Improving post-earthquake emergency response using indoor tracking

Improving Post Earthquake Emergency Response Using Indoor Tracking

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Localization and indoor tracking of rescuers and victims is essential during emergency management in post-earthquakes conditions because it allows search and rescue teams to be faster and more efficient. While several indoor tracking technologies have been developed over the past years, localization and tracking are still a challenge during emergency conditions when power and telecommunication networks are often missing. This paper presents a new indoor positioning technique for emergency support that is based on Ultra Wide Band network using fixed nodes (anchors) and moving nodes (tags) in the form of a smart watch. The main challenge addressed by the system design is a self-calibrating positioning that is able to transfer also user vital signals parameters. The paper describes the system architecture and the key aspects of the prototype components. Two applications for indoor tracking and emergency rescue are illustrated while the performance of the system is validated by performing tests in a complex building.

Keywords: Indoor tracking; emergency rescue; Ultra Wide Band; structural health monitoring; vital signal;

INTRODUCTION

Natural disasters such as earthquakes may cause severe damage to structural and non-structural components of buildings, including collapse. Such damage may also cause a large number of injuries and deaths especially in public buildings that are usually crowded in certain times of the day. Therefore, in order to improve their resilience, it is necessary to decrease their probability of failure and to improve the emergency response in rescuing people inside the

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buildings. Since saving life is a time dependent procedure, the faster rescue teams search for victims, the more injured people will survive.

For a fast and efficient Search And Rescue (SAR) procedure, information such as the level and distribution of damage in the structure as well as the location of victims are needed. Thus, having real-time access to a reliable database which includes all these data is essential. Several technologies have been recently proposed in literature to address indoor positioning challenges. The indoor tracking systems are generally classified according to signal type, measurement metrics, and dependency on pre-existing infrastructures (Bastos et al. 2015). A number of applications adopting different types of techniques, such as infrared, Bluetooth, WiFi, Radio Frequency Identification (RFID), Ultra Wide Band (UWB), and Micro-Electro-Mechanical Sensors (MEMS), have been developed (Liu et al. 2007) .

Bahl and Padmanabhan (2000) were the first to propose an indoor localization system based on radio frequency. Later, several researchers have used similar approaches for indoor tracking (Hatami 2006; Zàruba et al. 2007). For example, Renaudin et al. (2007) presented an almost self-deployable indoor positioning solution based on RFID Tags that are set on the building during the inspection of the first team, while MEMS sensors are used to localize the team 's members. Then, the second group of rescuers equipped with sensors can be localized in the building by the new generated network. However, the system can only track rescuers and not victims. In addition, a geographical coordinate database is required to identify each Tag located in the building. Harmer et al. (2008) proposed an indoor positioning and communication system for emergency personnel based on an UWB wireless network. A reference coordinate system is provided by the outdoor terminals connected to the GPS service. These units also serve as data sink to collect the information from the mobile units carried by agents, and to transfer the data to a control center via Wireless Local Area Network (WLAN).

Femminella and Reali (2011) presented a technology for outdoor and indoor tracking based on the joint usage of GPS receivers and WLAN devices to augment the GPS coverage where it is scarce or is unavailable. However, this approach requires outdoors station to be connected to GPS service to estimate the indoor position. In addition, this system visualizes the agents' position on a map relying on preloaded data (e.g. Google map).

Giuliano et al. (2013) proposed an indoor localization system based on RFID technology. RFID Tags are fixed inside a building and are able to detect an agent equipped with a RFID reader. The RFID reader transmits the data received from the detected Tags to a user device such as smartphone or tablet. Finally, this device is able to transfer the information to an outdoor center to collect and process the localization data using internet networks. Faramondi et al. (2013) addressed localization and tracking problems for first responders. They used inertial sensors and magnetometer, mounted on the waist of the rescuers, to localize their positions. This technology also requires the installation of pre-deployed RFID Tags to update the position estimate. The positioning data are then forwarded to a control system through 2G/3G/4G wireless networks.

Many researchers have used WIFI-based technology because it is recently available in most indoor environment to localize smartphones (Kothari et al. 2012; Liu et al. 2012; Martin et al. 2010; Subbu et al. 2013; Yim 2013). Omkar and Koul (2015) developed an indoor localization and tracking system based on Received Signal Strength Indication (RSSI). The RSSI values are calculated with the help of WiFi Access points installed inside the building. Then, the position of the user's smartphone is localized using the accelerometer and the Gyroscope sensors embedded in the cellphone.

Innovations and technologies for SAR operations are needed to create a new generation of rescue tools taking into account the priorities of rescuers. Statheropoulos et al. (2015) studied recently the structural collapses and proposed priorities in enhancing SAR tools and technologies. They proposed seven critical factors that can improve SAR operations by reducing rescue time, recovery and treatment of victims. These factors are classified as: (i) *best practices and lessons learned*, (ii) *rescue technology*, (iii) *community involvement*, (iv) *information systems*, (v) *technology integration*, (vi) *crisis management* and (vii) *budgets available*. In this context, SAR technologies are needed to formulate and adopt standard rescue techniques in partnership with manufacturers (*rescue technology*). Furthermore, informed decision in SAR operations is dependent on reliable situational awareness that can reduce uncertainty, false assumptions and consequently increase safety risks (*information system*). Lastly, the efficacy and reliability of SAR technologies should be tested and validated (*technologies integration*).

Despite the development of several indoor positioning technologies over the past years, localization and tracking are still a challenge during emergencies. Most of the studies focused only on the adopted techniques without considering a specific application for emergency condition (Bastos et al. 2015). Recently, Peña-Mora et al. (2010) developed a digital device to support civil engineering emergency response operations. The device is based on wireless and ad-hoc networks and collects critical building information after a disaster. Later on, Rantakokko et al. (2011) proposed a positioning system using multiple sensors to support first responders. In their system, GPS receivers are used to keep the localization accuracy at acceptable levels. Another study was done by Li et al. (2014) who proposed an environment-aware beacon deployment algorithm integrated with Building Information Modeling (BIM) and metaheuristics. In this system, smartphones are used as mobile sensing platforms carried by first responders and building occupants to localize their positions. Following this study, Yoon et al. (2015) presented a smartphone-based system for in-building emergency response assistance comprising victim positioning system and victim status assessment system. Smartphones connected to existing WLAN-based indoor localization systems are used for victim positioning. The status of victims linked to the movement (sitting, lying, walking, and running) is estimated using 3D acceleration measurements from the smartphones.

Several tracking technologies have been recently developed and tested for buildings collapse scenarios. The Second Generation Locator for Urban Search and Rescue Operations (SGL for USaR) is a European project aiming to solve critical problems following massive destruction and structural collapses in urban areas. Within this project, a Remote Early Detection System (REDS) has been developed to monitor the signs of life and hazardous conditions in a collapsed building. It localizes the victims by integrating information collected from cameras, microphones and chemical sensors (Mäyrä et al. 2011). The system consists of four fixed anchors and seven mobile (probes). The anchors are GPS/LPS nodes used to provide geographical coordinates of probes on a map of the disaster area (Känsälä et al. 2011).

Ground-Based Seismic Sensor system (GBSS) is another SAR tool developed under INACHUS project (Athanasiou et al. 2015). It detects and locates knocking signals from victims trapped in debris heaps assisted by simulation tools for predicting structural failures. The GBSS consists of a network of vibration-sensitive sensors connected to a signal processing unit. The system characterizes signature of a knocking signal by detecting vibration noises at the site (e.g. traffic, people walking, power generators). ICARUS is another European project concentrated on development of unmanned SAR technologies. The unmanned devices are equipped with sensors that detect the presence of victims (Cubber et al. 2017). The devices are connected to a base station using a wireless network of mobile communication nodes. Data are transferred to the base station, processed and combined with geographical information to enhance the situational awareness of the personnel during SAR operations.

While recent research provides significant directions for improving the rescue process in terms of safety, reliability, and accuracy, a prototype ready to be employed in real disaster conditions is still lacking. Maintaining communication network (e.g. internet connection) after a major disaster such as an earthquake may be unfeasible due to interruption or collapse of critical infrastructures. This leads to reduce the efficiency and make useless the current indoor positioning systems for emergency supports. No specific system to support emergencies, independent from mobile phone and communication infrastructures (Wi-Fi, GPS, GPRS, cellphones, etc.), is currently available. Therefore, an indoor positioning solution independent from both telecommunication and power network is crucial. Furthermore, the real time monitoring of vital parameters of the agent during SAR procedures is an essential feature that should be implemented in an effective localization and tracking system.

This paper proposes an indoor tracking system using UWB (Ultra Wide Band) technology. The system is based on a Wearable Sensor Network (WSN) and a customized SHM system for indoor tracking of rescuers and victims. It covers all the main features available in literature, plus additional unique features such as vital signals and indoor-outdoor localization. The proposed system has the peculiar characteristic of being independent from internet infrastructure or cell phone connection. The system creates its own independent communication infrastructure through a customized Structural Health Monitoring (SHM) system (Anchors network) to identify and locate rescuers and possible indoor victims from an external control unit. Furthermore, it can be used for post-disaster damage detection procedures equipping the Anchors units with additional sensors (e.g. accelerometers).Table 1 summarizes the different features of the proposed technique with respect to some other available technologies in literature.

Table 1. Comparison between the proposed technique and available technologies.

Author	Year	Technology	Indoor (I)/outdoor (O) localization	Vital signals	SHM	Communication network independent	Pre-existing system independent	Reliability (m) or percentage (%)	Wearable device
Renaudin et al.	2007	RFID Tags and MEMS sensors	I	No	No	Yes	Yes	5	No
Harmer et al.	2008	UWB	I/O	No	No	No	Yes	1	No
Femminella et al.	2011	GPS receivers and WLAN	I/O	No	No	No	No	10	No
Giuliano et al.	2013	RFID	I	No	No	No	No	2.5	No
Faramondi et al.	2013	RFID	I	No	No	No	No	3	No
Li et al.	2014	Wireless deployed ad-hoc network	I	No	No	No	Yes	80%	No

Yoon et al.	2015	Smartphone-WLAN-RSSI	I	Yes	No	No	Yes	87%	No
Omar and Koul	2017	RSSI	I	No	No	No	No	2	No
Cimellaro et al.	2018	UWB	I/O	Yes	Yes	Yes	No	1	Yes

The proposed device is designed to work efficiently in different sectors. The primary application is to support first responders operating after a disaster. For example, it can be used for post-earthquake events when detecting people inside a damaged building is needed. Moreover, in some earthquake scenarios fire might be developed. In fact, in the last decade, fire following earthquake (FFE) was one of the major cascading effects that occurred in seismic region (Flynn 2010). A review of the major historical fires following earthquake includes the San Francisco 1906 (M 8.3) event where the fire caused more damages than the earthquake itself. Twenty years later, the Tokyo-Yokohama 1923 (M 7.9) earthquake cause a fire in Tokyo downtown causing more than 38,000 deaths. In both cases, this technology might be helpful for search and rescue teams to speed up their emergency operation and therefore save more lives.

As another application, the system can be used by firefighters who are frequently injured or in severe cases are victims of disasters. In particular, the team members most at risk are those who enter first in the building on fire because they do not know the map, source of fire, location of victims, and level of building damage. Figure 1 shows US firefighter deaths in line of duty from 1977 to 2016 (USFA 2017). It depicts, despite the development of the modern technologies, there are still about 67 firefighters' deaths in 2016.Also most victims die from smoke or toxic gases and not from burns (Hall 2004).Therefore, an efficient SAR of people inside the building is the key to reduce casualties. The proposed system provides real-time data including an accurate map of the position of both victims and rescuers, their vital conditions, and the damage state of the building. This information can help firefighters to perform fast and efficient SAR operations.

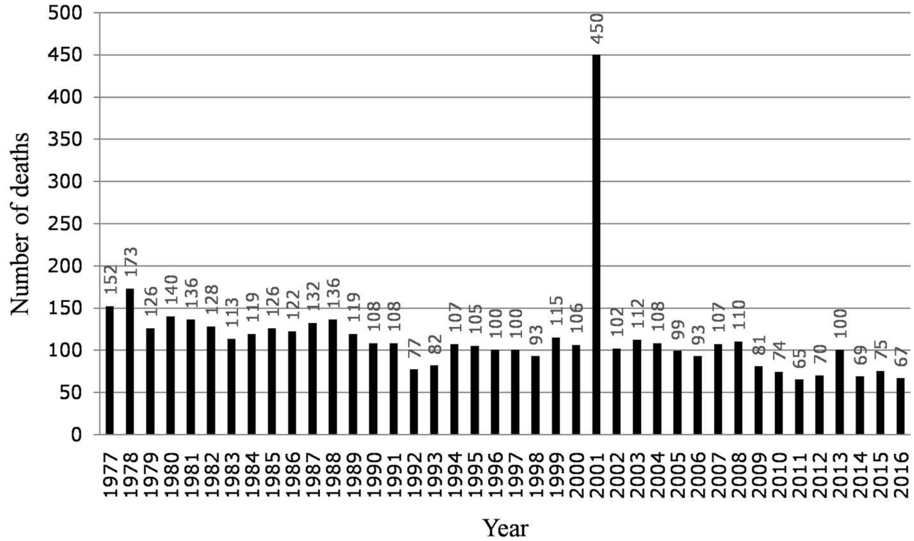

Figure 1. On-duty US firefighter fatalities including 9/11/01 WTC deaths.

In addition, the proposed system can also help industries operating in hazardous condition, aiming to protect their workers by means of real-time localization and health monitoring status. Explosives and ordinances producers, tunneling and mining companies, chemical and electrical manufacture are some examples of these potential customers. As secondary application, building control and automation segments can be interested to control the lights, temperatures, etc., which cause higher level of energy efficiency and comfort for inhabitants. Health care facilities and schools, nonprofit organizations tracking wild animals, and insurance companies are other examples that could be interested in the system.

In this paper, first the developed system is described highlighting algorithms, signal metrics, and procedures adopted to transmit the data information. The methodology to measure the vital signals including heart rate and oximetry using the pulsed-infrared reflection is presented. Then, the prototype's architecture and components are described and two system applications including indoor tracking and emergency rescue are provided.

SYSTEM DESCRIPTION

The system is based on a Wearable Sensor Network (WSN) and a customized SHM system for indoor tracking of rescuers and victims. The wearable devices are nodes (Tags) of WSN, while the customized SHM system is composed of fixed nodes (Anchors) installed in the buildings. Anchors are able to communicate with the Tags, independently from the communication infrastructure, collect the data from the Tags, and transmit to a control unit. The data is in real time including victims' indoor position and overall status (dead/alive and conscious/unconscious). The SHM system can also be used for structural health monitoring applications (by measuring vibration, displacement, temperature, etc.). In addition, by using rechargeable batteries, all the system can work without any external power supply. Hence, in case of power outage, the network remains functional being able to receive data from the wearable nodes (victims).

The localization system is based on Ultra Wide Band (UWB) technology following IEEE 802.15.4-2011 standard. In detail, the module UWB DecaWaveMDEK1001 is used for anchors while UWB DWM1001 module is used for tags. Thanks to the UWB technology, the system can localize target objects (tags) both indoors and outdoors with acceptable accuracy. This technology is able to transmit the signal through walls, as well as to spread within enclosed spaces such as houses and public places (shopping centers for example).

The localization technique consists of two subsequent phases. To locate an agent that is associated with a Tag, a set of fixed reference points (Anchors), with pre-defined positions are necessary. Such Anchors are positioned according to local arbitrary coordinates in a 3D space. The position of Anchors does not rely on the GPS/GNSS or any other global positioning system. Figure 2 shows as an example the positioning of Anchors (A) and a Tag (T) in x-y plane.

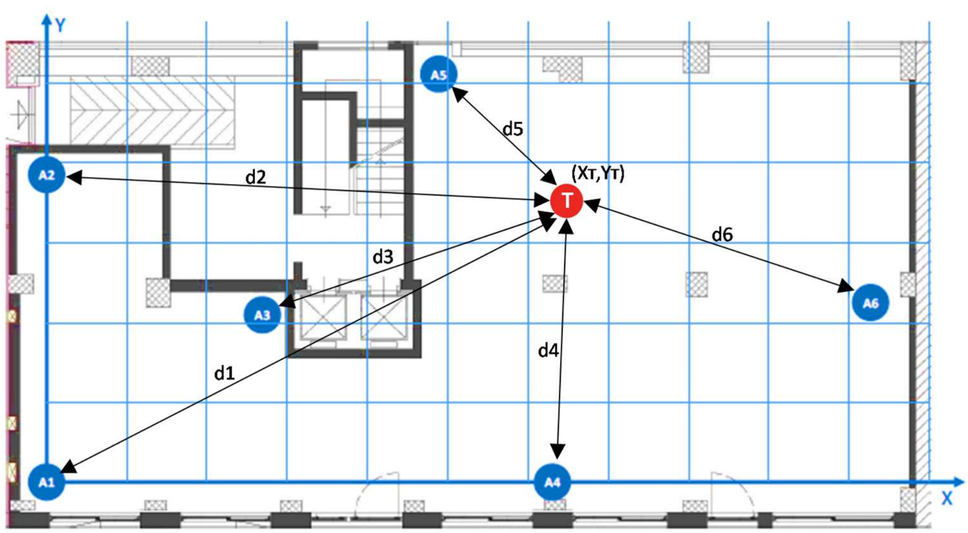

Figure 2. An example of Anchors positioning (SHM system set up).

At the first phase, UWB pulses are exchanged between Anchors (A_1, A_2, …) and Tag (T), and the delay from the outgoing pulse and the response pulse is measured. The Tag transmits a very short pulse to one Anchor. The Anchor re-transmits the same pulse back to the Tag, with a defined delay. The retransmitted pulse is finally received (along with some potential reflections due to multipath effect) by the Tag. Thus, the total time of the pulse flight corresponding outgoing and ingoing pulses is calculated by subtracting the known delay at the Anchor from the total pulse delay (Figure 3). This time interval is proportional to the distance travelled by the pulse and thus allows to define a set of length measurements (d_1, d_2, …) from the Tag and each Anchor of the network (Figure 2). This procedure is referred as “ranging”.

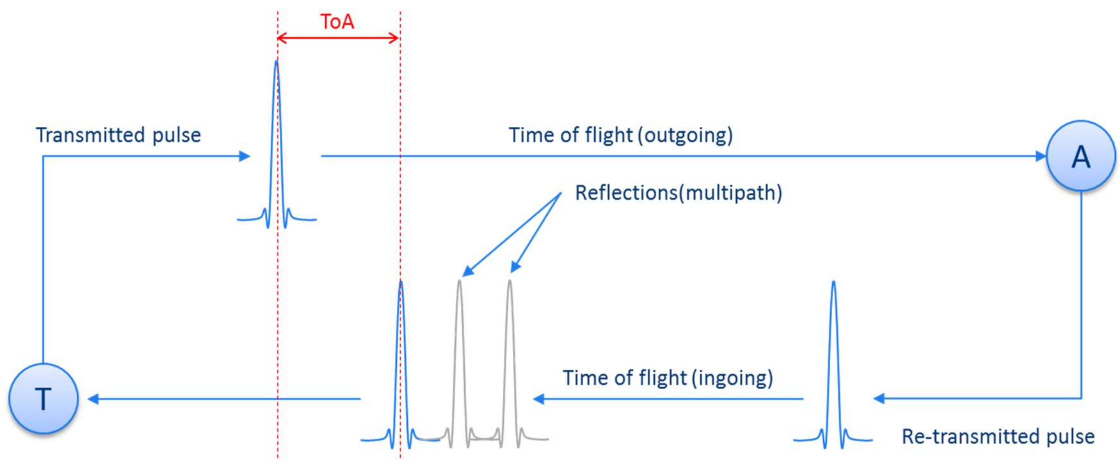

Figure 3. Pulse transmission from Tag (T) to Anchor (A).

Through the set of distances generated by the ranging phase and the absolute position of the Anchors, the trilateration method can be applied to determine the Tag coordinates (X_T,Y_T) with respect to the Anchors coordinate system. Since ranging measurements are affected by statistical deviation, each measure is repeated at the frequency of 100Hz and the mean value is used to provide a more accurate result at a down-sampled rate of up to 10Hz. The current implementation of the system produces positioning data at 5Hz, each 200ms.

The second phase is pulsed-infrared reflection for heart rate and oximetry estimation. An infrared pulse is transmitted with a certain frequency (typically 100Hz) from the tag source (at the bottom part of the Tag in contact with the skin) towards the skin. Part of the pulse is absorbed by the epidermis, the derma and the subcutaneous tissue, and part is reflected back to the source. The difference between the transmitted and the received pulse allows indirectly measuring the entity of the absorption. The average value of the absorption is related to the blood oximetry, while the variations are correlated to the blood flow over the veins indicating the heart-rate. Figure 4 shows schematically the pulsed-infrared reflection for heart rate and oximetry estimation.

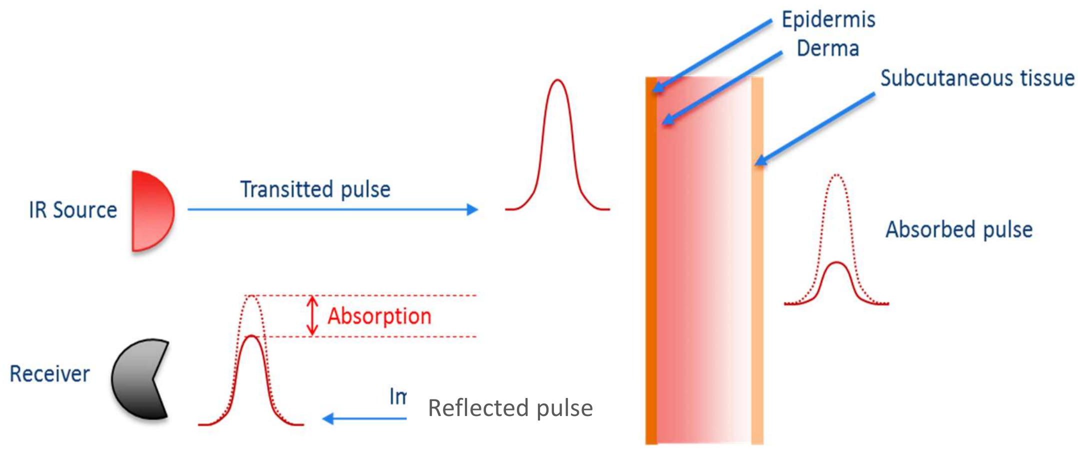

Figure 4.Pulsed-infrared reflection for heart rate and oximetry estimation.

The last feature of the system related to the data transmission. DecaWave UWB module (DecaWave 2018) is used based on a time-division approach, according to which a fixed time interval is divided into "slots" (Figure 5). Out of *N* time slots, *N*-1 are dedicated to the UWB pulses needed for ranging against *N*-1 Anchors and one is reserved for data transmission. In the present implementation of the firmware provided by DecaWave, the data slot cannot be accessed and thus no additional data (e.g. biometric information) can be packed into that slot and sent over the UWB network. To overcome this limitation, the parallel backhaul network based on a multi-hop, self-organizing ZigBee network (IEEE 802.15.4-based specification) is implemented.

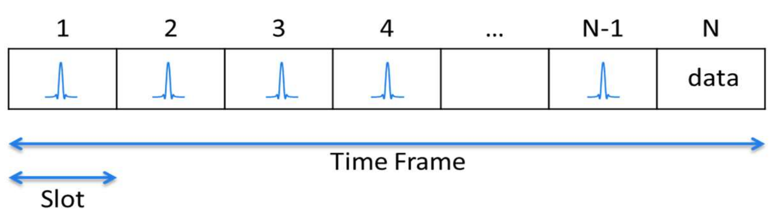

Figure 5.Time division approach related to data transmission.

SYSTEM ARCHITECTURE

The system is composed of five different components illustrated in Figure 6. Each of the components is described in detail below.

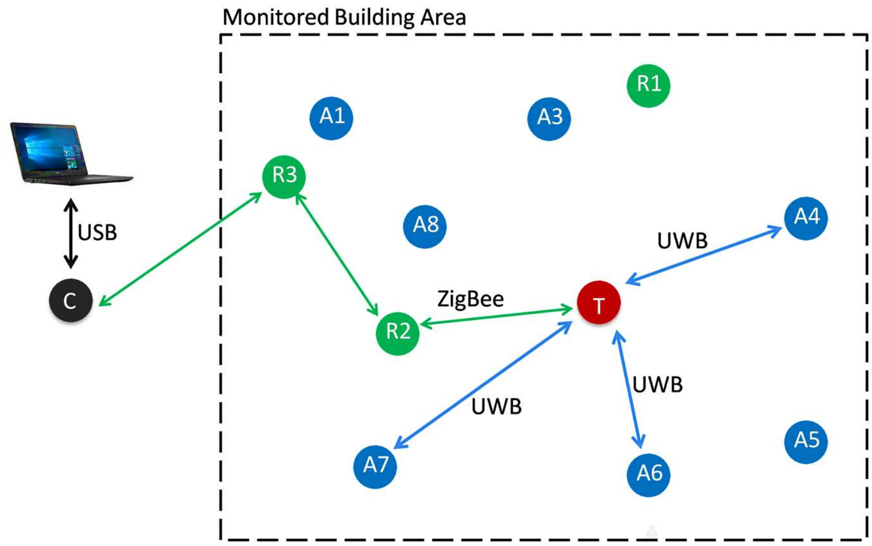

Figure 6. Overall system architecture.

Anchors (A): UWB receivers and transmitters with manually assigned position in 3D space. They are installed in the building and collect the information from the WSN (Tags) transferring to a host station located outside of the monitored building. Furthermore, they are also intended to act as SHM system. The communication of data is based on an autonomous, self-organized and dedicated infrastructure that does not depend on the existence of local WiFi or cellular networks. In addition, the Anchors do not depend on the availability of power supply because they operate with dedicated batteries. The battery used is 3.7V RCR123a protected lithium ion rechargeable battery, with built-in protection of overcharging and discharging. It has specification such as maximum discharge protection, short-circuit protection, and triple over-heat protection with high capacity at low temperature (-10°C). The battery shelf life is regularly 7-10 years, making it also suitable for devices which are used only occasionally (earthquake event). Based on the functionality level of wearable devices (standby mode/normal mode) and environmental condition, the battery life can vary from 12 to 16 hours. The performed tests showed that in a normal situation, the battery life is about 10-12 hours demonstrating the system reliability in case of emergencies such as power outage. However, RTLS units can be powered via USB mains power supplies. Figure 7 shows the developed Anchor within this project.

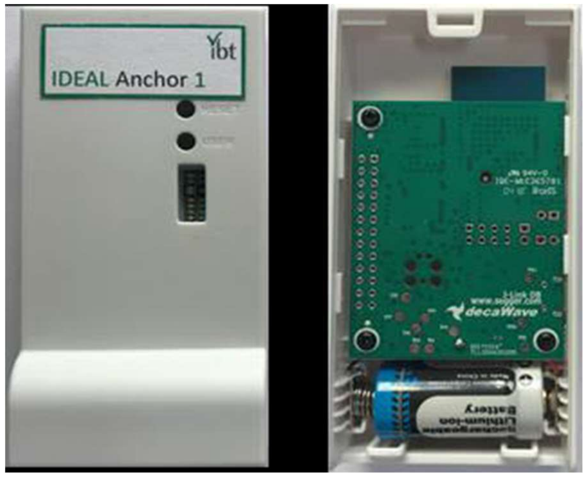

Figure 7. Anchor as a fixed node.

Tags (T): In the form of wristwatch, Tags are mobile devices, intended to be worn by the person being monitored. Tags collect information about the distance from the Anchors and the biomedical conditions (heart rate and oximetry) of the monitored individual. Based on the distance from the Anchors, the device performs trilateration and estimates the individual's position. The tags work with battery rechargeable with a standard USB power source (e.g. a laptop or a mobile phone AC/DC transformer). The battery life is about 6-8 hours in a normal usage, while the time required to fully recharge is about 20-30 minutes. Figure 8 shows the Tag design schematically. Tags are battery-operated and their size is compatible with practical usage (Figure 9).

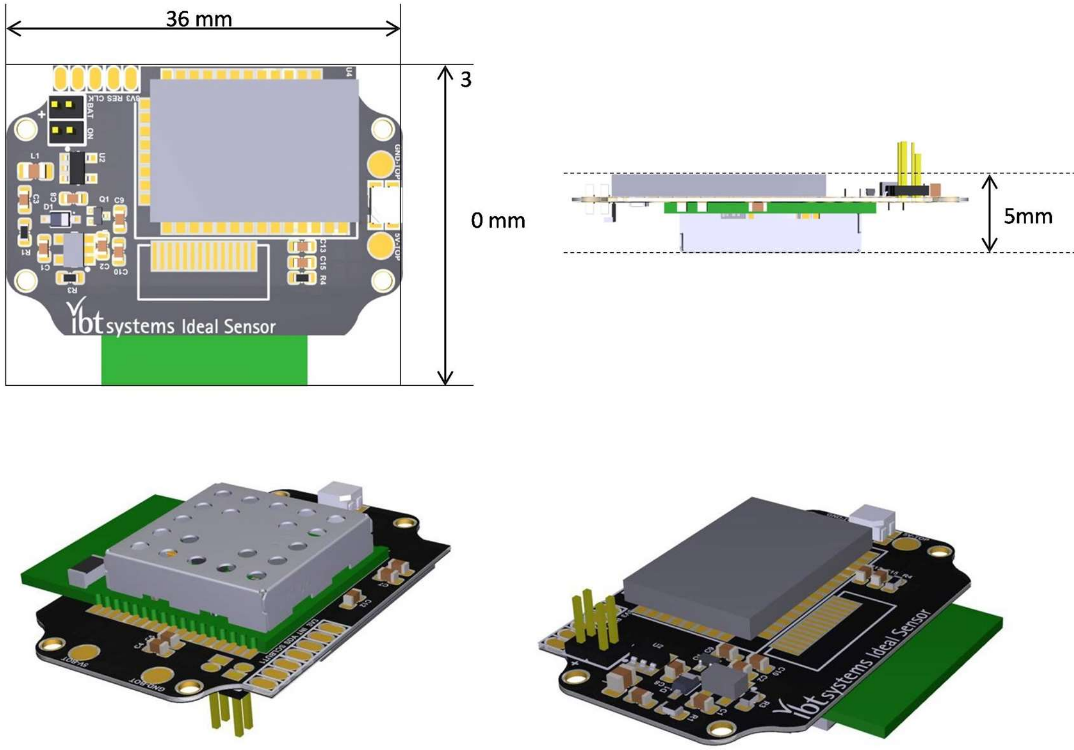

Figure 8. Developed Tag design.

Figure 9. The Tag as a wearable device.

Routers (R): Information collected by Tags and Anchors are then transmitted through the network to the external unit. A back-haul ZigBee network has been employed to transfer data over the UWB network. The routers are battery-operated and, therefore, independent of power supply. Figure 10a shows an overview of the developed router.

(a) (b)

Figure 10. Router to collect data from different tags (a) and system coordinator (b)

Coordinator (C): A ZigBee-to-USB device interfacing the data network to a host PC (the external control unit) (Figure 10b). The coordinator is connected directly to the PC to collect all the data from the system and to pass them to the software.

GUI Host: A graphical user interface (GUI) running on the host PC to visualize the monitored data and to display the monitored area, the Anchors' position (fixed), the Tag's position and the associated oximetry and heart rate pulses. Figure 11 shows the developed graphical user interface.

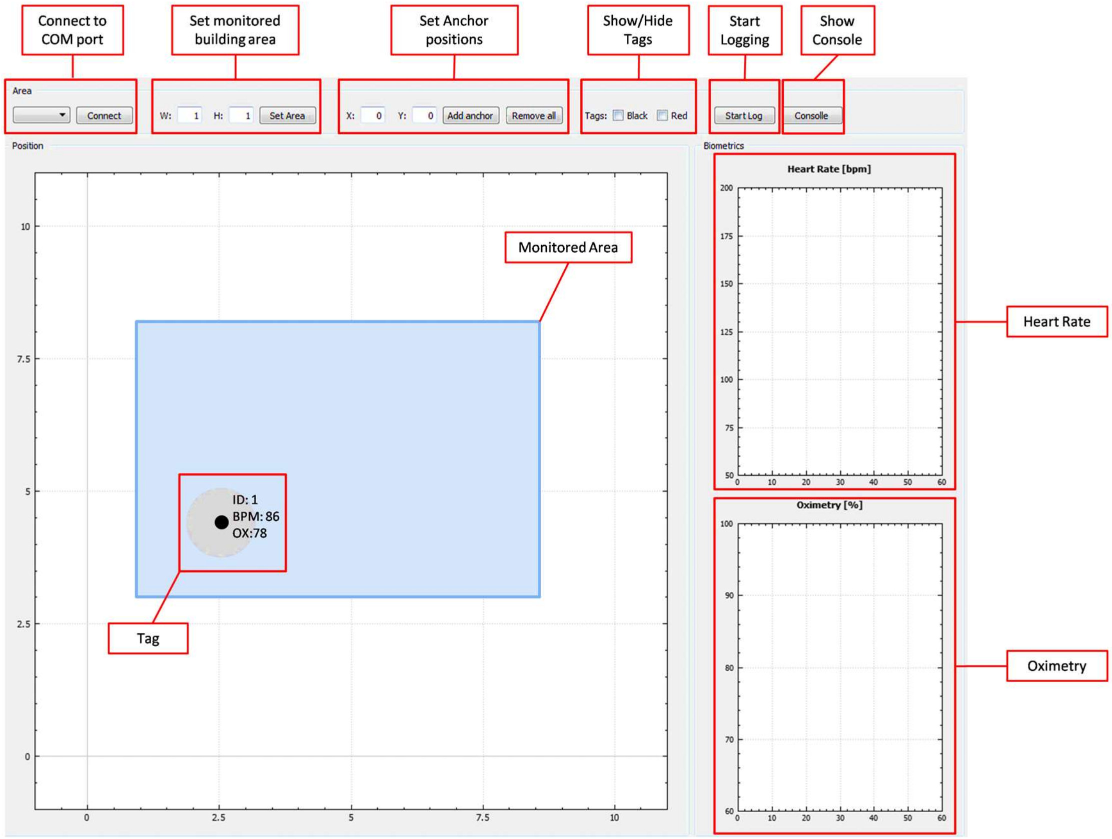

Figure 11. System graphical user interface (GUI).

SYSTEM SETUP

The setup procedure consists of: (i) driver and software installation, (ii) anchor positioning, and (iii) creating a network using the coordinator and the routers. The system can be easily configured and localize the tags through the GUI using a PC or a tablet running an Android application. The communication between the positioning network and the GUI requires specific drivers to be installed on the PC used as "GUI host". To install the software, an executive windows installer file is provided for different PC architectures (x86 or x64).

Once the GUI host is properly set up, the anchors can be placed in the area to be monitored. Anchors can be mounted on walls or tripods, preferably at the same elevation. The anchors should be positioned at least 15cm off the walls or any other obstacles approximately in a rectangular configuration. They can be powered using USB power supplies or rechargeable batteries. Then, their position (relatively to a local reference point) needs to be defined to the network localization engine by means of Decawave DRTLS Manager Application. The anchor location can be defined using either "Auto-Positioning function" as a quick setup feature or manually. However, the first feature may result in a small error in anchor location, making the tag locations less accurate. To optimize the system setup it is recommended that the location of anchors are measured accurately and manually entered. The anchors can be installed inside the building before the emergency in a permanent position or the can be temporarily set up during an emergency. After placing and configuring the anchors, the communication infrastructure must be deployed. The communication infrastructure consists of the GUI host PC, the coordinator node and the router nodes. The first step consists in connecting the coordinator to the PC that turns on the coordinator allowing to automatically establish the multi-hop network necessary to cover larger areas. It is important to connect the coordinator to PC before all the other router nodes. In the case of small spaces, the coordinator itself might be sufficient where maximum distance between the coordinator and any position in the area being monitored is approximately below 20-25m in open air, or 10-15m in presence of walls. Then, the routers can be placed in such a way that maximum distance between any two routers are less than 25m in line of sight, or 15m otherwise. Once the anchors location has been specified and the network is created, the system is ready for tracking the tags. Tags need not to be configured and it is sufficient to turn them on using switch embedded inside the watch case. The proper operation of tags is indicated by a green flashing led. Finally, the data including tag's position including heart rate and oximetry data can be monitored graphically in real time using the provided GUI.

The range and system coverage depend on application environment (e.g., open-space vs. many rooms, obstacles, wet environment). For the case of open-space area, the point to point coverage range is up to 60 m in Line-of-Sight conditions, while it can be expected about 20-25m for indoor environment when Fresnel zones are avoided. The presence of obstacles such as rubble, walls, metallic objects between the anchors and the tags, can affect the functionality of the system. However, if the system is planned to be installed in such special conditions, more powerful and effective antennas can be adopted to overcome such limitations. Changing antenna height and optimized distribution of anchors can have a significant impact on maximum transmission range.

Each tag is indicated by a solid dot surrounded by a shaded circle indicating the accuracy of the estimated position. As the circle is larger, the uncertainty in positioning the tag is higher. The radius of the shaded area over the time is saved as a log file to determine the system accuracy. Performed tests showed that the system accuracy is about 50cm depending on the test condition. In particular, such accuracy could be limited if overcrowded space area around the tags is considered. Indeed, the human body can have an impact on the electromagnetic wave propagation, mainly because of the water in body that can reduce the system accuracy. Thus, the optimal solution is to install the anchors as much as possible at the height above the heads. Furthermore, the presence of obstacles close to anchors can cause asymmetry in the antenna pattern resulting in deflection angle related errors. To avoid the distortion of the UWB pulse, it is suggested to position anchors at least 15cm off the walls or any obstacle.

APPLICATION

The developed system can be a breakthrough for a number of applications. In the present paper, the indoor tracking of agents and the emergency support to victims after disasters are considered. The system technical details and applications characteristic are presented in Table 2. Results show the system reliability in both applications with an accuracy of about 50cm. To determine the system accuracy, 50 tests were performed by moving the tags along the corridor. Thus, the corresponding error was calculated as difference between real tag coordinate and the one visualized by the system. In Figure 12 is shown the system efficiency vs. the operative distance for each test. The result shows that the system accuracy is about 4-8 cm when the tag moves between the area surrounded by anchors (blue area in Figure 14), while it increases exponentially moving the tag outward the anchor area. Furthermore, the maximum readable distance measured from the external anchors (A1-A2 & A7-A8) was about 22.7m (Figure 12).

Table 2. System technical detail and applications characteristics

Application	Environment	No. of anchor	Max. anchor distance (m)	Anchor height (m)	Setup area (m^2)	Setup time (min)	Max. readable distance (m)	Accuracy at 15m distance (cm)	Tag update rate (Hz)	Data rate frequency (GHz)
#1	corridor	8	5	1.2	102	7	22.7	46.5	10	3.5-5.2
#2	corridor/room	8	4.2	1.2	90	10	14	54	10	5-6.5

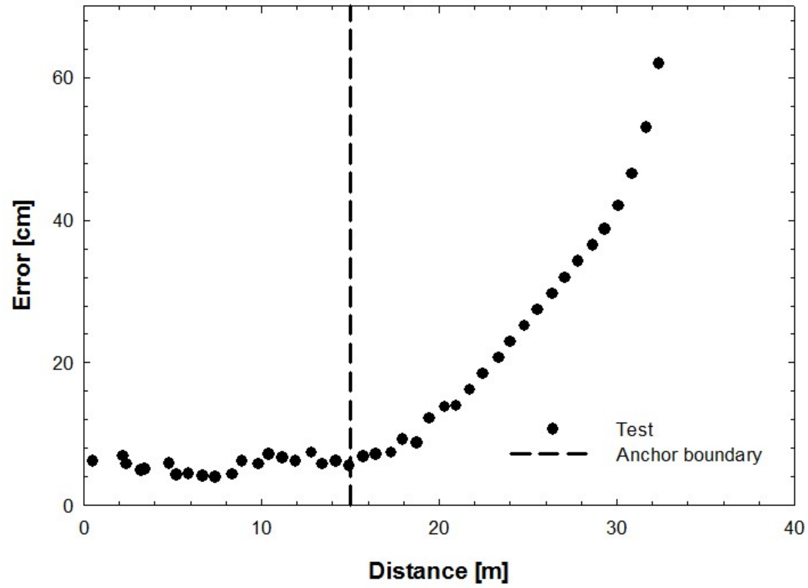

Figure 12. System efficiency vs operative distance.

Application #1: Indoor localization

GPS performance in indoor cases is very limited because of impaired line of sight (LOS) to the GPS satellites. Through the proposed system it is possible to use the WSN for the indoor localization to obtain the accurate position of the Tags. The network (Tags and Anchors) provides the possibility to measure absolute location or relative location between group of nodes both in 2D and 3D spaces. The positioning infrastructure is sufficiently accurate and the average maximum error in normal operating conditions is below 1m. The real-time position of Tags is transferred to a host station located outside the area of the monitored building and it can be visualized through the GUI. Therefore, it is possible to obtain in real time the position of victims who have been trapped inside a damaged building.

The performance of the prototype for the indoor localization has been investigated via a series of validation tests. In this paper, the validation test was carried out at the 2nd floor of Department of Structural, Geotechnical, and Building Engineering (DISEG) of Technical University of Turin located in Turin, Italy. The building has been equipped with 8 Anchors (A1-A8) distributed along the corridor and their local positions have been defined in GUI. The real-time positions of two persons wearing the wristwatches (Tags: ID:1 and ID:2) have been monitored through a unit control located outside the building. Figure 13 shows the plan of the building and the distribution of the Anchors. The result of the test for indoor tracking is shown in Figure 14. The results show an acceptable level of accuracy of about 50cm for positioning persons inside the building. In addition, the vital signal of the Tags (hear rate and oximetry) can be visualized through the GUI.

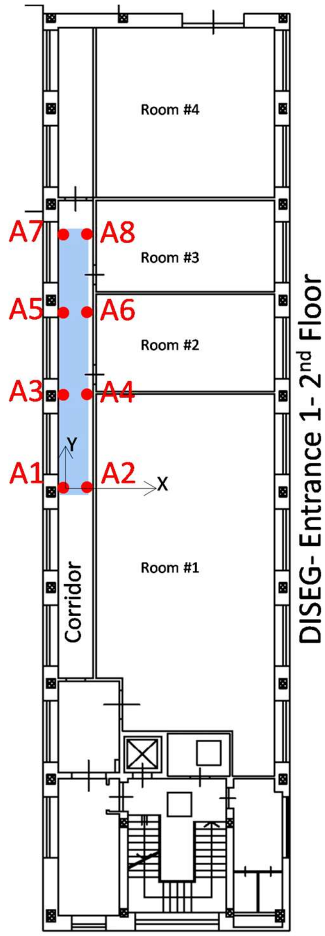

Figure 13. Building plan and anchors distribution for indoor localization test.

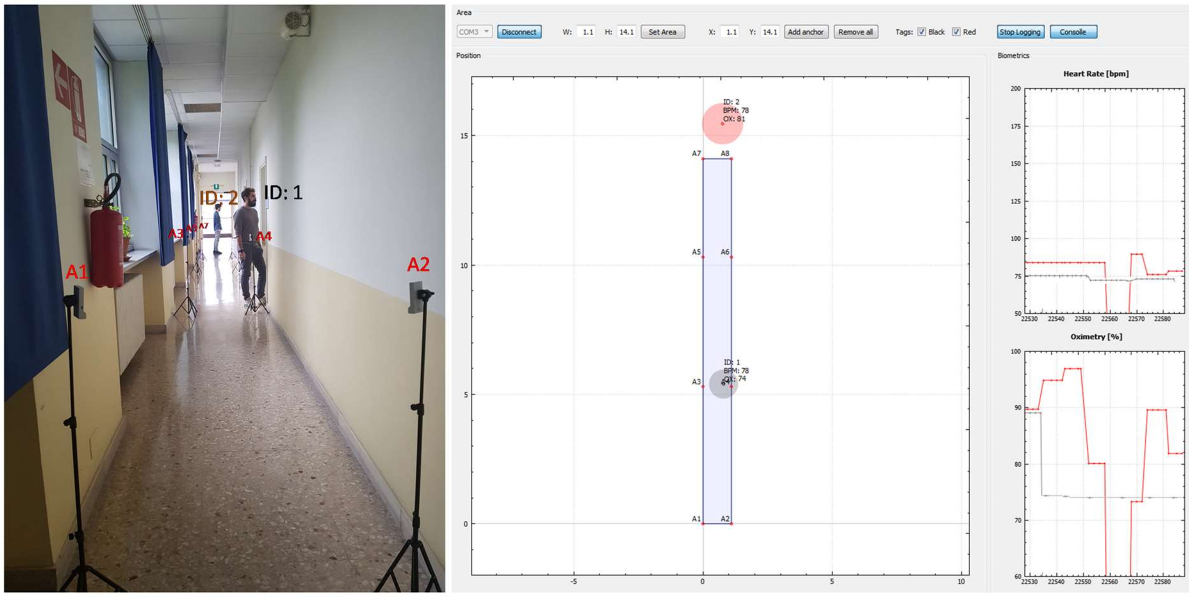

Figure 14. A sample of indoor localization.

Application #2: Emergency Rescue

Searching and rescuing are time consuming procedures. On the other hand, saving life is time-dependent. In fact more victims will survive if the rescue teams work faster. Therefore, time management in SAR procedure plays an important role. After a disaster such as an earthquake, rescue teams start searching for victims. If they have access to a map that shows the location and the number of victims in real-time with their status, the rescue team can manage the time more efficiently, helping more people, and saving more lives.

On the other hand, due lifeline disruption of power and telecommunication networks for example, it not possible to ask for help through common methods such as cell phone. Moreover, victims may be unconscious to respond to any signal. Figure 15 shows an example of the possible system application for post-earthquake emergency situation. The system provides continuously output data including the victim's location and condition for emergency responders.

Figure 15. An example of the system application for post-earthquake emergency response.

The validation test for emergency rescue has been conducted on the 2nd floor of DISEG at the Technical University of Turin. The floor has been equipped with 8 Anchors (A1-A8) distributed both in corridor and the room number 2 (Figure 16). The test was performed assuming that there is smoke inside the building due to fire following an earthquake. Figure 17 shows the location and vital signal of a person wearing the developed wristwatch moving inside the building (Tag ID:1). After a while, the person (Tag ID:1) faints smelling the smoke inside the building and his vital signals become abnormal (Figure 18). The real time information about the victim position and his vital signals is reported to the rescue team (Tag ID:2) through the control unit located outside the building. This information is provided through the graphical user interface in real-time (Figure 19). The results show that the device can help the rescuer during emergencies to reach faster the victims and save their life.

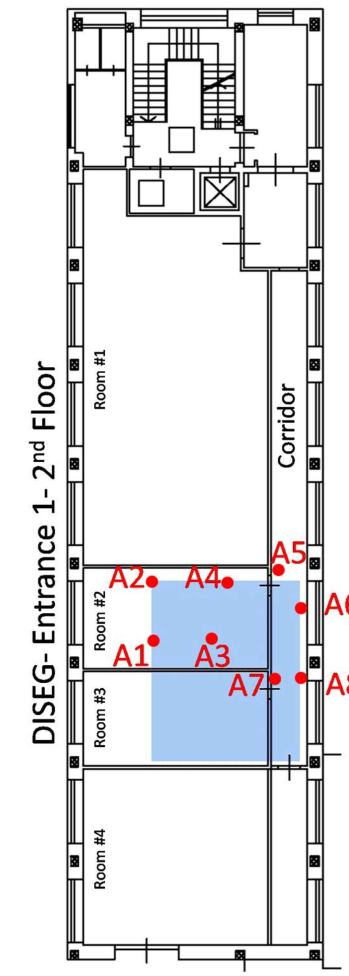

Figure 16. Building plan and anchors distribution for emergency rescue test.

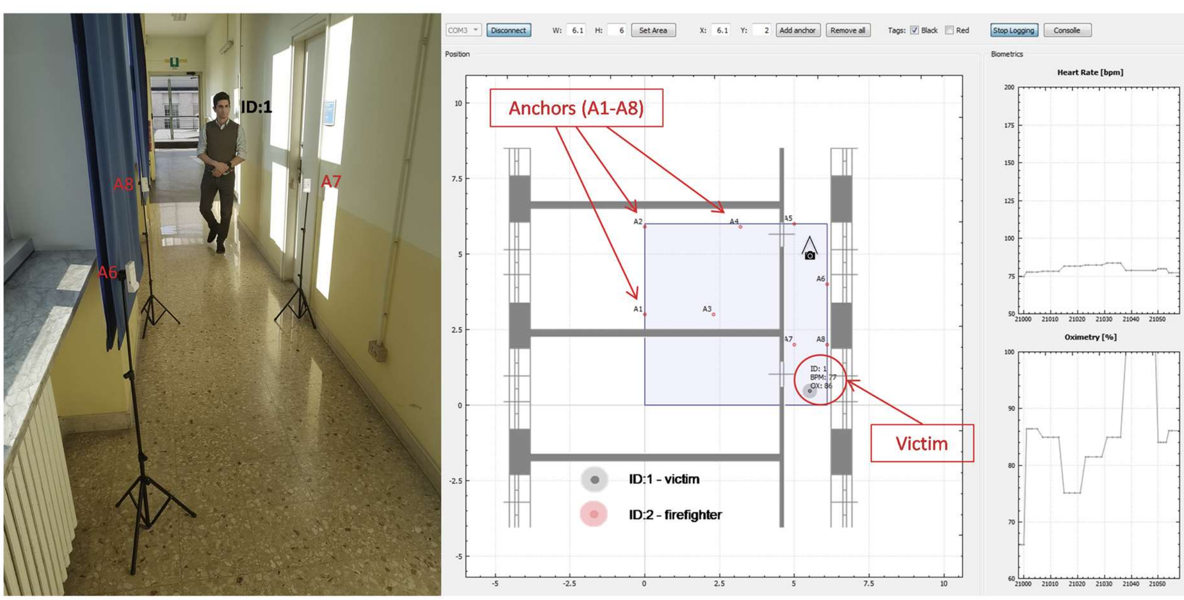

Figure 17. Victim Localization (Tag ID:1) inside the building.

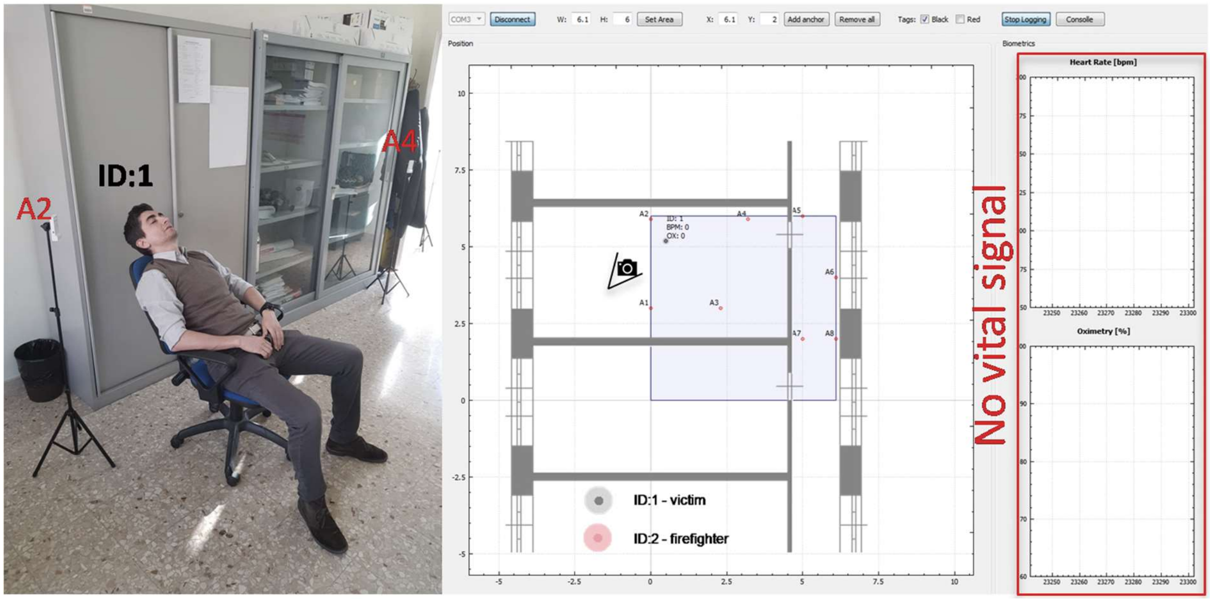

Figure 18. Victim localization and vital signal visualization.

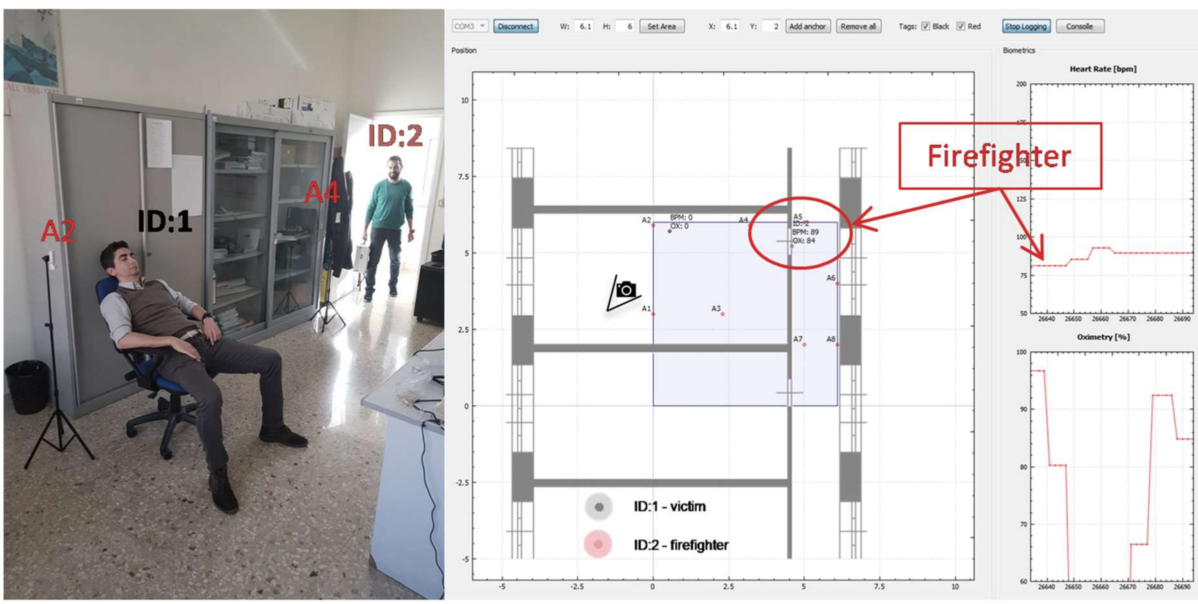

Figure 19. Search and emergency rescue procedure.

CONCLUSIONS

This paper describes a novel indoor tracking system based on Ultra Wide Band network, especially designed for emergency management after a major disaster such as an earthquake, in which the communication and power networks are usually out of services. The system creates its own independent communication infrastructure that is a major advance considering the large amount of constraints in post-earthquake emergency interventions. The system is able to continuously evaluate the position and vital signals of mobile users in both indoor and outdoor environments. In order to assess the feasibility of the proposed technology, two experimental tests for indoor tracking and emergency rescue have been performed. Different conditions such as different configuration of Anchors, the presence of obstacles like walls and metal objects, have been considered. The results confirm the effectiveness of the proposed system and they are very promising both in terms of position accuracy (average accuracy of 50 cm) and system robustness. Future work will focus on extensive performance evaluation and optimization of the overall system, especially in terms of independency on the pre-installed structure.

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