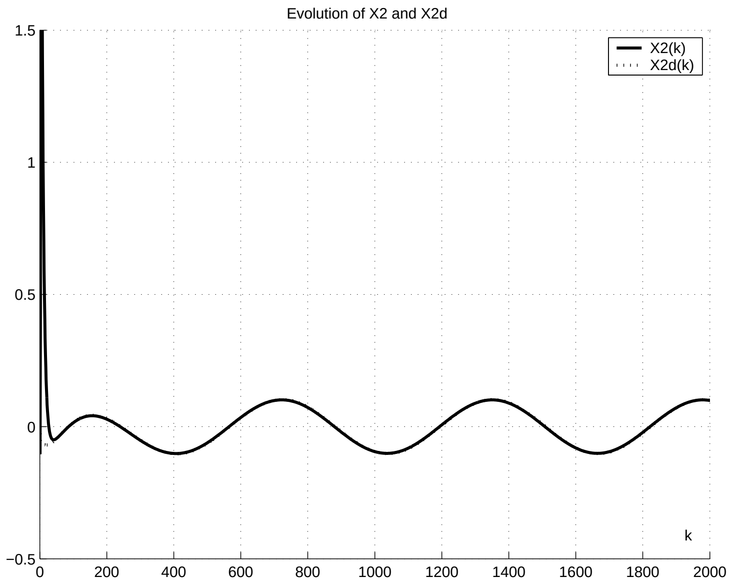


Figure 9: Evolution of *x2* and de *x2d*.

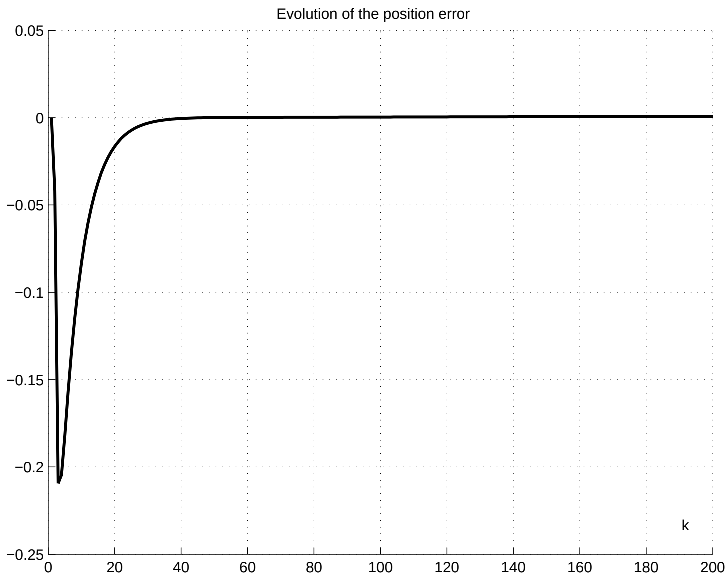


Figure 10: Evolution of the position error

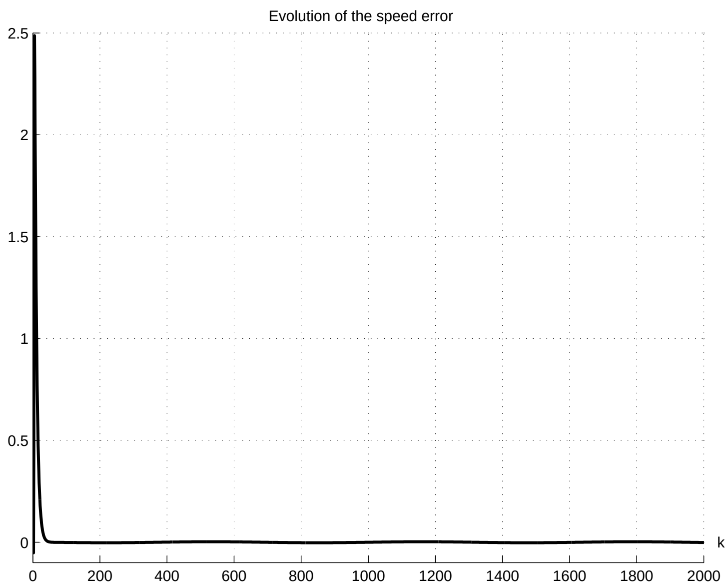


Figure 11: Evolution of the speed error

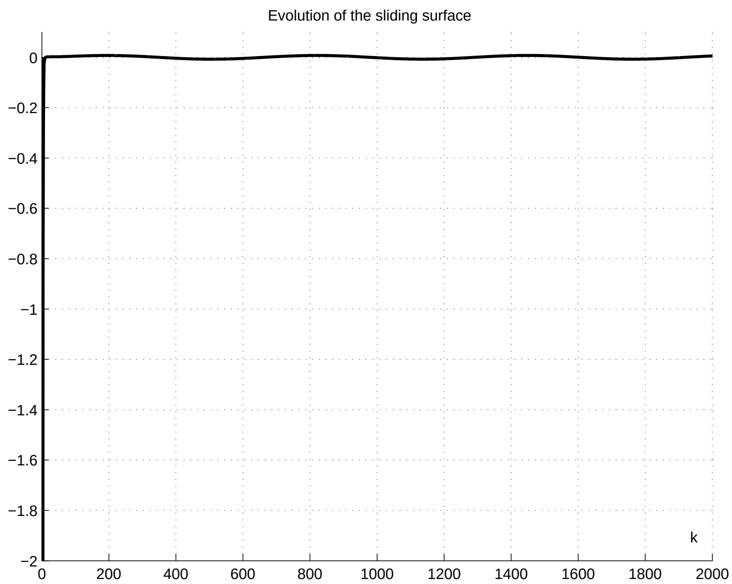


Figure 12: Evolution the sliding surface

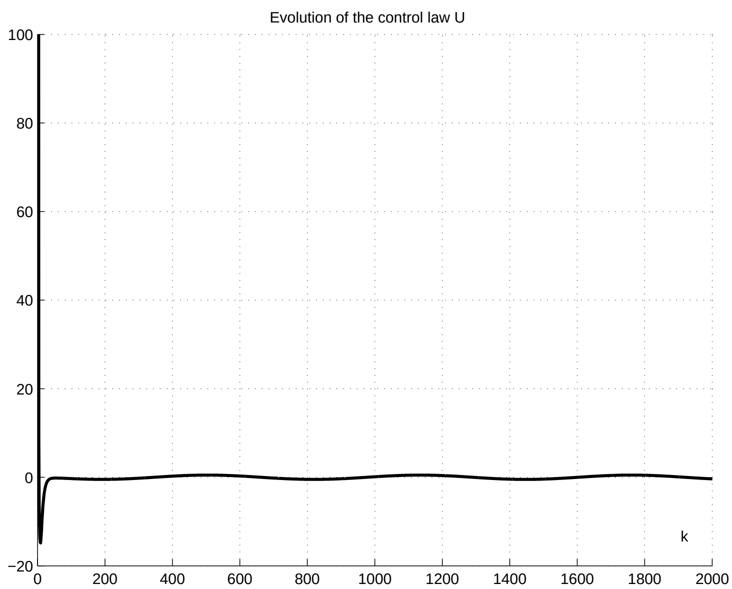


Figure 13: Evolution of the control law

5 Conclusions

In this paper we present a robust fuzzy sliding mode controller for discrete nonlinear systems. First, we recall the discrete Takagi-Sugeno type fuzzy model, then the principe of the sliding mode control in discrete time. The uncertainty are assumed to be verifie the matching conditions. We develop a robust controller based on the sliding mode and the dynamic T-S fuzzy state model. The uncertainties are replaced bye the bigger eigen-value of the upper bound matrices of uncertainties. The expressions in discrete time of both equivalent control term and hitting term are developed. The tracking control law is developed. Simulation results for inverted pendulum and mass spring damper with parameters variation show the performance of the proposed control law.

Bibliography

[1] Michio Sugeno "On Stability of fuzzy Systems expressed by rules with singleton consequents, *(IEEE Transaction on Fuzzy Systems*,Vol 7 N 2 Feb 1999).

[2] T.Takagi and M.Sugeno, *Fuzzy identification of systems and its applications to modeling and control* IEEE trans syst. Man,Cybern. Vol15. 116-132 Jan/Feb1985.

[3] W.Chang, J.Bae Park, Y.Hoan Joob and G.chen *Design of robust fuzzy model-based controller with sliding mode control for SISO non-linear systems* Fuzzy Sets and Systems 125 (2002) pp 1-22.

[4] Hafedh Abid Mohamed Chtourou et Ahmed Toumi, *A Sliding Mode Based Robust Fuzzy Controller For a Class of Uncertain Systems* SSD05, Mrach 2005 Sousse Tunisia.

[5] Y. dote and R.G..hoft, *Microprocessor based sliding mode controller for dc motor drives* presented at the Industrial Application. SOC. Annu. Meeting, Cincinnati, OH, 1980.

[6] D. Milosavljevic, *General conditions for the existence of a quasi-sliding mode on the switching hyperplane in Discrete Variable Systems* Automat. Remote Contr., vol. 46, pp(307-314) 1985.

[7] S. Z. Sarpturk, Y Istefanopulos, and O. Kaynak, *On the stability of Discrete-time sliding mode control systems* IEEE Trans. Automat. Contr., vol. 32, N 10, pp(930-932) 1987..

[8] K. Furuta, *Sliding Mode Control of a discrete system" , Systems and Control* Letter, Volume 14, pp145-152.

[9] Weibing Gao, Yufu Wang and Abdollah Homaifa, *Discrete-Time Variable Structure Control Systems* IEEE Transactions on Industrial, Electronics, volume 42, N 2, April 1995, pp(117-122).

[10] Weibing Gao., and Hung, J.C., *Variable structure control of nonlinear systems: a new approach* IEEE Transactions on Industrial Electronics, 40, 45, 1993

[11] H. Lee, E. Kim, H.J. Kang et M. Park, *A new sliding-mode control with fuzzy boundary layer* Fuzzy Sets and Systems 120 (2001), pp. 135-143

[12] Utkin, V. I, *Sliding Modes and their Application in Variable Structure Systems* (Moscow: Nauka) 1974 (in Russian, and also, 1978, Mir, in English).

[13] Utkin, V. I, *Variable structure systems with sliding mode"* IEEE Transactions on Automatic Control, Vol. AC-22, No. 2, pp 212-222, April., (1977).

[14] Yu, X. H., Man, Z. H. and Wu, B. L *Design of fuzzy sliding-mode control systems*, Fuzzy Sets and Systems, 95, pp.295-306. ., (1998)

[15] Ting, C. S., Li, T. H. S, and Kung, F. C., *An approach to systematic design of the fuzzy control system* Fuzzy Sets and Systems, 77, pp. 151-166. (1996).

[16] Slotine, J. J. E. and Li. W., *Applied nonlinear control* , Prentice Hall, Englewood Cliffs, NJ.(1991),

[17] Kazuo Tanaka, Takayuki Ikeda and Hua O.Wang, *Robust stabilization of a class of uncertain nonlinear systems via fuzzy control: Quadratic stability, H∞ Control Theory, and linear Matrix Inequalities* IEEE Trans on Fuzzy System, Vol 4 N 1 Feb 1996.

[18] Mehrdad Hojati and Saeed Gazor *Hybrid Adaptive Fuzzy Identification and Control nonlinear Systems*IEEE Transactions ON Fuzzy Systems vol 10, N 2. April 2002 pp 198-210.

Hafedh Abid[1,3], Mohamed Chtourou[2], Ahmed Toumi[3]

[1]Institut supérieure des études technologiques de Sfax
Laboratoire d'Automatique, Génie Informatique et Signal
Cité Scientifique, BP 48, 59651 Villeneuve d'Ascq, France

[2]Unité de Commande Intelligente, design et optimisation des
Systèmes complexes(ICOS) ENIS, B.P. W, 3038 sfax, Tunisie

[3]Unité de Procédés Industriels Unité de Commande Automatique
(UCPI) ENIS,B.P. W, 3038 sfax, Tunisie

E-mail: Hafedh.abid@isetso.rnu.tn
Mohamed.chtourou@enis.rnu.tn
Ahmed.toumi@sta-tn.com

Received: June 13, 2007

International Journal of Computers, Communications & Control
Vol. III (2008), No. 1, pp. 21-32

Electroglottographic Measures Based on GCI and GOI Detection Using Multiscale Product

Aicha Bouzid, Noureddine Ellouze

Abstract: This paper deals with glottal parameter estimation such as local pitch and open quotient from electroglottographic signal (EGG). This estimation is based on glottal closing instants and glottal opening instants determined by a multi-scale product of this signal. Wavelet transform of EGG signal is made with a quadratic spline function. Wavelet coefficients calculated on different dyadic scales, show modulus maxima at localized discontinuities of EGG signal. The detected maxima and minima correspond to the glottal opening and closing instants called GOIs and GCIs. To improve the estimate precision, we operate the multi-scale product of wavelet transform coefficients of three successive dyadic scales. This processing enhances edge detection. A Multi-scale product is a nonlinear combination of successive scales; it reduces noise and spurious peaks. We apply cubic root amplitude on the product to improve the representation of weak amplitudes. The method has a good representation of GCI and a best detection of GOI. The method was tested on the Keele University database; it is effective and robust in multiple cases even for a typical signal showing undetermined GOIs and multiple peaks at GCIs. Finally precise measurement of these instants allows accurate estimation of prosodic parameters as local pitch and open quotient.
Keywords: wavelet transform, multi-scale product, electroglottographic signal, glottal closing instant, glottal opening instant

1 Introduction

Electroglottography is a non-invasive medical exploration technique of a glottal activity. The resulting signal called electroglottogram (EGG) is a common and efficient reference signal for pitch estimation. EGG signal can be used to determine glottal closing instant (GCI) and glottal opening instant (GOI). GCI is commonly used in speech processing like voiced/unvoiced classification, accurate source parameter estimation and robust instant detection; it is very useful in synchronous speech analysis and synthesis. GOI is useful for voice quality estimation and other voice and speaker characterization. In the present work, the estimated GCI and GOI are used to calculate the local fundamental frequency and the glottal open quotient. Referring to Childers [1], EGG signal presents an important amplitude variation at GCI, indicating a rapid behaviour change of the source (glottis). The derivative of the EGG signal, called DEGG shows strong peaks at closing instants and weak ones at opening instants. Referring to Mallat [2], important information lies in sharp transitions on the signal or its derivative. These singularities are detected by following the wavelet transform modulus maxima at fine scales. As we have shown in previous work [3], wavelet transform is efficient in most cases for detecting singularities in EGG signal at closing instants, but not so for glottal opening instant detection. In fact, large variations of amplitude on EGG signal can be observed at GCIs, however at GOIs the discontinuities are less obvious and can hardly be detected on the signal [4]. Referring to Sadler [5], [6], the multiscale product method (MPM) is the product of wavelet transform coefficients on different scales. The scale multiplication gives better results of discontinuity detection than any single scale, especially on the localization performance [7], [8], [9]. This method is used for edge detection in image processing. The aim of this paper is to present a new measurement method of glottal parameters from EGG signal, such as GOI, GCI, the signal fundamental frequency F0 and the open quotient Oq. Different time and spectral based methods have been proposed for estimating the pitch period and the open quotient Oq. In this work, we propose to apply the multiscale product method (MPM) on the EGG signal, in order to improve the accuracy of GOI and GCI measurement, so as to obtain better estimation of pitch and open quotient measures.

The present paper is organised as follows. After introduction, section 2 focuses the well-known methods applied on EGG signal for GCI and GOI detection and their related problems. The first method uses various thresholds (or crossing levels) of the EGG signal, the second method is based on the derivative of EGG signal. Besides, it is shown that in many cases, these methods present undetermined GOI and in fewer cases ambiguous GCI. Section 3 presents the multiscale product method and its application to EGG signal, in order to improve the detection of GOIs and GCIs. Section 4 presents a multiscale product enhancement for GCI and GOI detection based on the cubic root of the MP (CRMP) and its comparison to the MP and the DEGG methods . Section 5 deals with EGG parameter measurements given by the CRMP, the crossing level and the DEGG extrema methods. Finally, section 6 concludes this work.

2 GCI and GOI Detection Methods and Limitations

Glottal opening instants (GOI) and closing instants (GCI) estimation can be carried out on EGG signal, by different methods using time or frequency based methods. Here, we present two basic methods: the first method is based on EGG amplitude crossing level (with different levels), and the second method is based on maxima and minima detection on the DEGG signal.

EGG threshold method

Rothenberg et al. [10] use the 50% crossing level of the signal amplitude from a base line. This method gives a direct value of GOI and GCI from EGG signal in the case of modal and tense voice. 35% of the maximum amplitude of the EGG has been also used as a threshold; this ratio gives also direct values of the GCI and GOI. Howard [11] uses the 3/7 maximum EGG amplitude threshold for GOI detection. Illustrations of these methods are depicted in figure 1. The major drawback of such methods is the lack of accuracy for the GCI detection and a missing of GOI.

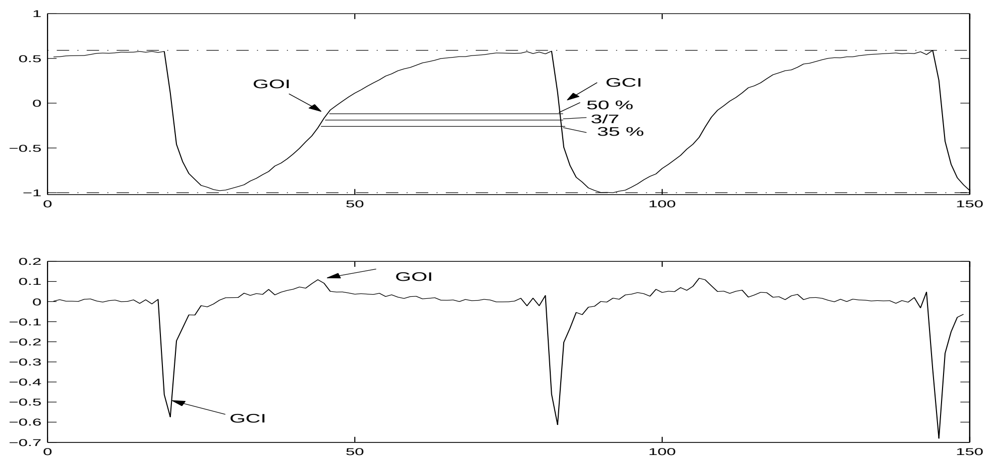


Figure 1: EGG signal (female voice, speaker f4, vowel [o]), 3 crossing levels, and the DEGG.

The top of figure 1 depicts the case of EGG signal of a female voice pronouncing the vowel [o], the crossing levels of 50%, 3/7 and 35% of the amplitude allowing the estimation of GOI and GCI.

DEGG maximum and minimum detection method

A more precise method for GCI detection uses the DEGG signal [12]. Childers characterises the EGG inflexion points by the DEGG [13], [14]. Experimental investigation shows that DEGG signal shows two opposite peaks in each period. The strong peak corresponds to GCI and the weak one corresponds to GOI [15], [16], [17]. An illustration of the derivative method is depicted at the bottom of figure 1.

GOI and GCI detection related problems

Methods based on EGG and DEGG, for GOI and GCI detection have different problems, such as missing events or duplication. Examples are taken from the Keele University database. It is a speech database containing acoustics and EGG signals simultaneously recorded in a soundproof room. It is made by five adult females and five adult males speakers. Each utterance consists of the same phonetically balanced English text. EGG and speech signals are given with the same sampling frequency of 20 KHz [18].

Many cases of missing peaks appear on DEGG at glottal closing instants [19]. Some GCIs and GOIs are indiscernible on the DEGG. This glottal behaviour is observed by Anastaplo and Karnell [20]. Pérez et al. underline the difficulty of GOI detection from the derivative of EGG signal [21].

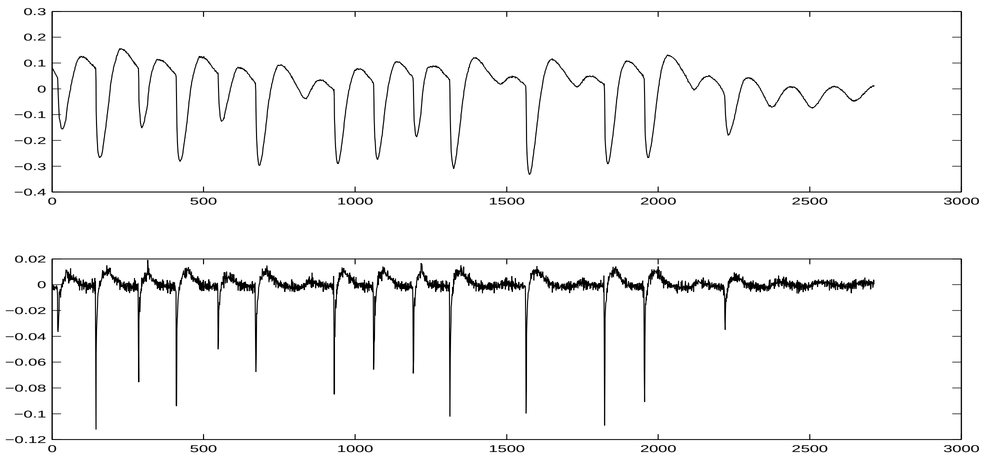


Figure 2: EGG signal of a male voice (speaker m2, voiced sound) and DEGG depicting the case of GCI and GOI missing.

GCI missing has a considerable effect on the time period measure. GOI missing influences the Oq measure.

Figure 2 illustrates problematical cases where threshold methods on EGG or DEGG fail to detect GCIs and GOIs. This example shows EGG signal of a voiced sound of the male speaker m2 and its derivative.

In many cases multiple peaks appear on DEGG at glottal closing instants and opening ones [19]. A typical example is presented in figure 3. In this case, the DEGG signal shows undetermined open instant and a double closing instant. EGG signal used for this example is a vowel [i] of the female speaker f2. We can distinguish that the EGG signal presents noise due to the subject movement during the recording.

Another typical example is shown on figure 4. Here the DEGG signal shows glottal opening and closing instants with a poor precision. The EGG signal used in this example is a voiced fricative [z] of the a male speaker m5. We can distinguish that the EGG signal presents natural noise of the fricative vowel.

3 GOI and GCI Detection by Multiscale Products

It is commonly known that wavelet transform is an efficient tool for detecting and characterizing signal singularities [2]. Singularities of the signal are detected by finding abscissa, where the wavelet modulus maxima converge at fine scales. The singularity type of the signal is characterised by wavelet vanishing moments and the decay of maxima across scales. This is explained by the fact that wavelet transform with n vanishing moments can be interpreted as a differential operator of nth order of the signal, smoothed by the primitive function of the wavelet called smoothing function. So if the wavelet is chosen to have one vanishing moment, modulus maxima appear at discontinuities of the signal, and

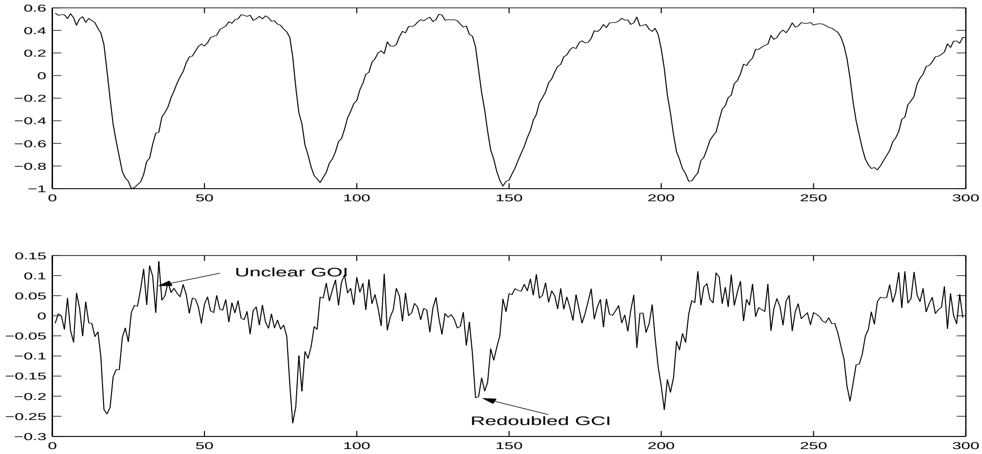


Figure 3: EGG signal (speaker f2, vowel [i]) and the DEGG depicting the case of double and imprecise peaks at GCI and GOI.

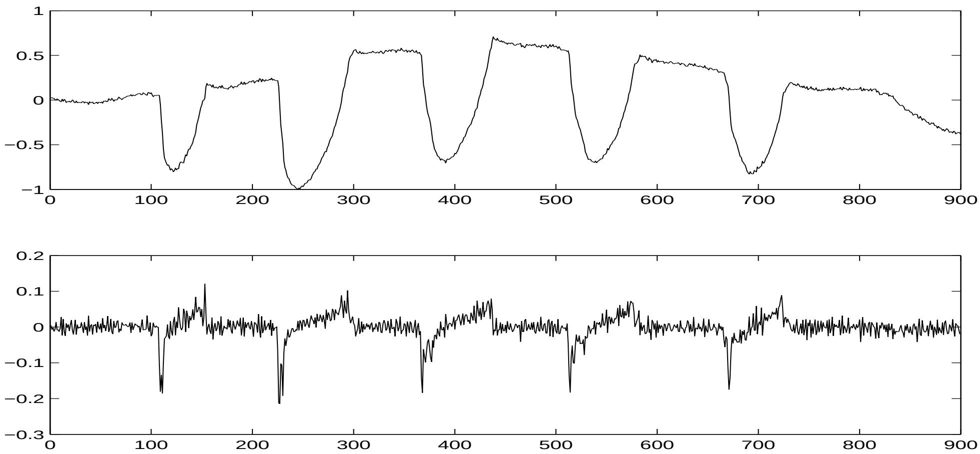


Figure 4: EGG signal (speaker m5, voiced fricative [z]) and the DEGG depicting the case of double and imprecise peaks at GCI and GOI.

represent the maxima of the first derivative of the smoothed signal. In previous work [3], we showed that the local regularity of the EGG signal can be characterised by the wavelet transform modulus maxima. Modulus maxima of EGG signal present two types of located singularities indicating glottal closing and glottal opening instants. The greater peak correspond to GCI and the weak one to the GOI. Modulus maxima give an estimation of the events with a better precision for small scales. But no scale can give an accurate value of GCI and GOI, so as singularities are too smoothed for large scales, and too weak for small scales, to be well located. Figure 5 shows the EGG signal of a voiced of speaker m2 followed by its wavelet transforms at the following scales 1/2, 1 and 2. Here wavelet transform (as well as DEGG), can't detect some singularities of the signal. Missed events still exist. That's why multiscale analysis seems to be necessary to improve the EGG edge localisation. The products of coefficients across scales are frequently used for image analysis. Witkin [20] provided the foundation for scale space theory by generalizing Rosenfeld's work [22], in which smoothing filters at dyadic scales are used. Based essentially on forming multiscale products of smoothed gradient estimates, this approach attempts to enhance the peaks of the gradients caused by true edges, while suppressing false peaks due to noise. The wavelet transform acts as an edge detector, and the detail coefficients should be equivalent to the estimated gradients. To distinguish edge maxima from noise and inappropriate maxima, Mallat and Zhong [23] analyze the singularity properties of wavelet transform domain maxima across various scales. The first derivative of a Gaussian and the quadratic spline are used to play this role. Xu et al. rely on the variations in scale of the wavelet transform. Direct multiplication of wavelet transform data at adjacent scales are used to distinguish important edges from noise [9]. Sadler and Swami [6] studied multiscale product method of a signal in presence of noise. In wavelet domain, it is well-known that edge structures are present at each subband while noise decreases rapidly along the scales. It has been observed that multiplying the adjacent scales could sharpen edges while diluting noise [6], [9]. The expression of multiscale product is given by:

$$p(n) = \prod_{j=1}^{3} \omega_{s_j}(f(n)) \tag{1}$$

Where $\omega_{s_j}(f(n))$ is the wavelet transform of the function for the dyadic scale sj. The product p(n) has the property to reveal peaks at signal edges, and has relatively small values elsewhere. Thus, singularities produce peaks along scale in wavelet transform. These peaks are reinforced by the product p(n). The signal peaks will just align across the first few scales, not all of them because increasing the amount of smoothing will spread the response and cause singularities separated in time to interact. Thus, choosing too large scales will result in misaligned peaks in p(n). An odd number of terms in the product preserves the sign of the edge. Choosing three dyadic successive scales is an optimal solution in multiscale product for detecting small peaks.

As multiscale product improves the edge detection, we apply MPM to EGG signal to outperform the detection of GCI and GOI and to improve the measure precision particularily for weak singularities at GOI.

At the bottom of figure 5, we find the MP of the EGG signal of a voiced sound of speaker m2. We can clearly see the effect of the product on cancelling the additional noise peaks present at its derivative depicted in figure 2 and consequently the best detection of GOI. We note the efficiency of the MPM to strengthen the GCI and its ability to detect GOIs that become clear enough. However, some missing events still exist. That's why multiscale product needs to be enhanced for an accurate GCI and GOI localisation.

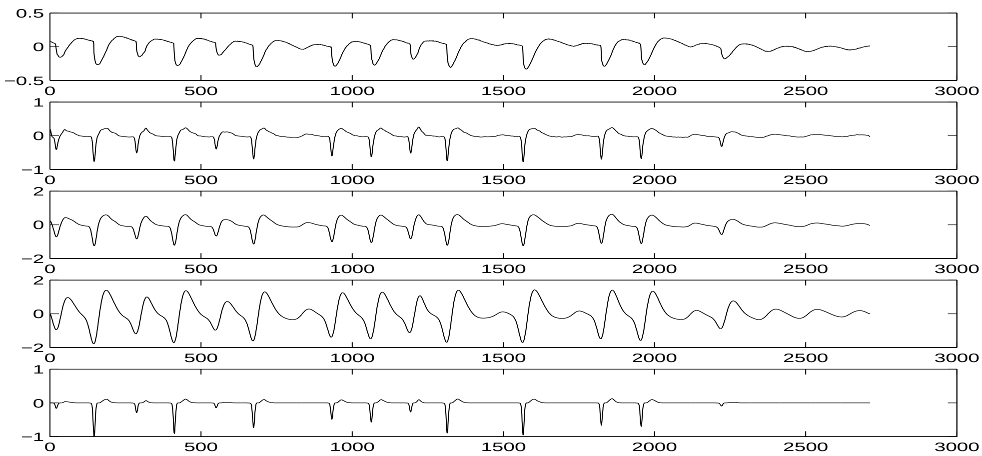


Figure 5: EGG signal of a voiced sound of speaker m2, the 3 wavelet transforms and their product.

4 Multiscale Product Enhancement for GOI and GCI detection

We have seen that multiscale product gives better results than wavelet coefficients. We use the cubic root of multiscale product to improve results for weak peaks. The cubic root of multiscale product has a zooming effect which enhances peak representation. This section deals with this basic enhancement and the comparative result detection of GCI and GOI detection by DEGG, MP and cubic root of MP. Specific examples from the Keele University database are presented below. Figure 6 shows an example of EGG signal and its derivative, which has precise peaks at GOI and GCI. The example is a frame of vowel [o] uttered by the speaker f4. The figure respectively shows the EGG signal, its derivative, the multiscale product of the following scales 1/2, 1 and 2 and the cubic root of the products. The multiscale product depicts the resulting cross-scale product p(n) for three scales and shows clean peaks aligned with the DEGG signal edges. First, we note two types of peaks in the cross-scale product; those corresponding to GCI are more distinguishable than those related to GOI. The modulus cubic root shows maxima at GOI and GCI, the weak peaks at GOIs given by the modulus cubic root of the product are better represented and effectively reinforced than those obtained by the multiscale product. Figure 7 illustrates the example of a female utterance of vowel [i] where the GOIs are undetermined and the peaks of GCI present irregular structures. We note double peaks of glottal closing that bring about inaccurate measurements. Besides, we can clearly see the effect of the product in cancelling the additional peaks, which, then, gives a better detection of GOI. The modulus cubic root is used to reinforce the small peaks corresponding to GOI. This figure underlines the importance of the modulus cubic root of the multiscale product.

Figure 8 shows the EGG signal of fricative [z] of speaker m5, the DEGG signal, the multiscale product and its modulus cubic root. Figure 9 shows the same representation for a voiced sound of speaker m2. These examples illustrate the modulus cubic root applied on the multiscale product of EGG signal. In figure 9, continuous lines indicate GCI and dotted lines indicate GOI for missing events. In fact the cubic root takes out peaks at GOI and GCI that don't exist either in DEGG signal or in the product. It's a complex case. Thus, we can see that modulus cubic root of multiscale product can give a better detection of GCI and GOI from the EGG signal than the threshold methods and the DEGG approach. The MP cubic root reinforces the GCI minima indiscernible not only at DEGG but also at MP. Consequently the MPM associated with the cubic root gives the most efficient reference measures of GOI and GCI.

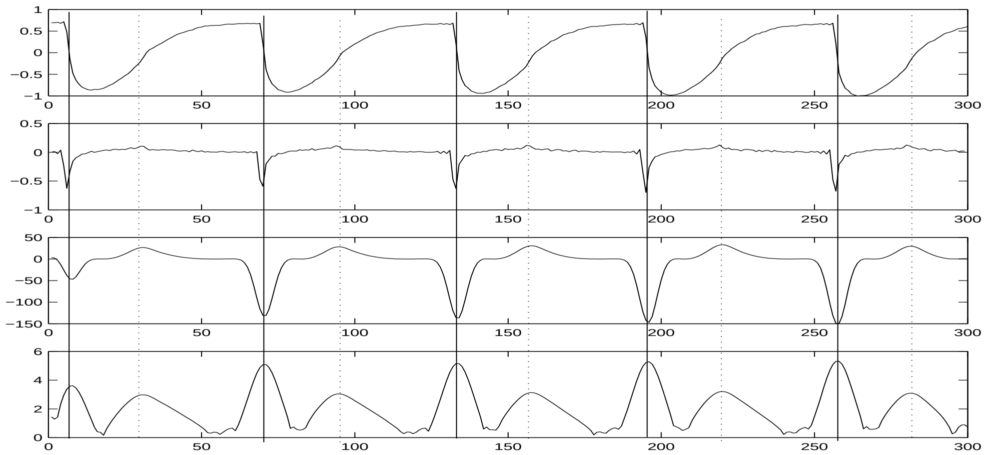


Figure 6: EGG signal of vowel [o] (speaker f4), DEGG, MP and its modulus cubic root.

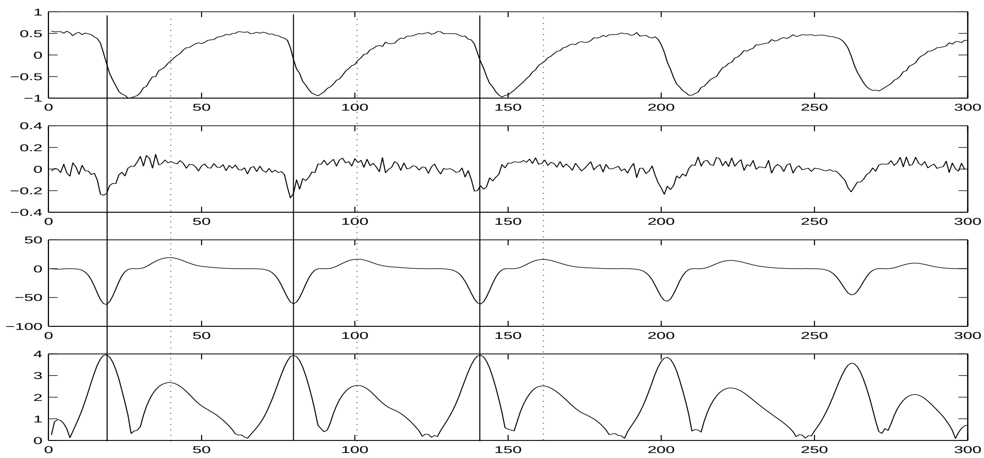


Figure 7: EGG signal of vowel [i] (speaker f2), DEGG, MP and its modulus cubic root.

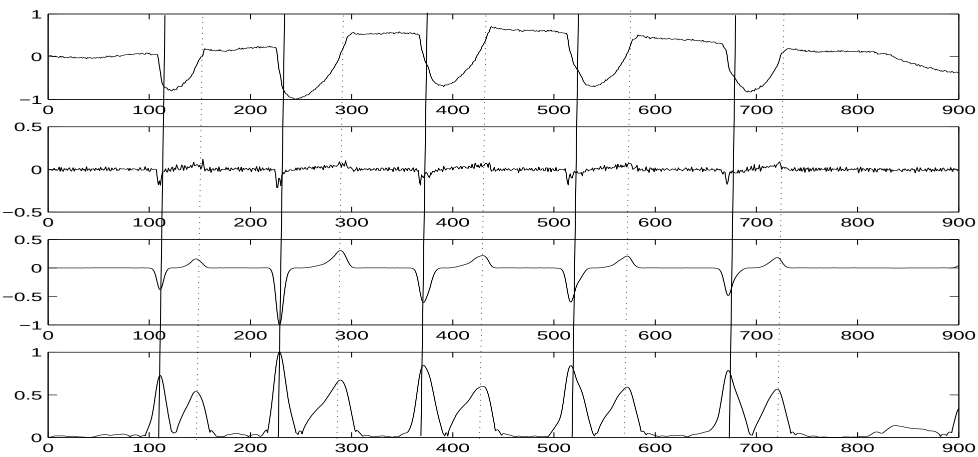


Figure 8: EGG signal of voiced fricative [z] (speaker m5), DEGG, MP and its modulus cubic root.

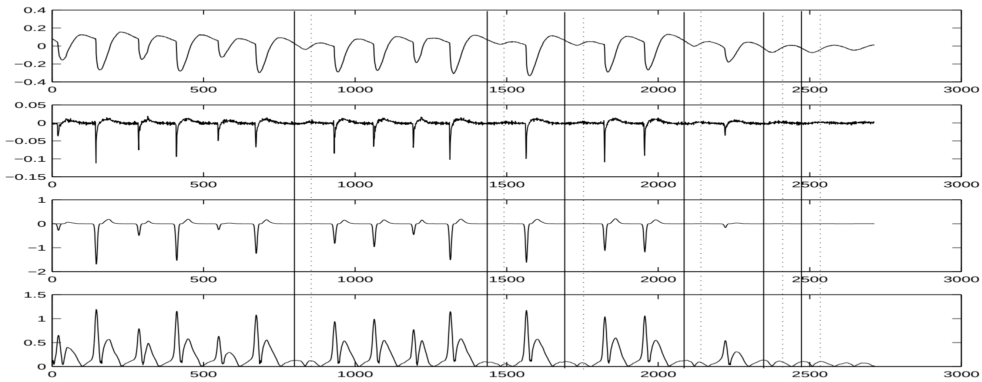


Figure 9: EGG signal of a voiced sound (speaker m2), DEGG, MP, and its modulus cubic root.

5 EGG Parameter Measurements

This section deals with the local pitch period and the local open quotient measurement. These can be calculated by using the GOI(k) and GCI(k). The glottal closing instant represent the beginning of the pitch period. The glottal opening instant GOI (k) corresponds to the beginning of the open phase.

Measurement of F0 and Oq

Local pitch period is given by the following formula

$$T_0(k) = GCI(k+1) - GCI(k) \tag{2}$$

The local fundamental frequency F0(k) is given by

$$F_0(k) = \frac{1}{T_0(k)} \tag{3}$$

The open quotient is defined as the ratio between the duration of the glottis open phase and the fundamental period. Open quotient is given by the following formula

$$Oq(k) = \frac{GCI(k+1) - GOI(k)}{T_0(k)} \tag{4}$$

In section 5, it is shown that the cubic root of MP outperforms the other methods in typical cases presented in this work. Moreover, this performance can be confirmed by evaluating prosodic parameter measures using the proposed method. Figure 10 depicts the local fundamental frequency F0 of a voiced sound of speaker m2 corresponding to a case where the DEGG method gives imprecise GOI and the threshold method fails in determining some ambiguous GCI and GOI. Figure 11 depicts the local open quotient for the same utterance determined by the same methods. The threshold methods mentioned above fail in detecting some GCIs and GOIs leading to aberrant and missing measures of the fundamental frequency and the open quotient. Besides, imprecise detection of GOI from DEGG signal leads to aberrant measures of Oq as shown in periods 12 and 14 of figure 11.

6 Conclusion

Parameter characterisation of EGG signal by glottal closing instant GCI and glottal opening instant GOI detection from this signal is carried out by a new method called multiscale product MPM. The proposed method consists of computing the product of the wavelet transform of EGG signal at three successive dyadic scales. The wavelet used is the quadratic spline. This wavelet has one vanishing moment

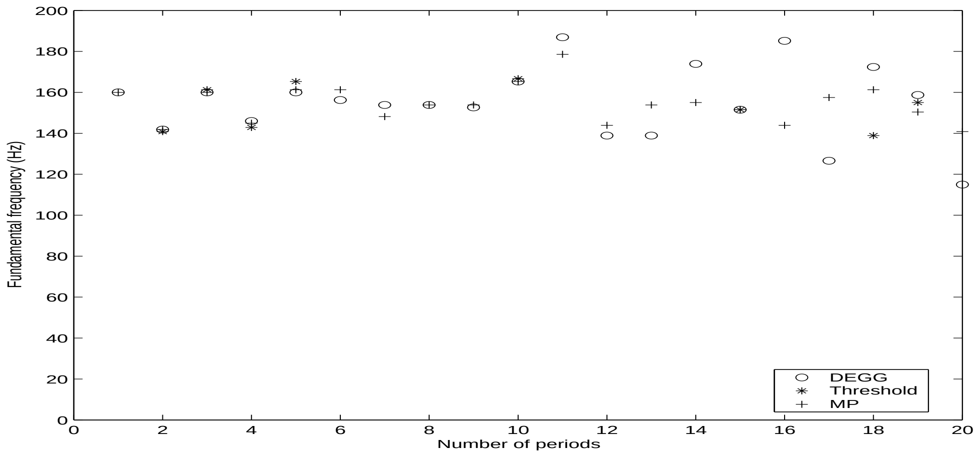


Figure 10: Fundamental frequency F0 given by DEGG (o), 3/7 threshold (*) and MP (+) methods for a voiced sound of speaker m2.

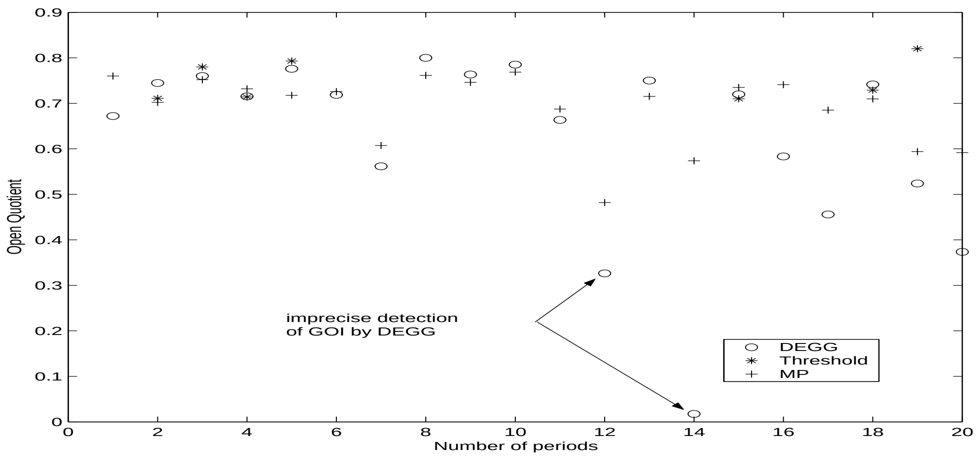


Figure 11: Open quotient Oq given by DEGG (o), 3/7 threshold (*) and MP (+) methods for a voiced sound of speaker m2.

and the calculated coefficients show modulus maxima at discontinuities of the signal. Wavelet transform is calculated at the following scales 1/2, 1 and 2. Then the cubic root amplitude of the product is calculated to enhance the resulting signal maxima. This method gives better GCI and GOI localisation than classical methods obtained by the crossing level or by the signal derivative, especially in typical cases of multiple peaks and undetermined GCI and GOI on DEGG signal. The non-linear products reinforce the cross-scale peaks produced at GCI and especially at GOI, and reduce spurious noisy peaks. Efficiency of the proposed method is proved. Comparative results are given with the threshold and derivative methods for glottal closing instants, glottal opening instants, and glottal parameter measurements like pitch frequency and open quotient. Locating GCI and GOI efficiently by using the cubic root of MP allows us to constitute a robust pitch and open quotient reference.

Bibliography

[1] D. G. Childers, A. M. Smith and G. P. Moore, Relationships Between Electroglottograph, Speech, and Vocal Cord Contact, *Folia Phoniatr.*, Vol. 36, pp. 105-118, 1984.

[2] S. Mallat, *A Wavelet Tour of Signal Processing*, Second Edition, Academic Press, San Diego 1999.

[3] A. Bouzid, and N. Ellouze, Local Regularity Analysis at Glottal Opening and Closing Instants in Electroglottogram Signal Using Wavelet Transform Modulus Maxima, in Proc. Eurospeech 2003, Geneve, pp. 2837-2840, 2003.

[4] N. Henrich, C. d'Alessandro, M. Castellongo, On the Use of the Derivative of Electroglottographic Signals for Characterization of Non-Pathological Phonation, *Journal of Acoustical Society of America*, Vol. 115, pp. 1321-1332, 2004.

[5] B. M. Sadler, T. Pham, and L. C. Sadler, Optimal and Wavelet Based Shock Wave Detection and Estimation, *Journal of Acoustical Society of America*, Vol. 104, no. 2, pp. 955-963, 1998.

[6] B. M. Sadler, and A. Swami, Analysis of Multiscale Products for Step Detection and Estimation, *IEEE Trans. Inform. Theory*, Vol. 45, no. 3, pp. 1043-1051, 1999.

[7] L. Zhang, and P. Bao, Edge Detection by Scale Multiplication in Wavelet Domain, *Pattern Recognition Letters*, Vol. 23, no. 14, pp. 1771-1784, 2002.

[8] P. Bao, L. Zhang, and X. Wu, Canny Edge Detection Enhancement by Scale Multiplication, *IEEE Trans. on Pattern Analysis and Machine Intelligence*, Vol. 27, no. 9, pp. 1485-1490, 2005.

[9] Y. Xu, J. B. Weaver, D. M. Healy, and J. Lu, Wavelet Transform Domain Filters: A Spatially Selective Noise Filtration Technique, *IEEE Trans. Image Processing*, Vol. 3, no. 6, pp. 747-758, 1994.

[10] M. Rothenberg, and J. J. Mahshie, Monitoring Vocal Fold Abduction through Vocal Fold Contact Area, *Journal of Speech and Hearing Research*, Vol. 31, pp. 338-351, 1988.

[11] D. M. Howard, Variation of Electrolaryngographically Derived Closed Quotient for Trained and Untrained Adult Female Singers, *Journal of Voice*, Vol. 9, no. 2, pp. 1212-1223, 1995.

[12] D. M. Howard, G. A. Lindsey, and B. Allen, Toward the Quantification of Vocal Efficiency, *Journal of Voice*, Vol. 4, no. 3, pp. 205-212, 1990.

[13] D. G. Childers, and A. K. Krishnamurthy, A Critical Review of Electroglottography, *CRC Critical Reviews in Biomedical Engineering*, Vol. 12, pp. 131-161, 1985.

[14] D. G. Childers, D. M. Hooks, G. P. Moore, L. Eskenazi, and A. L. Lalwani, Electroglottography and Vocal Fold Physiology, *Journal of Speech Hearing Research*, Vol. 33, pp. 245-254, 1990.

[15] D. G. Childers, and J. N. Lara, Electroglottography for Laryngeal Function Assessment and Speech Analysis, *IEEE Trans. on Biomedical Engineering BME*, Vol. 31, No. 12, pp. 807-817, 1985.

[16] S. Anastaplo, and M. P. Karnell, Synchronized Videoscopic and Electroglottographic Examination of Glottal Opening, *Journal of Acoustical Society of America*, Vol. 83, no. 5, pp. 1883-1890, 1988.

[17] M. H. Hess, and M. Ludwigs, Strobophotoglottographic Transillumination as a Method for the Analysis of Vocal Fold Vibration Patterns, *Journal of Voice*, Vol. 14, no. 2, pp. 255-271, 2000.

[18] F. Plante, G. F. Meyer, and W. A. Ainsworth, A Pitch Extraction Reference Database, in . Eurospeech 1995, pp. 837-840, 1995.

[19] A. Bouzid, N. Ellouze, *Contribution à la Détection des Instants d'Ouverture et de Fermeture de la Glotte sur les Signaux de Parole Voisé par Transformée en Ondelettes*, Thése de doctorat, ENIT, Juillet 2004.

[20] A. Witkin, Scale-Space Filtering, Proc. Int. Joint Conf. Artif. Intell., pp. 1019-1021, 1983.

[21] J. Pérez, and A. Bonafonte, Automatic Voice-Source Parametrization of Natural Speech, in Proc. ICSLP 2005, Lisboa, Portugal, 2005.

[22] A. Rosenfeld, A Non Linear Edge Detection, *Proc. IEEE*, Vol. 58, pp. 814-816, 1970.

[23] S. Mallat, and S. Zhong, Characterization of Signals from Multiscale Edges, *IEEE Trans. on Pattern Analysis and Machine Intelligence*, Vol. 14, no. 7, pp. 710-732, 1992.

Aicha Bouzid
ENIT
Signal Processing Lab
ENIT B. P. 37, le Belvédère 1002, Tunis, Tunisia
E-mail: aicha.bouzid@enit.rnu.tn, bouzidacha@yahoo.fr

Noureddine Ellouze
ENIT
Signal Processing Lab
ENIT B. P. 37, le Belvédère 1002, Tunis, Tunisia
E-mail: N.Ellouze@enit.rnu.tn
Received: September 1, 2007

Dr. Aicha Bouzid was born in 29 April, 1975. She has Diploma in Electrical Engineering at Ecole Nationale d'Ingénieurs de Tunis (ENIT) in 1998, Master degree on automatic and signal processing in 2000 and Ph. D. Thesis at signal processing laboratory (LSTS), in July 2004. She has joined the Institut Supérieur des Etudes Technologiques de Sfax as associate professor in 1999. Currently she is working as assistant professor in the department of electronic at the Institut Supérieur d'Electronique et de Communication de Sfax. She has more than 30 publications in international journals and conferences. Her research areas of interest are signal processing, speech processing and applied mathematics.

Pr. Noureddine Ellouze was born in 19 December, 1945. He received a Ph.D. degree in 1977 at INP (Toulouse- France), and Electronic Engineering Diploma from ENSEEIHT in 1968 University P. Sabatier. in 1978. Pr. Ellouze joined the Electrical Engineering Department at ENIT (Tunisia). In 1990, he became Professor in signal processing, digital signal processing and stochastic process. He was the head of the Electrical Department from 1978 to 1983 and General Manager and President of IRSIT from 1987-1994. He is now Director of Research Laboratory LSTS at ENIT, and is in charge of ATS Master Degree at ENIT. Pr. Ellouze has directed multiple Masters and Thesis and published more than 300 scientific papers in journals and proceedings, in the domain of signal processing, speech processing, biomedical applications, pattern recognition, and man machine communication.

International Journal of Computers, Communications & Control
Vol. III (2008), No. 1, pp. 33-40

Learning about Learners: System Learning in Virtual Learning Environment

Zhengxin Chen

Editorial Note: The program committee of ICVL 2007 sent to IJCCC nine of the best papers presented at the conference, with the recommendation to be published in an extended form. After a new evaluation, our reviewers decided that five of those papers can be published in IJCCC, two of which in this issue.

Abstract: Virtual learning is not just about a set of useful IT tools for learning. From an examination on where virtual learning stands in the overall learning spectrum, we point out the important impact of natural computing on virtual learning. We survey and analyze selected literature on important role of natural computing aspects, such as emergence (using swarm intelligence to achieve collective intelligence) and emotion, to virtual learning. In addition, in order to effectively incorporate these aspects into virtual learning, we propose using infrastructural support for virtual learning through *system learning*: The virtual learning environment not only provides facilities for learners, but also observes the behavior of learners and takes actions, so that its own performance can be improved (i.e., to better serve the learners). In this sense, system learning is concerned with learning about learners. Consequently, a virtual learning environment is a true human-machine symbiosis, paired by human learning and system learning.
Keywords: Natural computing, collective intelligence, emergence, emotion, system learning, virtual learning architecture

1 Introduction

As a software system, a virtual learning environment is intended to offer a virtual environment for learning where the learning process is based on information technology (IT). Virtual learning environment facilitates computerized learning or computer-enhanced learning (e-learning). Many projects in virtual learning have been designed to facilitate teachers in the management of educational courses for their students, especially by helping teachers and learners with course administration. The system can often track the learners' progress, which can be monitored by both teachers and learners. With advanced learning technology (ALT) it supports, virtual learning makes learning as a life-long journey easier to achieve than anytime else in history, and the entire world now becomes an open university.

However, although virtual learning has started producing fruitful results, fundamental issues related to virtual learning is seldom examined. Related to this is the pulic misconception that virtual learning is just a set of IT (information technology) tools or techniques. To address this problem, in this paper we first take a look at the learning spectrum, so that we can have a better understanding about where virtual learning stands in this big picture (Section 2). Since this examination reveals the importance of natural computing for virtual learning, we provide a brief review on natural learning (Section 3). We then examine two important features related to natural computing, namely, emergence and emotion, and review existing work relevant to virtual learning (Section 4 and Section 5). The introduction of natural computing in virtual learning necessities the concept of system learning; its important role is examined (Section 6). We conclude this paper by indicating the need for investigating a virtual learning architecture (or a framework) where human virtual learning is paired with system learning (Section 7).

2 The learning spectrum

Virtual learning is concerned with IT assisted human learning and much of research work in virtual learning addresses various technical issues to enhance human learning. However, any discussion concerned with learning using contemporary IT techniques is incomplete if we do not take a look on the issue of machine learning (http://robotics.stanford.edu/people/nilsson/mlbook.html), a subfield in AI devoted to developing algorithms for enhanced performance of computers. Although virtual learning (for humans) and machine learning are two separate research areas, they are both related to learning with computers. So if we examine them together, we should have a better understanding about where virtual learning stands in the big picture.

This broad perspective raises an important issue: Virtual learning should not be simply viewed as just a set of IT tools (or techniques) to assist learning or education. It reminds us the importance of examining fundamental issues related to learning, such as nature of intelligence, various forms of intelligence, consciousness and thinking, as well as recent research progress related to brain and mind, and even study activities observed in various forms of life - not just humans, but animals as well, so long as they demonstrate a kind of learning ability. These studies could shed meaningful insight for developing better virtual learning environments. As noted in [16], in recent years educators have explored links between classroom teaching and emerging theories about how people learn. Recommended educational approaches, consist primarily of trying to maintain a relaxed, focused atmosphere that offers options for learning in individually satisfying ways. One thing we must be kept in mind is that the brain is complex and while research has revealed some significant findings, there is no widespread agreement about their applicability to the general population or to education in particular. Nevertheless, brain research provides rich possibilities for education [16]. Articles in the magazine Scientific American Minds (http://www.sciammind.com/) also shed interesting lights on brain/mind research and education.

The issue of studying various forms of learning activities leads to the next question: Is anything setting in between virtual learning and machine learning? Although this may be an open question which is subject to debate, we would like to offer a possible answer: learning from nature through natural computing, which is the computational version of the process of extracting ideas from nature to develop "artificial" (computational) systems ("artificial" means human-made). Since natural computing is aimed to model the nature or even compute with the nature, it looks for intellectual inspiration from all forms of life (not restricted to human beings) - such as flocks or ants. Since natural computing sets between the research of "full human" (i.e., virtual learning) and non-human (i.e., machine learning), it fits in the missing link in the learning spectrum. Amending the hierarchical diagram provided by [1], we have the learning hierarchy as shown in Figure 1. (Note: For more details on various forms within distance learning, refer to the original figure in [1]).

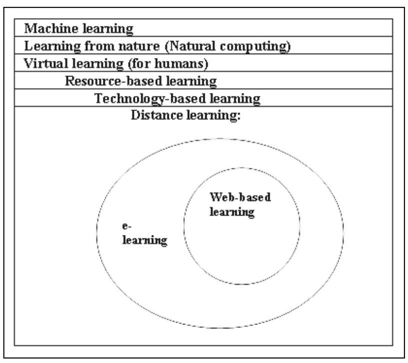


Figure 1: Learning spectrum from machine learning to various forms of virtual learning

But why should we bother natural computing at all in the context of virtual learning? The answer is simple: It may provide new interesting ideas not addressed in traditional learning or education context, so that virtual learning can benefit from that. Note that natural computing is not new to virtual learning community: As we are going to see soon, projects using various natural computing techniques have been conducted for virtual learning. Yet there is a need to conduct more systematic research on the rich impact of natural computing in virtual learning. Such kind of investigation will eventually benefit the study of natural computing as well, because the diverse applications in virtual learning extend the horizon of natural computing.

3 Basics of natural computing

In order to discuss how natural computing can help, first we have to provide a brief introduction on what natural computing is. There are numerous resources available for natural computing. For beginners, [4] provides a comprehensive coverage on the major fields with natural computing. The brief review in this section is based on that book.

The philosophy of natural computing lies in that most of computational approaches natural computing deals with are based on highly simplified versions of the mechanisms and processes present in the corresponding natural phenomena. Research work in natural computing can be grouped into three major categories, namely, computing inspired by nature, simulation and emulation of natural phenomena in computers, and computing with natural materials. Since the last one does not have direct impact on virtual learning (at least for now), we will not address it here.

The first category, computing inspired by nature, refers to making use of nature as inspiration for the development of problem solving techniques. The main idea is to develop computational tools (algorithms) by taking inspiration from nature for the solution of complex problems. The diverse areas (or approaches) under this category include evolutionary computing, neurocomputing, swarm intelligence, etc. Swarm intelligence refers to a property of systems of unintelligent agents of limited individual capabilities exhibiting collectively intelligent behavior, and has drawn attention from researchers to find useful applications in virtual learning (as to be briefly described later).

The second category, simulation and emulation of natural phenomena in computers, refers to a synthetic process aimed at creating patterns, forms, behaviors, and organisms that (do not necessarily) resemble "life-as-we-know-it." Its products can be used to mimic various natural phenomena, thus increasing our understanding of nature and insights about computer models. An interesting area under this line of research is artificial life, which is the study of man-made systems that exhibit behaviors characteristic of natural living systems. It has been hoped that by extending the empirical foundation upon which biology is based beyond the carbon-chain life that has evolved on Earth, artificial life can contribute to theoretical biology by locating life-as-we-know-it within the larger picture of life-as-it-could be.

Regardless of computing inspired by nature or simulation and emulation of natural phenomena in computers, there are several general concepts underlying various approaches in natural computing, such as agent, parallelism and distributivity, interactivity, adaptation, feedback, self-organization, emergence, etc. In addition, emotion is demonstrated not just in human beings, but many species of animals as well. Emotion has also been studied in artificial life.

Various natural computing concepts have already been used by authors working in virtual learning. Much effort has been put on researchers' "traditional" favorite such as adaptation. Yet successful employment of natural computing in virtual learning goes far beyond adaptation. Below we examine selected literature involving two crucial elements of natural computing and provide comments on their relevance to virtual learning: Emergence and emotion.

4 Exploring emergence for virtual learning

Using simple terms, emergence can be defined as "a coming into view." However, emergence is definitely not a simple concept, and the computational study on emergence [6] is still in its infancy. As a typical demonstration of computational approach for emergence, swarm intelligence is a property of systems of unintelligent agents of limited individual capabilities exhibiting collectively intelligent behavior. Swarm intelligence includes any attempt to design algorithms or distributed problem-solving devices inspired by the collective behavior of social insects and other animal societies. Swarm intelligence is an emergent property of the swarm system as a result of principles of the five principles: proximity, quality, diversity, stability and adaptability. Two main lines of research in swarm intelligence are either based on social insects, or based on the ability of human societies to process knowledge [4].

The ability of ants to find short routes between nests and food sources suggests an approach to cost-effective, flexible and implementable wayfinding support. Paths identified by ants are not preplanned, but emerge, spontaneously, as a result of indirect communication between members of an ant colony - a form of indirect social navigation. Ants deposit a chemical substance called pheromone which can be sensed by other ants, thus achieving a kind of stigmergy, which refers to the process of indirect communication. This property can be very useful for virtual learning. In a virtual learning environment considered by [17], learners' interactions with learning resources and activities are recorded automatically as they progress through a body of knowledge. The time stamping of these interactions allows learning sequences to be identified which can be processed and aggregated to derive a given "pheromone strength" favoring paths along which more learners have been successful. This information can be fed back to other learners, providing a new source of navigational guidance indicating "good" ways through the body of knowledge - a self-organizing, stigmergic approach to wayfinding support.

In another experiment by [15], ant colony optimization (ACO) heuristics was applied to an e-learning problem: the pedagogic material of an online teaching Web site for high school students is modeled as a navigation graph where nodes are exercises or lessons and arcs are hypertext links. The arcs' valuation, representing the pedagogic structure and conditioning the Web site's presentation, is gradually modified through the release and evaporation of virtual pheromones that reflect the successes and failures of students roaming around the graph. A compromise is expected to emerge between the pedagogic structure as originally dictated by professors, the collective experience of the whole pool of students and the particularities of each individual. Collective behavior as demonstrated from ant colonies and simulated in computer programs exemplifies collective intelligence (or symbiotic intelligence), an intelligence that emerges from the collaboration and competition of many individuals – an intelligence that seemingly has a mind of its own. Yet emergence is not restricted in collective intelligence. In general, emergence refers to the way complex systems and patterns arise from a multiplicity of relatively simple interactions [4].

Two influential monographs on emergence should find profound impact on virtual learning: through a series of narratives to show complex adaptive systems that display emergent behavior governed by small sets of local rules, the discussion in [8] may shed useful intuitive thoughts on infrastructural support to achieve emergence in virtual learning, while [6] provides more technical insights on modeling issues of emergence in a more general, abstract setting, where emergence is explained through a reductionist perspective. We summarize system learning with the following features related to emergence. Exploring emergent properties using swarm intelligence and other techniques should be continued and strengthened for research virtual learning. Yet, current research related to emergence in virtual learning is largely confined in specific tasks. More systematic studies of the role of emergence in virtual learning are needed, particularly those related to the overall infrastructure of virtual learning. In addition, in the context of learning/education (including virtual learning), there is a need to distinguish emergence as a process (such as emerging ideas) from emergence as a product (such as an emerging pattern) - a feature which has not attracted enough attention it deserves. Here is a partial list of issues to be studied about emergence related to virtual learning:

Nature of emergence (relevant to learning), such as: what are the relationships and differences between emergence and other features related to learning and discovery?

What can be achieved through emergence? - In the case of emerging ideas:

o Specific creative task (such as construction of analogs through emergence for analogical problem solving)

What can be achieved through emergence? - In the case of emerging "products":

o Global solution (such as an optimization of student pedagogical path);

o Solution for individuals (learning by taking advantage of emergence), such as how to come up with creativity thoughts in general.

In addition, there is a more general question: Is there a need to have a dedicated software component at system level to support emergence in a virtual learning environment? If yes, how to achieve this?

5 Exploring emotion in virtual learning

Recently the importance of emotion in education has drawn attention from researchers. For example, according to [16], educators may find the most useful information in research that focuses less on the physical and biochemical structure of the brain and more on the mind – a complex mix of thoughts, perceptions, feelings, and reasoning. Studies that explore the effects of attitudes and emotions on learning indicate that stress and constant fear, at any age, can circumvent the brain's normal circuits. A person's physical and emotional well-being is closely linked to the ability to think and to learn effectively. Emotionally stressful home or school environments are counterproductive to students' attempts to learn. While schools cannot control all the influences that impinge on a young person's sense of safety and well-being, classrooms and schools that build an atmosphere of trust and intellectual safety will enhance learning. Letting students talk about their feelings can help them build skills in listening to their classmates' comments. Finding ways to vent emotions productively can help students deal with inevitable instances of anger, fear, hurt, and tension in daily life. In an experimental study, the author of [12] interviewed eleven students studying online. These students identified emotions which were critical to their online learning.

In order to better understand where emotion stands in learning and education, it would be beneficial to take a look at the two books on general aspects of emotions with quite different emphases. From a psychological perspective, the experimental research of [9] showed that emotion can occur without cognitive processing in the cortex. In particular, we can learn some general principles of emotions by studying fear. In evolutionary terms, "fearless" animals would have been less likely to survive. The author further demonstrates that fear can be related to learning and fear learning is implicit. Although by no means we should endorse any kind of "learning through fear," this example does indicate emotion can have impact on education in a controlled manner, and with more secretes of emotion to be revealed in the future, some of the previously unknown principles involving emotions can be incorporated into virtual learning environment. Published one decade later, from a computational perspective, [10] aimed to establish a theory of how emotions get created. According to this theory, each emotional state is a different style of thinking. So there is no general theory of emotions, because the main idea is that each of the major emotions is quite different. For an adult person, the management is able to use these different ways of thinking very quickly as part of ordinary, common-sense thinking. What is the indication of this discussion to learning/education? The notion of emotion as a theory of thinking implies a potential opportunity to incorporate emotion into "mainstream" education theories, including those related to virtual learning.

In a recent comprehensive volume directly address the issue of emotion in education [14], various theoretical perspectives on emotions in education have been examined, include the discussions on control-value theory of achievement emotions, self-regulation and social-constructivist learning, emotions as a main component of attributional theory, implications of goal-theory for achievement-related emotions, macro-cultural psychology, etc. The theoretical work is complemented with sets of studies on students' emotions in educational context, as well as teachers' emotions in educational contexts. The comprehensive of research on emotion in education as described in this volume sheds light for future work of dealing with the emotion factor in a virtual learning environment (even the book does not address issues directly related to virtual learning).

As the literature surveyed above shows, so far the important issue of emotion for education is still largely discussed at the traditional classroom setting. Nevertheless researchers have started addressing this issue in the context related to virtual learning. For example, [3] presents an analysis of the issues pertaining to computational emergence and emotion in (cognitive) agent systems and describes how a developing computational theory of cognition can be used to monitor and manage interactions with and within complex systems; this would harness unwanted and emergent states and behaviors before the computational system becomes dysfunctional. In another work, [13] describes a modular hybrid neural network architecture, called SHAME, for emotion learning. In addition, computational experiments on emotion also exist. For example, [7] proposes the architecture of learning companion agent with facial expression of emotion. Based on architectures referred to as ABC and ToK, the emotion agent architecture contains five modules to realize the interaction in the world. A particular part of this research is the transition between emotion space in emotion module and facial expression space in facial expression module. Although this work is not directly related to virtual learning, it represents an interesting step toward computational emotion, and may shed light to the study of emotion in virtual learning.

Summarizing the above discussion, we note that current research status shows that emotion for virtual learning is a vast area yet to be systematically explored. The following are some sample issues need to be investigated:

From a learning perspective, how many types of emotions can be distinguished?

Under which conditions certain type of emotions should be controlled and under which conditions educators can take advantage of it?

What are basic operations of emotions (such as filter out, enlargement, etc.) related to learning and how to develop computational mechanisms to support them?

Finally, just like the case of the discussion related to emergence, we may wonder whether there is a need to implement any forms of emotion at the system level in virtual learning.

6 Learning about learners: The role of system learning

Summarizing our discussion in the last two sections, if we agree that natural computing can make significant contributions to virtual learning, and important features such as emergence and emotions should be incorporated into the virtual learning process, then we have to provide infrastructural support in virtual learning environments. (In other words, we would like to have a positive answer for the last question appearing at the end of Section 4 and Section 5.) This can be achieved through *system learning*: The virtual learning environment not only provides facilities for learners, but also observes the behavior of learners and takes actions, so that its own performance can be improved (i.e., to better serve the learners). In this sense, system learning is concerned with learning about learners. (Note that the term system learning may not necessarily new to virtual learning; but it has a new meaning as it is presented here.) Among the basic functionalities of system learning are: trace activities of learners, apply various natural computing algorithms to support specific tasks of virtual learning (such as find a global solution or to find a solution for an individual learner), invoke appropriate operators to deal with emotions at various degrees to learners with different profiles, notify teachers to change strategies based on learners' performance, coordinate all the activities in the virtual learning environment, as well as others. Consequently, a virtual learning environment is a true human-machine symbiosis, paired by human learning and system learning.

In order to support system learning, a number of issues need to be examined. Here we list two of them. First, system learning is not just an abstract concept; it has to be implemented. It consists of self-adjustable software distributed in the entire virtual learning environment. As a second issue, we point out the important role of a system-wide database for storage and retrieval of learners' behavior, based on which various natural learning algorithms can be applied, so that new solutions can emerge. Note that the important role of database management in virtual learning environment [5] is rarely examined in literature, and this should be changed in the future.

7 Conclusion

In this paper we examined virtual learning in the comprehensive learning spectrum, and emphasized the importance of natural computing for virtual learning. Within this context, we also discussed important features of emergence and emotions. In addition, our introduction of natural computing into virtual learning makes the new concept of system learning necessary. This also implies the need for investigating a virtual learning architecture (or at least, a framework, in a sense similar to [11]) where human virtual learning is paired with system learning. Significant amount of work is needed for this direction of research.

Acknowledgement

This is the extended version of an earlier paper [2] appeared in International Conference of Virtual Learning (ICVL 2007). The author thanks Technical Program Committee (Chaired by Dr. Grigore Albeanu) of ICVL 2007 for recommendation of publishing this paper in IJCCC.

Bibliography

[1] A. Anohina, The terminology used in the fields of Virtual Learning, Analysis of the terminology used in the field of virtual learning, *Educational Technology & Society*, Vol. 8, No. 3, pp. 91-102, 2005 (http://www.ifets.info/journals/8_3/9.pdf).

[2] Z. Chen, Learning from Nature: Natural Computing Meets Virtual Learning, *Proc. 2nd Int'l Conf. Virtual Learning (ICVL 2007)*, pp. 117-124, 2007.

[3] D. N. Davis, Computational emergence and computational emotion, *Proc. IEEE Conf. Systems, Man and Cybernetics (SMC)*, 1999. (http://www2.dcs.hull.ac.uk/NEAT/dnd/papers/smc99.pdf)

[4] L. N. de Castro, *Fundamentals of Natural Computing: Basic Concepts, Algorithms, and Applications*, Chapman & Hall/CRC, 2006.

[5] A. Dong and H. Li, Ontology-based information integration in virtual learning environment, *Proc. IEEE/WIC/ACM Int'l Conf. Web Intel. (WI'05)*, 2005.

[6] J. H. Holland, *Emergence: From Chaos to Order*, Oxford University Press, 1998.

[7] C.-C. Huang, R. Kuo, M. Chang, J.-S. Heh, Foundation analysis of emotion model for designing learning companion agent, *Proc. IEEE Int'l Conf. Advanced Learning Technologies (ICALT)*, pp. 326 - 330, 2004.

[8] S. Johnson, *Emergence: The Connected Lives of Ants, Brains, Cities and Software*, Penguin Books, 2002.

[9] J. LeDoux, *The Emotional Brain*, Simon and Schuster, 1996.

[10] M. Minsky, *The Emotion Machine: Commonsense Thinking, Artificial Intelligence, and the Future of the Human Mind*, Simon and Schuster, 2006.

[11] A. Nguyen, T. Nakano, T. Suda, *Learning from nature: Network architecture inspired by biology*, ACM Crossroads, 2004 (http://portal.acm.org/citation.cfm?id=1144389.1144391).

[12] K. O'Regan, Emotion and e-learning, *Journal of Asynchronous Learning Networks*, Vol. 7, No. 3, 2003.

[13] M. Poel, R. op den Akker, A. Nijholt, A. J. van Kesteren, Learning emotions in virtual environments. *Proc. European Meeting on Cybernetics and Systems Research (EMCSR)*, 2002.

[14] P. Shutz, R. Pekrun, G. D. Phye (eds.), *Emotion in Education*, Academic Press, 2007.

[15] Y. Semet, E. Lutton, P. Collet, Ant colony optimisation for E-learning: observing the emergence of pedagogic suggestions, *Proc. IEEE Swarm Intelligence Symposium (SIS)*, pp. 46 - 52, 2003.

[16] Southwest Educational Development Laboratory, How can research on the brain inform education? *Classroom Campus*, Vol. 3, No. 2 (http://www.sedl.org/scimath/compass/v03n02/1.html).

[17] B. van den Berg, R. van Es, R., C. Tattersall, J. Janssen, J. Manderveld, F. Brouns, H. Kurvers, R. Koper, Swarm-based Sequencing Recommendations in E-learning, *Proc. 5th International Conference on Intelligent Systems Design and Applications (ISDA'05)*, pp. 488-493., 2005

Zhengxin Chen
University of Nebraska at Omaha
Department of Computer Science
Omaha, NE 68182-0500, USA
E-mail: zchen@mail.unomaha.edu
Received: November 28, 2007

Zhengxin Chen received PhD degree in computer science from Louisiana State University in 1988. He is interested in a number of issues related to intelligent systems, database management systems, and data mining. Among his publications are three books: *Computational Intelligence for Decision Support, Data Mining and Uncertain Reasoning: An Integrated Approach* and *Intelligent Data Warehousing*. He also co-edited several books, includingIntelligent Agents and Their Applications in Systems Design* and *Data Mining and Knowledge Management*.

International Journal of Computers, Communications & Control
Vol. III (2008), No. 1, pp. 41-50

Composite Predictive Functional Control Strategies, Application to Positioning Axes

Jean-Yves Dieulot, Tarik Benhammi, Frédéric Colas, Pierre-Jean Barre

Abstract: Different predictive control strategies have been validated on a DC motor. ICascaded predictive control, which consists of a cascaded loop where the traditional servo algorithms are replaced by PFCs, could enhance the cycle time. Predictive Functional Control alone is simpler to tune and can exhibit comparable performances, except that the controller is more sensitive to nonlinear phenomena such as dry friction, which were not taken into account into the model and generate a static error.
Keywords: Model-based control, DC motor, Predictive control.

1 Introduction

The traditional cascaded-loop servo algorithm of a positioning device consists of a current, a speed and a position loop, for which the individual controllers within each loop use Proportional or PI algorithms [2, 4]. This control structure is robust with respect to disturbances and easy to tune, loop after loop, when the inner loops dynamics are much faster than that of the outer loops. This is not always the case and the tracking lag may cumulates through the loops thus achieving poor performances.

Among various alternative control algorithms, Model-based Predictive Control which embeds both feedforward and a servo algorithms, is known for its tracking abilities - due to multiple-step-ahead prediction - and robustness with respect to model uncertainties [1]. In this paper, the focus will be on the implementation and fast tuning of the Predictive Functional Control Algorithm introduced by Richalet (e.g. [7, 8, 9, 10, 12]) which has been shown to be able to control a variety of complicated robot structures (see e.g. [11]). However, the main drawbacks of those Predictive Control methods are the need for a preliminary black-box model identification which hampers the implementation in real-time industrial world where tuning procedures should be simple and as short as possible.

Since a global controller may lose some of the advantages of cascaded loops, i.e. rejection of disturbances for each loop, dry friction compensation... . cascaded control structures have been introduced, where both position and speed loop can be replaced by a predictive controller. Since the PFC tracking performance is better, the lag in the inner loops should be reduced and better overall performances is assumed [5, 6].

In this paper, a comparison is drawn for different cascaded Predictive Functional Control strategies, which combines the PFC controller with a grey box model which parameters are related to physical characteristics.

2 Predictive Functional Control

2.1 PFC philosophy

In this section, the outline of model PFC algorithm, which is fully detailed in [7, 9] is recalled. PFC is based on a discrete linear model,

$$\left\{ \begin{array}{r} x_M(n+1) = F_M x_M(n) + G_M u(n) \\ y_M(n) = C_M^T x_M(n) \end{array} \right. \quad (1)$$

x_M is the state variable, un is the input, y_M the system output, F_M ,G_M ,C_M are constant matrices. The predictive control strategy is summed up in Fig. 1. A control sequence is designed to enforce the model output to stick to a reference trajectory y_R at given coincidence points. Over this receding horizon, the reference trajectory which is the path to the future set point, is resetted at every instant and is given by:

$$C(n+i) - y_R(n+i) = \alpha^i.(C(n) - y_P(n)), 0 \leqslant i \leqslant h \tag{2}$$

where $C(n)$ is the set-point, $y_p(n)$ the real process output, α is a parameter $\alpha : 0 \leqslant \alpha \leqslant 1$, which represents the exponential convergence of the algorithm, and thus fixes the closed-loop behavior.

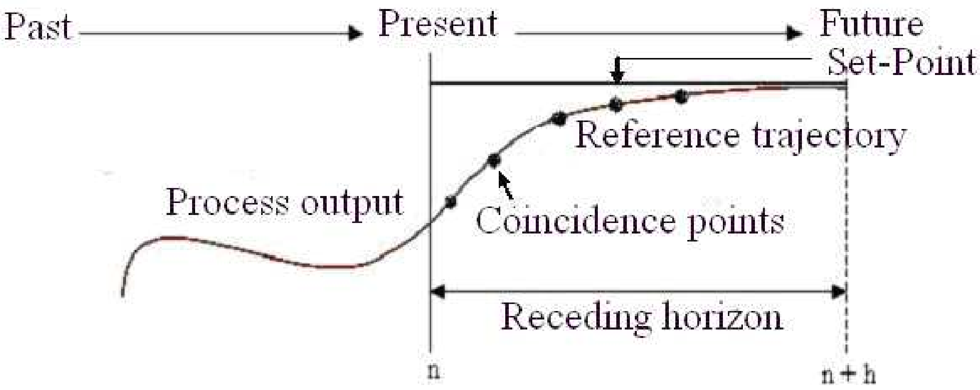


Figure 1: Principle of PFC control

2.2 Computation of control

The future controls sequence should optimize the performance index ((4)) which turns to find the minimum in the least-square sense of the tracking error at fixed set-points with respect to the future control sequence:

$$D(n) = \sum_{j=1}^{n_h} \{\hat{y}_P(n+h_j) - y_R(n+h_j)\}^2 \tag{3}$$

where $h_j, 1 \leq i \leq h$ are the coincidence points.

In order to compute easily the control, it will be assumed that the latter is a composition of a priori orthonormal base functions (usually time-dependent polynomials $U_{B_k}(i) = i^{k-1}$),

$$u(n+i) = \sum_{k=1}^{n_B} (\mu_k(n) U_{B_k}(i)), i \geq 0, \tag{4}$$

where $U_{B_k}(i), 1 \leq k \leq n_B$ are the base functions, the optimization problem reducing to find the corresponding weights $\mu_(k)$.

Of course, one could apply the whole control sequence, but, in fact, only the current control (5) is used, and the whole algorithm is computed again next step.

$$u(n) = \sum_{k=1}^{n_B} (\mu_k(n) U_{B_k}(0)). \tag{5}$$

For computational purposes, the model output is divided into a free (unforced) response, where the control is set to zero, and a forced response to the control (4).

$$y_M(n+i) = y_F(n+i) + y_{UF}(n+i), 1 \leqslant i \leqslant h \tag{6}$$

where $y_F(n+i) = \sum_{k=1}^{n_B} \mu_k(n).y_{B_k}(i), 1 \leqslant i \leqslant h$ is the forced output, and y_{B_k} is the response to the base function u_{B_k}, $y_{UF}(n+i) = C_M^T F_M^i x_M(n)$ is the unforced output. Let the predicted future error be approximated by a polynomial function:

$$\hat{e}(n+i) = e(n) + \sum_{i=1}^{d_e} e_m(n)\, i^m \tag{7}$$

where $h_j, 1 \leqslant j \leqslant n_h$ is a fixed approximation degree,

Finally, the controller is obtained by setting $\frac{\partial D(n)}{\partial \mu} = 0$ (see [9], for details). The parameters only depend on the base functions, the convergence exponent and the coincidence points and can be computed off-line:

$$u(n) = k_0\{c(n) - y_p(n)\} + \sum_{m=1}^{\max(d_c,d_e)} k_m\{c_m(n) - e_m(n)\} + v_x^T x_M(n) \tag{8}$$

where d_c is the degree of the polynomial approximation of the set-point and

$$k_0 = v^T \begin{bmatrix} 1-\alpha^{h_1} \\ 1-\alpha^{h_2} \\ \vdots \\ 1-\alpha^{h_{n_h}} \end{bmatrix},\ k_m = v^T \begin{bmatrix} h_1^m \\ h_2^m \\ \vdots \\ h_{n_h}^m \end{bmatrix},\ v_x = \begin{bmatrix} C_M^T(F_M^{h_1} - I) \\ C_M^T(F_M^{h_2} - I) \\ \\ C_M^T(F_M^{h_{n_h}} - I) \end{bmatrix}^T v$$

$$v = \left(\sum_{j=1}^{n_h} y_B(hj) y_B(hj)^T \right)^{-1} \begin{bmatrix} y_B(h_1) & \ldots & y_B(h_{n_h}) \end{bmatrix} U_B(0)$$

The algorithm consists thus of a feedforward term devoted for tracking error, a disturbance rejection term and of a state-space controller. In the application considered, control tuning will involve a "flat " prediction ($\hat{e}(n+i) = e(n)$) and a parameter α, the parameters will be chosen with a rule of thumb [9] as

$$\alpha = e^{\frac{-3Te}{CLRT}} \tag{9}$$

along with three coincidence points

$$H = (\begin{bmatrix} CLRT/3 & CLRT/2 & CLRT \end{bmatrix} / T_e) \tag{10}$$

where CLRT is the closed-loop rise time and T_e is the sampling period.

3 Industrial control and PFC strategies

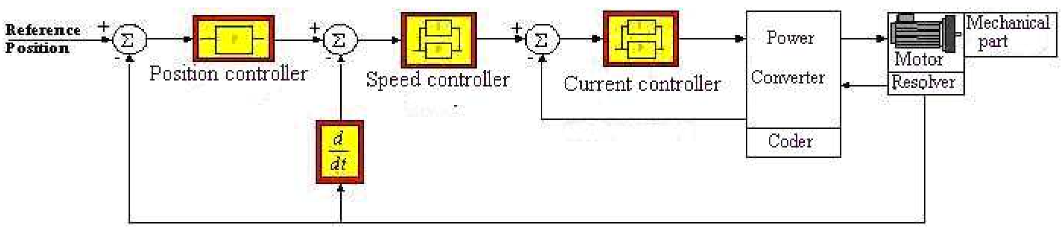


Figure 2: Full structure of the industrial cascaded-loop control

The industrial control consists of nested loops and assumes that the dynamics of the inner loops are the fastest ; the current loop has generally a high dynamics and is thus neglected, the speed loop involves a PI structure and the position loop only a proportional controller, and sometimes a low-pass filter which has been shown to improve the dynamics of axes, particularly in presence of flexibilities. Traditionally, the set-point is a bang-bang in acceleration which takes in account limitations in speed and acceleration and is a time-optimal trajectory. As was explained in introduction, this controller has an easy step-by-step tuning procedure, from the fastest to the slowest loop, and saturations, disturbances can be easily handled at every loop level. However, it is known that performances are not as good as those of a global controller, because the tracking lag is cumulating over the successive loops. The speed controller is simply $C(s) = k_v\left(1+\frac{1}{\tau_v s}\right)$ where k_v, τ_v are the speed loop proportional and integral gains.

As an alternative to this cascaded controller or to a global controller (such as a PFC), a composite cascaded structure where the speed loop PI controller is replaced by a speed loop PFC controller, hence realizing the decoupling of the different dynamics (Fig. 3).

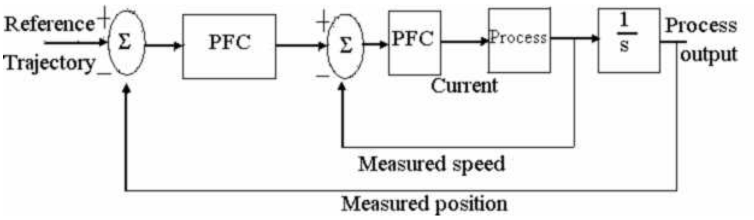


Figure 3: Composite cascaded controller

The last scheme consists of the introduction of a cascaded PFC control which is the same as the classical industrial controller except that PFC servo algorithms are embedded into both loops (Fig. 4).

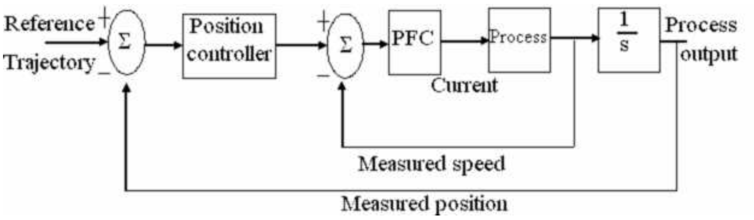


Figure 4: Cascaded PFC controller

4 Modelling and experimentation

The experimental set-up is a brushless DC servo-motor (PARVEX F9M-4-57), equipped with a tacho-generator (F9TS-7-270) and a position coder (resolver), which drives a rotating shaft mounted on bearings, optionnally coupled to an additional flywheel.

When neglecting the electrical resistances, the global model of the brushless motor is:

$$J_{eq}\frac{d\omega}{dt} = C_m - f_v\omega, C_m = K_t i \tag{11}$$

where ω is the rotating speed, C_m and i are the control torque and current, K_t is the torque constant, J_eq is the equivalent motor inertia, f_v is the viscous damping coefficient.

Most PFC algorithms require a proper identification and modeling stage; the motor inertia was estimated from the known motor and load moment of inertia which were added to the inertia resulting from the transmission coupling. Only the viscous and dry friction coefficients were estimated experimentally from a plot of the motor current versus the shaft rotation speed. Characteristics are summed up in Table 1.

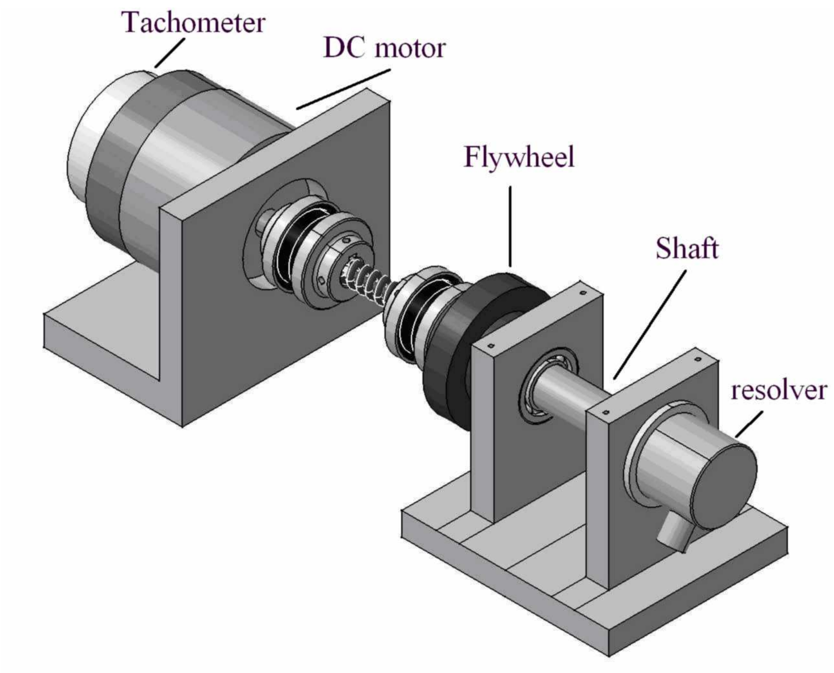


Figure 5: Experimental DC motor

Controller	K_p $(rad.A^{-1})$	$CLRT$ (s)
PFC	N/A	0.02
Cascaded PFC	N/A	Speed loop 0.01 Position Loop 0.06
Composite PFC	10	0.05
Industrial control	10	N/A

Table 1: Motor characteristics

Nominal Torque N.m	Nominal Speed $Tr.min^-1$	Electric Power W	Equivalent inertia $Kg.m^2$	Flywheel inertia $Kg.m^2$	Viscous damping cf. $Nmsrad^-1$
0.346	3000	108	1.5.10-4	8.5.10-4	7.8

Table 2: Control parameters

The measure of speed was low-pass filtered with a filter cut-off frequency of 2.10^{-3} s. Measurements recording and real-time control were achieved using a DSpace 1103 board with a sampling period of $T_e = 5.10^{-4}$ s. The experimental reference position was set to 12 rad, the maximum speed V_max to 150 $rads^-1$, the maximum acceleration to $A_{\max} = 346$ $rads^{-2}$. The traditional trajectory for positioning axes consists of a time-optimal controller [3] with constrained speed and acceleration. The control gains for each experiment are given in Table 2. The integral gain of the PI speed is calculated to compensate the first-order pole, with $\tau_v = \frac{f_v}{J_{eq}}$, the speed gain K_v is tuned so that the control torque does not exceed the peak torque, which gives $K_v = 1$ rad.s.A^{-1}. PFC algorithms were tuned after performing simulations in a way that the maximum current does not overcome that of the industrial loop.

5 Experimental Results and discussion

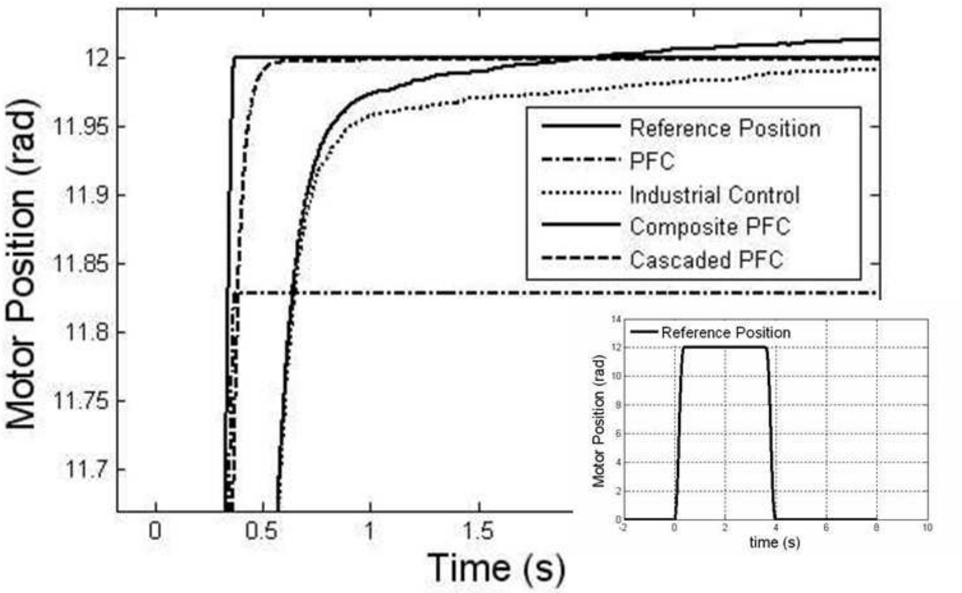


Figure 6: Comparison of control performances

Fig. 6 shows the basic results that will serve as a comparison of the different control structures: one can see that a global controller such as a PFC or a controller with a fast closed-loop position controller exhibits a small rise time due mainly to the cancellation of the phase lag in the speed loop and in the position loop. The performances of PFC controllers outperform that of the traditional industrial control, for a comparable current maximum amplitude. However, these controllers have two main drawbacks: the PFC has an important static error because the dry friction is not taken into account into the model. This phenomenon does not occur with the cascaded loop because these errors appear firstly in the speed loop, and can then be compensated with the position loop as in traditional control. Cascaded PFC seems to be the most appealing, but one has to remind that the tuning is far more delicate because it involves two PFC loops. One should take an appropriate CLRT ratio between the loops (at least 5) in a way that the position loop be truly the fastest.

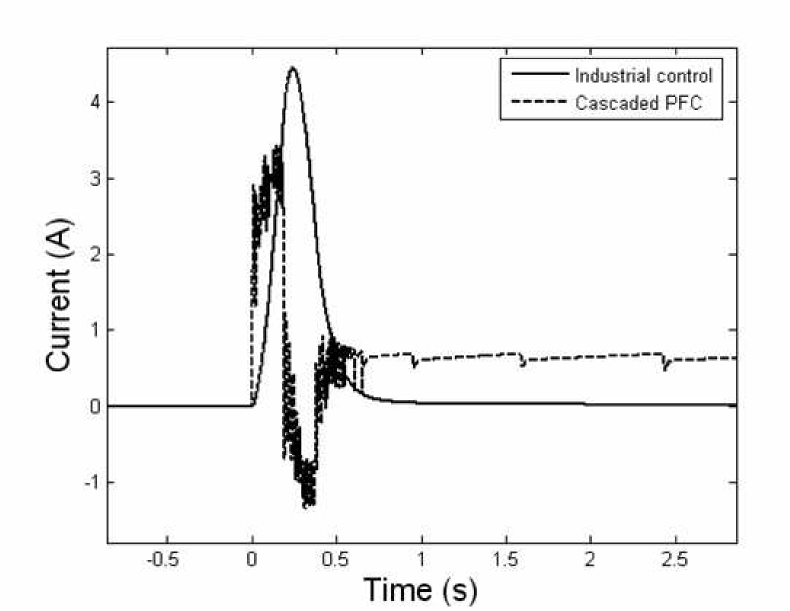


Figure 7: Drive current - control -

Fig. 7 shows that, for cascaded PFC -as for other PFC algorithms - , less energy may be needed, but the current signal is less smooth than with an industrial control scheme; clearly, this could excite vibration modes when a very flexible load is carried.

Most controls are robust when the additional inertia has been removed, only the rise-time is a little higher. The composite controller does not improve the industrial loop by much, except when an external disturbance is applied (e.g. braking with the hand) - results are not shown here -, with a better rejection. In this case, classical PFC is the less robust with respect to other controls.

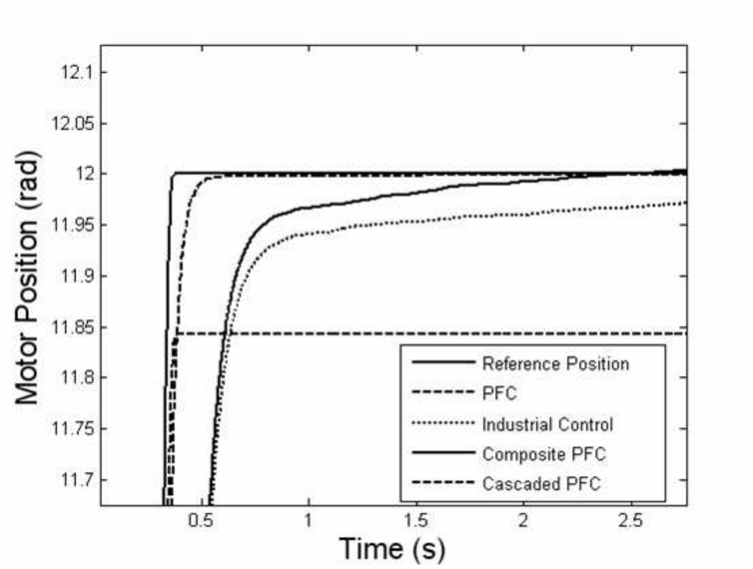


Figure 8: Control Performances with no load

6 Conclusion

Composite Predictive Functional Control algorithms - a cascaded structure where only the speed loop servo algorithms or both speed and position controllers were replaced by PFCs - were validated on a DC servo-motor. The tuning procedure was quite simple and involved the general rigid model which can be found from the physical characteristics of the motor and a single experiment (for the determination of the viscous friction parameter). Cascaded predictive control could improve the tracking and was shown to be more robust to load mass variations. Classical PFC is easier to tune (only one PFC loop) , the closed-loop performances being nearly the same; however, the controller is more sensitive to unmodelled nonlinear phenomena such as dry friction, which were not taken into account into the model. The resulting static error can be unacceptable and alternative solutions have, in this case, to be proposed. Future work will focus on application to flexible manipulators.

Bibliography

[1] Clarke, D. W., Mohtadi, C.,Tuffs, P. S. Generalized predictive control. Part I: the basic algorithm. Part II: Extensions and interpretations, *Automatica*, Vol. 23, 1987, pp 137 - 160.

[2] Ellis, G., Control system design guide (2nd edition), *Academic Press*, Boston, 2000.

[3] Erkorkmaz, K., Altintas, Y., High-speed CNC system design. Part III: high speed tracking and contouring control of feed drives, *Int. J. Machine Tools & Manuf.*, Vol. 41, 2001, pp. 1637 - 1658.

[4] GroSS, H., Harmann, J., Wiegârtner, G., Electrical feed drives in automation, *MCD corporate Publishing*, SIEMENS, ISBN 3-89578-148-7, 2001.

[5] Guemghar, K., Srinivasan, B., Mullhaupt, Ph., Bonvin, D., Analysis of cascade structure with predictive control and feedback linearisation, *IEE Proceedings-Control Theory and Applications*, Vol. 152, 2005, pp 317 - 324.

[6] Hedjar, R., Toumi, R., Boucher, P., Dumur, D., Two cascaded nonlinear predictive controls of induction motor, Proceedings of 2003 IEEE Conference on Control Applications., 2003

[7] Richalet, J., Industrial applications of model-based predictive control, *Automatica*, Vol. 29, 1993, pp 1251 - 1274.

[8] Richalet, J., Estival, J.L., Fiani, P., Industrial applications of predictive functional control to metallurgical industries, Proc. 4th IEEE Conf. Control Applications, 1995.

[9] Richalet, J., Abu, E., Arber C., Kuntze, H.B., Jacubasch, A., Schill, W., Predictive functional control. Application to fast and accurate robot, 10th IFAC World Congress, Munich, Germany, 1997

[10] Rossiter, J. A., Predictive functional control: more than one way to prestabilise, 15th IFAC World Congress. Barcelona, Spain, 2002.

[11] Vivas, A., Poignet, P., Predictive functional control of a parallel robot, *Control Engineering Practice*, Vol. 13, 2005, 863 - 874.

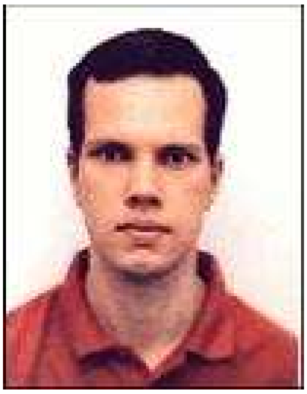
[12] Yim W., Singh S. N., Nonlinear inverse and predictive end point trajectory control of flexible macro-micro manipulators, *J. Dyn. Dyst. Meas. Control*, Vol. 119, 1997, pp 412 - 420.

Jean-Yves Dieulot
ENSAM de Lille
Research Technological Team CEMODYNE
8 bd Louis XIV, 59000 LILLE Cedex
E-mail: jean-yves.dieulot@polytech-lille.fr

Tarik Benhammi
ENSAM de Lille
Research Technological Team CEMODYNE
8 bd Louis XIV, 59000 LILLE Cedex
E-mail: jean-yves.dieulot@polytech-lille.fr

Frédéric Colas
ENSAM de Lille
Research Technological Team CEMODYNE
8 bd Louis XIV, 59000 LILLE Cedex
E-mail: frederic.colas@centraliens-lille.org

Pierre-Jean Barre
ENSAM de Lille
Research Technological Team CEMODYNE
8 bd Louis XIV, 59000 LILLE Cedex
E-mail: barre@lille.ensam.fr
Received: November 6, 2007



Jean-Yves Dieulot graduated from French Ecole d'Ingénieurs Institut Industriel du Nord in 1990, and obtained a PhD from the University of Lille in 1993. He is currently Associate Professor at Ecole Polytechnique Universitaire de Lille, France, and with LAGIS (Laboratory of Automatic Control) His main interests are in fuzzy, nonlinear and robot control.

Tarik Benhammi graduated from Ecole Nationale Supérieure des Arts et Métiers, in Meknès, Morocco, in 2007.

Frédéric Colas graduated from Ecole Centrale de Lille, France, in 2003. He has obtained a PhD from Ecole Centrale de Lille, France, in Robotics and Automatic Control, which was funded by cartesian robot manufacturers.

Pierre-Jean Barre is a Full Professor and Head of Ecole Nationale Supérieure des Arts et Métiers, in Lille, since 2004. He has also developed a Technological Research Platform devoted to high-speed flexible robot control and planning, funded by many French and European manufacturers.

International Journal of Computers, Communications & Control
Vol. III (2008), No. 1, pp. 51-59

Mobile Message Passing using a Scatternet Framework

Brendan J. Donegan, Daniel C. Doolan, Sabin Tabirca

Abstract: The Mobile Message Passing Interface is a library which implements MPI functionality on Bluetooth enabled mobile phones. It provides many of the functions available in MPI, including point-to-point and global communication. The main restriction of the library is that it was designed to work over Bluetooth piconets. Piconet based networks provide for a maximum of eight devices connected together simultaneously. This limits the libraries usefulness for parallel computing. A solution to solve this problem is presented that provides the same functionality as the original Mobile MPI library, but implemented over a Bluetooth scatternet. A scatternet may be defined as a number of piconets interconnected by common node(s). An outline of the scatternet design is explained and its major components discussed.
Keywords: Bluetooth, Scatternet, Message Passing, Network Formation

1 Introduction

Mobile technology is one of the fastest growing fields of technology, with over one billion mobile phones shipped during 2006 [8]. The power of mobile devices is also growing quickly, in October 2005 ARM announced the ARM Cortex A8 [1][2], having a clock speed of 1Ghz. This increase in both availability and performance makes mobile devices a prime candidate for parallel computing systems. Having a multitude of mobile devices available one can now take advantage of the situation by performing complex computational tasks across several devices. The original MMPI library was restricted in terms of its world size by the upper bound of the piconet network standard, this limits the maximum number of nodes in an MMPI world to eight. The evolution of the MMPI library to allow for scatternet formation requires significantly more work behind the scenes, both to setup the network infrastructure and to allow for complete inter-device communication.

1.1 Need for Mobile Parallel Computing

The MMPI library was created to allow for parallel computing across mobile devices [6]. Mobile devices have very limited resources and processing capabilities. The Nokia 6630 and 6680 [14] mobile phones have 220Mhz processors and just a few megabytes of memory. Along with such limited capabilities they also have a finite amount of battery power. Running processor intensive applications on such devices drains battery power at a higher rate than standard phone usage. Therefore if one device doesn't have sufficient battery power it may not be capable of solving a complex problem. Such a problem would also take too long to process from the users perspective. Splitting the processing among several devices not only speeds up the processing, but also distributes the battery drain across all devices, allowing more computationally intensive tasks to be performed.

1.2 Review of Scatternet Formation Algorithms

The Bluetooth Specification [3], describes the concept of a scatternet. A scatternet (Figure 1) is defined as two or more piconets joined together through the mechanism of a common node (bridging node). Significant research has been conducted on scatternets, much of it focusing on how they can be optimized. Miklos [10] described some of the aspects of scatternet formation, including the performance bottleneck caused by the bridging node switching between the frequency hopping patterns of its masters.

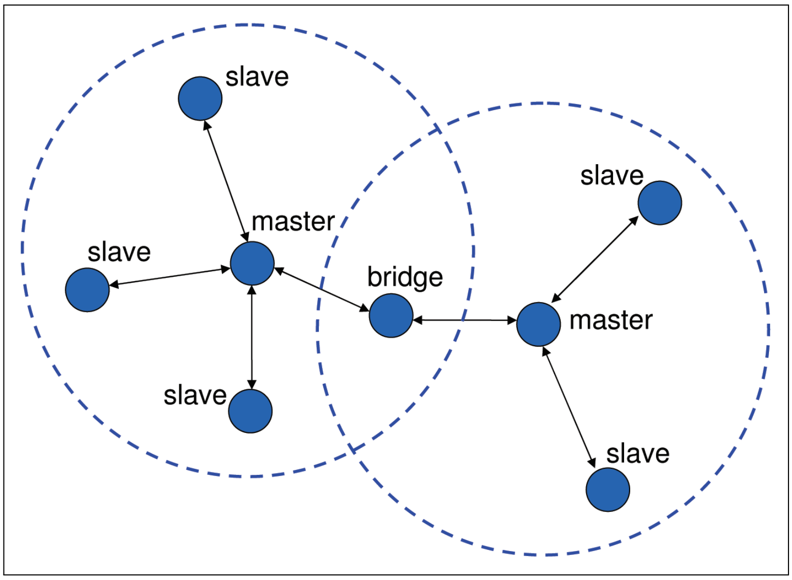


Figure 1: Scatternet Topology

The DynaMP project [13] is a mobile parallel computing architecture that uses Bluetooth Scatternets as the underlying infrastructure. The application area for this body of work is in mobile robotics, specifically that of the Cybot toy. The main reason for the parallel computing architecture is real-time image processing of data acquired from the robots sensor system. To avoid the upgrading of the processing capabilities of the robots, the path of distributing the processing requirements across a group of robots was investigated. The target architecture is the TINI from Dallas Semiconductor that uses java as its native environment. The iPAQ PDA is also used, running a Linux based OS and the Keffe JVM.

Unlike native message passing libraries such as the C and Fortran based MPI that use a static number of nodes, a far more dynamic approach is required within the mobile environment. The head node is therefore responsible for discovering all the active nodes within the network. This is achieved by broadcasting a Process Request packet throughout the network. An example of a simple node topology is given in the paper that shows a linear like architecture, thereby communication between distant nodes would certainly require one or more intermediary nodes for forward on the message.

Bluetrees [15] generates a tree-like scatternet. The network formation algorithm is initiated by a single node that forms the root of the tree. The root node begins by acquiring slave devices that are within it vicinity. These in turn page their own neighbours. In order to limit the number of slave devices connected to another node at the level above some branch reorganization may be required.

Jayanna & Zaruba [9] use an approach where by all nodes maintain a dynamically generated list of its neighbours based on the number of hops required to reach the node in question. The strategy ensures that if neighbour information is included for one and two-hop piconets, then two adjacent piconets can share only one bridging node. Therefore all nodes of one piconet share a single path to all nodes of a neighbouring piconet.

1.3 Mobile Message Passing Interface

The Mobile Message Passing Interface (MMPI) [6] provides many of the functions that can be found in a standard MPI [11] [12] implementation. The main difference between MMPI and standard MPI implementations is that it is designed for mobile devices that communicate via Bluetooth [4] [5]. The library has one drawback that makes it less than an ideal candidate as a platform to support parallel computation on mobile devices. It was designed to operate only on a Bluetooth piconet of up to eight devices. In a parallel computing system in general one can achieve faster computation by throwing more processors at the problem.

2 Enhanced MMPI Library Structure

The problem of creating scatternets and performing communication within them after they have been created is a complex one. The original MMPI library could not simply be adapted, as the differences between communication in a piconet and communication in a scatternet are too great. A new solution was therefore designed from the ground up, whilst retaining all of the original functionality. The enhanced library comprises of a number of distinct components that provides an abstraction from lower level layers.

2.1 Components of the Library

The enhanced MMPI library is made up of a number of components. The most important parts of the architecture are shown in Figure 2

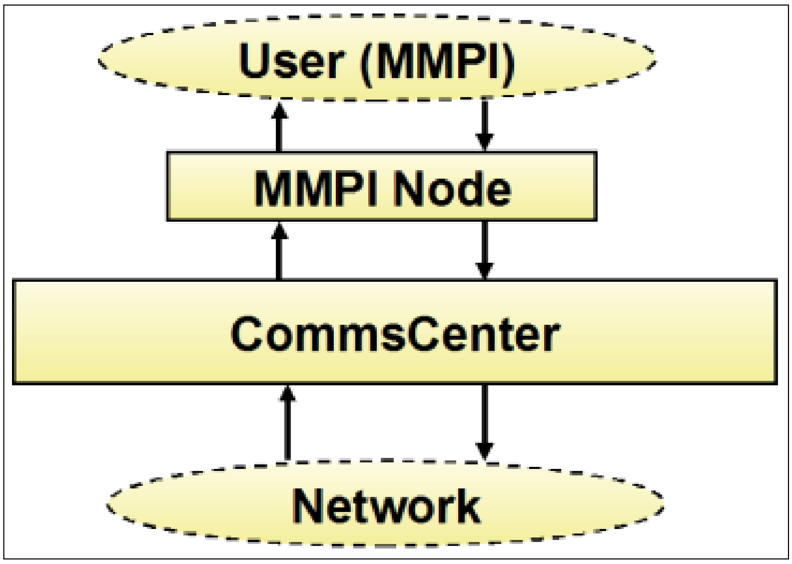


Figure 2: Library Components

The CommsCenter class forms the heart of the library. Its role is to receive raw data from the network and translate it into MMPI messages. The MMPINode class provides the interface between the CommsCenter and the MMPI class and also performs the initial device discovery. Finally, the MMPI class is the interface to the library as a whole, and is the only class whose methods are exposed to the developer using MMPI. Relevant data is fed up through the hierarchy, starting at the CommsCenter and continuing up to the MMPI class. This simplifies matters greatly as information that is relevant at a particular level of the hierarchy is available only at that level.

2.2 Messages

On receipt of a message by the CommsCentre it must inspect the header to identify the type of the message it has received and accordingly perform the appropriate action.

The message types are categorised as follows:

- Bridge - The node should take up the role of bridging node.

- Master - The node should take up the role of master.
- Slave - The node should be a slave exclusively.
- Confirm - The network formation is complete.
- Data - The message contains a data payload.

The first four messages are used only during the formation of the scatternet and the Data message is used only after the scatternet is formed. Messages will only be processed by the node for which they are addressed, otherwise they will be forwarded by the message routing system.

2.3 Scatternet Formation

Formation of the scatternet is initiated at a chosen node (the 'root node') by first performing an inquiry for devices that provide the MMPI service. The root node then determines how many piconets are required to support this number of nodes. In the case of thirteen MMPI capable devices are discovered then two piconets will be created. The root node selects a device to be the bridge node and sends it a list of addresses of the other nodes in the network (Algorithm 1).

```
Data: List of all MMPI capable devices
initialize list of devices to send to bridge node;
foreach device in the list do
    if bridge node then
        create slave connection;
        add bridge node to routing table;
    else if prior to bridge node then
        create slave connection;
        add slave node to routing table;
        send Slave message;
    else if after bridge node then
        add device to list of devices to send to bridge node;
        add node to routing table;
add number of devices to Bridge message;
add list of devices to the Bridge message;
send Bridge message;
```

Algorithm 1: Establishing initial connections at the root node

The bridge node then chooses one of these to be the master of the other piconet and sends it the list minus the device chosen (Algorithm 2). The second master makes connections to each device on the list, completing the scatternet formation. It then sends a confirmation message which propagates through the network via the message routing system.

2.4 Message Routing

In order for a message to reach a recipient with which the sender has no direct connection, the message must be routed through the network. The library uses a simple message routing table (Table 1) where each node keeps a table of all the nodes except itself. Each entry in the routing table contains an index that is used to navigate between nodes.

Data: list of devices sent by root node
initialize list of devices to send to additional master;
foreach *device in the list* **do**
    if *second master* **then**
        create master connection;
        add second master to routing table;
    else
        add node to routing table;
add number of devices to Master message;
add list of devices to the Master message;
send Master message;

Algorithm 2: Establishing connections at the bridge node

Node	Node 2	Node 0	Node 5	Node 6
0	0	-	0	0
1	0	0	0	0
2	-	1	0	0
3	0	2	0	0
4	0	3	0	0
5	0	4	-	0
6	0	4	1	-
7	0	4	1	1
8	0	4	1	2
9	0	4	1	3

Table 1: Routing tables for nodes 2, 0, 5 & 6 of a ten node scatternet

In order to send a message from node 2 to node 8 (Figure 3), the following steps are taken. Node 2 looks up node 8 in its routing table (Table 1). Since node 2 has only one link, the index will be 0, and the message will be sent through that link to node 0. Node 0 then looks up its routing table, finding the index 4, and sends the message through that link to node 5. Node 5 looks up the routing table again and sends the message through link 1 to node 6. Node 6 then looks up node 8, finding the index 2 and sends the message to it through that link.

In summary, for a slave node of piconet one (on the left) (Figure 3) to communicate to a slave node of piconet two (on the right) all communications traffic is first routed through the master node for piconet one and forwarded on to the bridge between the two networks. This is then picked up the the master node of piconet two and again forwarded on to the correct end point. For a node such as the master node of piconet one to communicate with the master node of piconet two, data need only be forwarded directly through the bridging node.

3 Using the Library

Using the library to write message passing programs is nearly identical to the original library. The operations that were supported in the original version of the library are still supported.

3.1 Creating an MMPI Node

To create an MMPI node, the developer first calls the Initialize(...) method of the MMPI class. A handle to the MIDlet which is using the MMPI library needs to be passed, as does a Boolean value

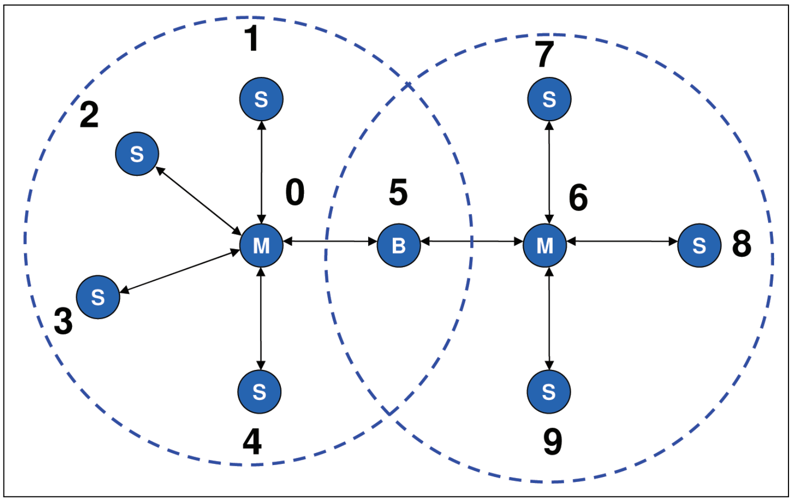


Figure 3: Structure of a ten node scatternet topology

indicating whether the node is the root node. The developer needs to determine how this value will be set themselves, and it should be ensured that all non-root nodes are set up before the root node. This is because calling Initialize(...) activates the Bluetooth device and registers the MMPI service, allowing the node to be discovered. The root nodes reaction to the Initialize(...) call will be to create the network. The non-root nodes reaction will be to wait until this event has occurred and completed. When network formation is complete, the program can continue execution.

3.2 Message Passing Operations

After calling Initialize the communications world has been created thus giving the developer the ability to work with both point to point and global communication methods (Listing 1). Unlike many methods of the original MMPI library (and the MPI libraries), several of the new communications methods return the actual data received as an object. This is quite different to the other libraries that would pass a reference into the method for population with the received data.

```
int Broadcast(Object buffer, int count, int dataType, int root, int tag)
int Scatter(Object sendbuf, int sendcnt, int sendtype, int rcvcnt, int rcvtype, int root)
int Send(Object buffer, int count, int dataType,int dest, int tag)
Object Receive(int count, int dataType, int source, int tag)
Object Gather(Object sendbuf, int sendcnt, int sendtype, int recvcnt, int recvtype, int root ↩
    )
Object Reduce(Object sendbuf, int count, int datatype, int op, int root)
```

Listing 1: MMPI Communication method prototypes

4 Evaluation

To fully test the library one needs a significant number of mobile devices (far in excess of eight). Such resources were unavailable at the time of implementation, but the system was developed and tested using the J2ME emulators of the Sun Wireless Toolkit. The system performed very well on the emulator, and several applications were developed for test purposes, including such classical applications as the Mandelbrot Set.

Using the Mandelbrot Set as an example it takes on average 139,360ms to generate an image of 200^2 pixels at 500 iterations on a single device using the WTK Emulator. This is significantly slower that a real world phone such as the Nokia 6630, capable of generating the same image in 52,344ms. When multiple instances of the emulator are running and carrying out a complex processing task they do not appear to achieve total parallelism as one would expect. Many of the emulated devices however do give processing times as expected on the order of 13 to 14 seconds, when the application is executed with a set of ten phones.

4.1 Other Applications

Although we have developed the framework mainly to alleviate the node restriction on the existing version of MMPI, it is not limited to this use only. MMPI itself has been used as a communications library for Bluetooth gaming [7] and this framework could be used to increase the number of players that may participate in the game.

5 Conclusion

This paper has outlined a library for creating scatternet based applications, which is capable of parallel computing on adhoc Bluetooth networks of more than eight devices, using the scatternet framework. The structure and operation of the library has been outlined. It was found that there is a performance overhead associated with message routing and parsing. The framework can be used for a myriad of applications, such as multiplayer gaming or chat applications, quite easily. The most important aspect of the framework is that it can be deployed to any mobile device with MIDP 2.0 and Bluetooth functionality, therefore it is capable of running on a significant number of todays mobile devices.

6 Acknowledgment

Development of the MMPI Library was funded under the “Irish Research Council for Science, Engineering and Technology” funded by the “National Development Plan”.

Bibliography

[1] ARM. ARM Cortex-A8, 2005. `http://www.arm.com/products/CPUs/ARM_Cortex-A8.html`.

[2] ARM. ARM Introduces Industry’s Fastest Processor for Low-Power Mobile and Consumer Applications, Oct 2005. `http://www.arm.com/news/10548.html`.

[3] Bluetooth-SIG. Bluetooth Specification Version 1.1.

[4] Bluetooth.com. The Official Bluetooth website. `http://www.bluetooth.com/`.

[5] Bluetooth.org. The Official Bluetooth Membership Site. `http://www.bluetooth.org/`.

[6] D. C. Doolan, S. Tabirca, and L. T. Yang., Mobile Parallel Computing, In *5th International Symposium on Parallel and Distributed Computing (ISPDC06)*, pp 161–167, Timisoara, Romania, July 2006.

[7] K. Duggan, D. C. Doolan, S. Tabirca, and L. T. Yang. Single to Multiplayer Bluetooth Gaming Framework. In *6th International Symposium on Parallel and Distributed Computing (ISPDC07)*, Hagenberg, Austria, July 2007.

[8] ITFacts. 1.019 Billion Mobile Phones Shipped in 2006. `http://www.itfacts.biz/index.php?id=P8049`.

[9] D. Jayanna, G. Zaruba, A Dynamic and Distributed Scatternet Formation Protocol for Real-life Bluetooth Scatternets In *Proceedings of the 38th Annual Hawaii International Conference on System Sciences (HICSS05)*, 2005.

[10] G. Miklos, A. Racz, Z. Turanyi, A. Valko, and P. Johansson. Performance aspects of Bluetooth scatternet formation. In *Mobile and Ad Hoc Networking and Computing, 2000. MobiHOC. 2000 First Annual Workshop on*, pages 147–148, 11 Aug. 2000.

[11] MPI. The Message Passing Interface (MPI) Standard. `http://www-unix.mcs.anl.gov/mpi/`.

[12] MPICH. Mpich - Free Implementation of MPI. `http://www-unix.mcs.anl.gov/mpi/mpich/`.

[13] R. Shepherd, J. Story, S. Mansoor, Parallel Computation in Mobile Systems Using Bluetooth Scatternets and Java In *Proceedings of the International Conference on Parallel and Distributed Computing and Networks*, 2004.

[14] Symbian Freak. Nokia 6680 is Loosing the Battle to 6630. `http://www.symbian-freak.com/news/0305/6680.htm`.

[15] G. Zaruba, S. Basagni, I. Chlamtac, Bluetrees - Scatternet Formation to Enable Bluetooth based adhoc Networks In *IEEE International Conference Communications (ICC2001)*, pp 273–277, 2001.

Brendan J. Donegan, Daniel C. Doolan, Sabin Tabirca
University College Cork
Department of Computer Science
College Road, Cork, Ireland
E-mail: d.doolan@cs.ucc.ie, tabirca@cs.ucc.ie
Received: October 18, 2007

Brendan J. Donegan, was a Postgraduate student in the Computer Science Department of University College Cork between 2005-2006, studying Mobile Networking and Computing. He is now working as Graduate Software Engineer for Symbian Software Limited in London. This work is the result of the MSc project titled "Mobile Parallel Computing" he undertook in the Mobile Multimedia group.

Daniel C. Doolan, is currently in the final stages of completing a PhD in the area of Mobile Computing. He holds a BSc in Computer Applications, an MSc in Multimedia Technology, and over half a dozen other degrees at certificate and diploma level in the areas of business and computing. He has authored approximately 40 publications, including 6 book chapters, covering topics such as mobile computing, computer graphics and parallel processing.

Sabin Tabirca is a lecturer in Department of Computer Science of National University of Ireland, Cork. His main research interest is on Mobile and Parallel Computing for Scientific Problems. He has published more than 100 articles in the areas of mobile multimedia, parallel computation, number theory and combinatorial optimization.

International Journal of Computers, Communications & Control
Vol. III (2008), No. 1, pp. 60-68

Evaluation of the Recorded State Mechanism for Protecting Agent Integrity Against Malicious Hosts

Kamalrulnizam Abu Bakar, B. S. Doherty

Abstract: As agent technology is expected to become a possible base platform for an electronic services framework, especially in the area of Electronic Commerce, reliable security protection is a crucial aspect, since some transactions in this area might involve confidential information, such as credit card number, bank account information or some form of digital cash, that has value and might therefore be attacked. In addition, without proper and reliable security protection, the wide spread use of agent technology in real world applications could be impeded. In this paper, evaluation of the Recorded State Mechanism (RSM) previously proposed by the authors is presented. The evaluation examines the RSM security protection and implementation overhead, in order to analyse the RSM security strength and implementation feasibility in real world application.

Keywords: Agent security, Malicious host, Recorded State Mechanism.

1 Introduction

Problem in agent technology arise when agents are used in an open and unsecured environment. For example, a customised agent application is sent out to visit several airline servers (in an open and unsecured environment) to find a suitable flight. In this example, the agent application is allowed to completely migrate to (the agent originating host transfer the agent's code, data and state to the remote server) and execute in (the remote server executed the receiving agent application) the remote server environment, to take advantage of exploiting resource near the data source and thus reducing network traffic [20]. This opens a greater opportunity for the agent application to be abused by the executing host, because the agent application is fully under control of the executing host [10, 19].

An example of attack by the executing host (the malicious host) is to tamper with the agent's data or state, so that the agent will forget all the previous visits and offers held by the agent, and thus force the agent (application) to accept an offer from the malicious host even though the malicious host's offer is not the best offer [10, 17, 19]. This kind of attack is known as a *manipulation attack* [11, 10]. In this attack, the owner of the agent may not know the attack has happened. This is because the malicious host may make subtle changes in the agent's code, data and state, which are difficult to detect, thus enabling the malicious host to achieve its objective. In addition, the agent (application) that returns from the malicious host does not show any different behaviour from an untampered agent, which makes the attack difficult to detect and prevent.

The problem of manipulation attack has been addressed by the authors using the Recorded State Mechanism (RSM) [1, 2]. The RSM uses the state of an agent, which is recorded during the agent execution process inside an execution host environment to detect the malicious host manipulation attack. In this paper the evaluation of the Recorded State Mechanism is presented. The evaluation analyse the RSM's security and overhead its feasibility in real world applications.

The paper is organized as follows: section 2 presents the evaluation of the Recorded State Mechanism, which includes the analysis on the security and implementation overhead of the RSM. Section 3 presents a discussion and the conclusion is presented in section 4.

2 The Evaluation of the Recorded State Mechanism

The Recorded State Mechanism is an integrity protection mechanism that is able to detect manipulation attacks from a malicious host. The mechanism consists of three different types of container, the RecordedReadOnly, RecordedExecuteOnly and RecordedCollectOnly that are used to record the agent state information. This recorded agent state information, which consists of the data of the agent (located in its variables) and the execution information (such as the program counter, the call stack and a few more items) is used for detecting any modification attacks from the malicious host in order to protect the integrity of the agent during agent execution inside the malicious host environment.

The evaluation of the Recorded State Mechanism is presented by examines the RSM security protection and implementation overhead that will be discussed in the next section.

2.1 The Security Analysis of the Recorded State Mechanism

To assess the strength of the Recorded State Mechanism, its ability to handle well-known attacks is discussed in Table 1.

Summary of evaluation of Recorded State Mechanism

The Recorded State Mechanism is able to detect most of the malicious host attacks that try to tamper with the agent's data and state integrity. This mechanism when combined with distributed migration pattern, can prevent collaboration attacks by two or more hosts and extraction of information by the malicious host. However attacks such as an execution host lying about input data cannot be detected or prevented by this mechanism, because the attack does not alter any state information, and so leaves no trace.

2.2 The Overhead of Implementing the Recorded State Mechanism

The experiments to measure the overhead of implementing the Recorded State Mechanism are conducted using six 400 MHz Sun Ultra Sparc 5 workstations with 128 MB of main memory. Each of the workstations is running the Solaris 8 operating system and is connected to the others using 100 Mbit/s UTP[1] cable. All of the workstations involved in this experiment were situated in the same room.

In this configuration, one workstation will be chosen among the six workstations to be the home host for the agent, and only this host has the permission to manage and dispatch the agent. The rest of the workstations are assumed to be the remote host, having only the capability to receive and dispatch the agent back to its home host.

To evaluate the security overhead for implementing the Recorded State Mechanism in an agent-based application, times are measured starting from sending of the agents to the remote hosts and ending by receiving the agents back from the remote hosts. The times, are measured using the "System.currentTimeMillis()" method in the Java language. This method produces a specific instant in time with millisecond precision [14].

The experiments are done using four different remote host starting with one remote host, two remote hosts, three remote hosts and five remote hosts on three different types of agent: plain agent[2], agent with cryptographic security mechanism (Crypto) and agent with these security mechanisms and the recorded state mechanism (Crypto+RSM). There are four different experiments used in examining the overhead for implementing the Recorded State Mechanism: one input and one cycle, one hundred inputs and one cycle, one input and one thousand cycles, and one hundred inputs and one thousand cycles. The input is

[1]Unshielded Twisted Pair Category 5e
[2]agents without security mechanisms

Attacks	Solutions
The malicious host could make subtle changes on read-only data inside the RecordedReadOnly container to enable it to achieve its objective, in such a way that the owner's digital signature that was signed in the RecordedReadOnly container still remains valid.	This attack can be ruled out, because the digital signature (using SHA1), which is used in the Recorded State mechanism is secured against brute-force collision and inversion attacks, where by using the SHA1 as the digital signature function could make the attacker computationally infeasible to find a message which corresponds to a given message digest, or to find two different messages which produce the same message digest.
The malicious host could also make subtle changes on both the read-only data and the digital signature for the RecordedReadOnly container, in order to make both of them appear to be valid.	This possible attack can also be ruled out because in order to create a new digital signature that will be valid for other host, the malicious host needs to have a private key of the agent owner. However, only the key owner has this key and no other entity can produce this key from a modified hash value.
The malicious host could also tamper with the agent state recorded in the RecordedExecuteOnly and RecordedCollectOnly container by modifying the agent state before the state is recorded into both containers. This due to the fact that the recorded process of the Recorded State Mechanism is under the malicious host's control and therefore, the malicious host can do anything to it.	This attack can also be ruled out because the malicious host has to use its own private key that contains its identity in order to compute and re-compute the digital signature on the tampered state, thus revealing itself during the verification process.
The malicious host could also attack the agent by launching collaboration attacks in cooperation with two or more consecutive hosts in order to deny the checking process for detecting any malicious host attack from the previous visit or to remove any agent state that records the changes made by the previous host on the agent during its execution session. In addition, the malicious host could also use the collaboration attack to extract information from the agent to win some competition over other hosts.	The attack can be ruled out since the used of master-slave agent architecture in implementing the Recorded State Mechanism only allows different agents to be sent and served by different remote hosts. An agent visits only one host, thus precluding the collaborating attack. In addition, the information extracted from a single agent does not give enough information to the malicious host to allow it to win any competition over other hosts because the extracted information is not sufficient by itself.
The malicious host could also lie about the input data, which is recorded in the RecordedExecuteOnly and the RecordedCollectOnly containers in order to deceive the owner of the agent.	This attack is unable to be ruled out by the Recorded State Mechanism because the input data that was supplied by the malicious host is assumed to be a correct data by the agent, since only the malicious host knows whether the input data is correct or incorrect. However, the owner of the agent knows the identity of the host, which supplies the input data to the agent because all the data and state are digitally signed by the execution host before the data and state leaved the execution host. Thus, the owner of the agent knows which execution host is responsible for supplying the false input data.
The malicious host could alter the Random Sequence 3-level obfuscation algorithm to execute in many different ways (incorrect execution attack)	This attack can be ruled out since the Recorded State Mechanism will check the results gathered by the returning slave agent by executing the same execution process that is assumed, has been done by the slave agent inside the remote host execution environment.

Table 1: Possible attacks and solutions of the Recorded State Mechanism

represents a character. This character is use as a data that need to be protected by the agent. The cycle, on the other hand represents a loop that is used to simulate an agent tasks.

Note that all of the experiments on the Recorded State Mechanism are using master-slave agent architecture and operates on the distributed migration pattern [1, 2].

The experiment is performed for 20 runs and the result for each run is gathered in milliseconds. From the author's observation, all the 20 runs in this experiment give very similar results and for this reason, 20 runs of the experiment are considered sufficient. The average result of all the 20 runs is taken and converted into seconds. The result is then rounded up and presented in two decimal places as given and illustrated in Tables 2 to 5 and Figure 1 to 4 respectively.

Number of Remote Hosts	Mean			Standard Error			Standard Deviation		
	Plain	Cyp	Cyp+RSM	Plain	Cyp	Cyp+RSM	Plain	Cyp	Cyp+RSM
1	1.54	29.15	28.91	0.003	2.18	1.23	0.01	9.73	5.52
2	2.49	30.89	31.11	0.003	2	1.38	0.02	8.93	6.19
3	3.37	31	32	0.004	0.93	0.98	0.02	4.15	4.38
5	5.35	36.36	36.03	0.011	1.5	1.87	0.05	6.7	8.37

Plain = Without Cryptographic Mechanism
Cyp (Crypto) = Cryptographic Mechanism
RSM = Recorded State Mechanism

Table 2: Summary Statistics of The Recorded State Mechanism Overhead (1 Input and 1 Cycle Experiment)

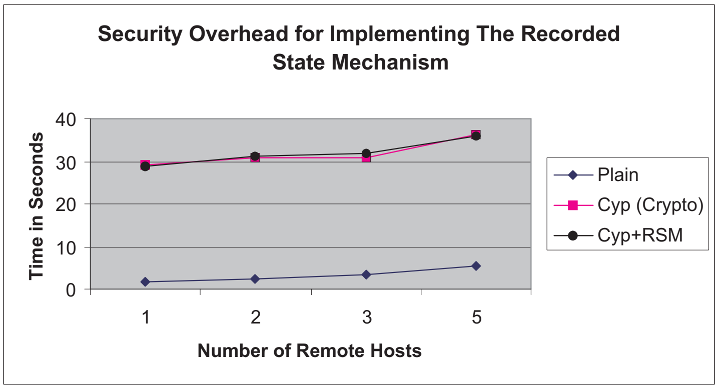


Figure 1: Security Overhead of The Recorded State Mechanism (1 Input and 1 Cycle Experiment)

Based on the observation on the results gained through the experiments done, it can be seen that the standard error and the standard deviation of the security overhead are similar regarding the number of remote host but different between agents. Agents with security mechanism give larger standard error since the agents have to execute many tasks such as generate the cryptography key, generate digital signature, verify digital signature and execute encryption and decryption.

From the results given in Table 2 and illustrated in Figure 1, it can be seen that the mean of the security overhead is almost the same for agents with security mechanism and agents with security mechanism plus RSM, where the security overhead for the agent with security mechanism plus RSM is just 7.82 % higher than the overhead for the agent with security mechanism. However, both agent's security overheads are higher by up to 1792.86 % than the overhead for the plain agent.

From Table 3 and Figure 2, the security overhead for the plain agent is almost the same as with one input given in Table 2 and Figure 1, but the security overhead for the agents with security mechanism is increased by up to 60.52 % along the security overhead with one input.

Results in Table 4, Table 5, Figure 3 and Figure 4 show that the security overhead for all the agents

Number of Remote Hosts	Mean			Standard Error			Standard Deviation		
	Plain	Cyp	Cyp+RSM	Plain	Cyp	Cyp+RSM	Plain	Cyp	Cyp+RSM
1	1.55	45.43	45.32	0.003	1.21	1.19	0.01	5.42	5.34
2	2.53	45.99	48.21	0.005	1.35	1.83	0.02	6.03	8.18
3	3.37	49.76	49.42	0.002	1.13	1.26	0.01	5.03	5.65
5	5.43	53.09	53.14	0.005	1.09	1.76	0.02	4.86	7.85

Table 3: Summary Statistics of The Recorded State Mechanism Overhead (100 Input and 1 Cycle Experiment)

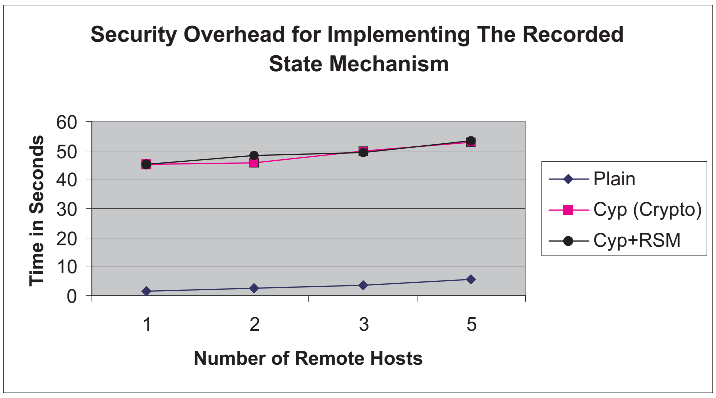


Figure 2: Security Overhead of The Recorded State Mechanism (100 Input and 1 Cycle Experiment)

is similar to the security overhead of the agents with the same number of input but different number of cycle given in Table 2, Table 3, Figure 1 and Figure 2 respectively. Therefore, it is worth noting that number of cycles does not affect the security overhead of the agents.

Number of Remote Hosts	Mean			Standard Error			Standard Deviation		
	Plain	Cyp	Cyp+RSM	Plain	Cyp	Cyp+RSM	Plain	Cyp	Cyp+RSM
1	2.41	27.65	28.94	0.008	0.77	1.55	0.04	3.45	6.94
2	3.53	30.91	31.31	0.008	1.38	1.68	0.04	6.18	7.53
3	5.17	30.94	33.36	0.005	1	1.04	0.02	4.46	4.65
5	7.34	38.46	37.57	0.01	1.29	1.69	0.05	5.76	7.55

Table 4: Summary Statistics of The Recorded State Mechanism Overhead (1 Input and 10000 Cycle Experiment)

Summary of experimental results

It can be seen from the results shown in Tables 2 to 5 and illustrated in Figures 1 to 4 that the implementation of the Recorded State Mechanism does increase the overhead by only up to an acceptable 7.82 % when compared to the agent with security mechanism but 2830.96 % when compared to the plain agent. However, the low overhead of the plain agent is not important since the plain agent does not have any security protection.

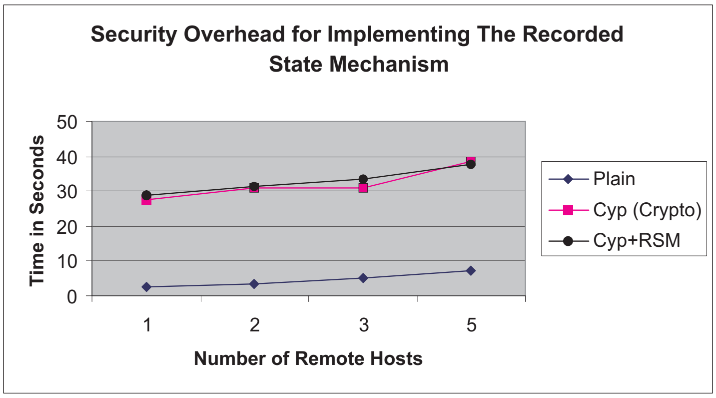


Figure 3: Security Overhead of The Recorded State Mechanism (1 Input and 10000 Cycle Experiment)

Number of Remote Hosts	Mean			Standard Error			Standard Deviation		
	Plain	Cyp	Cyp+RSM	Plain	Cyp	Cyp+RSM	Plain	Cyp	Cyp+RSM
1	2.39	45.93	47.26	0.005	1.06	1.11	0.02	4.76	4.97
2	3.56	48.63	48.85	0.005	0.73	1.42	0.02	3.28	6.36
3	5.17	50.86	51.54	0.008	1.52	1.57	0.03	6.82	7.01
5	7.4	54.36	54.48	0.015	1.8	1.94	0.07	8.05	8.66

Table 5: Summary Statistics of The Recorded State Mechanism Overhead (100 Input and 10000 Cycle Experiment)

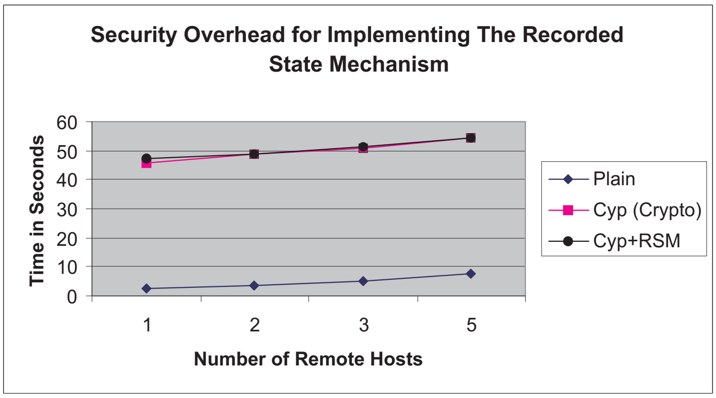


Figure 4: Security Overhead of The Recorded State Mechanism (100 Input and 10000 Cycle Experiment)

3 Discussion

Integrity protection is one of the main requirements for protecting agents against a malicious host attacks. The requirement was successfully fulfilled[3] by the Recorded State Mechanism, which is able to detect most of the malicious host attacks that try to tamper with the agent's data and state integrity.

The analysis on security strength and implementation feasibility of the Recorded State Mechanism in real world applications has been conducted. The security strength of the Recorded State Mechanism has

[3] detect or prevent some attacks and made others more difficult

been analysed by evaluating the mechanism against well-known attack scenarios, and from the results, it can be seen that the mechanism is capable to prevent or detect some of the attacks and made other attacks more difficult. The implementation feasibility is measured by examining the overhead imposed by the mechanism in protecting agents integrity against malicious host attacks. The result shows that the RSM imposed an acceptable overhead.

4 Conclusion

This paper presented the evaluation of the Recorded State Mechanism for protecting the integrity of the agents against the malicious host attacks. The evaluation produced significant results on the strength of the Recorded State Mechanism, where it is able to prevent or detect some attacks and made other attacks more difficult with an acceptable overhead. In conclusion, the mechanism offered significant advances in protection of agents against malicious host attacks and is therefore suitable for use in real world applications.

Bibliography

[1] Abu Bakar, K. and Doherty, B. S. A New Model for Protecting Mobile Agents against Malicious Host. Proceedings of the IADIS International Conference WWW/Internet. IADIS Press, Portugal (2002) 780-784

[2] Abu Bakar, K. and Doherty, B. S. Protecting Mobile Agents Against A Malicious Host Attacks Using Recorded State Mechanism. Proceedings of the 2003 International Conference on Informatics, Cybernetics and Systems. I-Shou University(2003) 396 – 401

[3] Chess, D.M. Security Issues in Mobile Code Systems. G. Vigna(Ed.): Mobile Agents and Security, Vol. 1419. Springer Verlag (1998) 1 – 14

[4] Chess, D.M. and Harrison, C.G. and Kershenbaum, A. Mobile Agents: Are They a Good Idea?. IBM Research Report. IBM Research Division (1995). http://www.research.ibm.com/iagents/publications.html

[5] Corradi, A. and Cremonini, M. and Montanari, R. and Stefanelli, C. Mobile Agents Integrity for Electronic Commerce Application. Information System. Elsevier Science (1999) 519 – 533

[6] Diaz, J. and Gutierrez, D. and Lovelle, J. An Implementation of A Secure Java2-Based Mobile Agent System. Proceedings of The Second International Conference on The Practical Application of Java. Practical Application Company (2000) 125 – 142

[7] Farmer, W.M. and Guttman, J.D. and Swarup, V.: Security for Mobile Agents: Issues and Requirements. Proceedings of the 19th National Information System Security Conference. Baltimore (1996) 591-597

[8] Ford, W. and Baum, M. Secure Electronic Commerce, Ed. 2nd. Prentice Hall (2001)

[9] Guan, X. and Yang, Y. and You, J. POM - A Mobile Agent Security Model against Malicious Hosts. Proceedings of IS & N'99 Spring Verlag (1999) 155 – 167

[10] Hohl, F. A Framework to Protect Mobile Agents by Using Reference States. In: Proceedings of the 20th international conference on distributed computing systems (ICDCS 2000). IEEE Computer Society (2000) 410 – 417

[11] Hohl, F.: Time Limited Blackbox Security: Protecting Mobile Agents from Malicious Hosts. In: G. Vigna (Ed.). Mobile Agent and Security. Lecture Notes in Computer Science, Vol. 1419. Springer-Verlag, Berlin(1998) 92–113

[12] Hohl, F. A Model of Attacks of Malicious Hosts Against Mobile Agents. In 4th ECOOP Workshop on Mobile Object Systems (MOS'98): Secure Internet Mobile Computations. (1998) http://mole.informatik.uni-stuttgart.de/papers.html

[13] Hohl, F. An Approach to Solve the Problem of Malicious Hosts. Institute of Parallel and Distributed High-Performance Systems (IPVR), University of Stuttgart, Germany (1997)

[14] Sun Microsystems, Inc. Java 2 Platform Std. Ed. V1.3.1 http://java.sun.com/j2se/ 1.3/docs/api/index.html (2004)

[15] Kun, Y. and Xin, G. and Dayou, L. Security in Mobile Agent System: Problems and Approaches. Operating System Review, Vol. 34, No. 1. ACM (2000) 21 – 28

[16] Reisner, J. and Donkor, E. Protecting Software Agents from Malicious Hosts using Quantum Computing. Proceedings of SPIE - The International Society for Optical Engineering. IEE (2000) 50 – 57

[17] Sander, T. and Tschudin, C.: Protecting Mobile Agent Against Malicious Hosts. In: G. Vigna (Ed.). Mobile Agent and Security. Lecture Notes in Computer Science, Vol. 1419. Springer-Verlag, Berlin(1998) 44-60

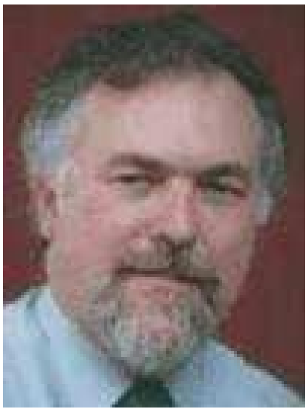
[18] Schneier, S. Applied Cryptography, Ed. 2nd. Wiley & Son (1996)

[19] Vigna, G. Cryptographic Traces for Mobile Agents. In: G. Vigna (Ed.). Mobile Agent and Security. Lecture note in Computer Science, Vol. 1419. Springer Verlag (1998) 137 – 153

[20] Wang, T., Guan, S. and Chan, T.: Integrity Protection for Code-on-Demand Mobile Agents in E-Commerce. The Journal of Systems and Software. Elsevier (2002) 211-221

Kamalrulnizam Abu Bakar
Faculty of Computer Science and Information System
Universiti Teknologi Malaysia
81310 UTM Skudai
Johor D. T.
Malaysia
E-mail: kamarul@fsksm.utm.my
B. S. Doherty
School of Engineering and Applied Science
Aston University
Aston Triangle, Birmingham B4 7ET
United Kingdom
E-mail: b.s.doherty@aston.ac.uk
Received: July 22, 2006

Kamalrulnizam Abu Bakar is a lecturer at Universiti Teknologi Malaysia, Malaysia. He received the diploma and degree of Computer Science in 1994 and 1996 respectively from Universiti Teknologi Malaysia, Malaysia. He then received Masters in Computer Communication and Networks degree from Leeds Metropolitan University, United Kingdom in 1998 and PhD in Network Security from Aston University, United Kingdom in 2004. His current research interests include computer and network security, distributed systems and parallel processing, grid computing, wireless and cellular network.



Bernard S. Doherty (born October 2nd, 1945) obtained the degrees of Bachelor of Engineering (Electrical), Bachelor of Arts and Master of Engineering Science from the University of Melbourne in 1967, 1971 and 1981 respectively. He has held positions with the State Electricicity Commission of Victoria, LM Ericsson Pty Ltd, Swinburne College of Technology (all in Melbourne) and, since 1980, at Aston University (Birmingham, UK), where is presently Lecturer in Computer Science. His main fields of teaching and research are Distributed and Networked applications and Information Security. In addition to supervising a number of Doctoral students, he has developed computer-based administration and teaching software, written a number of papers and presented papers at international conferences.

International Journal of Computers, Communications & Control
Vol. III (2008), No. 1, pp. 69-79

OLC, On-Line Compiler to Teach Programming Languages

Cayetano Guerra Artal, Maria Dolores Afonso Suarez
Idafen Santana Perez, Ruben Quesada Lopez

Editorial Note: The program committee of ICVL 2007 sent to IJCCC nine of the best papers presented at the conference, with the recommendation to be published in an extended form. After a new evaluation, our reviewers decided that five of those papers can be published in IJCCC, two of which in this issue.

Abstract: The advance of Internet towards Web 2.0 conveys the potential it has in a wide range of scopes. The ongoing progress of the Web technology and its availability in teaching and learning, as well as a students' profile increasingly more used to managing an important amount of digital information, offers lecturers the opportunity and challenge of putting at students' disposal didactic tools making use of the Internet. Programming is one of the essential areas taught in university studies of Computer Science and other engineering degrees. At present, it is a knowledge acquired through tutorial classes and the practice with different tools for programming. This paper shows the acquired experience in the development and use of a simple compiler accessible through a Web page. In addition it presents a teaching proposal for its use in subjects that include programming languages lessons. OLC - On-Line Compiler - is an application which greatly lightens the student's workload at the initial stage of programming. During this initial period they will neither have to deal with the complexities of the installation and the configuration of these types of tools, nor with the understanding of multiple options which they present. Therefore students can concentrate on the comprehension of the programming structures and the programming language to be studied.
Keywords: Compiler, e-learning, interactivity, virtual laboratory, web 2.0, video tutorials.

1 Introduction

New Information and Communication Technologies (ICT's) still imply changes in a wide range of society scopes. A society in which the information, its use and distribution in digital format are part of a number of tasks carried out every day. New generations understand their environment in a natural way as well as the use of these technologies. This is reflected in university students who are increasingly getting used to managing this kind of information [1]. From the beginning Internet has meant a milestone in communication at a world wide level [2]. It provides Net users with an hypertext document system with a rich content and hyperlinks that allow to reference another resource: text document, image, animation, audio or video. In its beginning, information was contained in HTML pages that were not updated very frequently. From here its evolution was directed to dynamic HTML pages that make use of CMS with data bases. Next, it was directed to Web 2.0, a concept that has turned into reality in Internet, through which contents and the way of interaction with these contents in Internet have changed. Users, from sharing these contents, have turned their role into the edition and classification of them.

2 Web 2.0

This term, Web 2.0 [3], coined for the first time in 2004, makes reference to a new vision of the Web which has evolved towards users' communities, interaction and social networks. Amongst the technologies that bring the Web 2.0 into reality we find: the ones that use the Web platform to host desktop applications; the ones that separate content and design using style sheets; the ones that support RSS or the ones that allow the management of users and communities. In the same way, there exists a set of Web services that can be considered indicators of the advance towards Web 2.0 [4]. These services provide communication mechanisms that make it possible to present information to users actively. Amongst these services we can find advertising services, shared photo-database, community-generated tag database, delivery of contents, encyclopaedias or personal web pages. Web navigators have experienced an important progress with regard to their function. They have been evolving from their beginnings, in which their function consisted in showing the contents of static web pages and their hyperlinks. Later on they went further, interpreting the interfaces that show one or various data bases' content. At present they support newest technologies that allow not only the interaction with dynamic web pages but also a wide range of web services. Amongst them social networks, that promotes information interchange between users. Internet has undergone a change which has made it become a relevant instrument for teaching and knowledge spreading, no matter the subject area. The presence of e-learning in Internet has allowed to increase education quality and its disposition. Its use to create teaching applications is fully interesting, being able to use, among other features, interactivity.

3 OLC: Learning Programming

Nowadays, programming is one of the essential areas taught in university studies of Computer Science and other engineering degrees, as well as in diplomas of Computer Science. At present, it is a knowledge acquired through theoretical classes and the practice with different tools for programming such as editors, compilers, linkers, debuggers or interpreters. In addition to this we find teacher tutorial classes. Being included in all programming subjects, compilers generate the executable programs made of the instructions written by the programmers. Compilation is a process carried out by means of the succession of a set of operations through which, using the instructions written in a programming language, we obtain the code written in another language that is understood by the computer. This is how we obtain executable programs. The Web 2.0 is at its very peak, this fact and the change in the web navigators' function allow to make use of them as production tools such as text editors, spreadsheets or, as we expound in the present work, a compiler. In this way we can move a multilanguage IDE from a computer to a Web page. OLC -On Line Compiler- is an application which greatly lightens the student's workload at the initial stage of programming. Its use is especially intended for subjects where the students must learn how to make programs. During this initial period they will neither have to deal with the complexities of the installation and the configuration of these types of tools, nor with the understanding of multiple options which they present. Therefore students can concentrate on the comprehension of programming structures and the programming language to be studied. The use made of the compiler in this initial stage is restricted to create programs from a set of instructions free of errors. The student will have written these instructions and the compiler will have helped to correct them. This way in later stages of the learning process and once the students have acquired the basic knowledge of the programming structures and the programming language, they can start using compilers with more complexities in the installation and configuration tasks as well as with a higher number of options. The knowledge acquired by the students in this first stage of the learning process helps them to get a better comprehension of the use and handling of the compilers.

3.1 Functionality

OLC interface is simple and intuitive.An interface defines the communication boundary between two entities, in this case between the students and the application. After the student identification, s/he must choose the programming language with which s/he is going to work. This can be performed from the selection language menu. Figure 1.

Figure 1: Welcome screen. Where the student chooses the programming language to work with.

Once the programming language is chosen, the screen on Figure 2 will be displayed. The tabs menu located at the top of the screen, offers users the navigation through the editor, the files, the tutorials and other sections.

In the section "My files" a list with the user's files located on the server for that language is shown. These files are displayed by the last modified date. The students can manage their files using the available options. They can also load files in the server and work with them. Under the tabs menu, the tools bar can be found, whose options make it possible to work with different files and the code. Below the screen is divided into two text areas:

- One for the code, at the top, where students will write the code of their programs.
- One for the results, at the bottom, only for reading, that will give information about the different actions performed in the files.

Local files are shown as a list with a colour code used to identify them. Figure 3.

Apart from the local files the application has a set of tutorials in video. By using them the information transmition can be carried out in a more efficient and interesting way for students. Through these videos Figure 4, a learning process can be established. These video tutorials have got a clear purpose: to assist users in learning how to manage the compiler and to follow the practical classes. These video tutorials are delivered through files embedded in the web page of OLC. This kind of material has got an increasingly didactic interest, since students will have the possibility of viewing again those chapters of the video where some doubts may have arisen. They could do this as many times as necessary [5] and from any device [6] with an Internet connection.

In the server we can find also a set of local files with examples. The teachers after the lessons can propose practical exercises using the different examples that can be found in the folders on-line. During the teaching period they can check the results of students' work, directing them in their learning process.

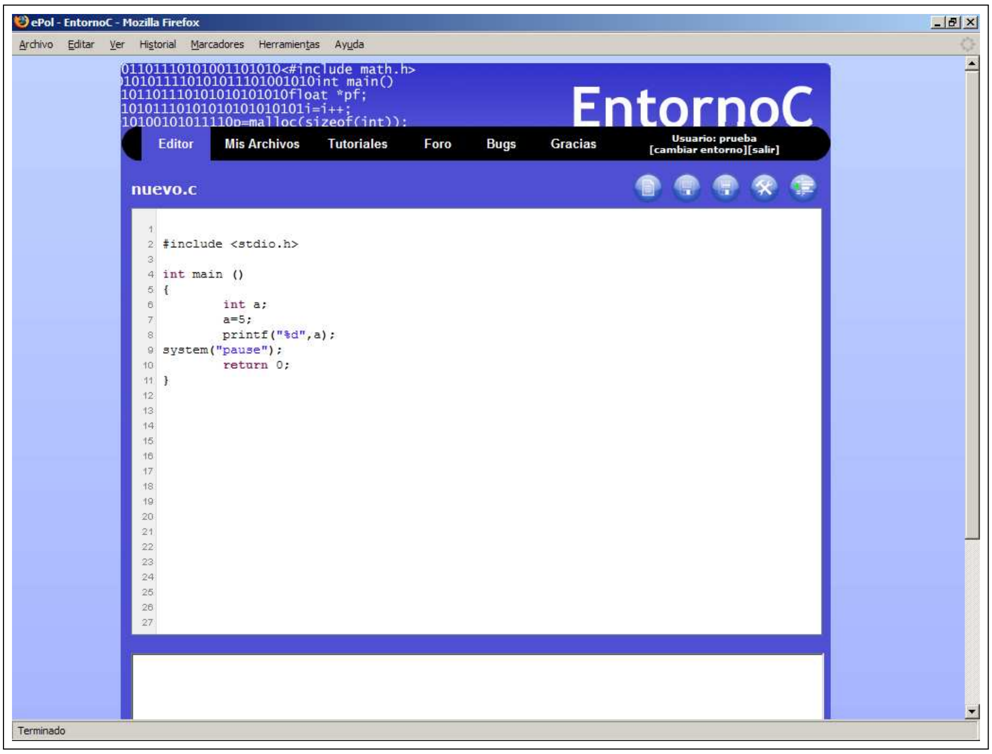


Figure 2: OLC Work screen. With the tabs menu, the tools bar, and two text areas: one for the code and the other one for the results.

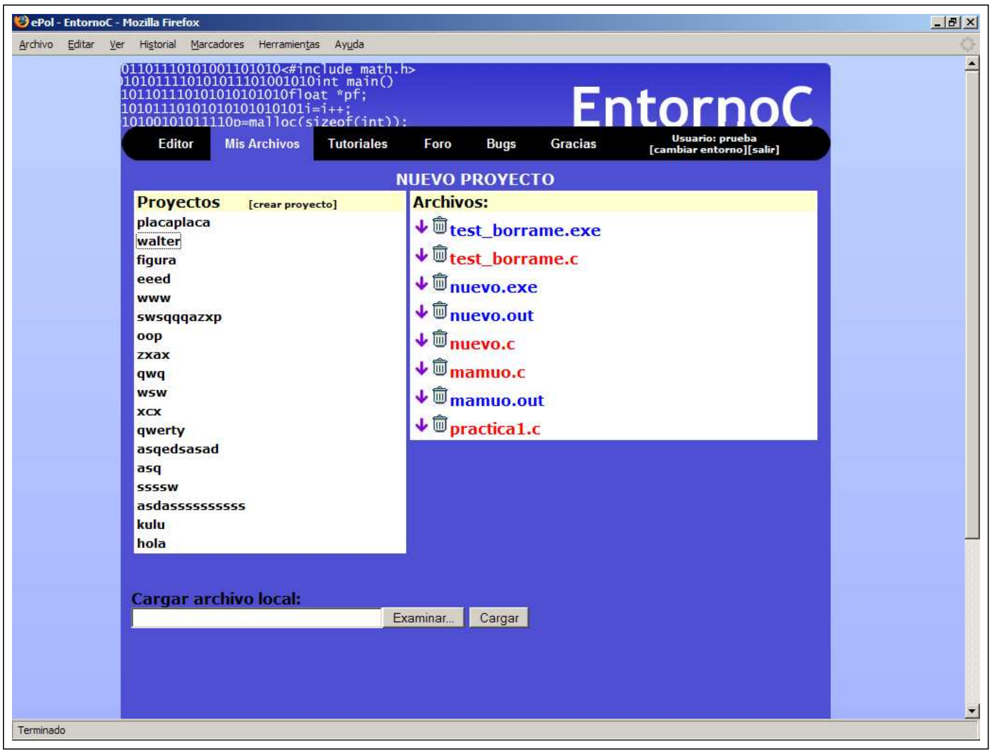


Figure 3: List of local files, with a colour code used to identify them.

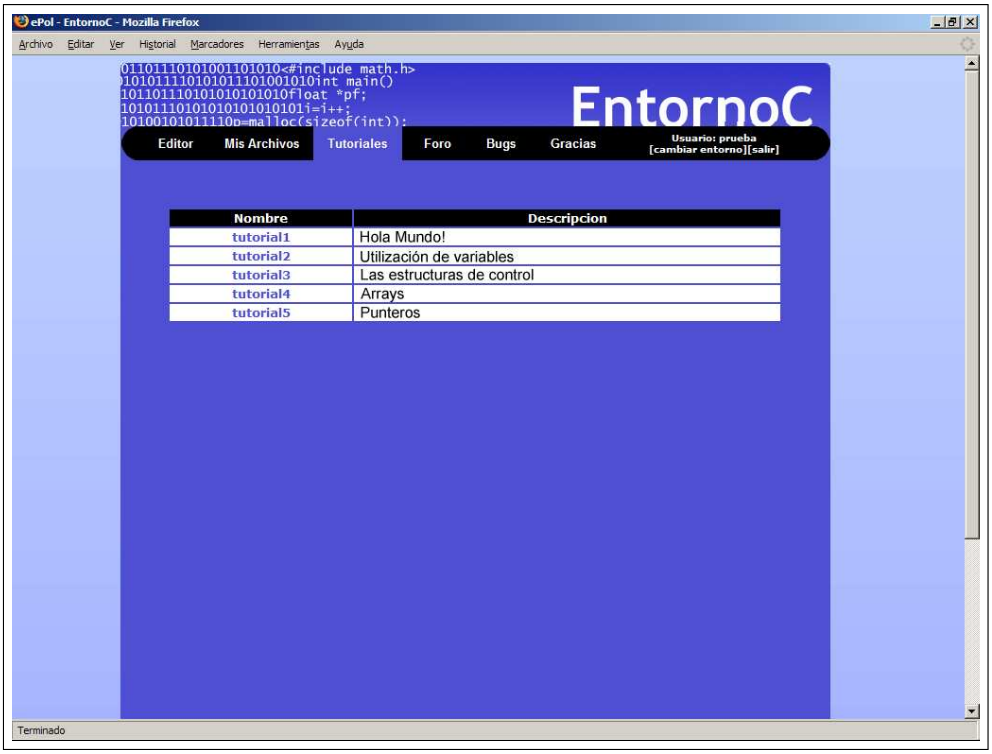


Figure 4: Multimedia Tutorials.

4 Teaching proposal with OLC

The subject "Fundamentals of Computer Science" is taught in the first year of various engineering degrees, amongst them the degree of "Chemical Engineering" of the "School of Industrial Engineering" that belongs to the University of Las Palmas de Gran Canaria. This subject, in this degree, is taught in the second term of the first academic year. Its aim is that students acquire basic knowledge of Computer Science in the theoretical classes and basic knowledge of programming in the practical classes. The theoretical hours are taught in the theory classrooms and the practical hours are taught in the laboratory. This is a classroom equipped with computers, one for each student, and connected to Internet. Programming knowledge is necessary for the use of certain tools that students will use in the following academic years, such as programmable calculators or software like Matlab. The number of teaching hours is three of theoretical lessons per week using traditional methods and one hour of practical lessons. This means fifteen practical hours during the term.

- In the first five hours of practical classes basic knowledge of programming, tools to use and C language are introduced. In the first hour of these five an introductory class of OLC will be taught. The following four hours the lessons will be taught through the video tutorials that will indicate how to make use of OLC and will ask the students to work with the examples proposed by the teachers. These first exercises will consist of simple programs that students will have to edit, modify and compile.

- In the following five hours, students will work in the modification and creation of computer programs. The proposal of modification made by the teachers will consist of making changes in programs that make use of a bit more complex structures than the ones used in the previous phase. A group of ten exercises could be completed, two for each practical hour, with an increasingly difficulty.

- For the last five hours the students must work in a practical exercise proposed by themselves. Teachers must give their approval to this proposal computer program. This will be the final exercise to evaluate and should be made with a more powerful compiler. At this stage of the learning process, students must already control the use of the compiler and its different options.

The independence acquired by the student after these stages using OLC and their control in the comprehension and use of other compiles should be noticeable. The assessment process will take into account the valuation of the supervision of their work with OLC and the final exercise proposed. According to this approach, using OLC compiler the role of teachers is greatly restated. They could dedicate time to transmitting motivation about the subject being studied and directing the students in their studies. Besides, the supervision of their work and the evaluation is a continuous process that could be done completely on-line. The role of students has also changed. The use of this kind of applications gives them more autonomy than in previous academic courses.

5 Didactic perspective

The work developed has been exposed to a group of five teachers [7] whose subjects deal with programming. All these subjects are included in the first academic year of several engineering studies. Different opinions about the exposition have been found. The features that the teachers have taken into account to give their viewpoint about OLC have been: the professional profile their students will have in the future; the use they will make of programming both in the academic and professional field, and the level of knowledge they must achieve during the academic course. To a lesser extent they have considered the percentage that programming has in the final evaluation and the number of hours they must dedicate to the practical part of the subject.

- *Teacher one.* He teaches "Basic Knowledge of Computer Science" belonging to the first course of "Chemical Engineering". To me the teaching proposal is the right one. The students find many difficulties in the understanding of compilers at the initial period of learning programming, he thinks. Furthermore, sometimes even the use of computer is complex for them, although they learn quickly. Professionally they will unlikely need to make computer programs. Nevertheless, in the following academic years, surely, they will need to understand what variables are and how to make use of them in small computer programs as well as using them in small functions created for MatLab. According to the teacher in their senior thesis, it is very probable that they will only need to manage statistics information and perhaps make some update or modification in a small computer program in order to obtain some of this information.

- *Teacher two.* She is the responsible for the practical part of the subject "Fundamentals of Computer Science". This subject corresponds to the group of training complements in the degree in Industrial Organization Engineering. In my opinion the teaching proposal with OLC is very well structured. Maybe the level of knowledge shown in the video tutorials is quite high, since generally the students who apply for this degree do not have a high interest in programming. The number of students that choose the subject is low. They try to pass the subject without paying attention to the tools they are using. Professionally it is not probable that they will make use of these programming skills in the future. That is why the percentage of the final evaluation is low, although the use of multimedia material could be proposed for other subjects, since these multimedia tools are ideal for teaching.

- *Teacher three.* He is the coordinator of the subject "Programming Methodology" belonging to the first course of "Technical Computer Science Engineering". He thinks it is a good proposal. In his department they have thought to develop a similar tool. However, they have not considered using multimedia tutorials, just only help files. We should take advantage of these multimedia capacities. His students will surely use the programming knowledge both at an academic level and in their professional life.

- *Teacher four.* She has taught "Fundamentals of Computers" in the first year of "Computer Science Systems Engineering". She finds the teaching proposal with OLC interesting. In fact in "Fundamentals of Computer" she uses a program developed for students to use in order to create computer programs in assembly language . Thus they will not have to make use of the machine compiler. According to her, the students are well trained in Computer Science; therefore they do not need to begin with a tool so simple. However there exists a fundamental aspect of this tool that should be exploited: to have production tools in the Web. Undoubtedly they mean a great advantage, she thinks. Proposals with more functions and accessible from the Web would be very interesting for her students.

- *Teacher five.* She teaches "Basic Knowledge of Computer Science" belonging to the first course of "Public Works Technical Engineering" in all its three specialities: "Hydrology", "Civil Building", and "Urban Transport and Services". She thinks that the proposal is of no interest for what she needs, bearing in mind the number of practical lessons per week and the teaching content, which do not match together. She believes that in the future students will not make much use of this programming knowledge. It is quite complex to make them understand some concepts. We are just in a period in which not all the students who reach university studies are equally trained in Computer Science, and only some of them have got a computer at home. Maybe the practical lessons should be concentrated on removing programming knowledge from the contents of the subject.

Some students have also given their opinion about the environment. Their profile extends from students of computer science engineering in their second year at the university to some professional that already have finished the bachelor of "Computer Science".

- *Student one.* He studies the 2nd year of the degree "Industrial Engineering" (basic knowledge). The possibility of make my programs without having to install any software in my computer (I have had problems trying to install some C compilers before), makes me save time and allows me to work in the same conditions independently of the place -laboratory or home-. Furthermore with no knowledge about Linux, I could compile my first program in that operating system.

- *Student two.* He studies the 2nd year of the bachelor degrees "Computer Science Engineering" (learning C programming language) The use of OLC is ideal to learn a programming language. Firstly, it hides tiresome options that do not add anything to a beginner user, as path specifications or debug options. Moreover the availability of the video tutorials while using the editor is much handy that making programs in a conventional programming environment, where you should read the tutorial in a web page or using paper format. Finally, the operations I can carry out with "my files" option are the necessary ones for a beginner (save, compile, indent, and download the .exe file), and can be made in an easy way.

- *Student three.* He has finished the bachelor degree "Computer Science Engineering" and in a few weeks will defend his senior thesis (high level of programming language knowledge). I like the idea implemented, to have the compiler in the web allow access from any computer with an Internet connection and it is useful to compile in a specific moment with no need to download and install a compiler. For students that just make a brief immersion in the programming studies is ideal in fact, but if you study Computer Science at a professional level you find limitations. Apart of this, to download the .exe file with the result of the compilation every time is not much useful cause it is more handy the characteristic exe button of an IDE.

- *Student four.* He still has to study three subjects to finish the degree "Computer Science Engineering" (high level of programming language knowledge). For me it wasn't a trouble to install the C compiler, this tool is not the compiler I would have liked to use at the beginning. I think that when I began to make programs in C language I installed the compiler in my computer at home so I had not used OLC at all. On the other hand I cannot execute the programs made on-line and this is something that I do not like. When you compile a program the first thing you want to prove is the result, and using OLC you must download the .exe file, I prefer to compile with my IDE. The great advantage could be to compile and execute on-line.

- *Student five.* He has finished the bachelor degree "Computer Science Engineering" and is developing his senior thesis (high level of programming language knowledge). Advantages: - Easy to use. - You do not have to install any software, just only an Internet connection is necessary. - You can work from everywhere: home, laboratories, any place with an Internet connection. Disadvantages: - To download the .exe file. - Just a few options of debug - I do not like that my programs be in the Web, for security reasons. In resume: It is interesting at an initial stage of programming or for easy programs in computers where you do not have a compiler installed but apart from that it does not offer much more. It could be more attractive if you could execute your programs on -line.

6 Conclusions

This work proposes an interesting initiative in the field of e-learning: to portray interactive applications on-line for didactic use [8]. A simple compiler accessible from the Web provides students with an easy way to learn at the initial stage of programming studies. OLC makes use of multimedia contents to support teachers in the teaching process. These contents show how to work with the on-line compiler and with the programming language [9]. Apart from these there are further advantages, such as having at students and teachers' disposal [10] the compiler through the Web and the possibility of making use of it at any time and from any computer with an Internet connection. Thus barriers of time and space are eliminated. Students will have access to the compiler, the contents and the files with which they have been working. Besides, there is no need to save the work in store devices nor to install software. To have remote virtual laboratories increases their efficiency [11] and reduces the costs of the resources used in learning [12]. OLC could not compete with the powerful traditional IDE's due to its limitations for the expert software development, but undoubtedly it fills the void that exists in the area of teaching programming at the initial stage. This experience has already passed from the development phase to the experimental one. At present we are working on a research of those subjects that include programming languages lessons, and the use of OLC could be suitable. As many other initiatives, to promote its acceptance and to achieve its use depend on Programming teachers, who have already valued the application positively and favourably. According to their opinion, to introduce the students in the field of programming is hard in the initial stage. Not only for the complexity of the control and data structures and the programming language to learn, but also for the complexity of the tools they need to use, such as compilers, bearing in mind that students only need to make use of a reduced number of functions at their initial period of their programming studies. Using this kind of applications with multimedia contents allow teachers to dedicate time to activities which improve the quality of teaching, transmitting a further motivation about the subject to be studied and the results they can obtain, as well as directing students closely in their studies. [13]. In the near future, we will continue this line of work. Our new projects involve the development of other applications accessible from the Web [14], used as OLC, in e-learning field. Some of these applications will count on a key feature: interactivity [15]. Thus students will develop new working methods [16] in order to ensure participation [17].

7 Acknowledgment

This article is an extended version of our paper [18], published in Proceedings of the 2nd International Conference on Virtual Learning Ű ICVL 2007 (M. Vlada, G. Albeanu, D.M. Popovici, eds).

We wish to thank the program committee of ICVL 2007 that select and recommended the publication of our extended work in IJCCC.

Bibliography

[1] P. Brey. "Evaluating the social and cultural implications of the internet". Volume 35, Issue 3 (September 2005). ACM Press.

[2] C. McHugo, T. Hall. "Enhancing ICT learning with Real-life problems". EMRC University of Limerik.".

[3] T. O'Reilly. "What Is Web 2.0 - Design Patterns and Business". Models for the Next Generation of Software

[4] A. Yong-yeol, H. Seungyeop, K. Haewoon, M. Sue, J. Hawoong. "Semantic web and web 2.0: Analysis of topological characteristics of huge online social networking services". Proceedings of the 16th international conference on World Wide Web WWW'07. ACM Press

[5] T. Hartsell, S. Chi-Yin Yuen. "Video Streaming in Online Learning". AACE Journal. 14(1), pp. 31-43. Chesapeake, VA: AACE.

[6] L. Neal. "Predictions for 2006: e-learning experts map the road ahead". Volume 2006 Issue 1 (January 2006). ACM Press. New York.

[7] S. Anderson. "Working together to develop a professional learning community". HERDSA 2002

[8] G. Lautenbach. "Engaging with e-learning: emerging epistemologies and increased pedagogic vision in higher education". IADIS Inter national Conference e-Learning 2007

[9] R. Rheeder, R. Diseko, G. Lautenbach. "The design of interactivity for a web based learning environment at a higher education institution." IADIS International Conference e-Learning 2007

[10] H. Samaras, T. Giouvanakis, D Bousiou, K. Tarabanis. "Towards a New Generation of Multimedia Learning Research". AACE Journal. 14 (1), pp. 3-30. Chesapeake, VA: AACE

[11] Lawson, E.A. Stackpole, W. (2006). IT education - online education: Does a virtual networking laboratory result in similar student achievement and satisfaction?. Proceedings of the 7th conference on Information technology education SIGITE'06. (October 2006). ACM Press.W. Nejdl, M. Wolpers "European e-Learning: Important research issues and application scenarios". L3S Research Center and University of Hannover.)

[12] W. Nejdl, M. Wolpers "European e-Learning: Important research issues and application scenarios". L3S Research Center and University of Hannover.

[13] K. Fraser, "A blended Learning Approach to Teaching" Introduction to Multimedia, The E-Bit!. AISHE Conference 2006

[14] A. Leene. "The MicroWeb". Using Content in theory and practice MicroLearning 2006, Innsbruck - 7 June 2006

[15] P. Valente, P. Sampaio. "Defining Goals for the design of Interactive Multimedia Documents". In Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2006 (pp. 955-962). Chesapeake, VA: AACE.

[16] N. Sala. "Web Based Learning Environment: an Example". In Proceedings of 2000 (pp. 807-808). Chesapeake, VA: AACE.

[17] C. Gráinne, "Making sense of today's technology-enhanced environment for learning: rethinking student and teacher roles" IADIS International Conference e-Learning 2007

[18] Cayetano Guerra Artal, Maria Dolores Afonso Suarez, Idafen Santana Perez, Ruben Quesada Lopez, "OLC, On-Line Compiler to teach programming languages", In (M. Vlada, G. Albeanu, D.M. Popovici, eds) Proceedings of the 2nd International Conference on Virtual Learning - ICVL 2007, October 26-28, 2007, Constanta, Romania, pp. 283-290, 2007.

Cayetano Guerra Artal, Maria Dolores Afonso Suarez
Idafen Santana Perez, Ruben Quesada Lopez
Instituto Universitario de Sistemas Inteligentes y
Aplicaciones Numéricas en Ingeniería IUSIANI
Universidad de Las Palmas de Gran Canaria
Departamento de Informatica y Sistemas
Edif. de Informatica y Matematicas.
Campus Universitario de Tafira. 35017. Las Palmas. Spain.
E-mail: cguerra@iusiani.ulpgc.es, mafonso@dis.ulpgc.es
idafensp@gmail.com, rubenql@gmail.com

Received: November 4, 2007

Cayetano Guerra Artal, graduated at the University of Las Palmas de Gran Canaria in Computer Science. He has been teaching Multimedia for seven years at the Computer Science and Systems Department of the University of Las Palmas de Gran Canaria. He received his Ph.D. in Computer Vision. His main research fields are Computer Vision, Computer Graphics, Multimedia and e-Learning.

Maria Dolores Afonso Suarez, graduated at the University of Las Palmas de Gran Canaria in Computer Science. She has worked in private enterprises developing software and as associated professor at the Computer Science and Systems Department of the University of Las Palmas de Gran Canaria. Her main research fields are Software Engineering, Multimedia, and e-Learning.

Idafen Santana Pérez, graduated at the School of Computer Science of the University of Las Palmas de Gran Canaria. He is a pre-graduated student of the Faculty of Computer Science of this university. His current research interests are in e-learning aplications and natural language processing.

Ruben Quesada Lopez, graduated at the School of Computer Science of the University of Las Palmas de Gran Canaria. He is a pre-graduated student of the Faculty of Computer Science of this university. His current research interests are in e-learning aplications and natural language processing.

International Journal of Computers, Communications & Control
Vol. III (2008), No. 1, pp. 80-89

Adaptive Compensation of Friction Forces with Differential Filter

Kouichi Mitsunaga, Takami Matsuo

Abstract: In this paper, we design an adaptive controller to compensate the nonlinear friction model when the output is the position. First, we present an adaptive differential filter to estimate the velocity. Secondly, the dynamic friction force is compensated by a fuzzy adaptive controller with position measurements. Finally, a simulation result for the proposed controller is demonstrated.
Keywords: nonlinear friction, adaptive controller, fuzzy basis function expansion, adaptive differential filter.

1 Introduction

Friction is one of the greatest obstacles in high precision positioning systems. Since it can cause steady state and tracking errors, its influence on the response of the systems must be considered seriously ([10]). Many friction models have been proposed that differ on the friction effects that are modeled in a lubricated contact. These models are divided into two categories: the kinetic and dynamic friction models. The kinetic friction models take into account the friction effects such as the viscous friction, the Coulomb friction, and the Stribeck effect. Another category of friction model includes dynamic friction model that embody the natural mechanism of friction generation such as the LuGre model ([2]).

The coefficients of the various friction-related effects are usually very difficult to measure. A number of methods for friction estimation and compensation have been proposed for these models: adaptive control, joint torque control, learning control, variable structure control, and so on. Friedland *et al.*[5] proposed a reduced-order nonlinear observer to estimate the velocity-dependent coefficient of the classical nonlinear friction model with velocity measurements. Huang *et al.*[9] presented an adaptive radial basis function observer to compensate for the effects of the dynamic friction model full-states measurements. Tomei[15] considered the tracking problem for robot manipulators with unknown parameters and dynamic LuGre model using full-states information. Ge *et al.*[6] presented adaptive controllers by combining neural network parameterization, dual observer for state estimation/stability and adaptive control techniques based on the dynamic LuGre friction model. Sato *et al.*[14] proposed an adaptive friction compensation method with an H_∞ performance using the neural network approximation that is equivalent to the radial basis function approximation or fuzzy basis function approximation. They used the neural network approximation to parameterize the nonlinear characteristics of the dynamic LuGre model. A sliding-mode type error function is introduced that requires full-states measurements. Canudas de Wit *et al.*[3] designed an observer-based adaptive friction compensation scheme for systems with generalized position/velocity static characteristics based on full stats measurement. The proposed controller guarantees the global asymptotic stability of the tracking error while preserving boundedness of all the internal signals. The nonlinear friction is approximated either by a linear span of set of continuous known function, or by a neural network of bounded basis function. Putra *et al.*[12] proposed an observer-based friction compensation for a class of the kinetic friction models with known system parameters based on the strictly positive real condition. In the case of partial-states measurements, an adaptive estimator that does not require the strictly positive realness of the plants is needed. Ray *et al.*[13] presented a non-model-based friction estimation method using extended Kalman-Bucy filtering. The filter is used to estimate a friction force with the full-states measurements. For the classical nonlinear friction model without velocity measurements, Xia *et al.*[17] employed a velocity observer based on state space nonlinear friction model and designed an adaptive controller that achieved a semi-global asymptotically stability. The velocity observer is a model-based estimator that requires plant parameters to estimate the velocity. Park *et al.*[11] proposed a non-model-based differential filter of a nonlinear function based on the adaptive control theory. The proposed differential filter is applied to estimate the time-derivative of a nonlinear function of the intensity for each pixel to detect moving objects within a scene acquired by a stationary camera. In estimating the friction forces, the differential filter is applicable to estimate the velocity with the position measurements.

In this paper, we design a friction compensator with the position measurement. To begin with, an adaptive differential filter that is a non-model based adaptive algorithm to estimate the derivative of a signal, is designed to estimate the velocity signal. Next, the velocity signal in friction compensator proposed by Canudas de Wit *et al.*[3] is replaced by the estimate of the adaptive differential filter. Finally, a simulation result of the proposed compensator is presented. From the simulation result, it is shown that the proposed compensator is robust against additive noises.

2 Adaptive differential filter

The velocity information is the most important data to estimate and compensate the friction forces. Most of the conventional papers assume that the velocity is measurable. If the velocity information is not available, we have to estimate the velocity signal. Park *et al.*[11] proposed the adaptive estimator of the time-derivative of an output that is called the adaptive differential filter. Their estimator causes the estimation error in the case of fast time-varying signals. In this paper, we present another adaptive differential filter applicable to fast time-varying signals.

Let $y(t)$ be a measurement signal at a time t and $f(y(t))$ be its nonlinear function. We define $\theta_T(t)$ as the derivative with respect to time of the nonlinear function $f(y(t))$, *i.e.*

$$\theta_T(t) = \frac{df(y(t))}{dt} = \frac{df(y)}{dy}\frac{dy(t)}{dt}. \tag{1}$$

If $\frac{df(x)}{dx}$ has the inverse $\left(\frac{df(x)}{dx}\right)^{-1}$, we have

$$\dot{y}(t) = \theta_T(t)\xi(t), \tag{2}$$

$$\xi(t) = \left(\frac{df(y)}{dy}\right)^{-1}. \tag{3}$$

The problem is defined as follows:

Problem 1. Design a differential filter to estimate the derivative, $\theta_T(t)$, of the nonlinear function $f(y(t))$ with available signal $y(t)$ and without any knowledge of its dynamics.

If the signal $\xi(t)$ is available, Problem 1 is equivalent to the estimation problem of the time-varying parameter θ_T in Eq.(2) with the available signals $y(t)$ and $\xi(t)$. It is assumed that the time-varying parameter in (2) is satisfied the following inequality:

$$|\theta_T(t) - \theta_{T0}| \leq \varepsilon_{T0}$$

where θ_0 is an unknown constant, and ε_0 is a known constant. Eq.(2) can be rewritten as

$$\dot{y} = \theta_{T0}\xi(t) + \varepsilon_T(t)\xi(t) \tag{4}$$

where $\varepsilon_T(t) = \theta_T(t) - \theta_{T0}$. We give an adaptive observer as

$$\dot{\hat{y}}_T = -k(\hat{y}_T - y) + \hat{\theta}_T(t)\xi(t) - \hat{\varepsilon}_T(t)\mathrm{sgn}(\hat{y}_T - y)|\xi(t)| \tag{5}$$

where $k > 0$. Defining the observer error as $e_T(t) = \hat{y}_T(t) - y(t)$, we obtain the error system as

$$\dot{e}_T = -ke_T + \tilde{\theta}_T(t)\xi(t) - \hat{\varepsilon}_T(t)\mathrm{sgn}(e_T)|\xi(t)| - \varepsilon_T(t)\xi(t) \tag{6}$$

where $\tilde{\theta}_T(t) = \hat{\theta}_T(t) - \theta_{T0}$.

The parameter update laws are selected as

$$\dot{\tilde{\theta}}_T(t) = \dot{\hat{\theta}}_T(t) = -\gamma e_T(t)\xi(t) \quad (7)$$

$$\dot{\hat{\varepsilon}}_T(t) = |e_T(t)||\xi(t)| \quad (8)$$

where $\gamma > 0$.

We can prove the following lemma:

Lemma 1. *Consider the error system (6). The parameter update laws guarantee the stability of the origin of the error system as follows:*

$$e_T(t) \to 0 \quad (t \to \infty).$$

Moreover, if $lim_{t\to\infty}\dot{e}_T(t) = 0$, *then* $lim_{t\to\infty}\tilde{\theta}_{T\varepsilon}(t) = 0$, *where* $\tilde{\theta}_{T\varepsilon}(t) = \hat{\theta}_T(t) - \theta_T(t)$.

Proof:
The whole system can be written by

$$\begin{aligned}
\dot{e}_T &= -ke_T + \tilde{\theta}_T(t)\xi(t) - \hat{\varepsilon}_T(t)\text{sgn}(e_T)|\xi(t)| - \varepsilon_T(t)\xi(t) \\
\dot{\tilde{\theta}}_T &= -\gamma e_T \xi(t) \\
\dot{\hat{\varepsilon}}_T &= |e_T||\xi(t)|.
\end{aligned}$$

Define a Lyapunov-like function as

$$V_1 = \frac{1}{2}\left(e_T^2(t) + \frac{1}{\gamma}\tilde{\theta}_T^2(t) + \tilde{\varepsilon}_T^2(t)\right)$$

where $\tilde{\varepsilon}_T(t) = \hat{\varepsilon}_T(t) - \varepsilon_{T0}$. Its time derivative is given by

$$\begin{aligned}
\dot{V}_1 &= e_T\dot{e}_T + \frac{1}{\gamma}\tilde{\theta}_T\dot{\tilde{\theta}}_T + \tilde{\varepsilon}_T\dot{\hat{\varepsilon}}_T \\
&= e_T(-ke_T + \tilde{\theta}_T(t)\xi(t) - \hat{\varepsilon}_T(t)\text{sgn}(e_T)|\xi(t)| \\
&\quad -\varepsilon_T(t)\xi(t)) + \frac{1}{\gamma}\tilde{\theta}_T\dot{\tilde{\theta}}_T + \tilde{\varepsilon}_T\dot{\hat{\varepsilon}}_T \\
&= -ke_T^2 + \tilde{\theta}_T\left(e_T\xi(t) + \frac{1}{\gamma}\dot{\tilde{\theta}}_T\right) - e_T\hat{\varepsilon}_T\text{sgn}(e_T)|\xi(t)| \\
&\quad -e_T\varepsilon_T\xi(t) + \hat{\varepsilon}_T\dot{\hat{\varepsilon}}_T - \varepsilon_{T0}\dot{\hat{\varepsilon}}_T \\
&= -ke_T^2 - (e_T\varepsilon_T\xi(t) + e_T\varepsilon_{T0}\text{sgn}(e_T)|\xi(t)|) \\
&= -ke_T^2 - (e_T\varepsilon_T\xi(t) + \varepsilon_{T0}|e_T||\xi(t)|) \\
&\le -ke_T^2 + |e_T||\varepsilon_T||\xi| - \varepsilon_{T0}|e_T||\xi(t)| \\
&\le -ke_T^2 \le 0.
\end{aligned}$$

Hence, we have $e_T \in L_2 \cap L_\infty, \tilde{\theta}_T \in L_\infty, \tilde{\varepsilon}_T \in L_\infty$. Since $e_T \in L_\infty, \tilde{\theta}_T \in L_\infty, \tilde{\varepsilon}_T \in L_\infty$, we have $\dot{e}_T \in L_\infty$. From Barbalat's lemma, we conclude that $\lim_{t\to\infty} e_T(t) = 0$. Moreover, setting u as

$$u_T = \tilde{\theta}_T(t)\xi(t) - \hat{\varepsilon}_T(t)\text{sgn}(e_T)|\xi(t)| - \varepsilon_T(t)\xi(t),$$

the error dynamics can be expressed in a first-order system:

$$\dot{e}_T(t) = -ke_T(t) + u_T(t).$$

If $lim_{t\to\infty}\dot{e}_T(t) = 0$, then

$$\lim_{t\to\infty}(\hat{\theta}_T(t) - \theta_{T0} - \varepsilon_T(t)) = \lim_{t\to\infty}(\hat{\theta}_T(t) - \theta_T(t)) = 0.$$

∎

We obtain the estimator for the differential of the signal $y(t)$ by selecting the nonlinear function $f(y(t))$ as the linear function $f(y(t)) = y(t)$. In this case, the regressor signal $\xi(t)$ is equal to 1. The adaptive observer and the update laws are given by

$$\dot{\hat{y}}_T = -k(\hat{y}_T - y) + \hat{\theta}_T(t) - \hat{\varepsilon}_T(t)\mathrm{sgn}(\hat{y}_T - y) \quad (9)$$

$$\dot{\hat{\theta}}_T(t) = -\gamma e_T(t), \dot{\hat{\varepsilon}}_T(t) = |e_T(t)| \quad (10)$$

where $e_T(t) = \hat{y}_T(t) - y(t)$. Thus, we get the estimate of the differential of the signal $y(t)$ as

$$\hat{\dot{y}} = \hat{\theta}_T = -\int_0^t \gamma e_T(\tau)d\tau. \quad (11)$$

We call this estimator (11) the adaptive differential filter.

3 Nonlinear friction model

Canudas de Wit *et al.* present a new dynamic friction model that captures dynamic friction effects (the Gahl effect, frictional memory, stick-slip motion) as well as steady state friction effects, including the Stribeck effect ([2, 8]). The interface between two surfaces is modeled by contact between sets of bristles. If z represents the average bristle deflection, $\dot{y}$ the velocity between two surfaces, the friction force F_f can be expressed as

$$\begin{aligned} F_f &= \sigma_0 z + \sigma_1 \dot{z} + \sigma_2 \dot{y} \\ \dot{z} &= -\alpha(\dot{y})|\dot{y}|z + \dot{y} \\ \alpha(\dot{y}) &= \frac{\sigma_0}{f_c + (f_s - f_c)\exp\{-(\dot{y}/\dot{y}_s)^2\}} \end{aligned}$$

where σ_0 is the stiffness for deflection angle, σ_1 the damping coefficient for slip, σ_2 the viscous friction coefficient, f_c the Coulomb friction level, f_s the level of the stiction force, and $\dot{y}_s$ the Stribeck velocity.

The system under discussion is the following equation:

$$M\ddot{y}(t) + F_f(t) = u(t) \quad (12)$$

where M is known and F_f is unknown.

As in Canudas de Wit *et al.*[3], the nonlinear function $\alpha(\dot{y})$ is approximated by FBFE as

$$\alpha(\dot{y}) = k^T\zeta(\dot{y}) + \varepsilon_f \quad (13)$$

$$k = [\ k_1, \ \cdots, \ k_M\ ]^T \quad (14)$$

$$\zeta(\dot{y}) = [\ \zeta^1(\dot{y}), \ \cdots, \ \zeta^M(\dot{y})\ ]^T \quad (15)$$

where ε is the approximation error and ζ^j is defined as

$$\zeta^j(\dot{y}) = \frac{\mu_{A^j}(\dot{y}(t))}{\sum_{j=1}^M \mu_{A^j}(\dot{y}(t))}.$$

where the membership functions are selected as the Gaussian functions:

$$\begin{aligned} \mu_{A^j}(v) &= \exp(-\frac{(v-\bar{v}_j)^2}{2\sigma_j^2}) \\ \sigma_j &= \sigma, \qquad j = 1, \cdots, M. \end{aligned}$$

The approximation error is assumed to be bounded and sufficiently small.

4 Controller design

Consider the tracking control problem of system (12) under the assumption that (i) the parameters $M, \sigma_0, \sigma_1, \sigma_2$ are known and the nonlinear function $\alpha(\dot{y})$ in unknown. The desired trajectory y_d is smooth enough and bounded. The tracking error and its derivatives are defined as

$$e = y_d - y, \dot{e} = \dot{y}_d - \dot{y}, \ddot{e} = \ddot{y}_d - \ddot{y}.$$

4.1 Adaptive controller with full-states measurements

We review the adaptive controller proposed by Canudas de Wit *et al.*[3] with full-states measurements. They presented the internal state observer for the average bristle deflection as:

$$\begin{aligned} \dot{\hat{z}} &= \dot{y} - \hat{k}^T \zeta(\dot{y})|\dot{y}|\hat{z} + k_0\tilde{z} + k_1 e \quad (16) \\ \tilde{z} &= \frac{m}{\sigma_1}\dot{e} + \frac{K_d - m\rho}{\sigma_1}e + e_f \quad (17) \\ \dot{e}_f &= -\rho e_f + c\rho e \quad (18) \end{aligned}$$

where $\hat{z}$ is the estimate of the average bristle deflection and $k_0 > 0, k_1 > 0, c = \frac{K_p - \rho K_d + m\rho^2}{\sigma_0}$.

Defining the estimation error of the average bristle deflection as

$$\tilde{z} = z - \hat{z}, \quad (19)$$

we have the following estimation error equation:

$$\dot{\tilde{z}} = -\alpha(\dot{y})|\dot{y}|\tilde{z} - \tilde{k}^T \zeta(\dot{y})|\dot{y}|\hat{z} - k_0\tilde{z} - k_1 e \quad (20)$$

where $\tilde{k} = k - \hat{k}$.

The controller is given as follows[3]

$$\begin{aligned} u &= m\ddot{y}_d + H(p)e + \hat{F}_f \quad (21) \\ \hat{F}_f &= \sigma_0\hat{z} + \sigma_1\dot{\hat{z}} + \sigma_2\dot{y} \quad (22) \end{aligned}$$

where $H(p)$ is the following differentiator:

$$H(p) = K_d p + K_p, \quad p = \frac{d}{dt}. \quad (23)$$

Moreover, we obtain the tracking error equation as

$$m\ddot{e} + K_d\dot{e} + K_p e = \sigma_1\dot{\tilde{z}} + \sigma_0\tilde{z}. \quad (24)$$

We give the same adaptive update law as in [3]:

$$\dot{\hat{k}} = -\Gamma\frac{1}{k_1}\zeta(\dot{y})|\dot{y}|\tilde{z}\hat{z}. \quad (25)$$

4.2 Adaptive controller with position measurements

In the position measurement case, we use the estimate $\hat{\dot{y}}$ of the adaptive differential filter instead of the velocity signal $\dot{y}$. They presented the internal state observer for the average bristle deflection as:

$$\begin{aligned} \dot{\hat{z}} &= \hat{\dot{y}} - \hat{k}^T \zeta(\hat{\dot{y}})|\hat{\dot{y}}|\hat{z} + k_0\tilde{z} + k_1 e \quad (26) \\ \tilde{z} &= \frac{m}{\sigma_1}\hat{\dot{e}} + \frac{K_d - m\rho}{\sigma_1}e + e_f \quad (27) \\ \dot{e}_f &= -\rho e_f + c\rho e \quad (28) \end{aligned}$$

where $\hat{\dot{y}}$ is the estimate of the velocity by the adaptive differential filter and $\hat{e} = \dot{y}_d - \hat{\dot{y}}$. Defining the estimation error of the adaptive differential filter ε as $\varepsilon = \hat{\dot{y}} - \dot{y}$, we have

$$\hat{\dot{e}} = \dot{e} - \varepsilon.$$

We have the following estimation error equation:

$$\dot{\tilde{z}} = -\alpha(\dot{y})|\dot{y}|\tilde{z} - \tilde{k}^T \zeta(\hat{\dot{y}})|\hat{\dot{y}}|\hat{z} - k_0\tilde{z} - k_1 e - k^T \varepsilon_0 \hat{z} - \varepsilon \tag{29}$$

where $\tilde{k} = k - \hat{k}$ and ε_0 is caused by estimation error of the adaptive differential filter. Moreover, we obtain the tracking error equation as

$$m\ddot{e} + K_d\dot{e} + K_p e = \sigma_1\dot{\tilde{z}} + \sigma_0\tilde{z} + (K_d - \sigma_2)\varepsilon. \tag{30}$$

The controller is given as follows:

$$u = M\ddot{y}_d + K_d\hat{\dot{e}} + K_p e + \hat{F}_f \tag{31}$$

$$\hat{F}_f = \sigma_0\hat{z} + \sigma_1\dot{\hat{z}} + \sigma_2\hat{\dot{y}}. \tag{32}$$

Replacing the velocity signal by its estimate of the adaptive differential filter, the adaptive update law is given by:

$$\dot{\hat{k}} = -\Gamma\frac{1}{k_1}\zeta(\hat{\dot{y}})|\hat{\dot{y}}|\tilde{z}\hat{z}. \tag{33}$$

4.3 Simulation example

Next example is the following LuGre model:

$$M = 10, \sigma_0 = 5, \sigma_1 = 2\sqrt{5}, \sigma_2 = 0.01, f_c = 1, f_s = 1.5, v_s = 0.1.$$

The initial conditions are selected as

$$y(0) = 0, \dot{y}(0) = 0.2, z(0) = 1.$$

The desired reference signals $y_d, \dot{y}_d, \ddot{y}_d$ are given by

$$y_d = 3\sin 0.02\pi t, \dot{y}_d = 0.06\pi\cos 0.02\pi t, \ddot{y}_d = -0.0012\pi\sin 0.02\pi t.$$

The parameters of the fuzzy basis function are selected as follows:

$$\sigma_j = 0.5 (j = 1, \cdots, 5),$$
$$\bar{v}_1 = -1, \bar{v}_2 = -0.5, \bar{v}_3 = 0.0, \bar{v}_4 = 0.5, \bar{v}_5 = 1.$$

The parameters of the adaptive differential filter is given by $k = 1, \gamma = 0.5$. The simulation parameters of the compensator are selected as follows:

$$K_d = K_p = 1,$$
$$k_0 = 1, k_1 = 0.1,$$
$$\Gamma = 50\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}.$$

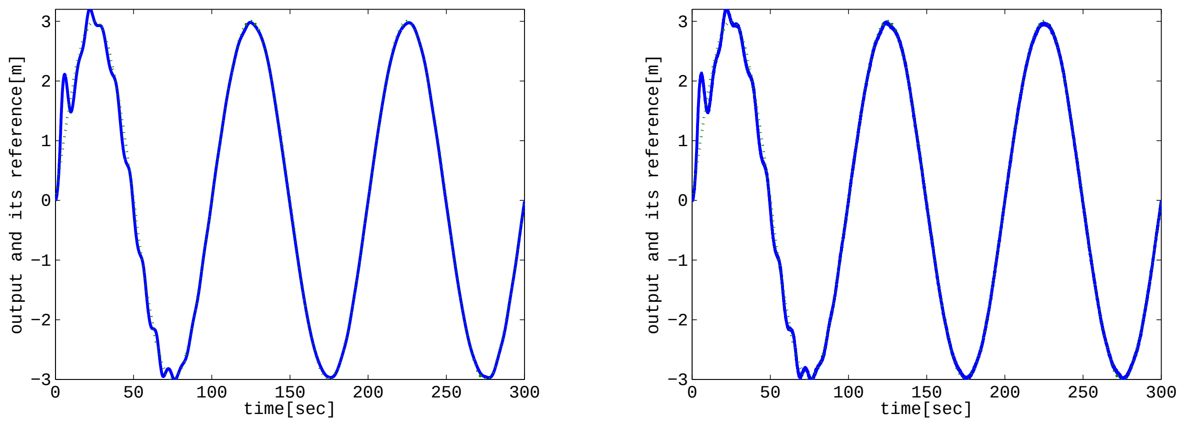


Figure 1: The output y(solid line) and its desired reference y_d(dotted line) in the time range $[0,300]$. Left: noise free ,Right: additive noise $N(0,10^{-4})$.

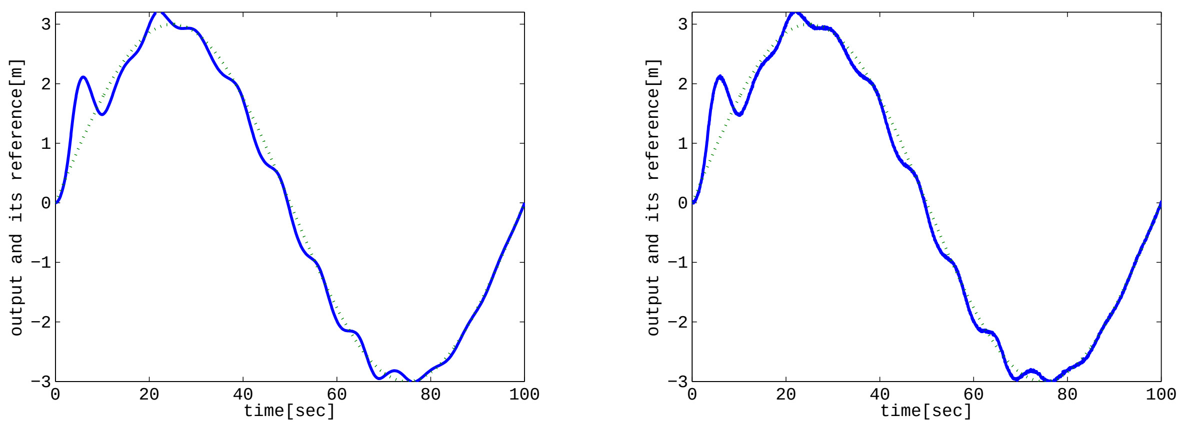


Figure 2: The output y(solid line) and its desired reference y_d(dotted line) in the time range $[0,100]$. Left: noise free ,Right: additive noise $N(0,10^{-4})$.

The simulation is carried out in the noise free case and in the case where the output y_d with the additive noise $N(0,10^{-4})$. Figure 1 shows the outputs y(solid line) and its desired references y_d(dotted line) in the time range $[0,300]$ in both cases. Figure 2 shows the outputs y(solid line) and its desired references y_d(dotted line) in the time range $[0,100]$ in both cases. Figure 3 shows the velocities $\dot{y}$(solid line) and its estimates $\hat{y}$ by the adaptive differential filter (dotted line) in both cases. Figure 4 shows the inputs u in both cases. Figure 5 shows the friction force(solid line) and its estimate(dotted line). From these figures, the proposed friction compensator is robust against the additive noise.

5 Conclusion

We proposed the adaptive differential filter and its application to friction compensation. Specifically, the velocity information in the friction compensator proposed by Canudas de Wit *et al.*[3] is replaced by the estimate with the adaptive differential filter. From the simulation results, the proposed friction compensator is robust against the additive noise.

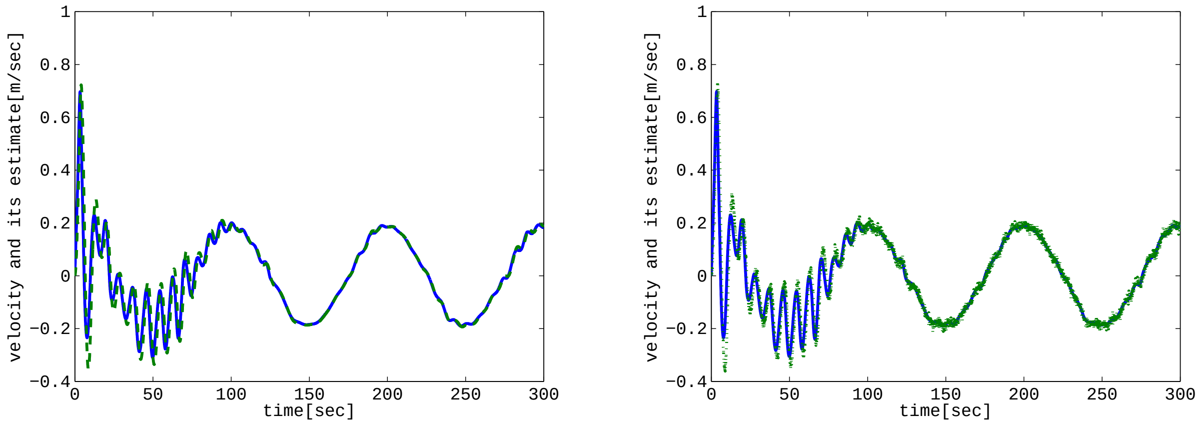


Figure 3: The velocity $\dot{y}$(solid line) and its estimate $\hat{\dot{y}}$(dotted line). Left: noise free ,Right: additive noise $N(0,10^{-4})$.

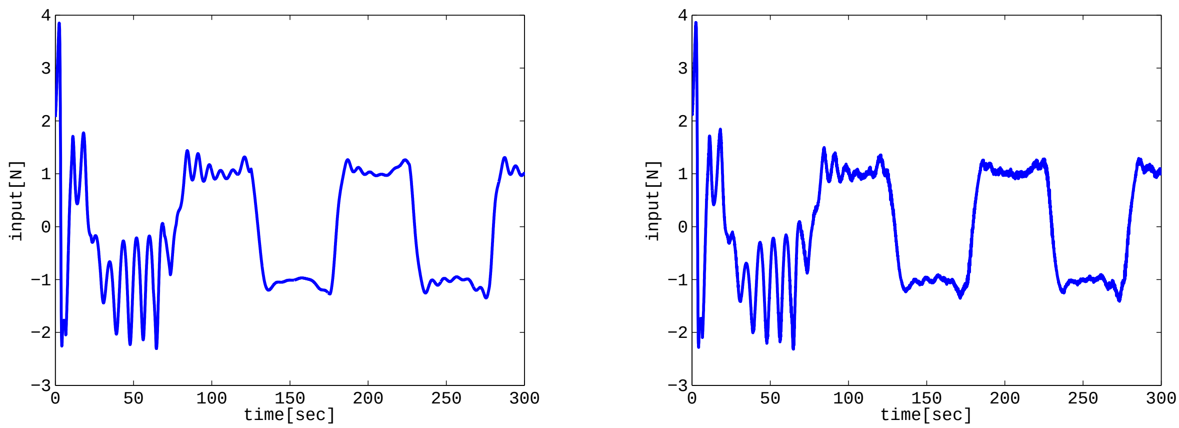


Figure 4: The input signal. Left: noise free ,Right: additive noise $N(0,10^{-4})$.

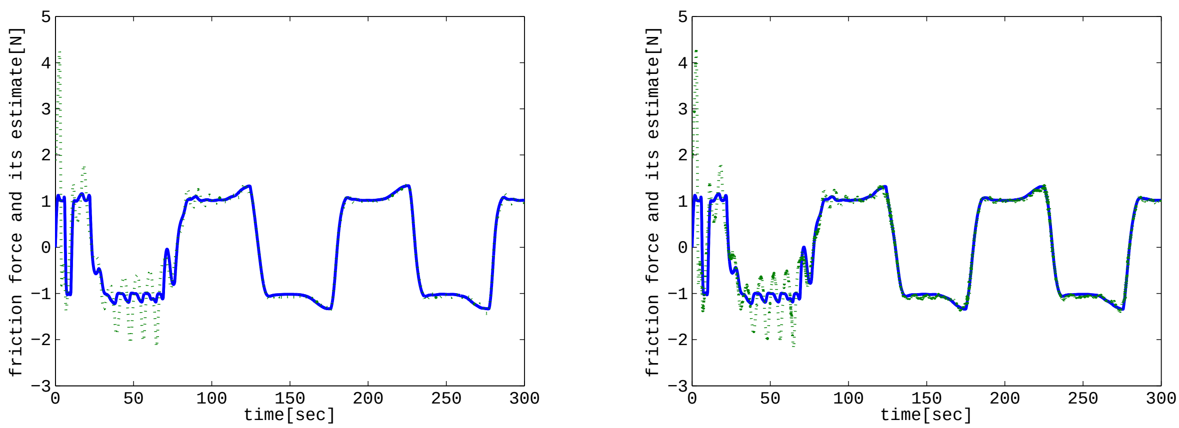


Figure 5: The friction(solid line) and its estimate(dotted line). Left: noise free ,Right: additive noise $N(0,10^{-4})$.

Bibliography

[1] B. Armstrong-Helouvry, P. Dupont, C. Canudas de Wit, “ A Survey of Models, Analysis Tools and Compensation Methods for the Control of Machines with Friction”. *Automatica*, vol.30, pp.1083–1138, 1994.

[2] C. Canudas de Wit, H. Olsson, K.J. Astrom, and P. Lischinsky, “ A New Model for Control of Systems with Friction”. *IEEE Transaction on Automatic Control*, vol.40-3, pp.419–425, 1995.

[3] C. Canudas de Wit and S.S. Ge, “ Adaptive Friction Compensation for Systems with Generalized Velocity/Position Friction Dependency”. *Proc. of the 36th IEEE Conference on Decision and Control*, pp.2465–2470, 1997.

[4] D. V.-Díaz and Y. Tang, “ Adaptive Robust Control of Nonlinear Systems”. *IEEE Trans. on Systems, Man, and Cybernetics, Part B*, vol.34-3, pp.1596–1601, 2004.

[5] B. Friedland and Y.-J. Park, “ On Adaptive Friction Compensation”. *IEEE Transaction on Automatic Control*, vol.37-10, pp.1609–1612, 1992.

[6] S.S. Ge, T.H. Lee, and J. Wang, “ Adaptive NN Control of Dynamic Systems with Unknown Dynamic Friction”. *Proc. of the 39th IEEE IEEE Conference on Decision and Control*, pp.1760–1765, 2000.

[7] H. Han and C.-Y. Su, “ Robust fuzzy control of nonlinear systems using shape-adaptive radial basis functions”. *Fuzzy Sets and Systems*, vol.125, pp.23–38, 2002.

[8] R.M. Hirschorn and G. Miller, “ Control of Nonlinear Systems with Friction”. *IEEE Trans. on Control Systems Technology*, vol.7-5, 588–595, 1999.

[9] S.N. Huang, K.K. Tan, T.H. Lee, “ Adaptive motion control using neural network approximations”. *Automatica*, vol.38, pp.227–233, 2002.

[10] E. Papadopoulos and G. Chasparis, “ Analysis and Model-based Control of Servomechanisms with Friction”. *ASME J. Dynamic Systems, Measurement and Control*, vol.126-4, pp.911–915, 2004.

[11] S.-H. Park and T. Matsuo, “ Time-Derivative Estimation of Noisy Movie Data Using Adaptive Control Theory”. *International Journal of Signal Processing*, vol.2-3, pp.170–177, 2005.

[12] D. Putra, L.P.M. Moreau, and H. Nijmeijer, “ Observer-Based Compensation of Discontinuous Friction”. *Proc. of the 43rd IEEE Conference on Decision and Control*, pp.4940–4945, 2004.

[13] L. R. Ray, A. Ramasubramanian, and J. Townsend, “ Adaptive Friction Compensation Using Extended Kalman-Bucy filter Friction Estimation”. *Control Engineering Practice*, vol.9, pp.169–179, 2001.

[14] K. Sato, Y. Mishima, K. Tsuruta, and K. Murata, “ Adaptive Positioning Control for Linear Slider with Friction Compensation”. *Trans. of Society of the Instrument and Control Engineers,Japan*, vol.40-2, pp.275–277, 2004 (in Japanese).

[15] P. Tomei, “ Robust Adaptive Friction Compensation for Tracking Control of Robot Manipulators”. *IEEE Transaction on Automatic Control*, vol.45-6, pp.2164–2169, 2000.

[16] J. Wang, S.S. Ge and T.H. Lee, “ Adaptive Friction Compensation for Servo Mechanism”. in: *Adaptive Control of Nonsmooth Dynamic Systems* G. Tao and F.L. Lewis (Eds.), Springer, pp.211–248, 2001.

[17] Q.H. Xia, S.Y. Lin, M.H. Ang Jr. and T.M. Lim, " Adaptive Joint Friction Compensation Using a Model-Based Operational Space Velocity Observer". *Proc. of IEEE International Conf. on Robotics and Automation*, pp.3081–3086, 2004.

Kouichi Mitsunaga
Oita Institute of Technology
Control Engineering Department
407-27 Higashihama, Nakatsu, Oita, Japan 871-0006
E-mail: mitu@oita-it.ac.jp

Takami Matsuo
Oita University
Department of Architecture and Mechatronics
700 Dannoharu, Oita, Japan 870-1192
E-mail: matsuo@cc.oita-u.ac.jp
Received: August 4, 2007

Kouichi Mitsunaga was born in Japan on July 19,1963. He received the B.S. degree in electrical engineering from Oita University, Oita, Japan, in 1986. He is currently an assistant professor in the Control Engineering Department, Oita Institute of Technology, Japan. He has worked in control system engineering.

Takami Matsuo was born in Japan on March 24,1958. He received the doctoral degree in engineering from Kyushu University, Fukuoka, Japan, in 1985. He is currently a Professor in the Department of Architecture and Mechatronics, Oita University, Japan. He has worked in control system theory and its applications. Matsuo is a member of IEEE, and SIAM.

International Journal of Computers, Communications & Control
Vol. III (2008), No. 1, pp. 90-102

A Formal Description of the Systemic Theory based e-Learning

Gabriela Moise

Abstract: This paper aims at presenting the systems theory-based approach to the learning (instructional) process. Such as approach is necessary, if one takes into consideration the the complex and holistic nature of the learning process. The presented modeling is based on the definition of an automatic regulation system and artificial intelligence techniques. For this purpose, an Intelligent Instructional System (IIS) is defined using the concepts: inputs, outputs, perturbations factors, regulation, feedback and AI learning techniques. The contextual environment of learning plays the major role in this system and it establishes the perturbation factors. The regulation consists in AI learning techniques, so the IIS is a flexible and adaptive system. The process' behaviour is described using pseudo-boolean and linear equations. This kind of approach enables solving the problems of the complexity and uncertainty of the learning (instructional) systems and, particularly, those of the e-learning (online and offline). Applications of the proposed approach may be found in e-learning courses for Mathematics, Computing, Architecture, Archaeology, Cultural Heritage, etc.
Keywords: online learning, system theory, feedback, intelligent instructional system.

1 Introduction

The theoretical bases of the instructional process design are formed of a set of theories such as the instruction and learning theory, the communication theory, the systems' theory. The system theory and the systemic thinking have a major influence on the field of the instructional design. The systemic approach of the instruction process design was issued by James Finn [7], who applied the systems theory in the educational technology. In 1978, Walter Dick and Lou Carey published the book entitled "The Systemic Design of Instruction". The model built by Dick and Carey [5] doesn't follow a linear approach, each level of the instructional process being revised for certainty of achieving the objectives of instructional process. The model is presented in figure no. 1.

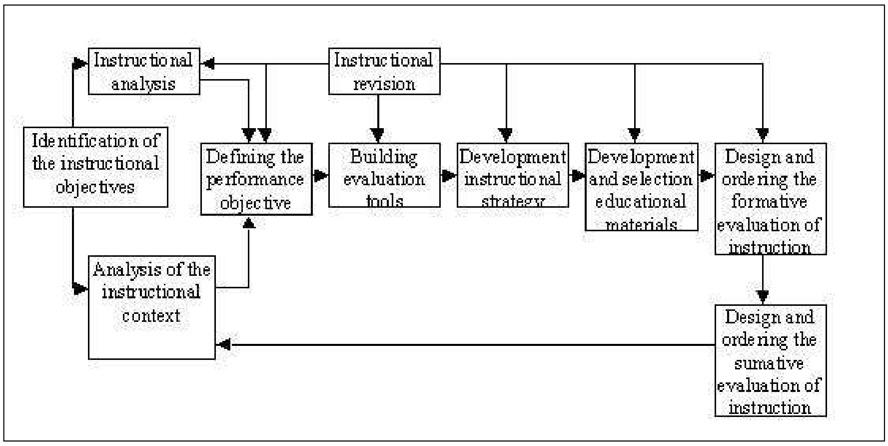


Figure 1: Dick and Carey's model

Any learning (instructional) form may be tackled from the point of view of the general systems theory, distance learning forms included. A system is defined by a set of elements that interact and work together in order to achieve an objective. Moore and Kearsley [15] present the importance of the systemic approach of the distance educational process. The distance educational system has to be viewed as a system within which all the elements are interdependent and interconnected. The consequence of this fact is that any change of an element of the system will affect the whole instructional process.

Moore (1983) defined the concept of transactional distance, in that he rigorously presented the relation between the teacher and the student: the distance between teacher and student is a geographical, an educational and a psychological one.[16]

Saba [17] refined the theory of Moore and proved trough experiments, that the transactional distance is a measure of the relation existing between the teacher and the student. Saba asserts: "transactional distance varies by rate of dialogue and structure", so that when dialogue increases, the structure and transactional distance decrease; when the structure increases, the transactional distance increases and the dialogue decreases (see figure 2).

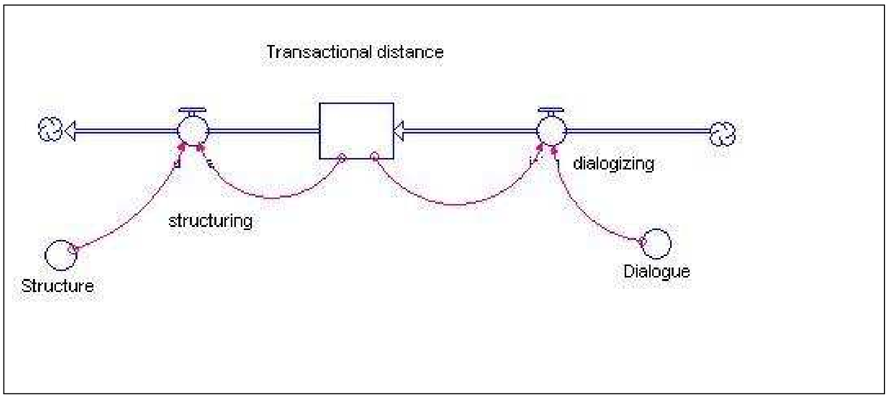


Figure 2: STELLA modeling of dynamic of Saba's system

$$transactional\,distance(t) = transactional\,distance(t-dt) + (dialogue - structure) * dt$$

Norbert Wiener [20] has introduced the cybernetic concept in the paper "The Human Use of Human Beings": "when we desire a motion to follow a given pattern the difference between this pattern and the actually performed motion is used as a new input to cause the part regulated to move in such a way as to bring its motion closer to that given by the pattern."

The notion of instructional system was introduced by Robert Glaser in 1962. The levels of the system defined by Glaser are represented in the figure no. 3. The individualized instruction is viewed as a continuous cycle of diagnose, specification and evaluation. The output condition is defined as follows: the student has learned all the proposed objectives.

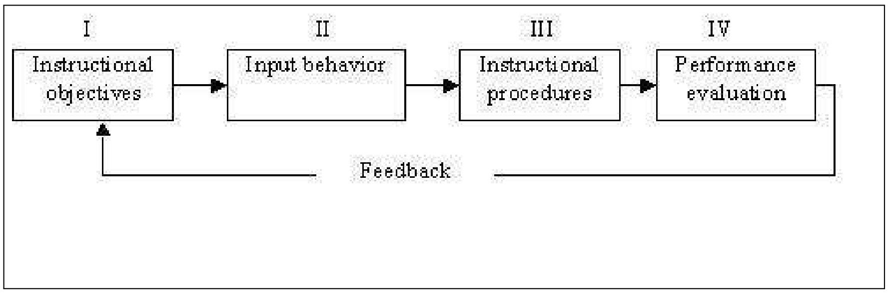


Figure 3: Glaser's instructional model with feedback

Banathy (1996) [2] comprised the educational system in the human activity systems (HAS). He defined the term of "system view of education": "we learn to think about education as a system, we can understand and describe it as a system, we can put the systems view into practice and apply it in educational inquiry, and we can design education so that it will manifest systemic behavior". The systemic approach of the educational system facilitates the exploration of the process according to the subsystems constituents: teacher, student, institution, administration etc. Banathy (1992) [1] proposed two phases of the systemic development of education, which are considered the principles of systems' design. (see figure 4)

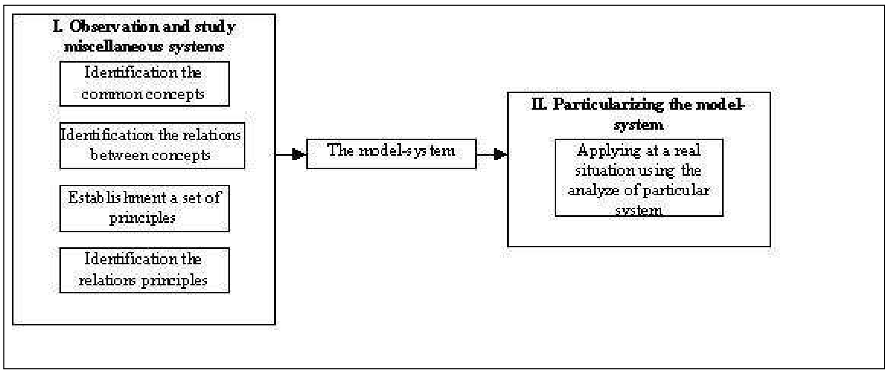


Figure 4: The phases of the development of a systemic approach of education (Banathy)

In 1992, Banathy [1] proposed three models of social systems namely the systems-environmental model, the functions-structure model and the process-behaviour model. These models were be used to describe the educational systems "open, dynamic and complex social systems". The systems-environmental model enables one to see the learning (instructional) systems into the context of the relationships, interactions and interdependencies between the system and the environment. The functions-structure model enables one to describe the goals of the systems and the functions that have to be implemented in order to achieve these goals. Also it defines the components of the system and the relations between them, thus defining the very structure of the system. The process-behavior model enables one to understand the behaviour of the system: which are the inputs of the system, how these inputs have transformed to produce the expected output. Also, Banathy identified four domains: systems' philosophy, theory, methodology, and application, constituting the conceptual system of systems inquiry in educational systems. A detailed report of the systems view of the distance learning may be found in [6]. The e-courses have to be design to incorporate active and cooperative learning techniques in a systematic way that addresses all aspects of the course: delivery, management, and assessment.[9]

In this paper, the author proposes a new model of the learning (instructional) process based on the systems theory. The model focuses on the regulation, so that the system will produce the expected results. The behaviour of the system is described using a mathematical model, based on the pseudo-boolean equations and linear equations, which was called "quasi-boolean system". The concept of the "quasi-boolean system" is introduced to portray the behaviour of the e-learning system. The genesis of the "quasi-boolean system" is the idea that the students are evaluated at the end of a training session and they get a grade: a number or a truth value (true or false). In the traditional learning (instructional) process, the teacher takes care of achieving the objectives of the learning (instructional) process. In the e-learning system, one uses a combined regulation: a feedback regulator and a predictive regulator. The predictive regulator uses AI learning techniques (Q-learning [13]).

The remaining part of the paper is organized as follows: in section 2, a systematic model of the learning (instructional) process is presented; in Section 3, a mathematical model is given; in section 4, an application is developed; in section 5 the complexity of the instructional (learning) process is identified and finally, in section 6 Summary and Conclusions, the advantages using the proposed model are presented.

2 A Systemic Model of the Learning (Instructional) Process

The multidisciplinary nature of the systems theory facilities the implementation of the system thinking in the learning (instructional) process.[3]

In this paper, the learning (instructional) process is modeled starting from the definition of an automatic regulation system.

Definition 1. An automatic regulation system (S,R,A) is defined according to the schema presented in figure no. 5.[11]

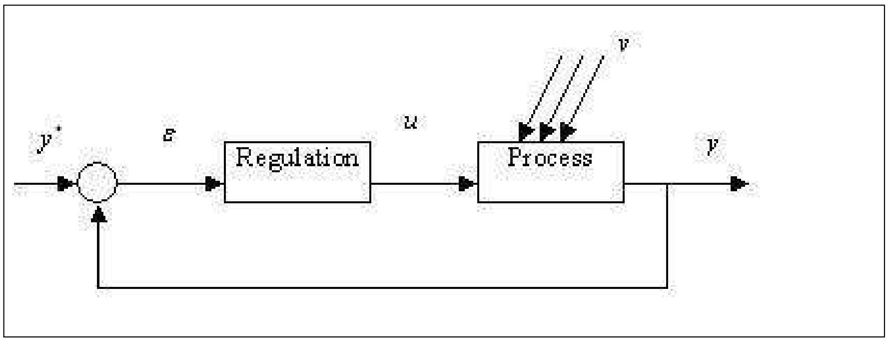


Figure 5: An automatic regulation system

y^* is the reference value, y is the output value, v are the perturbation factors, u is the input value, ε is the error between the reference value and the output value.

Definition 2. An intelligent instructional system (IIS) with a feedback regulator is defined according to the schema:

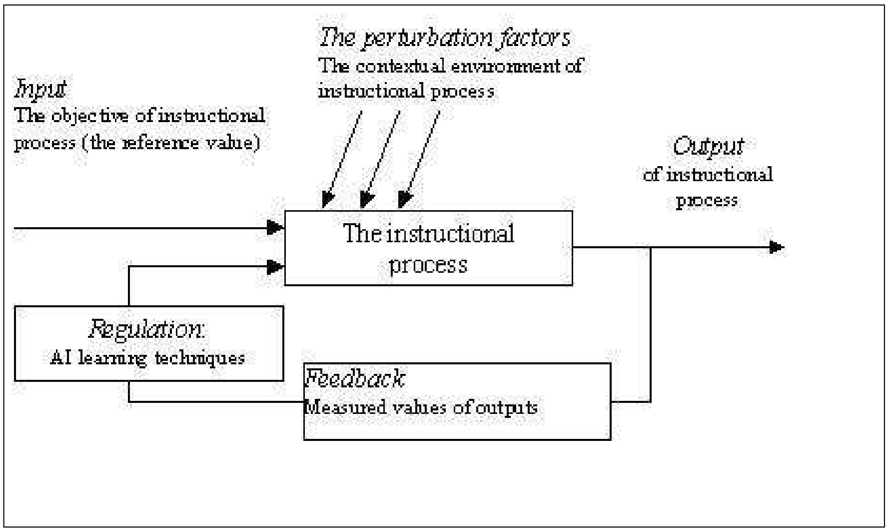


Figure 6: The intelligent instructional system

The instructional system is a system with inverse connection that decides the behavior view to nullify the error.

Definition 3. An intelligent instructional system (IIS) with a combined regulation is defined according to the schema presented in the figure no. 7.

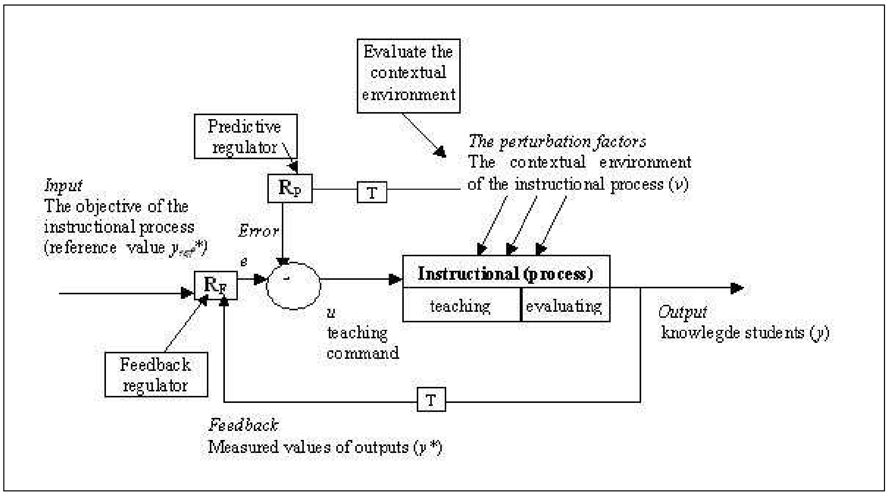


Figure 7: Intelligent instructional system

The *input* of the system represents the reference value, what the students have to realize after the learning (instructional) process has finished. The *state* at *k* step (the system is sequential) is defined by the students' knowledge and skills at step *k*. The instruction context may be referred as a social, an emotional, a mental, school, technological, knowledge context.[14] In this approach, all factors that affect the learning - motivation, goals, previous knowledge, interest, teaching styles, learning styles, classroom climate, parents, preoccupations, hobbies, etc - represent the *perturbations*.

Definition 4. An intentional model of instruction is a structure with the form: (com, con, cri), where com, con, cri have the following meanings:

- *com* defines the behaviour
- *con* describes the conditions in which the students prove learning
- *cri* is a precise setting of acceptable standards and performance

The teacher has to consider the inferences in the learning process, starting from measurable pieces of evidence that can be measured, while the learning can not be measured directly. The goals of learning are formulated according to the domains of learning: the cognitive domain, the affective domain and the psychomotor one. The teacher and the instructional designer have the major role in defining the goals of learning.

Definition 5. The input values of IIS are defined by the goals of the instructional process, the intentional models of behaviour.

The goals of a course describe the intention of the teacher referring to the students, who attend the course. The goals define what is expected from the students after the instructional process has finished.

$y^*_{ref} = (com^*_{ref}, con^*_{ref}, cri^*_{ref}, grade_{ref})$, where

- com^*_{ref} defines the reference behaviour
- con^*_{ref} describes the reference conditions in which the students prove learning
- cri^*_{ref} is the setting of the reference standards and performance
- $grade^*_{ref}$ is the reference grade (the accepted grade)

For example:

$y^*_{ref} =$
$(behaviour: write\,a\,program, conditions: using\,C++\,language\,in\,15\,minutes,$
$criteria: program\,runs\,without\,errors\,and\,display\,correct\,results, 8)$

or

y^*_{ref}
$= (write\,a\,program, C++\,language, 15\,minutes, programs\,run\,without\,errors,$
$display\,correct\,results, 10)$

$$y^*_{ref} = \left(com^*_{ref}, con^*_{ref}, cri^*_{ref}, grade^*_{ref}\right), \begin{cases} com^*_{ref} = write\ a\ program \\ con^*_{ref} = \begin{cases} language = C++ \\ time = 15\,min \end{cases} \\ cri^*_{ref} = \begin{cases} run\ \ without\ \ errors \\ display\,correct\ \ results \end{cases} \\ grade^*_{ref} = \begin{cases} 10 \end{cases} \end{cases}$$

Meaning: At the end of the module, the student will be able to write a program to sum the first n integer numbers, using C++ language, in 15 minutes, the program will run without errors and the result will be correct, the reference grade is 10.

Definition 6. The outputs of the IIS system are defined as follows: $y = (y_1, y_2, ..., y_m)$, where y_i are defined according to Gagne [8]

- Declarative knowledge;
- Procedural knowledge;
- Cognitive strategies;
- Attitudes;
- Psychomotor abilities.

The outputs (the students' knowledge) are measured (y^*) in a way that allows them to be compared with the reference values.

In order to evaluate the outputs of the IIS system, a measuring system (MS) is to be established.

$MS: Y \to M$, Y is the possible outputs' sets.

The measuring system has to take into account goals of the instruction (the reference value of the IIS system). The behaviour of the student has to be evaluated in the conditions defined by the goals of the instruction and has to satisfy a set of criteria. The measuring system evaluates the outputs of the system (what the student realize in the evaluation phase) and produces feedback, so the measuring system establishes an output behaviour model.

$$y^* = (com^*, con^*, cri^*, grade^*), \begin{cases} com^* = write\ a\,program \\ con^* = \begin{cases} language = C++ \\ time = 30\,min \end{cases} \\ cri^* = \begin{cases} run\ \ without\ \ errors \\ display\,incorrect\ \ results \end{cases} \\ grade^* = \begin{cases} 8 \end{cases} \end{cases}$$

Meaning: At the end of the module, the student has to write a program to sum the first n integer numbers, using C++ language, in 30 minutes, the program runs without errors and the result is correct, the grade is 8.

The output of the IIS system is evaluated according to the MS and has the following values:

$y^* = MS(y) = (com, con, cri, grade)$

The error is defined as a difference between two models (patterns). To determine the difference between two behaviour patterns, a patterns' analyzer (defined through a procedures collection) will be used.(see figure 8)

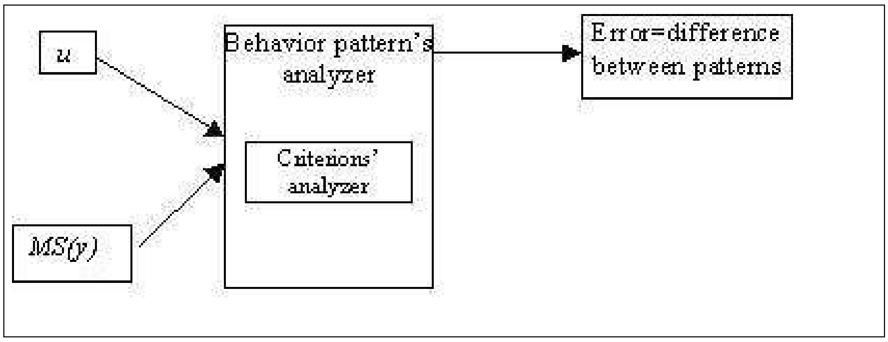


Figure 8: Patterns' analyzer

The analysis of the behaviors' patterns imply the following steps:

1. the criteria will be decomposed in primitive criteria;

2. the primitive criteria are analyzed according to some rules based procedures;

3. the analysis procedures are updated according to learning techniques taken from artificial intelligence.

In the example above:

$cri^* = \begin{cases} run\,without\,errors \\ display\,correct\ \ results \end{cases} \qquad - cri^*_{ref} = \begin{cases} run\,without\,errors \\ display\,incorrect\ \ results \end{cases}$

The criteria analysis establishes that the program written by the student has a logical error. The value of the error: invalid logical program.

Definition 7. The perturbation factors are defined by the contextual environment of the learning (instructional) process.

The contextual learning is built on all conditions that affect the instructional process. Cole and Griffin have shown the complexity of this concept.[4]

The predictive regulator of the IIS system decides what kind of instructional techniques and information will be used in the learning process, analyzing the contextual factors. The predictive regulation contains AI techniques to instruction of the IIS system. The predictive commands are rules having the following structure:

$r = (c_1 \wedge c_2 \wedge ... \wedge c_n\ ) \rightarrow (a_1; a_2; ...; a_k)\,, where\, c_i, i = 1, ..., n\, are\, the\ \ conditions\, and$

$a_i,\ i = 1, ..., k\ are\, the\, actions$

In the IIS system, the conditions are perturbation factors and they are inputs of the system. The feedback regulator of the IIS system checks the value of the error and provides a corrective command. While the IIS system is not a numeric system, the behaviour of the system cannot be described using equations with real numbers.

3 A Mathematical Model of the Instructional System

Definition 8. A vector of n elements, where the elements are real numbers and logical values, is called a quasi-boolean vector.

$x = \left(x^1, x^2, ..., x^k, x^{k+1}, .., x^n\right)$ where $x^i \in \mathbf{R}, i = \overline{1,k}$ and $x^i \in \mathbf{B}_2, i = \overline{k+1,n}$

The real part of x is noted with $R(x)$ and the boolean part of x is noted $B(x)$ and they are defined as:

$R(x) = \left(x^1, x^2, ..., x^k\right)$

$B(x) = \left(x^{k+1}, x^{k+2}, ..., x^n\right)$

Definition 9. It is called a quasi-boolean sequential system a pair of functions $(f = (f_1, f_2, f_3), g)$ defined as:

$x_k^i = f_1^i(B(x_{k-1}), B(u_{k-1}), B(v_{k-1})) + f_2^i(R(x_{k-1}), R(u_{k-1}), R(v_{k-1})), i = \overline{1, n_1}$

$x_k^i = f_3^i(B(x_{k-1}), B(u_{k-1}), B(v_{k-1})), i = \overline{n_1 + 1, n}$

$y_k^i = g_1^i(B(x_k), B(u_k)) + g_2^i(R(x_k), B(u_k)), i = \overline{1, p_1}$

$y_k^i = g_3^i(R(x_k), R(u_k)), i = \overline{p_1 + 1, p}$

where:

$x \in X = \mathbf{R}^{n_1} \times \mathbf{B}_2^{n_2}, n_1 + n_2 = n$ represent the set of the states of the system,

$u \in U = \mathbf{R}^{m_1} \times \mathbf{B}_2^{m_2}, m_1 + m_2 = n$ represent the set of the input signals of the system,

$v \in V = \mathbf{R}^{r_1} \times \mathbf{B}_2^{r_2}, r_1 + r_2 = r$ represent the set of the perturbations of the system,

$y \in Y = \mathbf{R}^{p_1} \times \mathbf{B}_2^{p_2}, p_1 + p_2 = p$ represent the set of the output signs of the system,

$f_1^i, i = \overline{1, n_1}$ are pseudo-boolean functions,

$f_2^i, i = \overline{1, n_1}$ are linear functions,

$f_3^i, i = \overline{n_1 1, n}$ are boolean functions,

$g_1^i, i = \overline{1, p_1}$ are pseudo-boolean functions,

$g_2^i, i = \overline{1, p_1}$ are linear functions,

$g_3^i, i = \overline{p_1 + 1, p}$ are boolean functions.

Remarks:

The signs of the quasi-boolean system are vectors with real numbers and boolean values elements. The complexity of the system is described through linear, pseudo-boolean and boolean functions. The informational state of the system is described using real numbers and truth values. Any boolean function can be expressed using a pseudo-boolean function. In order to model the learning (instructional) process, there will be used integer numbers from an interval, instead of real numbers, so the instructional system will become a finite states system. Using the interpolation formula for pseudo-boolean functions [10], the equations of the system become:

$x_i^k = \sum c_\gamma x_{k-1}^{\alpha_{n_1+1}}, ..., x_{k-1}^{\alpha_n}, u_{k-1}^{\alpha_{m_1+1}}, ..., u_{k-1}^{\alpha_m}, v_{k-1}^{\alpha_{r_1+1}}, ..., v_{k-1}^{\alpha_r} + f_2^i(R(x_{k-1}), R(u_{k-1}), R(v_{k-1}),$

$i = \overline{1,n}, c_\gamma = f_1^i(\alpha_{n_1+1}, ..., \alpha_n, \alpha_{m_1+1}, ..., \alpha_m, \alpha_{r_1+1}, ..., \alpha_r)$

$y_i^k = \sum b_\delta x_{k-1}^{\delta_{n_1+1}}, ..., x_{k-1}^{\delta_n}, u_{k-1}^{\delta_{m_1+1}}, ..., u_{k-1}^{\delta_m} + g_2^i(R(x_{k-1}), R(u_{k-1})),$

$i = \overline{1,n}, b_\delta = g_1^i(\delta_{n_1+1}, ..., \delta_n, \delta_{m_1+1}, ..., \delta_m)$

The equations of the system can be expressed using linear polynomial dependent on the states, the perturbations and the inputs of the system. If the pseudo-boolean functions are linear pseudo-boolean functions, they can be expressed as follows:

$T(x) = c_1 x_1 + c_2 x_2 + ... + c_n x_n + d$, where

$c_1, c_2, ..., c_n, d$ are coefficients (in the system described in the paper, the coefficients are integer number).

The topic of the paper is not to describe the quasi-boolean systems. These quasi-boolean of systems (in particular cases) are observable, controllable and there may be defined regulation laws (feedback regulation and predictive regulation). The methods of solving linear pseudo-boolean equations could be found in [10].

Example:

One considers an online course with three modules. The initial state is:

$x_0 = (0,0,0)$ i.e. there is no teaching

The inputs (commands) of the system are:

$u_0 = (0,0,0)$ i.e. there is no teaching process

$u_1 = (1,0,0)$ i.e. the system teaches module no. 1

$u_2 = (0,1,0)$ i.e. the system teaches module no. 2

$u_3 = (0,0,1)$ i.e. the system teaches module no. 3

The perturbations are:

$(0,0)$ i.e. the electrical power is interrupted

$(0,1)$ i.e. the Internet connection failed

$(1,0)$ i.e. the computer is failed

The equation of the system is:

$x_{k+1} = (x_k^1 v_k^1 v_k^2 + u_k^1 v_k^1 v_k^2 - x_k^1 u_k^1 v_k^1 v_k^2, x_k^2 v_k^1 v_k^2 + u_k^2 v_k^1 v_k^2 - x_k^2 u_k^2 v_k^1 v_k^2, x_k^3 v_k^1 v_k^2 + u_k^3 v_k^1 v_k^2 - x_k^3 u_k^3 v_k^1 v_k^2)$

The reference value is: $y^*_{ref} = (1,1,1)$

If there is no perturbation, the evolution of the system is: $x_1 = (0,0,0)$ $x_2 = (1,0,0)$ $x_3 = (1,1,0)$ $x(4) = (1,1,1)$

The regulator verifies the obtained value $(1,1,1)$ with the reference value $(1,1,1)$. If there is a difference between them (considering a perturbation), the output value could be $(0,1,1)$.

The error formula is:

$y^*_{ref} = (y^1_{ref}, y^2_{ref}, y^3_{ref})$

$y^* = (y^{*1}, y^{*2}, y^{*3})$

$e = (y^1_{ref}\overline{y^{*1}}, y^2_{ref}\overline{y^{*2}}, y^3_{ref}\overline{y^{*3}})$

The patterns' analyzer described in section 2 is expressed as a boolean equation.

In the former case, the error is $e = (0,0,0)$ and the process finished with success. In the latter case, the error is $e = (1,0,0)$ and the feedback regulation has to order to teach the first module.

4 An Application Example

The objective of the learning(instructional) process:

At the end of the teaching session, students will be able to design a simple web page using HTML language and the web page will be written correctly. In order to achieve this goal, the system have to teach: (1) module no. 1: the structure of the web pages, (2) module no.2: the $< html >$, $< head >$, $< title >$, $< body >$, $< p >$ tags, (3) module no. 3: applications. For each module, the learning (instructional) system has a set of pedagogical resources.

The reference value is: $y^*_{ref} = (1,1,1,10)$, where

1 is the true value=the student has written a web page,

1 is the true value=the student has used the HTML language,

1 is the true value=the structure of the web page is correct

The perturbation considered are defined by the learning styles (visual, auditive, kinesthetic) and the age categories (three categories).

$(1,0,0,1,0,0)$ i.e. learning style=visual and age category=1

$(0,1,0,1,0,0)$ i.e. learning style=auditive and age category=1

$(0,0,1,1,0,0)$ i.e. learning style=kinesthetic and age category=1

$(1,0,0,0,1,0)$ i.e. learning style=visual and age category=2

$(0,1,0,0,1,0)$ i.e. learning style=auditive and age category=2

$(0,0,1,0,1,0)$ i.e. learning style=kinesthetic and age category=2

$(1,0,0,0,0,1)$ i.e. learning style=visual and age category=3

$(0,1,0,0,0,1)$ i.e. learning style=auditive and age category=3

$(0,0,1,0,0,1)$ i.e. earning style=kinesthetic and age category=3

The instructional system has to teach three modules; for each module there is a set of pedagogical resources (noted with PR_k=pedagogical resources with identification k).

The commands of the system are:

$(0,0,0,0)$ i.e. invoke a virtual meeting between the teacher and the student

$(1,0,0,PR_1)$ i.e. teach module no. 1 using the pedagogical resource with identification 1

$(1,0,0,PR_2)$ i.e. teach module no. 1 using the pedagogical resource with identification 2

$(1,0,0,PR_3)$ i.e. teach module no. 1 using the pedagogical resource with identification 3

$(1,0,0,PR_4)$ i.e. teach module no. 1 using the pedagogical resource with identification 4

$(1,0,0,PR_5)$ i.e. teach module no. 1 using the pedagogical resource with identification 5

$(0,1,0,PR_6)$ i.e. teach module no. 2 using the pedagogical resource with identification 6

$(0,1,0,PR_7)$ i.e. teach module no. 2 using the pedagogical resource with identification 7

$(0,1,0,PR_8)$ i.e. teach module no. 2 using the pedagogical resource with identification 8

$(0,0,1,PR_9)$ i.e. teach module no. 3 using the pedagogical resource with identification 9

$(0,0,1,PR_{10})$ i.e. teach module no. 3 using the pedagogical resource with identification 10

$(0,0,1,PR_{11})$ i.e. teach the module no. 3 using the pedagogical resource with identification 11

$(0,0,1,PR_{12})$ i.e. teach module no. 3 using the pedagogical resource with identification 12

So, there are five pedagogical resources for module no. 1, three pedagogical resources for module no. 2, and four pedagogical resources for module no. 3.

The equations of the system are:

$x_k^1 = x_{k-1}^1 + u_{k-1}^1 - x_{k-1}^1 u_{k-1}^1$

$x_k^2 = x_{k-1}^2 + u_{k-1}^2 - x_{k-1}^2 u_{k-1}^2$

$x_k^3 = x_{k-1}^3 + u_{k-1}^3 - x_{k-1}^3 u_{k-1}^3$

$x_k^4 = x_{k-1}^4 + u_{k-1}^1 u_{k-1}^4$

$x_k^5 = x_{k-1}^5 + u_{k-1}^2 u_{k-1}^5$

$x_k^6 = x_{k-1}^6 + u_{k-1}^3 u_{k-1}^6$

A state of the form $(1,1,0,4,7,0)$ means that the student has followed the modules no.1 and 2 using the pedagogical resources no. 4 and 7.

The output is: $y = (x_k^1 x_k^2 x_k^3, x_k^1 x_k^2 x_k^3, x_k^1 x_k^2 x_k^3, \alpha x_k^1 x_k^2 x_k^3 + \beta x_k^1 x_k^2 x_k^3 + \gamma x_k^1 x_k^2 x_k^3)$, where $\alpha + \beta + \gamma = 10$ are given coefficients.

This means that a student may obtain at the evaluation the grade=10, if the behaviour has the value 1, the conditions have the value 1 and the criteria have the value 1.

A scenario of the system's behavior is: a new student has to learn web pages. The student has a learning style and an age category. The predictive controller has learned which pedagogical resources fit with the profile of the student. This can be realized using AI learning techniques [13] or the algorithm proposed in [18].

The error is:

$e = y_{ref}^{4*} - y^{4*} + \alpha y_{ref}^{1*} \overline{y^{1*}} + \beta y_{ref}^{2*} \overline{y^{2*}} + \gamma y_{ref}^{3*} \overline{y^{3*}}$

If the error is too big, the feedback controller provides a command to invoke a virtual meeting between the teacher and the student.

5 Problems of the Online Instructional Systems

The major problems connected to the online instructional systems are posed by their complexity and uncertainty. Generally speaking, the uncertainty refers to the impossibility of exact prediction. The uncertainty is a feature of the human behaviour. The human factor is a part of the online instructional systems and the instructional process act on humans (figure no. 9). So, an online instructional system has to be viewed from the point of its complexity and uncertainty. The uncertainty of the system means that the inputs of the system don't determine exactly the outputs of the system. The outputs of the system have

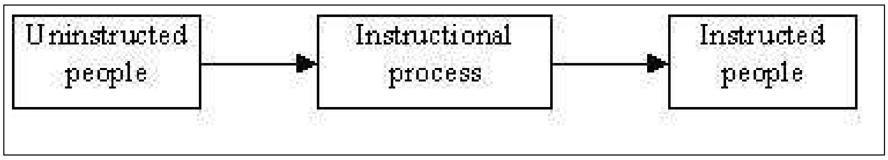


Figure 9: Inputs and outputs of the instructional process

to satisfy the standards knowledge according to the objectives of the instructional process. The authors of the paper "Defining Uncertainty a Conceptual Basis for Uncertainty Management in Model-Based Decision Support" [19] define the uncertainty concept taking into consideration three dimensions:

- the location of the uncertainty;
- the level of uncertainty;
- the nature of the uncertainty - the source of uncertainty, the imperfection of the knowledge, the diversity of the values, etc.

At a macro level, there may be distinguished two sources of the uncertainty:

1. the variability;
2. the limit of the knowledge.

The instructional systems are developing from the new scientific perspective of the analysis of their uncertainty. If we consider an instructional system with perturbation factors having null values, the outputs of the system cannot be predicted with accuracy. The instructional process is unpredictable and can not be reduced at linear sequences to produce predictable outputs. Considering the perturbation factors and the complexity of the relations between the parts of the system and the relations between system and the environment, the instructional system is a complex system. To obtain a reference value, the instructional system has to be defined as a complex adaptive system.

A Complex Adaptive System - (CAS) is a system with a lot of internal and external relations; the system can adapt itself and evaluate according to changes from the environment. It is important to see that there is not a precise boundary between the system and the environment. The system influences and changes the environment. An instructional system is linked with other systems, so that the changes have to be considered in terms of a co-evolution with other systems. An instructional system has to be designed from the viewpoint of the internal variable side and external variable side. The system records information about the environment, this information determines the behaviour of the system, the system transmits information to the environment and acts in accordance with the environment.

Another viewpoint of instructional process is the hermeneutic aspect, in which the learning is defined as an interpretation act, inseparable from the cultural and historical context. Jonassen [12] states that the instructional design theory has to consider the learning as an open system, which receives inputs from many sources, such as individual differences, emotional states, social and economical factors, demographical factors and so forth. The instructional designers have to understand the complex and holistic nature of the learning process and have not to isolate this kind of systems in closed systems.

6 Summary and Conclusions

In the perspective of the evolution of the whole society, it is necessary to approach the instructional process from the viewpoint of the systems theory. This perspective enables to solve the problems of the instructional process, in special considering the distance learning process. Practically, the distance instructional process, speaking about online learning process, can be successfully applied only using the techniques from systems theory and artificial intelligence. In this paper, the author has modeled the learning (instructional) process using the general systems theory. In this paper, the term of "quasi-boolean system" was introduced in order to provide a mathematical model describing the behaviour of the instructional system. The AI techniques are used in the regulation of the system. The possible applications of the proposed approach may be found in the instructional system to teach Mathematics, Computer Science, Architecture [21], Physics, Chemistry, etc. This kind of approach enables solving the problems of the complexity and uncertainty of the instructional systems, especially those of the online instructional systems.

Bibliography

[1] B. H. Banathy, *A Systems View of Education: Concepts and Principles for Effective Practice*. Englewood Cliffs, N.J.: Educational Technology Publications, 1992.

[2] B. H. Banathy, *Systems Inquiry and Its Application in Education*, In D. H. Jonassen (ed), Handbook of research for educational communication and technology, New York: MacMillan Library Reference, 1996.

[3] D. Chen and W. Stroup, *Toward a Conceptual Framework for Science and Technology Education for All*, Journal of Science Education and Technology, Volume 2, No.3, 1993.

[4] M. Cole., P. Griffin, *Contextual Factors in Education. Information Analyses Report*. Prepared for Committee on Research in Mathematics Science, and Technology Education, Commission on Behavioral and Social Sciences and Education, National Research Council. Wisconsin Center for Education Research, Madison, 1987.

[5] W. Dick, L. Carey, *The Systematic Design of Instruction,* Glenview,IL.:Scott,Foresman, 1978.

[6] R.R. Du Mont, *Distance Learning: A Systems View an Assessment and Review of the Literature*, Research report, grant awarded by the Ohio Learning Network in cooperation with Research Center for Educational Technology Kent State University, 2002.

[7] J.D. Finn, *Automation and Education: I. General aspects,* AV Communication Review, 5(1), 1957.

[8] R. Gagné, L. Briggs, W.W. Wager,*Principles of Instructional Design,*(3rd ed.). New York, NY: Holt, Rinehart and Winston, Inc., 1988.

[9] G. Gonzalez, *A Systematic Approach to Active and Cooperative Learning in CS1 and its Effects on CS2,* Technical Symposium on Computer Science Education, Proceedings of the 37th SIGCSE technical symposium on Computer science education, 2006.

[10] P.L. Hammer(Ivanescu), S. Rudeanu, *Methodes Booleennes en Recherche Operationelle*, Dunod, Paris, 1970.

[11] C. Ilas, *Teoria Sistemelor de Reglare Automata,* Matrix Rom, Bucuresti, 2006.

[12] D.H. Jonassen, et al. *Certainty, Determinism, and Predictability in Theories of Instructional Design: Lessons from Science,* Educational Technology, (37)1, 1997.

[13] G. Moise, *A Software System for Online Learning Applied in the Field of Computer Science,* IJCCC, Volume: II, No: 1, 2007.

[14] G. Moise, *A rules Based on Context Methodology to Build the Pedagogical Resources*, Proceedings of the 2nd International Conference on Virtual Learning, Bucharest University Press, 2007.

[15] M.G. Moore and G. Kearsley, *Distance Education: A Systems View,* Belmont, CA:Wadsworth Publishing Co., 1996.

[16] M.G. Moore,*Theory of Transactional Distance,* In D. Keegan (Ed.) Theoretical Principles of Distance Education. New York: Routledge, 1993.

[17] F. Saba, R.L. Shearer,*Verifying Key Theoretical concepts in a Dynamic Model of Distance Education,* The American Journal of Distance Education, 8 (1), 1994.

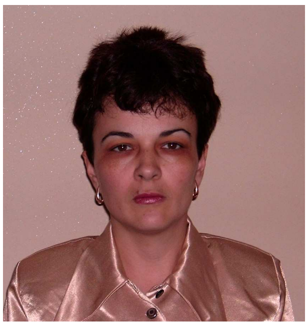
[18] A.D. Styliadis, I. D. Karamitsos, D. I. Zachariou, *Personalized e-Learning Implementation - The GIS Case,* International Journal of Computers, Communications & Control, Vol. I, No.1, 2006.

[19] W.E. Walker, P. Harremöees, J. Rotmans, J.P. VAN DER Sluijs, M.B.A. VAN Asselt, P. Janssen AND M.P. Krayer VON Krauss, *Defining Uncertainty A Conceptual Basis for Uncertainty Management in Model-Based Decision Support,* Integrated Assessment , Vol. 4, No. 1, 2003.

[20] N. Wiener, *The Human Use of Human Beings : cybernetics and society,* Second Edition Revised, Doubleday Anchor, 1954.

[21] A.D. Styliadis, *E-learning Documentation of Historical Living Systems with 3D Modeling Functionality,* Informatica, Vol. 18, No. 3, pp. 419-446, 2007.

Gabriela Moise
Petroleum-Gas University of Ploiesti
Computer Science Department
no. 39 Bd. Bucuresti, Ploiesti, Romania
E-mail: gmoise@upg-ploiesti.ro
Received: February 13, 2007



Gabriela Moise (born on February 13, 1969) graduated the Faculty of Mathematics, specialization Informatics of the Bucharest University. She worked in the software industry, developing IT solutions. Since 2003 she is Lecturer at Petroleum-Gas University of Ploiesti. Her research fields are: e-learning, graph theory, pedagogical agents, knowledge representation, e-health. She has (co)authored seven books and more than twenty research papers. She has participated to many international conferences in the e-learning and e-business area.

International Journal of Computers, Communications & Control
Vol. III (2008), No. 1, pp. 103-109

State Analysis of Time-Varying Singular Bilinear Systems by RK-Butcher Algorithms

V. Murugesh, K. Batri

Abstract: The Runge-Kutta (RK)-Butcher algorithm is used to study the time-varying singular bilinear systems with the exact solutions. The results (discrete solutions) obtained using the Haar wavelets, Single-Term Walsh series (STWS) and RK-Butcher algorithms are compared with the exact solutions of the time-varying singular bilinear systems. It is found that the solution obtained using the RK-Butcher algorithm is closer to the exact solutions of the time-varying singular bilinear systems. The RK-Butcher algorithm can easily be implemented using a digital computer and the solution can be obtained for any length of time, which is an added advantage of this algorithm.
Keywords: Time-varying singular bilinear systems, Haar wavelets, Runge-Kutta Butcher algorithm, STWS algorithm.

1 Introduction

The development of singular bilinear systems has been studied by some researchers. Campbell [1] had done some preliminary work, but there was no available closed-form solution in that paper. In some analysis of neural networks, both singular systems [2] and bilinear systems [3] have been used. The multipliers and algebraic interconnections between singular systems and bilinear systems are allowed in dynamical systems. For singular bilinear systems, Lewis et al. [4] have been discussed extensively in the literature. However, the solution due to Lewis et al. only applies for the time-invariant case. Hsiao and Wang [5] applied the Haar wavelets for the solution of time -varying singular bilinear systems. Sepehrian and Razzaghi [6] applied the STWS approach for finding the numerical solution of time-varying bilinear systems.

Runge-Kutta (RK) methods have become very popular both as computational techniques and as a topic for research [7-12]. Butcher [8] derived the best RK pair, together with an error estimate, and in all statistical measures this approach is known as the RK-Butcher algorithm. This algorithm appears to be of sixth order because it requires six function evaluations, but in practice the 'working order' is closer to five (fifth order). However, the accuracy of the results obtained is better than that of all other algorithms examined including the RK- Fehlberg, RK-Merson, RK-centroidal mean (RKCeM) and RK-arithmetic mean (RKAM) algorithms.

Murugesh and Murugesan [13-15] introduced the RK-Butcher algorithm in Raster and Time-multiplexing CNN simulations. Recently, [16, 18] the RK-Butcher algorithm is used to find the numerical solution of an industrial application problem. In this article, we present a new approach for solving the time-varying singular bilinear systems using the RK-Butcher algorithm with more accuracy.

2 The RK-Butcher Algorithm

The normal order of an RK algorithm is the approximate number of leading terms of an infinite Taylor series which calculates the trajectory of a moving point [17]. The remainder of the infinite sum, which is excluded, is referred to as the local truncation error (LTE). These RK algorithms are forward-looking predictors, i.e. they do not use any information from preceding steps to predict the future position of a point. For this reason, they require a minimum of input data and consequently are very simple to program and use.

The general p-stage Runge-Kutta method for solving an IVP is

$$y' = f(x,y) \tag{1}$$

with the initial condition $y(x_0) = y_0$ is defined by

$$y_{n+1} = y_n + h\sum_{i=1}^{p} b_i k_i$$

where

$$k_i = f\left(x_n + c_i h,\ y_n + h\sum_{j=1}^{p} a_{ij}k_j\right), \quad i = 1,2,3,......,p$$

and

$$c_i = \sum_{j=1}^{p} a_{ij}, \quad i = i,2,3,.....,p$$

In the preceding equations c and b are p-dimensional vectors and A(a_{ij}) is the $p \times p$ matrix. Then the Butcher array takes the form

$$\begin{array}{c|cccc}
c_1 & a_{11} & & & \\
c_2 & a_{21} & a_{22} & & \\
c_3 & a_{31} & a_{32} & a_{33} & \\
. & . & . & . & \\
. & . & . & . & \\
. & . & . & . & \\
. & . & . & . & . \\
c_p & a_{p1} & a_{p2} & a_{p3} & a_{pp} \\
\hline
 & b_1 & b_2 & b_{p-1} & b_p
\end{array}$$

The RK-Butcher algorithm of equation (1) is of the form

$$\begin{aligned}
k_1 &= hf(x_n,\ y_n) \\
k_2 &= hf\left(x_n + \frac{h}{4},\ y_n + \frac{k_1}{4}\right) \\
k_3 &= hf\left(x_n + \frac{h}{4},\ y_n + \frac{k_1}{8} + \frac{k_2}{8}\right) \\
k_4 &= hf\left(x_n + \frac{h}{2},\ y_n - \frac{k_2}{2} + k_3\right) \\
k_5 &= hf\left(x_n + \frac{3h}{4},\ y_n + \frac{3k_1}{16} + \frac{9k_4}{16}\right) \\
k_6 &= hf\left(x_n + h,\ y_n - \frac{3k_1}{7} + \frac{2k_2}{7} + \frac{12k_3}{7} - \frac{12k_4}{7} + \frac{8k_5}{7}\right)
\end{aligned} \tag{2}$$

5^{th} order predictor

$$y_{n+1} = y_n + \frac{1}{90}(7k_1 + 32k_3 + 12k_4 + 32k_5 + 7k_6)$$

4^{th} order predictor

$$y^*_{n+1} = y_n + \frac{1}{6}(k_1 + 4k_4 + k_6)$$

The local truncation error estimate (EE) is

$$EE = y_{n+1} - y^*_{n+1}$$

Then the formation of the Butcher array of the above equation (2) takes the following form

$$
\begin{array}{c|cccccc}
0 & & & & & & \\
\frac{1}{4} & \frac{1}{4} & & & & & \\
\frac{1}{4} & \frac{1}{8} & \frac{1}{8} & & & & \\
\frac{1}{2} & 0 & -\frac{1}{2} & 1 & & & \\
\frac{3}{4} & \frac{3}{16} & 0 & 0 & \frac{9}{16} & & \\
1 & \frac{3}{7} & \frac{2}{7} & \frac{12}{7} & \frac{12}{7} & \frac{8}{7} & \\
\hline
 & \frac{7}{90} & 0 & \frac{32}{90} & \frac{12}{90} & \frac{32}{90} & \frac{7}{90} \\
 & \frac{1}{6} & 0 & 0 & \frac{4}{6} & 0 & \frac{1}{6}
\end{array}
$$

3 Analysis of Time-Varying Singular Bilinear Systems

Consider the linear first order time-varying singular system

$$K\dot{x}(t) = Ax(t) + B(t)u(t) \tag{3}$$

with $x_0 = x(0)$, where K is an $n \times n$ singular matrix, A is an $n \times n$ matrix, B is an $n \times r$ matrix. x(t) is n-state vectors and u(t) is an r-input vector.

The time-varying singular bilinear system is of the form

$$E(t)\dot{x}(t) = A(t)x(t) + \sum_{i=1}^{q} N_i(t)x(t)u_i(t) + B(t)u(t) \tag{4}$$

equation (4)is written in the form (3) as

$$E(t)\dot{x}(t) = \left(A(t) + \sum_{i=1}^{q} N_i(t)u_i(t) \right) x(t) + B(t)u(t) \tag{5}$$

where the singular matrix $E(t) \in R^{n\times n}$, the state $x(t) \in R^n$, the control $u(t) \in R^q$, $A(t) \in R^{n\times n}$ and $B(t) \in R^{n\times q}$. $N_i(t) \in R^{n\times n}$ and $u_i(t), i = 1,2,3,....,q$, are the components of $u(t)$. The response $x(t), 0 \leq t \leq t_i$, is required to be found. The time-varying singular bilinear systems are much more difficult to solve than the time invariant singular bilinear systems. Therefore, many authors have tried various transform methods to over come these difficulties. In this article, we introduce RK-Butcher algorithms with more accuracy to solve these time-varying singular bilinear systems.

4 Numerical Example

Consider the time-varying singular bilinear system of the following form (Hsiao and Wang [5]) and Sepehrian and Razzaghi[6]).

$$
\begin{aligned}
E(t) &= \begin{bmatrix} 0 & -t & 0 \\ 1 & 0 & t \\ 0 & 1 & 0 \end{bmatrix} A(t) = \begin{bmatrix} -2 & t & 1 \\ 0 & -4 & 2 \\ -2t & 0 & 1 \end{bmatrix} N_1(t) = \begin{bmatrix} 1 & -t & 1 \\ 0 & 3 & -2 \\ 2t & 0 & -2 \end{bmatrix} \\
B(t) &= \begin{bmatrix} 2 & 1 & 3 \end{bmatrix}^T, \ u(t) = 1, \text{with initial condition } x(0) = \begin{bmatrix} 12 & 2 & 5 \end{bmatrix}^T
\end{aligned} \tag{6}
$$

when we solve (5), the analytic solution for $x(t)$ can be shown as

$$x(t)=\begin{bmatrix} (2-t)\left(exp\left(\frac{-t}{2}\right)+exp\left(t\right)\right)+8 \\ 2exp\left(\frac{-t}{2}\right)-exp\left(t\right)+1 \\ exp\left(\frac{-t}{2}\right)+exp\left(t\right)+3 \end{bmatrix} \tag{7}$$

The discrete solutions of equation (5) are evaluated using the RK-Butcher algorithms (with step size t = 0.25) represented in equation (2) and the results are compared with the solutions obtained by the Haar wavelets method by Hsiao and Wang [5] and the STWS method by Sepehrian and Razzaghi [6]. The results are shown in tables 1 - 3 along with the exact solutions calculated using equation (7). Errors between the exact and discrete solutions are also given in Tables 1 - 3.

S.No	Time	Discrete solution x_1 Values						
		Exact Solutions	Haar Solutions	Haar Error	STWS Solutions	STWS Error	RK-Butcher Solutions	RK-Butcher Error
1	0	12.000000	12.0000	0.000000	12.00000	0.000000	12.000000	0.000000
2	0.25	11.886053	11.8861	0.000047	11.88605	0.000003	11.886053	0.000000
3	0.5	11.791414	11.7914	0.000014	11.79142	0.000006	11.791414	0.000000
4	0.75	11.711533	11.7115	0.000033	11.71154	0.000007	11.711533	0.000000
5	1	11.641283	11.6413	0.000017	11.64128	0.000003	11.641283	0.000000
6	1.25	11.574810	11.5748	0.000010	11.57481	0.000000	11.574810	0.000000
7	1.5	11.505362	11.5054	0.000038	11.50537	0.000008	11.505362	0.000000
8	1.75	11.425089	11.4251	0.000011	11.42510	0.000011	11.425089	0.000000
9	2	11.324812	11.3248	0.000012	11.32481	0.000002	11.324812	0.000000

Table 1: Solutions for the problem at various values of x_1.

S.No	Time	Discrete solution x_2 Values						
		Exact Solutions	Haar Solutions	Haar Error	STWS Solutions	STWS Error	RK-Butcher Solutions	RK-Butcher Error
1	0	2.000000	2.0000	0.000000	2.00000	0.000000	2.000000	0.000000
2	0.25	1.745678	1.7457	0.000022	1.74568	0.000002	1.745678	0.000000
3	0.5	1.480968	1.4810	0.000032	1.48097	0.000002	1.480968	0.000000
4	0.75	1.203067	1.2031	0.000033	1.20307	0.000003	1.203067	0.000000
5	1	0.908880	0.9089	0.000020	0.90888	0.000000	0.908880	0.000000
6	1.25	0.594985	0.5950	0.000015	0.59498	0.000005	0.594985	0.000000
7	1.5	0.257579	0.2576	0.000021	0.25758	0.000001	0.257579	0.000000
8	1.75	-0.107578	-0.1076	0.000022	-0.10758	0.000002	-0.107578	0.000000
9	2	-0.505221	-0.5052	0.000021	-0.50522	0.000001	-0.505221	0.000000

Table 2: Solutions for the problem at various values of x_2.

5 Conclusions

The discrete solutions obtained using the RK-Butcher algorithm gives more accurate values when compared to the Haar wavelets method discussed by Hsiao and Wang [5] and the STWS method by

S.No	Time	Discrete solution x_3 Values						
		Exact Solutions	Haar Solutions	Haar Error	STWS Solutions	STWS Error	RK-Butcher Solutions	RK-Butcher Error
1	0	5.000000	5.0000	0.000000	5.00000	0.000000	5.000000	0.000000
2	0.25	5.072562	5.0726	0.000038	5.07256	0.000002	5.072562	0.000000
3	0.5	5.166522	5.1665	0.000022	5.16652	0.000002	5.166522	0.000000
4	0.75	5.284021	5.2840	0.000021	5.28402	0.000001	5.284021	0.000000
5	1	5.427522	5.4275	0.000022	5.42752	0.000002	5.427522	0.000000
6	1.25	5.599862	5.5999	0.000038	5.59986	0.000002	5.599862	0.000000
7	1.5	5.804289	5.8043	0.000011	5.80429	0.000001	5.804289	0.000000
8	1.75	6.044524	6.0445	0.000024	6.04451	0.000014	6.044524	0.000000
9	2	6.324812	6.3248	0.000012	6.32480	0.000012	6.324812	0.000000

Table 3: Solutions for the problem at various values of x_3.

Sepehrian and Razzaghi [6]. From the tables 1-3, one can observe that the solutions obtained by the RK-Butcher algorithm match well with the exact solutions of the time-varying singular bilinear systems, but the Haar wavelets and STWS methods yields a little error. Hence the RK-Butcher algorithm is more suitable for studying the time-varying bilinear systems.

Bibliography

[1] Campell, S.L., 1987, Bilinear nonlinear descriptor control systems, *CRSC Technical Report 102386-01, Department of Mathematics, N.C. State University, Raleigh, NC 27695*.

[2] Declaris, N. and Rindos, A., 1984, Semistate analysis of neural networks in Apysia Californica, *Proceedings of the 27th MSCS*, 686-689.

[3] Wiener, N., 1948, *Cybernetics* (Cambridge, MIT Press).

[4] Lewis, F. L., Mertzios, B. C., and Marszalek, W., 1991, Analysis of singular bilinear systems using Walsh functions, *IEE Proceedings Part-D*,138, 89-92.

[5] Hsiao, C. H., and Wang, W. J., 2000, State Analysis of time-varying Singular Bilinear Systems via Haar wavelets, *Mathematics and Computers in Simulation*, 52, 11-20.

[6] Sepehrian, B., and Razzaghi, M., 2003, State Analysis of time-varying Singular Bilinear Systmes by Single-Term Walsh Series, *International Journal of Computer Mathematics*, 80, 413-418.

[7] Alexander, R.K. and Coyle, J.J.,1990, Runge-Kutta methods for differential-algebraic systems. *SIAM Journal of Numerical Analysis*, 27, 736-752.

[8] Butcher, J.C., 1987, The Numerical Analysis of Ordinary Differential Equations: Runge-Kutta and General Linear Methods (Chichester: JohnWiley).

[9] Butcher, J.C., 2003, Numerical Methods for Ordinary Differential Equations (Chichester: JohnWiley).

[10] Shampine, L.F., 1994, Numerical Solution of Ordinary Differential Equations (NewYork: Chapman & Hall).

[11] Yaakub, A.R. and Evans, D.J., 1999, A fourth order Runge-Kutta RK(4,4) method with error control. *International Journal of Computer Mathematics*, 71, 383-411.

[12] Yaakub, A.R. and Evans, D.J., 1999, New Runge-Kutta starters of multi-step methods. *International Journal of Computer Mathematics*, 71, 99-104.

[13] Murugesh, V., and Murugesan, K., 2004, Comparison of Numerical Integration Algorithms in Raster CNN Simulation, *Lecture Notes in Computer Science*, 3285, 115-122.

[14] Murugesh, V. and Murugesan, K., 2005, Simulation of Cellular Neural Networks using the RK-Butcher algorithm, *International Journal of Management and Systems*, 21, 65-78.

[15] Murugesh, V., and Murugesan, K., 2006, Simulation of Time-Multiplexing Cellular Neural Networks with Numerical Integration Algorithms, *Lecture Notes in Computer Science*, 3991, 115-122.

[16] Devarajan Gopal, Murugesh, V., and Murugesan, K., 2006, Numerical Solution of Second-order Robot Arm Control Problem using Runge-Kutta Butcher Algorithm, *International Journal of Computer Mathematics*, 83, 345-356.

[17] Shampine, L.F. and Gordon, M.K., 1975, Computer Solutions of Ordinary Differential Equations: The Initial Value Problem (San Francisco, CA:W.H. Freeman).

[18] V. Murugesh and K. Batri, "An Efficient Numerical Integration Algorithm for Cellular Neural Network Based Hole-Filler Template Design", *International Journal of Computers, Communications & Control*, Vol. II (2007), No. 4, pp. 367-374.

V. Murugesh
Department of Information and Communication Engineering
Hannam University
133 Ojung-dong Daeduk-gu, Daejeon 306-791, Republic of Korea
E-mail: murugesh72@gmail.com

K. Batri
Department of Computer Science and Engineering
Muthayammal Engineering College
Rasipuram 637 408
India
E-mail: krishnan.batri@gmail.com

Received: November 26, 2007

Dr. V. Murugesh obtained his Bachelor of Science in Computer Science and Master of Computer Applications degree from Bharathiar University, Coimbatore, India during 1992 and 1995 respectively. Completed his PhD in Computer Science from Bharathidasan University, Tiruchirappalli, India during 2006. He has held various positions at National Institute of Technology, Tiruchirappalli, India and Sona College of Technology, Salem, India. Currently, he is working as Assistant Professor in the Department of Information and Communication Engineering at Hannam University, Daejeon, Republic of Korea. His fields of interest are in Neural Network based Image Processing and Scientific computing. He has published more than 30 technical papers in International, National journals and conferences.

Krishnan Batri received the M.E. from Madurai Kamarj University in 2003. He is a Research Scholar with the Department of Computer Science and Engineering in the National Institute of Technology Tiruchirapalli, Tamil Nadu, India. Currently he is working as a Assistant Proffessor with the department of Computer Science and Engineering at Muthayammal Engineering College,Rasipuram, Tamilnadu, India . His research interests include Information Retrieval, Data fusion and Genetic algorithms.

Author index

Description

International Journal of Computers, Communications & Control (IJCCC) is a quarterly peer-reviewed publication started in 2006 by Agora University Editing House - CCC Publications, Oradea, ROMANIA.

Beginning with 2007, EBSCO Publishing is a licensed partner of IJCCC Publisher.

Every issue is published in online format (ISSN 1841-9844) and print format (ISSN 1841-9836). Beginning with 2008, we offer free online access to the abstracts only. Access to the full text of papers will be limited. The printed version of the journal should be ordered, by subscription, and will be delivered by regular mail.

IJCCC is directed to the international communities of scientific researchers from the universities, research units and industry.

IJCCC publishes original and recent scientific contributions in the following fields:

- Computing & Computational Mathematics
- Information Technology & Communications
- Computer-based Control

To differentiate from other similar journals, the editorial policy of IJCCC encourages especially the publishing of scientific papers that focus on the convergence of the 3 "C" (Computing, Communication, Control).

The articles submitted to IJCCC must be original and previously unpublished in other journals. The submissions will be revised independently by minimum two reviewers and will be published only after end of the editorial workflow.

The peer-review process is single blinded: the reviewers know who the authors of the manuscript are, but the authors do not have access to the information of who the peer-reviewers are.

IJCCC also publishes:

- papers dedicated to the works and life of some remarkable personalities;
- reviews of some recent important published books

Also, IJCCC will publish as supplementary issues the proceedings of some international conferences or symposiums on Computers, Communications and Control, scientific events that have reviewers and program committee.

The authors are kindly asked to observe the rules for typesetting and submitting described in Instructions for Authors.

Editorial Workflow

The editorial workflow is performed using the online Submission System.

The peer-review process is single blinded: the reviewers know who the authors of the manuscript are, but the authors do not have access to the information of who the peer-reviewers are.

The following is the editorial workflow that every manuscript submitted to the IJCCC during the course of the peer-review process.

Every IJCCC submitted manuscript is inspected by the Editor-in-Chief/Associate Editor-in-Chief. If the Editor-in-Chief/Associate Editor-in-Chief determines that the manuscript is not of sufficient quality to go through the normal review process or if the subject of the manuscript is not appropriate to the journal scope, Editor-in-Chief/Associate Editor-in-Chief *rejects the manuscript with no further processing*.

If the Editor-in-Chief/Associate Editor-in-Chief determines that the submitted manuscript is of sufficient quality and falls within the scope of the journal, he sends the manuscript to the IJCCC Executive Editor/Associate Executive Editor, who manages the peer-review process for the manuscript.

The Executive Editor/Associate Executive Editor can decide, after inspecting the submitted manuscript, that it should be rejected without further processing. Otherwise, the Executive Editor/Associate Executive Editor assigns the manuscript to the one of Associate Editors.

The Associate Editor can decide, after inspecting the submitted manuscript, that it should be rejected without further processing. Otherwise, the Associate Editor assigns the manuscript to minimum two external reviewers for peer-review. These external reviewers may or may not be from the list of potential reviewers of IJCCC database.

The reviewers submit their reports on the manuscripts along with their recommendation of one of the following actions to the Associate Editor: Publish Unaltered; *Publish after Minor Changes; Review Again after Major Changes; Reject* (Manuscript is flawed or not sufficiently novel).

When all reviewers have submitted their reports, the Associate Editor can make one of the following editorial recommendations to the Executive Editor: Publish Unaltered; Publish after Minor Changes; Review Again after Major Changes; Reject.

If the Associate Editor recommends *"Publish Unaltered"*, the Executive Editor/Associate Executive Editor is notified so he/she can inspect the manuscript and the review reports. The Executive Editor/Associate Executive Editor can either override the Associate Editor's recommendation in which case the manuscript is rejected or approve the Associate Editor's recommendation in which case the manuscript is accepted for publication.

If the Associate Editor recommends "Review Again after Minor Changes", the Executive Editor/Associate Executive Editor is notified of the recommendation so he/she can inspect the manuscript and the review reports.

If the Executive Editor/Associate Executive Editor overrides the Associate Editor's recommendation, the manuscript is rejected. If the Executive Editor approves the Associate Editor's recommendation, the authors are notified to prepare and submit a final copy of their manuscript with the required minor changes suggested by the reviewers. Only the Associate Editor, and not the external reviewers, reviews the revised manuscript after the minor changes have been made by the authors. Once the Associate Editor is satisfied with the final manuscript, the manuscript can be accepted.

If the Associate Editor recommends *"Review Again after Major Changes"*, the recommendation is communicated to the authors. The authors are expected to revise their manuscripts in accordance with the changes recommended by the reviewers and to submit their revised manuscript in a timely manner. Once the revised manuscript is submitted, the original reviewers are contacted with a request to review the revised version of the manuscript. Along with their review reports on the revised manuscript, the reviewers make a recommendation which can be "Publish Unaltered" or "Publish after Minor Changes" or "Reject". The Associate Editor can then make an editorial recommendation which can be "Publish Unaltered" or "Review Again after Minor Changes" or "Reject".

If the Associate Editor recommends rejecting the manuscript, either after the first or the second round of reviews, the rejection is immediate.

Only the Associate Editor-in-Chief can approve a manuscript for publication, where Executive Editor/Associate Executive Editor recommends manuscripts for acceptance to the Editor-in-Chief/Associate Editor-in-Chief.

Finally, recommendation of acceptance, proposed by the Associate Editor Chief, has to be approved by the Editor-in-Chief before publication.

Instructions for authors

The papers must be prepared using a LaTeX typesetting system. A template for preparing the papers is available on the journal website http://journal.univagora.ro. In the template.tex file you will find instructions that will help you prepare the source file. Please, read carefully those instructions. (We are using MiKTeX 2.4).

Any graphics or pictures must be saved in Encapsulated PostScript (.eps) format.

Papers must be submitted electronically to the following address: ccc@univagora.ro. You should send us the LaTex source file (just one file - do not use bib files) and the graphics in a separate folder. You must send us also the pdf version of your paper.

The maximum number of pages of one article is 20. The publishing of a 12 page article is free of charge (including a bio-sketch). For each supplementary page there is a fee of 50 Euro/page that must be paid after receiving the acceptance for publication. The authors do not receive a print copy of the journal/paper, but the authors receive by email a copy of published paper in pdf format.

The papers must be written in English. The first page of the paper must contain title of the paper, name of author(s), an abstract of about 300 words and 3-5 keywords. The name, affiliation (institution and department), regular mailing address and email of the author(s) should be filled in at the end of the paper. Manuscripts must be accompanied by a signed copyright transfer form. The copyright transfer form is available on the journal website.

Please note: To avoid unnecessary delays in publishing you are kindly asked to consider all recommendations expressed in the template. We do not accept submissions in other formats (pdf only, Microsoft Word, etc).

Checklist:

1. Completed copyright transfer form.
2. Source (input) files.
    - One LaTeX file for the text.
    - EPS files for figures in a separate folder.
3. Final PDF file (for reference).

Order

If you are interested in having a subscription to "Journal of Computers, Communications and Control", please fill in and send us the order form below:

ORDER FORM		
I wish to receive a subscription to "Journal of Computers, Communications and Control"		
NAME AND SURNAME:		
Company:		
Number of subscription:	Price Euro	for issues yearly (4 number/year)
ADDRESS: City: Zip code: Country: Fax: Telephone: E-mail:		
Notes for Editors (optional)		

1. Standard Subscription Rates for Romania (4 issues/2007, more than 400 pages, including domestic postal cost): 90 EURO.

   2. Standard Subscription Rates for other countries (4 issues/2007, more than 400 pages, including international postal cost): 160 EURO.

For payment subscription rates please use following data:
HOLDER: Fundatia Agora, CUI: 12613360
BANK: BANK LEUMI ORADEA
BANK ADDRESS: Piata Unirii nr. 2-4, Oradea, ROMANIA
IBAN ACCOUNT for EURO: RO02DAFB1041041A4767EU01
IBAN ACCOUNT for LEI/ RON: RO45DAFB1041041A4767RO01
SWIFT CODE (eq. BIC): DAFBRO22
Mention, please, on the payment form that the fee is "for IJCCC".

EDITORIAL ADDRESS:
CCC Publications
Piata Tineretului nr. 8
ORADEA, jud. BIHOR
ROMANIA
Zip Code 410526
Tel.: +40 259 427 398
Fax: +40 259 434 925
E-mail: ccc@univagora.ro, Website: www.journal.univagora.ro

Copyright Transfer Form

To The Publisher of the International Journal of Computers, Communications & Control

This form refers to the manuscript of the paper having the title and the authors as below:

The Title of Paper (hereinafter, "Paper"):

....

The Author(s):

....

....

....

....

The undersigned Author(s) of the above mentioned Paper here by transfer any and all copyright-rights in and to The Paper to The Publisher. The Author(s) warrants that The Paper is based on their original work and that the undersigned has the power and authority to make and execute this assignment. It is the author's responsibility to obtain written permission to quote material that has been previously published in any form. The Publisher recognizes the retained rights noted below and grants to the above authors and employers for whom the work performed royalty-free permission to reuse their materials below. Authors may reuse all or portions of the above Paper in other works, excepting the publication of the paper in the same form. Authors may reproduce or authorize others to reproduce the above Paper for the Author's personal use or for internal company use, provided that the source and The Publisher copyright notice are mentioned, that the copies are not used in any way that implies The Publisher endorsement of a product or service of an employer, and that the copies are not offered for sale as such. Authors are permitted to grant third party requests for reprinting, republishing or other types of reuse. The Authors may make limited distribution of all or portions of the above Paper prior to publication if they inform The Publisher of the nature and extent of such limited distribution prior there to. Authors retain all proprietary rights in any process, procedure, or article of manufacture described in The Paper. This agreement becomes null and void if and only if the above paper is not accepted and published by The Publisher, or is withdrawn by the author(s) before acceptance by the Publisher.

Authorized Signature (or representative, for ALL AUTHORS): ....

Signature of the Employer for whom work was done, if any: ....

Date: ....

Third Party(ies) Signature(s) (if necessary): ....

ICCCC 2008
International Conference on Computers, Communications & Control (ICCCC 2008), Băile Felix (Oradea), Romania, 15-17 May 2008

The IEEE 2nd International Conference on Computers, Communications & Control (ICCCC 2008) is organized by Agora University and IEEE Computer Society - Romania Section.
ICCCC 2008 provides a forum for international scientists in academia and industry to present and discuss their latest research findings on a broad array of topics in computer networking and control.
The Program Committee is soliciting paper describing original, previously unpublished, completed research, not currently under review by another conference or journal, addressing state-of-the-art research and development in all areas related to computer networking and control.
The papers will be reviewed by two members of the program committee or other specialists.
The conference proceedings will be available at the conference. Some selected papers will be published in: International Journal of Computers, Communications & Control (IJCCC).

General topics of interest include, but are not limited to, the following:

1. Artificial Intelligence
2. Automata and Formal Languages
3. Computational Mathematics
4. Cryptography and Security
5. Control
6. Economic Informatics
7. E-Activities
8. Fuzzy Systems
9. Information Society - Knowledge Society
10. Natural Computing
11. Network Design & Internet Services
12. Multimedia & Communications
13. P2P Systems and Internet applications
14. Parallel and Distributed Computing

This event is dedicated to the Centenary of *John Bardeen* (1908-1991) the co-inventor of the transistor, a very important element in the development of the computers and the communications.
For more details see www.iccc.univagora.ro

Keynote Speakers

Lotfi A. Zadeh (University of California, USA) is a Professor in the Graduate School, Computer Science Division, Department of EECS, University of California, Berkeley. In addition, he is serving as the Director of BISC (Berkeley Initiative in Soft Computing). Lotfi A. Zadeh is an alumnus of the University of Teheran, MIT and Columbia University. He held visiting appointments at the Institute for Advanced Study, Princeton, NJ; MIT; IBM Research Laboratory, San Jose, CA; SRI International, Menlo Park, CA; and the Center for the Study of Language and Information, Stanford University. His earlier work was concerned in the main with systems analysis, decision analysis and information systems. His current research is focused on fuzzy logic, computing with words and soft computing, which is a coalition of fuzzy logic, neurocomputing, evolutionary computing, probabilistic computing and parts of machine learning. The guiding principle of soft computing is that, in general, better solutions can be obtained by employing the constituent methodologies of soft computing in combination rather than in stand-alone mode. Lotfi A. Zadeh is a Fellow of the IEEE, AAAS, ACM, AAAI, and IFSA. He is a member of the National Academy of Engineering and a Foreign Member of the Russian Academy of Natural Sciences. He is a recipient of the IEEE Education Medal, the IEEE Richard W. Hamming Medal, the IEEE Medal of Honor, the ASME Rufus Oldenburger Medal, the B. Bolzano Medal of the Czech Academy of Sciences, the Kampe de Feriet Medal, the AACC Richard E. Bellman Central Heritage Award, the Grigore Moisil Prize, the Honda Prize, the Okawa Prize, the AIM Information Science Award, the IEEE-SMC J. P. Wohl Career Acheivement Award, the SOFT Scietific Contribution Memorial Award of the Japan Society for Fuzzy Theory, the IEEE Millennium Medal, the ACM 2000 Allen Newell Award, and other awards and honorary doctorates. He has published extensively on a wide variety of subjects relating to the conception, design and analysis of information/intelligent systems, and is serving on the editorial boards of over fifty journals.

Pierre Borne (Ecole Centrale de Lille FRANCE) was born in Corbeil, France in 1944, he received the Master degree of Physics in 1967, the Masters of Electronics, of Mechanics and of Applied Mathematics in 1968. The same year he obtained the Diploma of "Ingénieur IDN" (French "Grande Ecole"). He obtained the PhD in Automatic Control of the University of Lille in 1970 and the DSc of the same University in 1976. He became Doctor Honoris Causa of the Moscow Institute of Electronics and Mathematics (Russia) in 1999, of the University of Waterloo (Canada) in 2006 and of the polytechnic University of Bucarest (Romania). He is author or co-author of about 200 Journal articles and book chapters, and of 34 plenary lectures and of more than 250 communications in international conferences. He has been the supervisor of 66 PhD thesis and is author of 20 books. He has been President of the IEEE/SMC society in 2000 and 2001. He is presently Professor "de classe exceptionnelle" at the Ecole Centrale de Lille and director of the French pluriformations national group of research in Automatic Control.

Stephan Olariu (Old Dominion University USA) is a tenured full professor in Computer Science at Old Dominion University, Norfolk, Virginia. He is a world-renowned technologist in the areas of parallel and distributed systems, parallel and distributed architectures and networks. He was invited and visited more than 120 universities and research institutes around the world lecturing on topics ranging from wireless networks and mobile computing, to biology-inspired algorithms and applications, to telemedicine, to wireless location systems, and demining. Professor Olariu is the Director of the Sensor Networks Research Group at Old Dominion University. He earned his Ph.D. (Computer Science) in three years at the McGill University, Montreal. He is author or co-author of more than 200 journal articles, 100 conference articles and books. Stephan is an Associate Editor of Networks, International Journal of Foundations of Computer Science, and serves on the editorial board of Journal of Parallel and Distributed Computing and served (until January 2003) as Associate Editor of IEEE Transactions on Parallel and Distributed Systems and VLSI Design.

Gheorghe Păun (Romanian Academy, Institute of Mathematics ROMANIA, University of Seville SPAIN) graduated the Faculty of Mathematics, University of Bucharest, in 1974 and received his Ph.D. in mathematics (with specialization in computer science) from the same university in 1977. He held a research position at the University of Bucharest, and from 1990 he is at the Institute of Mathematics of the Romanian Academy, where he is currently a senior researcher. He visited numerous universities in Europe, Asia, and North America, with frequent and/or longer stays in Turku (Finland), Leiden (The Netherlands), Magdeburg (Germany, including an Alexander von Humboldt fellowship, in 1992-93), Tarragona, Madrid, and Sevilla (Spain, including a Ramon y Cajal scholarship, in 2001-2006), London-Ontario (Canada), Rome, Milano, Pisa (Italy), Tokyo (Japan), Warsaw (Poland), Vienna (Austria), Budapest (Hungary), etc. His main research areas are formal language theory and its applications, computational linguistics, DNA computing, and membrane computing; this last research area was initiated by him, in 1998, and the respective models are now called P systems, see http://psystems.disco.unimib.it). He has published a large number of research papers (collaborating with many researchers worldwide), has lectured at over 100 universities, and gave numerous invited talks at recognized international conferences. He has published eleven books in mathematics and computer science (some of them translated in Japanese, Chinese, Russian), has edited over forty collective volumes, and also published many popular science books, books on recreational mathematics (games), and fiction books. He is a member of the editorial boards of more than a dozen international journals and was/is involved in the program/steering/organizing committees for many recognized conferences and workshops. In 1997 he was elected a member of the Romanian Academy and from 2006 he is a member of Academia Europaea. He also got other honors, in Romania or abroad.

Honorary Conference Chair:

- Lotfi A. ZADEH, Berkeley University of California, USA.

Honorary Program Committee Chair:

- Florin FILIP, Romanian Academy, ROMANIA

Conference Chairs:

- Mişu-Jan MANOLESCU, Agora University, Oradea, ROMANIA
- Nicolae ŢĂPUŞ, Politehnica University, Bucharest, ROMANIA

Program Chairs:

- Ioan DZIŢAC, Agora University, Oradea, ROMANIA
- Imre J. RUDAS, Budapest Tech, HUNGARY

Organizing Committee Chairs:

- Răzvan ANDONIE, Central Washington University, Ellensburg, USA
- Adriana MANOLESCU, Agora University, Oradea, ROMANIA

This event is dedicated to the Centenary of John Bardeen (1908-1991), the co-inventor of the transistor, a very important element in the development of the computers and the communications.