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First Responders' Localization and Health Monitoring During Rescue Operations

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Abstract

Currently, first responders' coordination and decision-making during res-cue, firefighting or police operations is performed via radio/GSM channels with some support of video streaming. In unknown premises, officers have no global situational awareness on operation status, which reduces coordination efficiency and increases decision making mistakes. This paper pro-poses a solution enabling the situational awareness by introducing an integrated operation workflow for actors localization and health monitoring. The solution will provide global situational awareness to both coordinators and actors, thereby increasing efficiency of coordination, reducing mistakes in decision making and diminishing risks of unexpected situations to appear. This will result in faster operation progress, lower number of human casualties and financial losses and, the most important, saved human lives in calamity situations.

Keywords: fuzzy set theory, probabilistic graphical model, simultaneous localization and mapping.

1 Introduction

Nowadays, calamities such as fires in buildings, bomb threats in stations/airports and infrastructure accidents are frequently occurring in the lives of citizens. During such large events, organizations like fire departments, police, hospitals etc. work together, but the information about the actual actions is limited and information sharing between organizations is restricted. Commonly, three important problems appear:

1. global coordination and individual agent decision making during operations is done only via the radio/GSM;

2. the coordinator has often no real-time information on the actual situation and the detailed positioning of individual actors;

3. the individual rescue worker (actor) enters an unknown hazardous site without knowing his position and the positioning of his colleagues.

This reduces coordination efficiency, hampers safe decision making and slows down the rescue process, so that the casualties and death toll becomes higher than necessary, besides, first responders operate at higher risks and a less safe infrastructure. Instead, rapid information is vital to plan the rescue action and to use resources correctly. Every day in Europe there are about 12 fire victims and 120 people severely injured by fire accidents and related hazards. The World Health Organization reports that there are approximately 300,000 deaths per year, globally from fire-related burns [1]. Those most at risk are both young babies/children and the elderly because they are least able to escape in the event of a fire, so they need a timely and efficient help from the fire-fighter officers. It is reported that at least 94% of these fires deaths 2 occurred in homes and buildings. The total direct and indirect cost of fires, including economic consequences of deaths and injuries, is estimated to be 1% of GDP in the developed world. This figure implies that timely and efficiently stopping a fire also reduces the indirect commercial losses of the burning company sites and members of their supply chain, leading to a higher economic efficiency. Apart from the financial and population losses, fire-fighters often become victims during the operation, partly due to inefficient coordination and organization of operations. In Britain, official figures report an average of one on-duty fire-fighter death every quarter since 1978 [2]. According to this report, there is no evidence to suggest that fire-fighters' health and safety in fire suppression operations has improved in recent years. So, while fire-fighting operations significantly decreased between 1996 and 2010, on-duty deaths in the same period continued to rise. Similar critical figures are presented in [3] on other calamities (i.e. earthquakes), where efficiency in rescue operations is vital to reduce or prevent losses. Nowadays, the rescue and fire-fighting brigades are not equipped with proper tooling that enables such efficient operations. The current equipment and coordination infrastructure do not benefit from recent technological advances at all. The state-of-the-art equipment and coordination facilities include RF or GSM communicators and, at best case, mono-cameras which stream the video data from the officers in action to a coordinator. This is certainly insufficient for efficient and timely coordination, since it:

- does not allow a coordinator to have an overview on the rapidly changing global situation;
- gives no detailed insight on local events and hazards;
- provides no decision support with alerts and notifications generated by a situation analysis tool.

The acting officers are currently equipped with an RF/GSM communicator which, similarly, is not sufficient for instant understanding of a local situation, partner positions, and a global overview of an operation. In [4] the authors reached good results in the interoperability for voice and data communication, command posts and user interfaces, as well as the following sets of sensors: biometric, video, optical gas, fire detection and radiation. By these results, a higher level of situational awareness has been achieved. Also, this project developed video annotation system alerting responders in case of hazardous situations. Visual navigation algorithms for controlled and unmanned vehicles are a research domain with long history and stable results. However, with appearance of low-cost depth and 3D-sensors, research community reported on advanced navigation/camera tracking algorithms based on captured 3D data [5] and stereo/depth data [6]. Such algorithms use the planar (and even volumetric) data obtained from laser/ structured light/stereo/time-of-flight sensors, to identify the mobile-platform position in space in real-time and control the platform based on the identified obstacle space and predictions on the optimal path to the target point. Algorithms for Simultaneous Localization and Mapping (SLAM) play a vital role in navigation technologies. A SLAM algorithm pipeline normally contains three blocks: feature detection/tracking, loop closure and bundle adjustment. Such approach enables nearly correct estimation on platform localization at every point in time. SLAM systems can operate based on a mono-camera input [7], on depth/stereo camera data, or on LIDAR 3D point-cloud data. However, the best performance results are obtained in approaches where SLAM algorithms are based on multi-modal input data, when 2D image data is fused with 3D/depth data [8]. The focus of this research is to build an innovative solution to improve awareness of the first respondent (actors) situation, by using multimodal fusion of data from RGB cameras, depth sensor, microphone system, mounted on the first respondents or UAVs, also an intelligent technology, integrated in a high-tech T-shirt on the actors. In the 1st section generalities about intervention management in case of calamities are discussed, while the 2nd one presents a detailed analysis of developing technologies in this field. In 3rd section the methods, models and devices used, respectively the first results generated with them are presented. Finally, conclusions are synthesized within the 4th section.

2 Technology analysis

The research in the domain of 3D scene reconstruction from moving platforms can be distinguished by the following two trends:

- development of moving sensor carriers;
- deployment of data fusion algorithms for multi-modal (2D/3D) data obtained from multiple sensor devices.

MoD [9] is a project that aims at the development of a flexible system to create on demand maps of buildings. The platform is a single UAV drone equipped with GPS, stereo cameras and ultrasound sensors. The vehicle has limited autonomy and is used for 3D reconstruction tasks. CONSTRUCT [10] is a project aiming at methods for modelling and surveying large construction sites. The project will make use of unmanned aerial vehicles at a construction site. The goal is to provide accurate static 3D models on a regular basis of construction sites by the use of unmanned aerial vehicles. The 3D models can then be used for documentation, visualization and change detection. Pegasus [11], the aim of this project is to develop a mobile vision system for overhead power line inspection. One of the challenges in this project is to achieve visual navigation, obstacle detection and model-based inspection under harsh environmental conditions. Current technological advances in 3D-data capturing devices (stereo cameras, LIDAR laser scans, time-of-flight cameras and structured light sensors) make the concept of hybrid-sensing feasible from the technological and the cost-of-materials points of view. Hybrid sensing provides much higher capturing coverage than multi-camera setups. The algorithms for multi-modal data fusion into a single enhanced representation (e.g. detailed 3D model) are in the major focus of vision and cognition research communities, led by Point Cloud Library (PCL) [12]. Such technologies as StereoTo3D and Kintinous [13] provide textured 3D models of the captured scene on the fly. The Kinfu Large Scale technology [14] from the TUE project partner is one of the PCL cornerstones for real-time 3D scene reconstruction. Ongoing development of emergency response applications targets issues such as distributed communication between mobile devices, simulation environments for training purposes, decision support systems processing events from numerous devices, sensors, social media, and formal domain modelling. Raven [15] supports the use of smart phones for collaborative disaster data collection and sharing through an exchange of the database and corresponding schema. Its current interface tracks lost and found people based on database records. Similarly, SocEDA [16] enables the exchange of social network data be-tween heterogeneous services through the distributed interaction of several event processing engines. An emergency response scenario during a nuclear disaster simulates virtual events from the involved partners. For visualizing human activity in 3D virtual environments/3D UIs, different kinds of camera and sensor technologies have been widely used. To automatically detect and visualize daily activities of people in 3D virtual environments, Shaikh [17] analyzed continuous voice samples recorded with a mobile device. Fleck [18] utilized smart cameras for detecting location and falling of elderly people. In addition to human activities, the previous work has focused on developing visualization methods for various types of spatiotemporal data [19]. This data may include, for instance, law enforcement data, syndromic surveillance data and population density. With the introduction of new Internet-of-Things (IoT) systems, sensor data visualization has also recently gained a lot of attention. The previous work has em-phasized that the sensor data may be complex and not always ready for direct visualization, and thus, further processing may be required [20][21]. Human-computer-interaction (HCI) research on 3D user interfaces (UI) has mainly addressed the use of 3D virtual worlds, and has typically focused on rather detailed aspects of the UI design, such as avatars. Recently, a broader approach to the 3D UI design has also been adopted. By extending the boundaries of the traditional usability research, user experience (UX) research investigates the interaction with a system in a holistic manner, taking into account both hedonic and utilitarian aspects related to the use of the technology [22].

3 People localization and monitoring

The project defines three levels of main roles/users in calamity-related operation involved with their responsibilities:

- actors, i.e. agents and rescue workers carrying out the rescue, fire -fighting or inspection operation;
- local coordinators managing the operation on the site, and
- global coordinators, supporting the operation at their premises (hospitals, police stations, fire departments, disaster-plan centers, etc.).

This project system proposes an integrated operation workflow (Figure 1), where these involved users have improved communication and understanding via a connection to a common data-, decision- and command- flow, obtaining situational awareness both at the detailed level (e.g. actor's positions and conditions) and at the over-view level (operation phase and status). The primary level and data-source for the information flow is a set of multi-modal sensors mounted onto the actors carrying out the operation (agents or unmanned vehicles). The actors and coordinators will use unified access interface to the dataflow, enabling timely reporting, coordination and data supply. The workflow is enhanced by a decision support engine, assessing the current situation based on the data flow, and generating alerts and notifications in real-time.

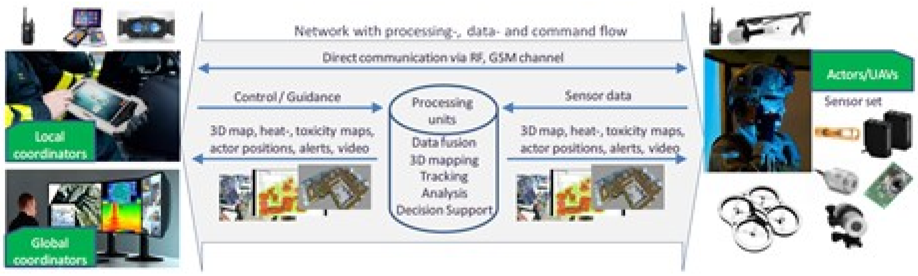

Figure 1: Integrated data-, decision- and command flow for main actors in calamity situations.

The project proposes to equip the acting agents (officers and/or unmanned vehicles as carriers) with sensors of multiple modalities (video, depth, thermal, acoustic, etc.) for robust data acquisition in any condition. The obtained data represents a local situation around the carrier: local layout, thermal conditions, acoustic sources and humans). During an operation, the sensor data from each individual carrier is transmitted wirelessly to a local processing unit. This unit integrates the multi-modal sensor signals from all carriers into:

- 3D geo-map of the premises reconstructed as carriers propagate and
- relevant geo-positioned labels, such as the carrier positions, identified human bodies, heat and noise extremes (see gray-box examples with yellow dots in Figure 2).

An automated analysis algorithm (e.g. video/audio content and context analytics) receives the sensor data and the gradually reconstructed geo-map with the labels. Based on this input, the algorithm assesses the overall situation, identifies abnormal situations, hazardous event build-ups and constantly reports to a decision support engine, or simply flags the detected alerts directly to actors/coordinators. The decision support suggests optimal actions to coordinators. All together, the 3D geo-map, carrier' positions, important labels, alerts and decision support data are visualized onto multiple layers on coordinator' displays. Moreover, the most important data is sent back wirelessly to the acting officers and is rendered on their glasses equipped with a 'see-through' graphical display. As a result, at every

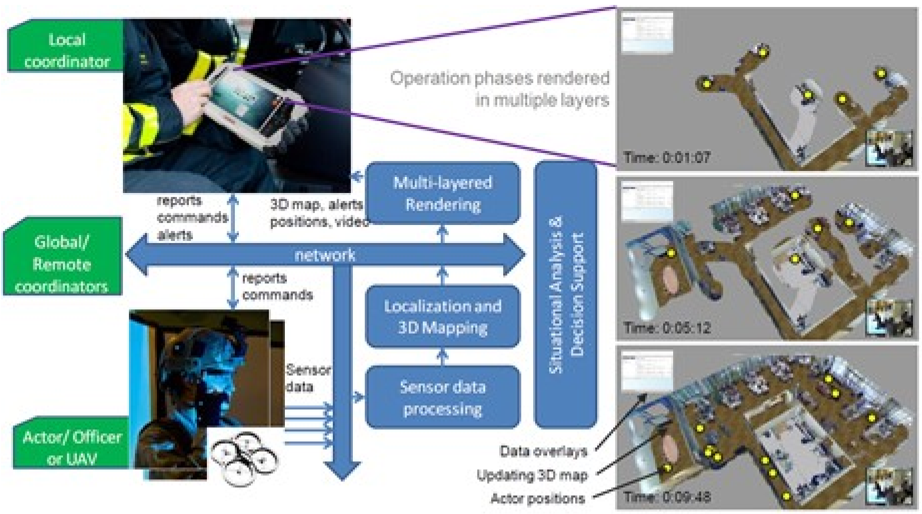

Figure 2: Project system concept.

moment in time, both coordinators and actors can see and understand both the global and local situation during the operation.

This paper presents only the part of the project that refers to the issue of using different sensors such as RGB cameras, RGB-D cameras, depth sensor (IR projector and a monochrome Complementary Met-al-Oxide Semiconductor), microphone system, integrated textile sensors, etc. in estimating the person's position (actors), respectively monitoring their health conditions. The paper aims to position and identify a person through information taken from fixed (through sensors mounted on the actors' equipment – e.g. helmet) and mobile (UAVs) location sensors. The aim is to detect human behavior in normal situations and in extreme situations through real-time location and monitoring algorithms. For this the SLAMS techniques or GPS location are used in the project. In situations where GPS location is not available, or higher location and mapping accuracy is required, accurate and robust SLAM algorithms are required. SLAM algorithms are difficult for UAVs due to the strict requirement for real-time processing. Wi-Fi technology is used for data transmission, but LPWA technology testing is also intended. While things are simpler in the case of processing data taken directly from the ac-tors' equipment, in the case of UAVs things are a little more complicated. In case of UAVs a first approach is to implement the system that controls a drone that is in flight to stabilize and maintain it regardless of external influences and inaccuracy of sensors. This is done by using the SLAM (Simultaneous Localization and Mapping) technique - that is, by tracking points that can be recognized in the camera image, while maintaining a 3D map of those points. The output location is then combined using a Kalman filter with odometry data to predict the future location using the dynamic model of the drone. The obtained location is then used for reactive drone flight control. All available sensors on the drone are used to estimate the current status and location of the drone, which in this project is the most difficult part of the stabilization issue. The sensor that provides the most information is, of course, the camera, being an essential source of data for the visual location used in the proposed system. Due to the limited computing power of the on-board processor, data processing is done on a computer, which is another challenge in delaying the time between observation and action.. The SLAM community has made great strides in recent decades. To date, the problem of 2D SLAM with distance detectors is considered to be solved, while the real-time 3D SLAM algorithm, especially high quality and robust Visual SLAM, remains an open problem. Thus, it is proposed to provide an overview of the recent evolution and development of SLAM algorithms and the focus is on real-time SLAM methods, which are suitable for unmanned aerial vehicles (UAVs).

4 Results and discussion

In the following, methods for recognizing human activities from video data taken from actors or/and UAVs are described. As a first step, the movement characteristics are calculated, and various system configurations are identified. The motion functions can be interpreted based on the entire sequence of images in Figure 3, system 1. Alternatively, certain features are associated with each route. In system 2, all object-specific paths are accumulated, and in the third system, the characteristics of the paths classified as human are accumulated. The interpretation of each individual route is done through system 4 (all object paths) and system 5 (only routes classified as human). Figure 3 shows the ways to combine the system components, in different configurations 1 - 5, ordered according to complexity.

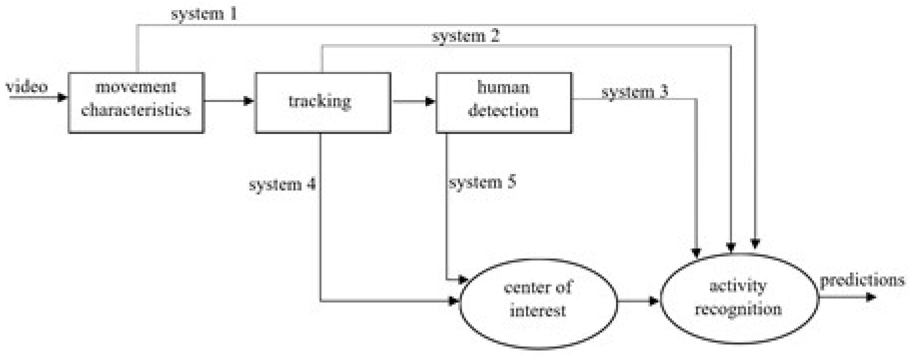

Figure 3: Monitoring system with data taken from sensors.

Regarding the features of the movement, the latest improved trajectories are adopt-ed. The movements of the camera are strict because they are compensated by stabilizing frame by frame and eliminating the characteristics due to ego-movement. The improved trajectories are represented by the limits of movement (on the contour of the objectives) and by the Histograms of the Gradients (HOG) and the Histograms of the Optical Flow (HOF), which proved to be distinctive for the recognition of human activity. The dedicated human detector FPDW (Fastest Pedestrian Detector of the West) and a motion detector are used for location. If the human detector is suitable for detecting people standing upright, the motion detector will be able to signal when the person will change position. The performance of tracking techniques was evaluated for two human activities and variable object sizes. This type of assessment highlights the limitations that may be encountered during detection by actors or/and UAV monitoring devices. Different configuration methods have been identified. The characteristics can be identified according to the whole sequence (system 1). At the same time, the characteristics associated a certain route; after which each route was interpreted (systems 2 and 5). The procedure for associating elements with a particular route is an example of detailing the focus. In system 2, all the characteristics of the routes are described and are accumulated as a representation of a characteristic for a given sequence. In the third system, the same operation is performed for the tracks designated as human. In systems 1, 2 and 3, all the characteristics of an image sequence are fed simultaneously by the human activity recognition algorithm. Systems 4 and 5 interpret each route individually based on the characteristics extracted. System 4 does this for each route, while system 5 interprets only the routes designated as human. For the final interpretation of human activity of a sequence of images, the maximum posterior probability is taken from all paths. To generate the first results, we used the following components:

- RGB camera - facilitates facial recognition and has other detection features by identifying three color components: red, green and blue.
- Depth sensor - an IR projector and a monochrome Complementary Metal-Oxide Semiconductor (CMOS) sensor work together to view in 3D regardless of lighting conditions;
- Microphone system - represents a series of 4 microphones that can isolate the players' voices from the room noise; this allows the player to be a few feet away from the microphone and still use voice commands.
- Laptop and various cables for connections.

The obtained results are presented in the following figures (Figure 4-8). Only in the case of figure 6 the device was mounted on a drone, the rest of the images were obtained by mounting the components on the actor's helmet.

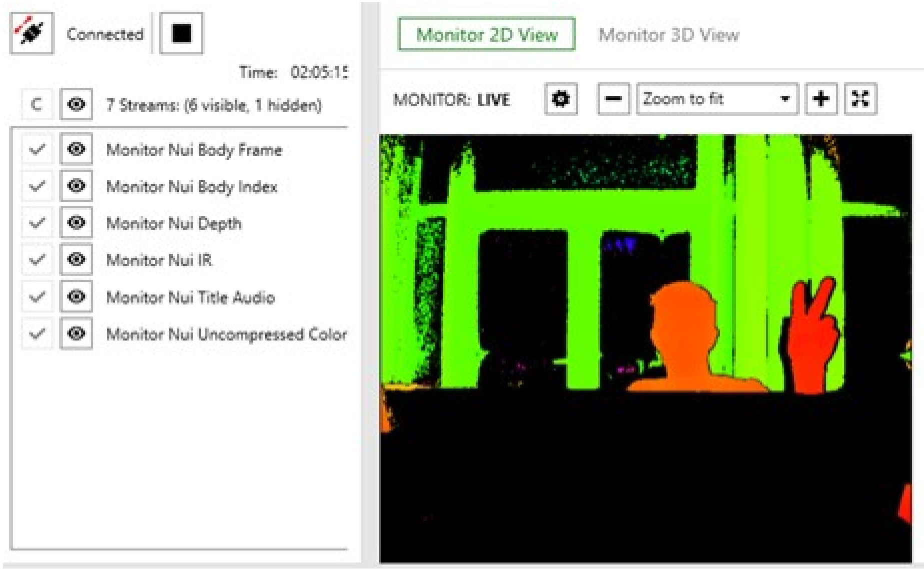

Figure 4: 2D image.

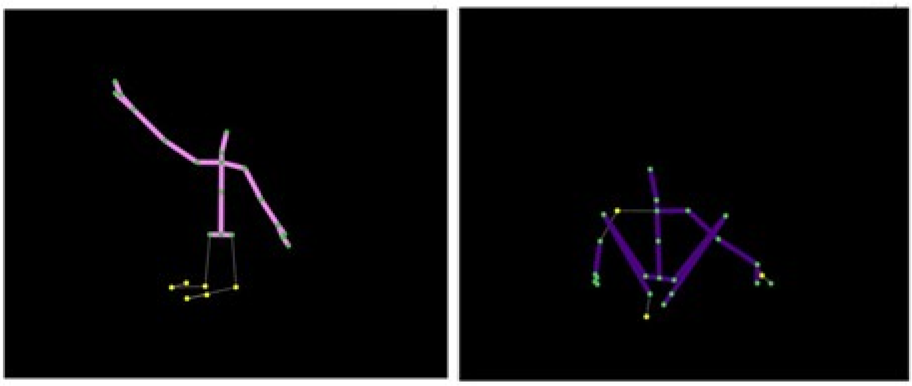

Figure 5: Body basic image.

The human activities recognition method starts from determining the characteristics of movement, the model of each activity being obtained based on the set of these characteristics, the elements of movement being transformed into visual words. Each feature set is represented by the frequency of these words. For the location and real-time tracking of objects in monocular image sequences we used the model proposed in [23]. A Kalman filter is used, which provides a rough prediction of the state of the object, which is then refined by a local detector that incorporates the image of the unique quality of the pixels and temporal information between two consecutive frames. Compared to existing methods, the proposed approach does not require manual initialization for tracking, and runs much faster than last minute, thus achieving competitive tracking performance over a large number of image sequences (Figure 6). Extensive experiments demonstrate the superior effectiveness and performance of the proposed approach. The proposed fast object localization and tracking algorithm is formulated in a robust Kalman filter framework to estimate the optimal state of the object in the map that specifies the details of each object in each frame in a sequence of given images. The tracking method is based on a recursive process of prediction, object detection, and correction. A linear, constant-speed dynamic model was used to represent the transition of the state of motion of the remarkable object in a scene. The tracking device is initialized on the first frame, using a map that details the pixel quality calculated on the entire image. The state of motion is predicted for each frame depending on

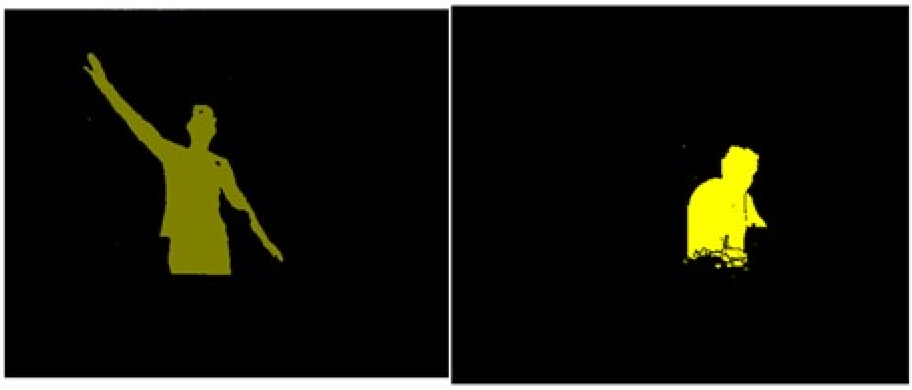

Figure 6: Body index basics image.

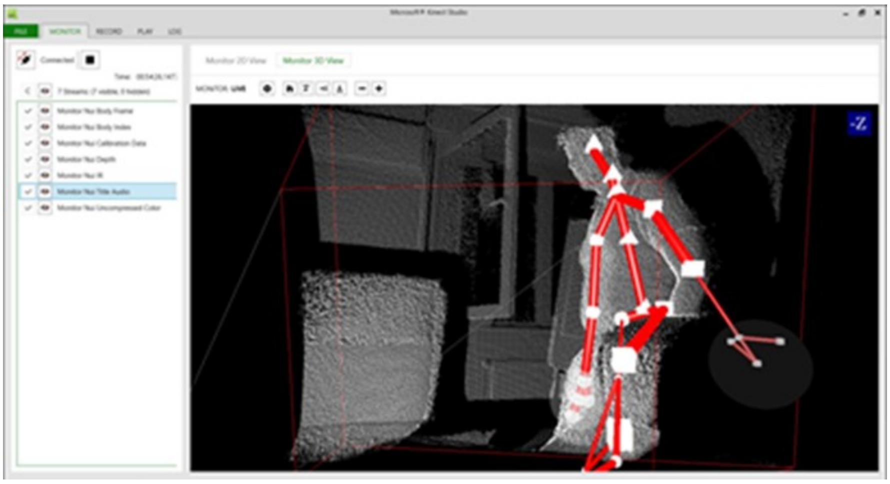

Figure 7: 3D image with body basic.

Figure 8: Face basic image.

the states of motion of the object of interest that was previously obtained (Figure 7). In the project, we also evaluated the method proposed by Zhang [24], for the rapid detection of the object based on the minimum transformation of the border distance. Because the pixel quality details map efficiently finds spatial information about distinct objects in a scene, it allows you to improve the accuracy of locating important objects while tracking. Thus, an adapted object tracking framework is proposed by integrating two processes: object detection and visual tracking. A Kalman filter was used to predict an approximate location of the object of interest. A detector is then used to improve the location of the object. The optimal state of the object in each frame is estimated by the recursive process of prediction, refinement, and correction. We used Probabilistic Graphical Model (PGM) methods to solve problems of structure recognition, computer vision, and signal processing problems (Figure 5-7). The actors vital data we monitored using an intelligent technology, integrated in a high-tech T-shirt (Ambiotex). The Ambiotex T-shirt consists of five components:

- The TechUnit is easy to attach to the T-shirt with magnetic contacts;
- Integrated textile sensors, characterized by robustness and the fact that the T-shirt can be machine washed;
- A functional textile material that can be washed and is comfortable to wear;
- The Ambiotex application, which visualizes, analyzes, stores and transmits data in real time;
- A user interface that allows interaction with other users.

The recorded data is taken, using an API, in our own application in which it can be tracked in real time by the coordinators (Figure 9-11), together with the provided 2D and 3D images (Figure 4-8).

Category	Distance	Ø Speed	Ø Heart rate	Actions
Weights	0.29 km	225.40 pace	137 BPM	Details
Weights	0.05 km	528.54 pace	130 BPM	Details
Walking	1.11 km	24.13 pace	123 BPM	Details
Weights	0.22 km	286.90 pace	149 BPM	Details
Weights	0.22 km	286.90 pace	149 BPM	Details
Walking	1.02 km	17.95 pace	110 BPM	Details
Weights	0.20 km	283.39 pace	142 BPM	Details
Walking	1.10 km	17.57 pace	115 BPM	Details

Figure 9: Recorded dada preview.

There were several issues that make data fusion a challenging task. Most of these issues arise from the data to be fused, imperfection and diversity of the sensor technologies, and the nature of the application environment: data correlation, data alignment/registration, operational timing, data imperfection. While many of these problems have been identified and heavily investigated, no single data fusion algorithm can address all the aforementioned challenges. The variety of methods in the literature focus on a subset of these issues to solve, which would be determined based on the application in hand. The existing fusion algorithms are explored based on how various data-related challenges are treated. Different data fusion algorithms can be roughly categorized based on one of the four challenging problems of input data that are mainly tackled:

- data imperfection;

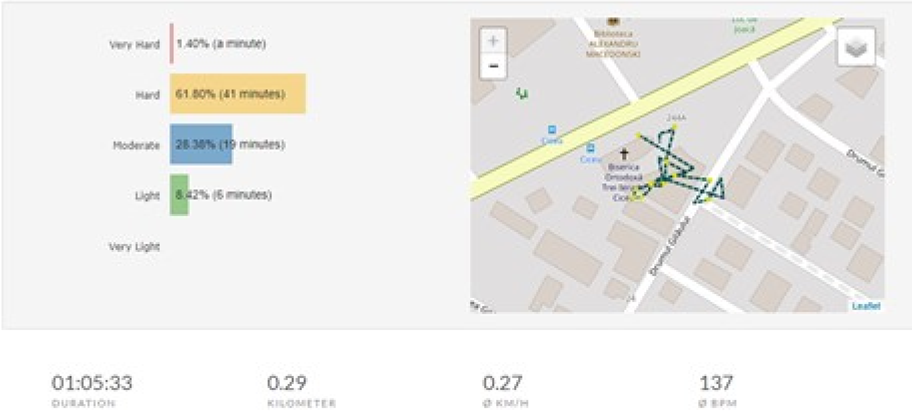

Figure 10: Training complexity diagram.

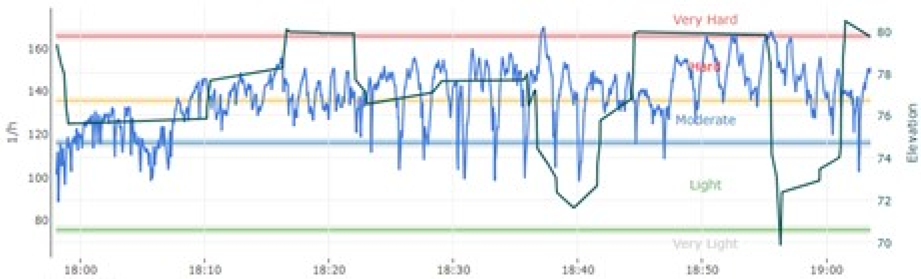

Figure 11: Heart rate statistics.

- data correlation;
- data inconsistency;
- disparateness of data form.

In our case the most complex problems arose regarding the data imperfection. The causes can be multiple, such as adhoc communication networks, new technologies with transmissions through small data packets (Low Power Wide Area technologies), etc. In our case the probabilistic methods didn't work. Alternative techniques such as fuzzy set theory and evidential reasoning have been proposed to deal with perceived limitations in probabilistic methods, such as complexity, inconsistency, precision of models, and uncertainty. But the best results (those in the figures 4-11) were obtained by hybrid frameworks such as Fuzzy Rough Set Theory (FRST) and Fuzzy Demp-ster–Shafer Theory (Fuzzy DSET) [25][26].

5 Conclusions

This paper presents an innovative approach to improve awareness of the first respond-ent (actors) localization and health monitoring, by using multimodal fusion of data from RGB cameras, depth sensor, microphone system, mounted on the first respondents or UAVs, also an intelligent technology, integrated in a high-tech T-shirt on the actors. Through this work the authors propose people localization and monitoring The design of the basic platform for the acquisition of geo-referenced data from GPS sensors mounted on drones/actors' helmet was evaluated, as well as the ways of transmitting this data to a 2D/3D visualization platform in which to be recorded, also the vital data of the actors. Where GPS location is not available, or higher location and mapping accuracy is required, accurate and robust SLAM algorithms are used. Probabilistic Graphical Model (PGM) methods to solve problems of structure recognition, computer vision, and signal processing problems have been shown to be effective, producing very good results. As future work, we are working to develop a new solution that will provide a global awareness of the situation both for the individual actors carrying out rescue operations and for coordination teams.

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Author contributions

The authors contributed equally to this work.

Conflict of interest

The authors declare no conflict of interest.

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