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Improving Post Earthquake Emergency Response Using Indoor Tracking

Gian Paolo Cimellaro^{a)}, Marco Domaneschi^{b)} and Ali Zamani Noori^{c)}

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

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

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

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

54 Giuliano et al. (2013) proposed an indoor localization system based on RFID technology.
55 RFID Tags are fixed inside a building and are able to detect an agent equipped with a RFID
56 reader. The RFID reader transmits the data received from the detected Tags to a user device

57 such as smartphone or tablet. Finally, this device is able to transfer the information to an
58 outdoor center to collect and process the localization data using internet networks. Faramondi
59 et al. (2013) addressed localization and tracking problems for first responders. They used
60 inertial sensors and magnetometer, mounted on the waist of the rescuers, to localize their
61 positions. This technology also requires the installation of pre-deployed RFID Tags to update
62 the position estimate. The positioning data are then forwarded to a control system through
63 2G/3G/4G wireless networks.

64 Many researchers have used WIFI-based technology because it is recently available in most
65 indoor environment to localize smartphones (Kothari et al. 2012; Liu et al. 2012; Martin et al.
66 2010; Subbu et al. 2013; Yim 2013). Omkar and Koul (2015) developed an indoor localization
67 and tracking system based on Received Signal Strength Indication (RSSI). The RSSI values
68 are calculated with the help of WiFi Access points installed inside the building. Then, the
69 position of the user's smartphone is localized using the accelerometer and the Gyroscope
70 sensors embedded in the cellphone.

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

84 Despite the development of several indoor positioning technologies over the past years,
85 localization and tracking are still a challenge during emergencies. Most of the studies focused
86 only on the adopted techniques without considering a specific application for emergency
87 condition (Bastos et al. 2015). Recently, Peña-Mora et al. (2010) developed a digital device to
88 support civil engineering emergency response operations. The device is based on wireless and

89 ad-hoc networks and collects critical building information after a disaster. Later on,
90 Rantakokko et al. (2011) proposed a positioning system using multiple sensors to support first
91 responders. In their system, GPS receivers are used to keep the localization accuracy at
92 acceptable levels. Another study was done by Li et al. (2014) who proposed an environment-
93 aware beacon deployment algorithm integrated with Building Information Modeling (BIM)
94 and metaheuristics. In this system, smartphones are used as mobile sensing platforms carried
95 by first responders and building occupants to localize their positions. Following this study,
96 Yoon et al. (2015) presented a smartphone-based system for in-building emergency response
97 assistance comprising victim positioning system and victim status assessment system.
98 Smartphones connected to existing WLAN-based indoor localization systems are used for
99 victim positioning. The status of victims linked to the movement (sitting, lying, walking, and
100 running) is estimated using 3D acceleration measurements from the smartphones.

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

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

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

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

144 **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

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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.

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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.

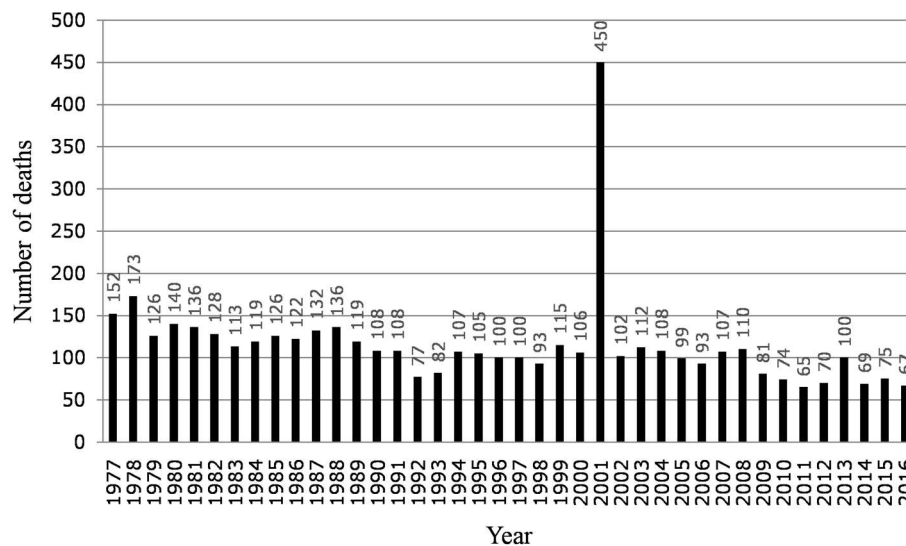


Figure 1. On-duty US firefighter fatalities including 9/11/01 WTC deaths.

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

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

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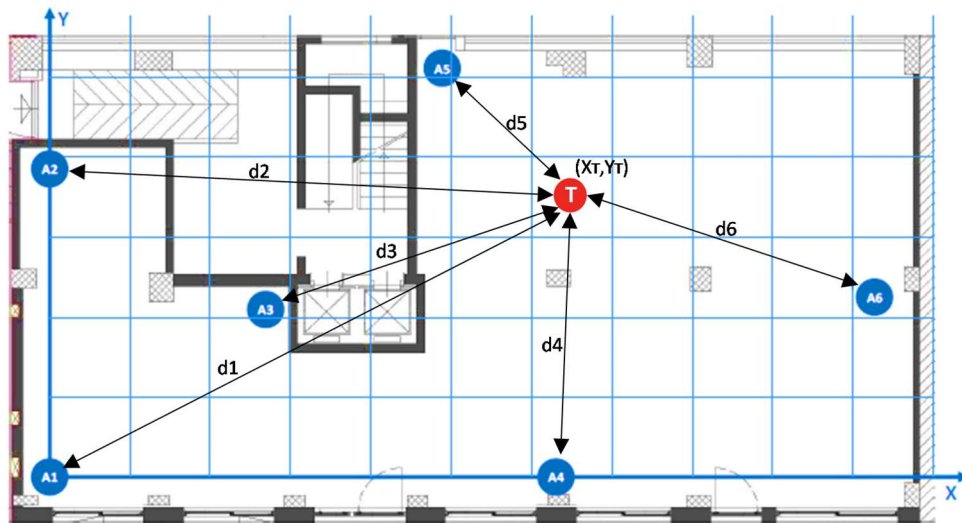
SYSTEM DESCRIPTION

184 The system is based on a Wearable Sensor Network (WSN) and a customized SHM system
 185 for indoor tracking of rescuers and victims. The wearable devices are nodes (Tags) of WSN,
 186 while the customized SHM system is composed of fixed nodes (Anchors) installed in the
 187 buildings. Anchors are able to communicate with the Tags, independently from the
 188 communication infrastructure, collect the data from the Tags, and transmit to a control unit.
 189 The data is in real time including victims’ indoor position and overall status (dead/alive and

190 conscious/unconscious). The SHM system can also be used for structural health monitoring
191 applications (by measuring vibration, displacement, temperature, etc.). In addition, by using
192 rechargeable batteries, all the system can work without any external power supply. Hence, in
193 case of power outage, the network remains functional being able to receive data from the
194 wearable nodes (victims).

195 The localization system is based on Ultra Wide Band (UWB) technology following IEEE
196 802.15.4-2011 standard. In detail, the module UWB DecaWaveMDEK1001 is used for anchors
197 while UWB DWM1001 module is used for tags. Thanks to the UWB technology, the system
198 can localize target objects (tags) both indoors and outdoors with acceptable accuracy. This
199 technology is able to transmit the signal through walls, as well as to spread within enclosed
200 spaces such as houses and public places (shopping centers for example).

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

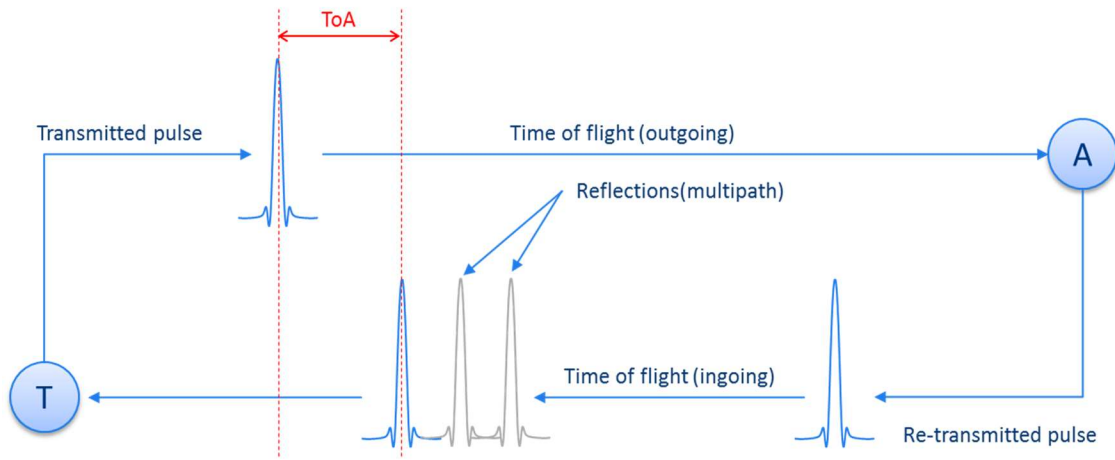


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208 **Figure 2.** An example of Anchors positioning (SHM system set up).

209 At the first phase, UWB pulses are exchanged between Anchors (A_1, A_2, \dots) and Tag (T),
210 and the delay from the outgoing pulse and the response pulse is measured. The Tag transmits
211 a very short pulse to one Anchor. The Anchor re-transmits the same pulse back to the Tag, with
212 a defined delay. The retransmitted pulse is finally received (along with some potential

213 reflections due to multipath effect) by the Tag. Thus, the total time of the pulse flight
214 corresponding outgoing and ingoing pulses is calculated by subtracting the known delay at the
215 Anchor from the total pulse delay (Figure 3). This time interval is proportional to the distance
216 travelled by the pulse and thus allows to define a set of length measurements (d_1, d_2, \dots) from
217 the Tag and each Anchor of the network (Figure 2). This procedure is referred as “ranging”.



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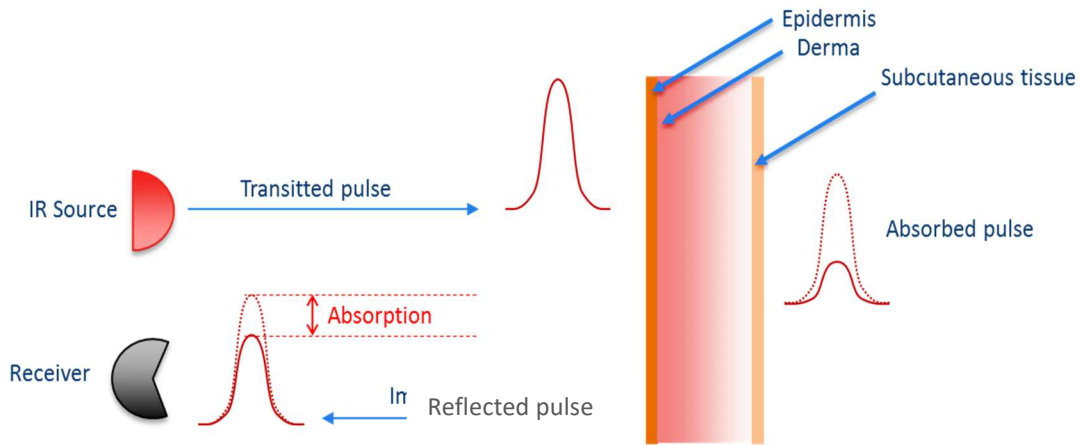
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Figure 3. Pulse transmission from Tag (T) to Anchor (A).

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

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



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

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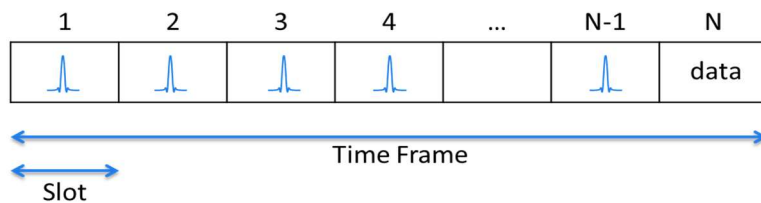
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The last feature of the system related to the data transmission. DecaWave UWB module (DecaWave 2018) is used based on a time-division approach, according to which a fixed time interval is divided into “slots” (Figure 5). Out of N time slots, $N-1$ 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.



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Figure 5. Time division approach related to data transmission.

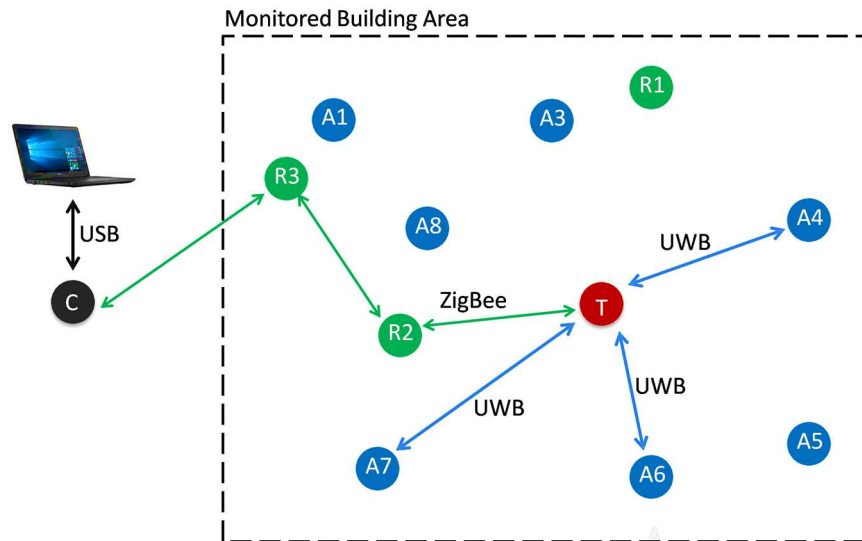
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SYSTEM ARCHITECTURE

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

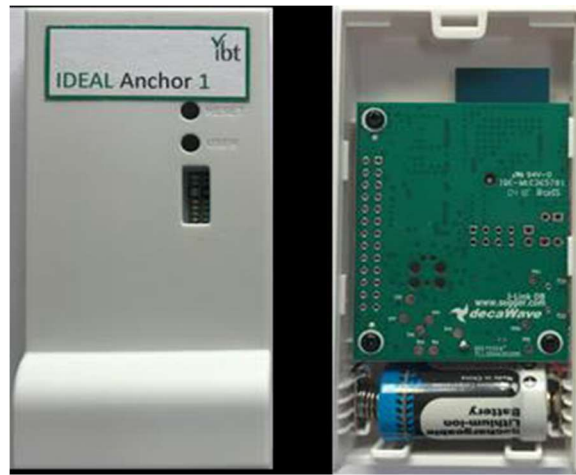


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Figure 6. Overall system architecture.

255 *Anchors (A)*: UWB receivers and transmitters with manually assigned position in 3D space.
 256 They are installed in the building and collect the information from the WSN (Tags) transferring
 257 to a host station located outside of the monitored building. Furthermore, they are also intended
 258 to act as SHM system. The communication of data is based on an autonomous, self-organized
 259 and dedicated infrastructure that does not depend on the existence of local WiFi or cellular
 260 networks. In addition, the Anchors do not depend on the availability of power supply because
 261 they operate with dedicated batteries. The battery used is 3.7V RCR123a protected lithium ion
 262 rechargeable battery, with built-in protection of overcharging and discharging. It has
 263 specification such as maximum discharge protection, short-circuit protection, and triple over-
 264 heat protection with high capacity at low temperature (-10°C). The battery shelf life is regularly
 265 7-10 years, making it also suitable for devices which are used only occasionally (earthquake
 266 event). Based on the functionality level of wearable devices (standby mode/normal mode) and
 267 environmental condition, the battery life can vary from 12 to 16 hours. The performed tests
 268 showed that in a normal situation, the battery life is about 10-12 hours demonstrating the
 269 system reliability in case of emergencies such as power outage. However, RTLS units can be
 270 powered via USB mains power supplies. Figure 7 shows the developed Anchor within this
 271 project.

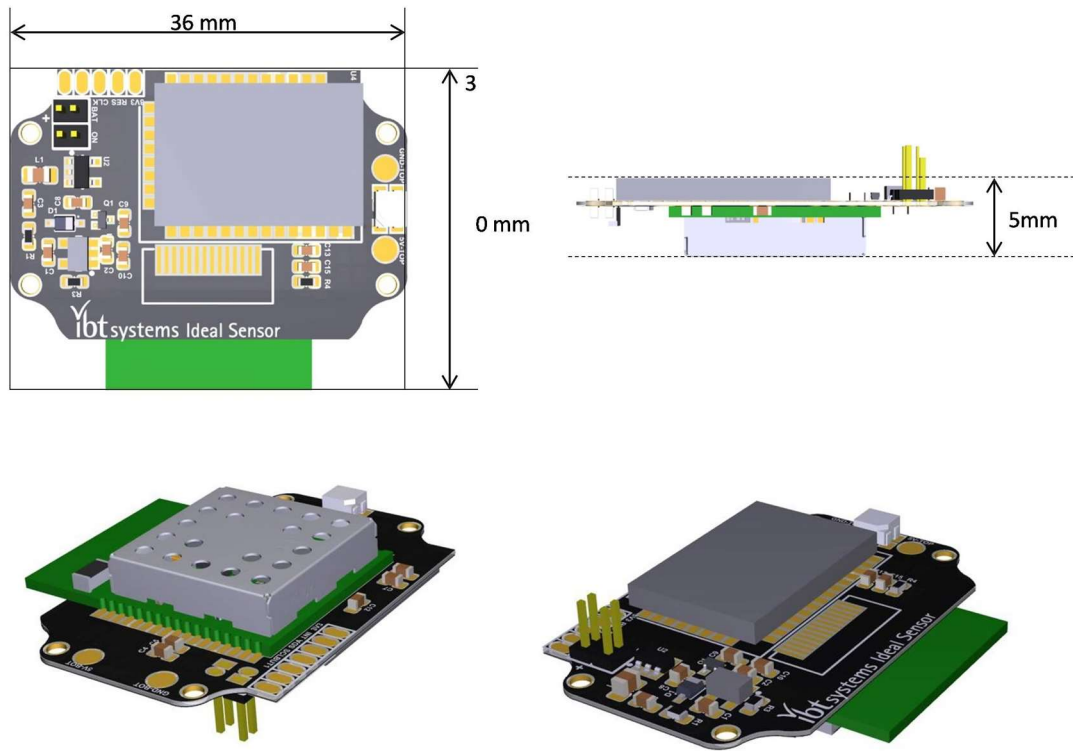


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Figure 7. Anchor as a fixed node.

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



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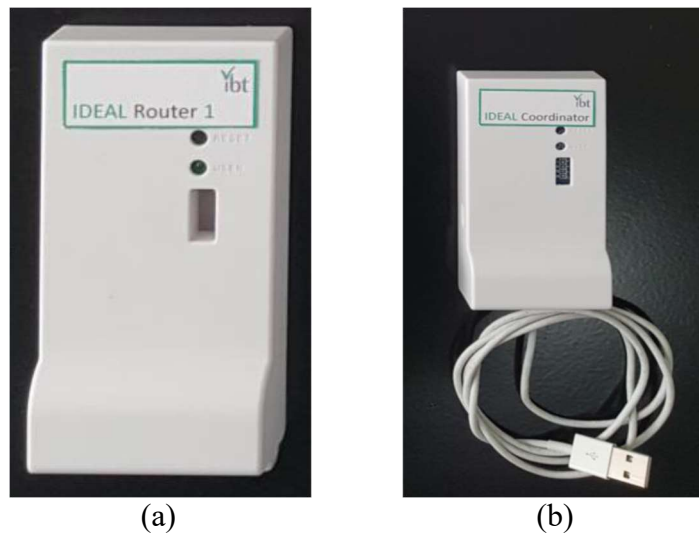
Figure 8. Developed Tag design.



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Figure 9. The Tag as a wearable device.

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



292 **Figure 10.** Router to collect data from different tags (a) and system coordinator (b)
293 *Coordinator (C):* A ZigBee-to-USB device interfacing the data network to a host PC (the
294 external control unit) (Figure 10b). The coordinator is connected directly to the PC to collect
295 all the data from the system and to pass them to the software.
296 *GUI Host:* A graphical user interface (GUI) running on the host PC to visualize the monitored
297 data and to display the monitored area, the Anchors' position (fixed), the Tag's position and
298 the associated oximetry and heart rate pulses. Figure 11 shows the developed graphical user
299 interface.

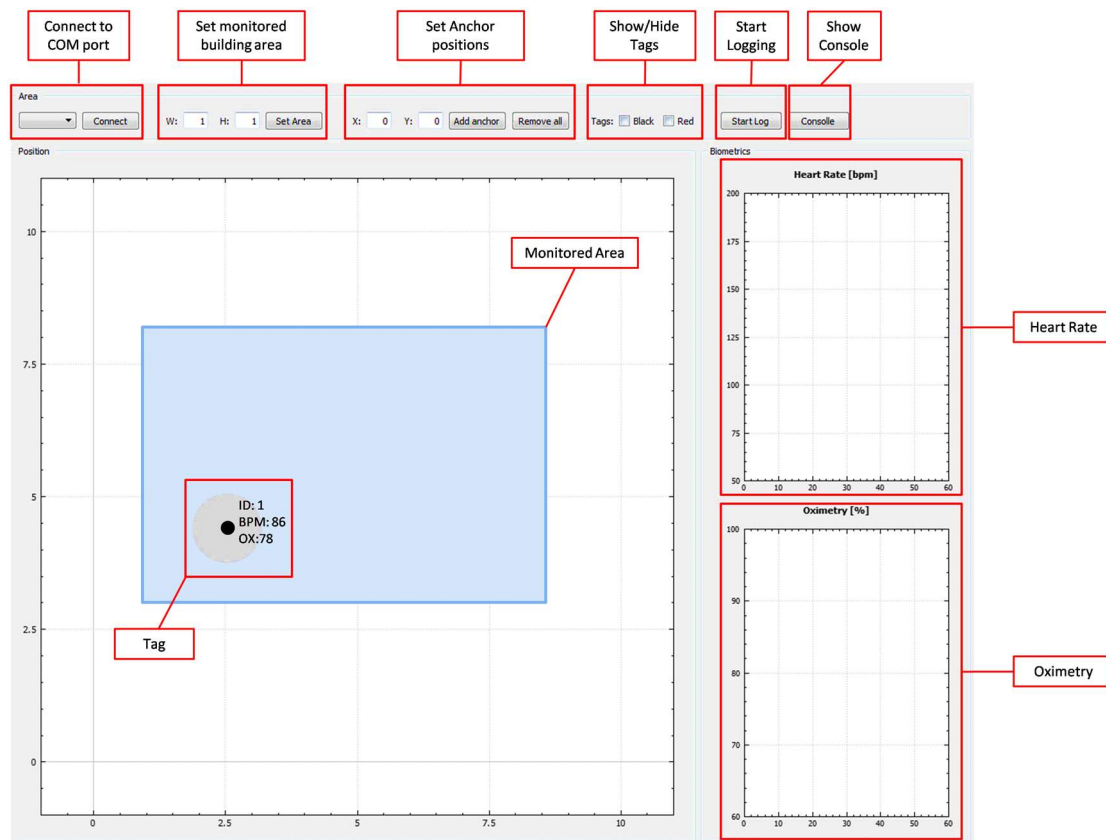


Figure 11. System graphical user interface (GUI).

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

317 tag locations less accurate. To optimize the system setup it is recommended that the location
318 of anchors are measured accurately and manually entered. The anchors can be installed inside
319 the building before the emergency in a permanent position or the can be temporarily set up
320 during an emergency. After placing and configuring the anchors, the communication
321 infrastructure must be deployed. The communication infrastructure consists of the GUI host
322 PC, the coordinator node and the router nodes. The first step consists in connecting the
323 coordinator to the PC that turns on the coordinator allowing to automatically establish the
324 multi-hop network necessary to cover larger areas. It is important to connect the coordinator to
325 PC before all the other router nodes. In the case of small spaces, the coordinator itself might
326 be sufficient where maximum distance between the coordinator and any position in the area
327 being monitored is approximately below 20-25m in open air, or 10-15m in presence of walls.
328 Then, the routers can be placed in such a way that maximum distance between any two routers
329 are less than 25m in line of sight, or 15m otherwise. Once the anchors location has been
330 specified and the network is created, the system is ready for tracking the tags. Tags need not to
331 be configured and it is sufficient to turn them on using switch embedded inside the watch case.
332 The proper operation of tags is indicated by a green flashing led. Finally, the data including
333 tag's position including heart rate and oximetry data can be monitored graphically in real time
334 using the provided GUI.

335 The range and system coverage depend on application environment (e.g., open-space vs.
336 many rooms, obstacles, wet environment). For the case of open-space area, the point to point
337 coverage range is up to 60 m in Line-of-Sight conditions, while it can be expected about 20-
338 25m for indoor environment when Fresnel zones are avoided. The presence of obstacles such
339 as rubble, walls, metallic objects between the anchors and the tags, can affect the functionality
340 of the system. However, if the system is planned to be installed in such special conditions,
341 more powerful and effective antennas can be adopted to overcome such limitations. Changing
342 antenna height and optimized distribution of anchors can have a significant impact on
343 maximum transmission range.

344 Each tag is indicated by a solid dot surrounded by a shaded circle indicating the accuracy
345 of the estimated position. As the circle is larger, the uncertainty in positioning the tag is higher.
346 The radius of the shaded area over the time is saved as a log file to determine the system
347 accuracy. Performed tests showed that the system accuracy is about 50cm depending on the
348 test condition. In particular, such accuracy could be limited if overcrowded space area around

349 the tags is considered. Indeed, the human body can have an impact on the electromagnetic
 350 wave propagation, mainly because of the water in body that can reduce the system accuracy.
 351 Thus, the optimal solution is to install the anchors as much as possible at the height above the
 352 heads. Furthermore, the presence of obstacles close to anchors can cause asymmetry in the
 353 antenna pattern resulting in deflection angle related errors. To avoid the distortion of the UWB
 354 pulse, it is suggested to position anchors at least 15cm off the walls or any obstacle.

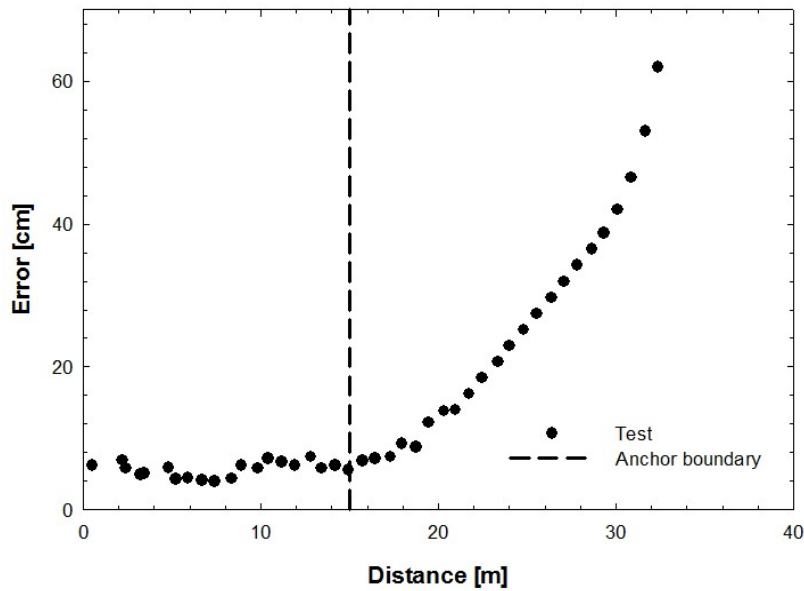
355 APPLICATION

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

367 **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

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Figure 12. System efficiency vs operative distance.

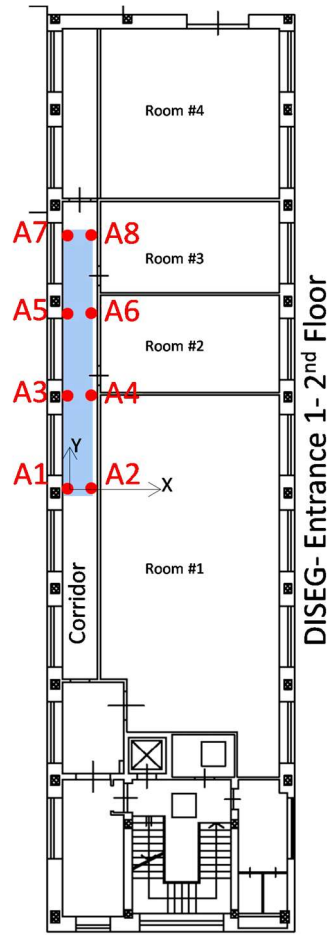
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372 **Application #1: Indoor localization**

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

382 The performance of the prototype for the indoor localization has been investigated via a
 383 series of validation tests. In this paper, the validation test was carried out at the 2nd floor of
 384 Department of Structural, Geotechnical, and Building Engineering (DISEG) of Technical
 385 University of Turin located in Turin, Italy. The building has been equipped with 8 Anchors
 386 (A1-A8) distributed along the corridor and their local positions have been defined in GUI. The
 387 real-time positions of two persons wearing the wristwatches (Tags: ID:1 and ID:2) have been
 388 monitored through a unit control located outside the building. Figure 13 shows the plan of the
 389 building and the distribution of the Anchors. The result of the test for indoor tracking is shown

390 in Figure 14. The results show an acceptable level of accuracy of about 50cm for positioning
391 persons inside the building. In addition, the vital signal of the Tags (hear rate and oximetry)
392 can be visualized through the GUI.

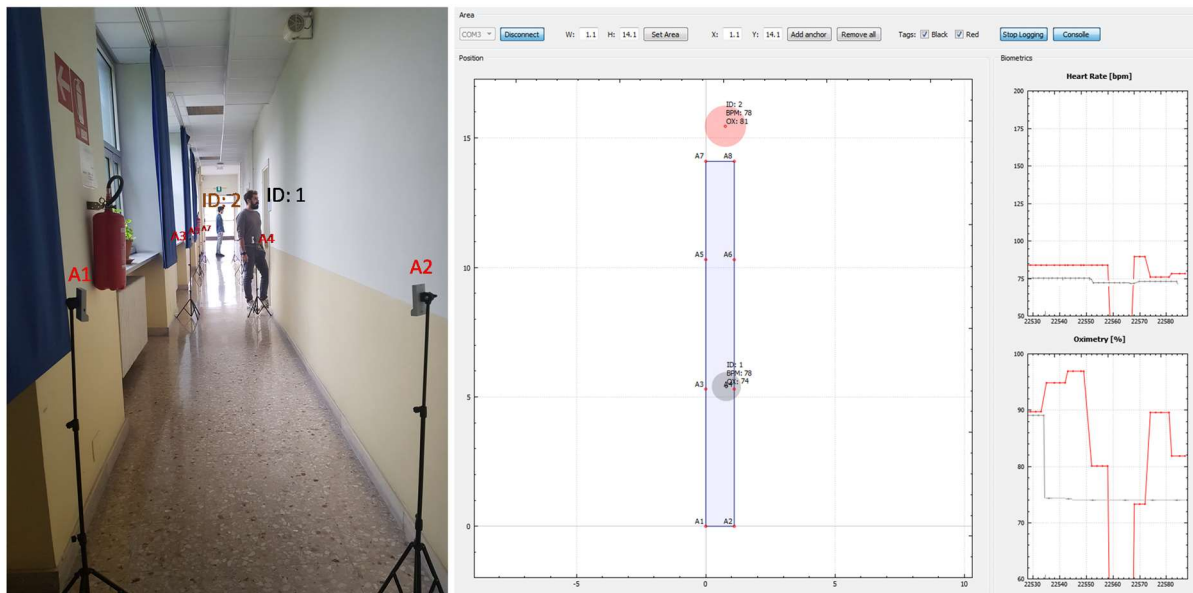


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Figure 13. Building plan and anchors distribution for indoor localization test.

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Figure 14. A sample of indoor localization.

398 **Application #2: Emergency Rescue**

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

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

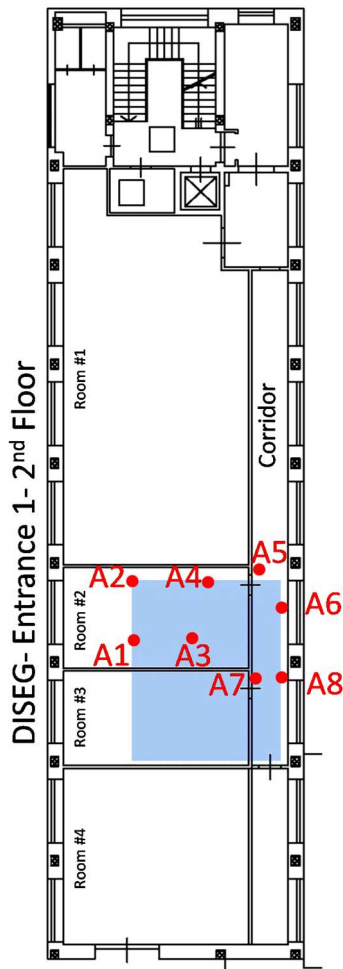


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412 **Figure 15.** An example of the system application for post-earthquake emergency response.

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

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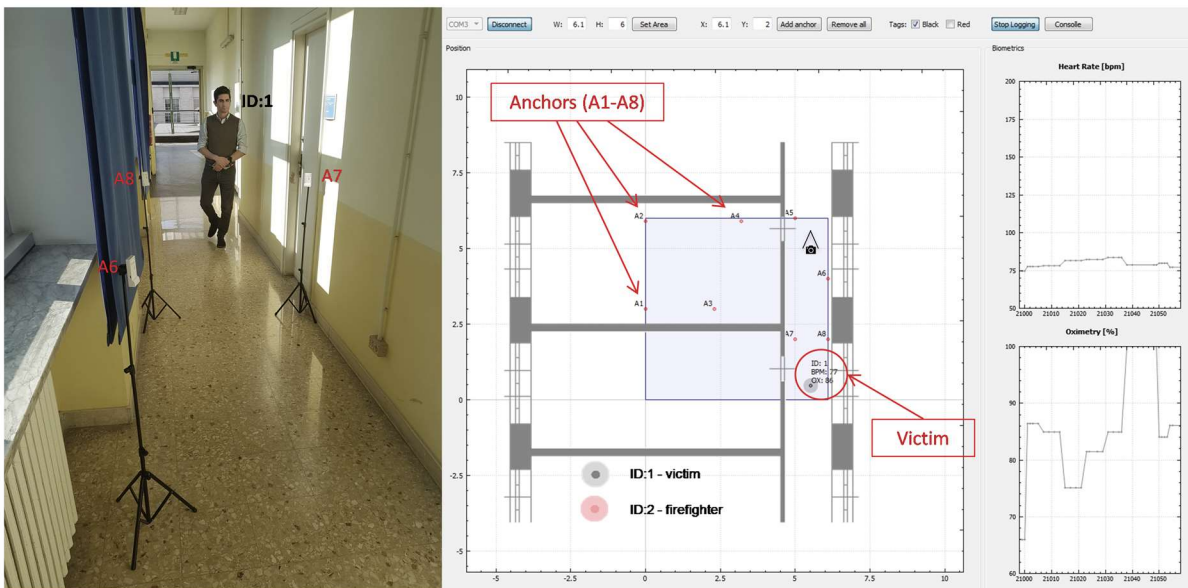


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Figure 16. Building plan and anchors distribution for emergency rescue test.

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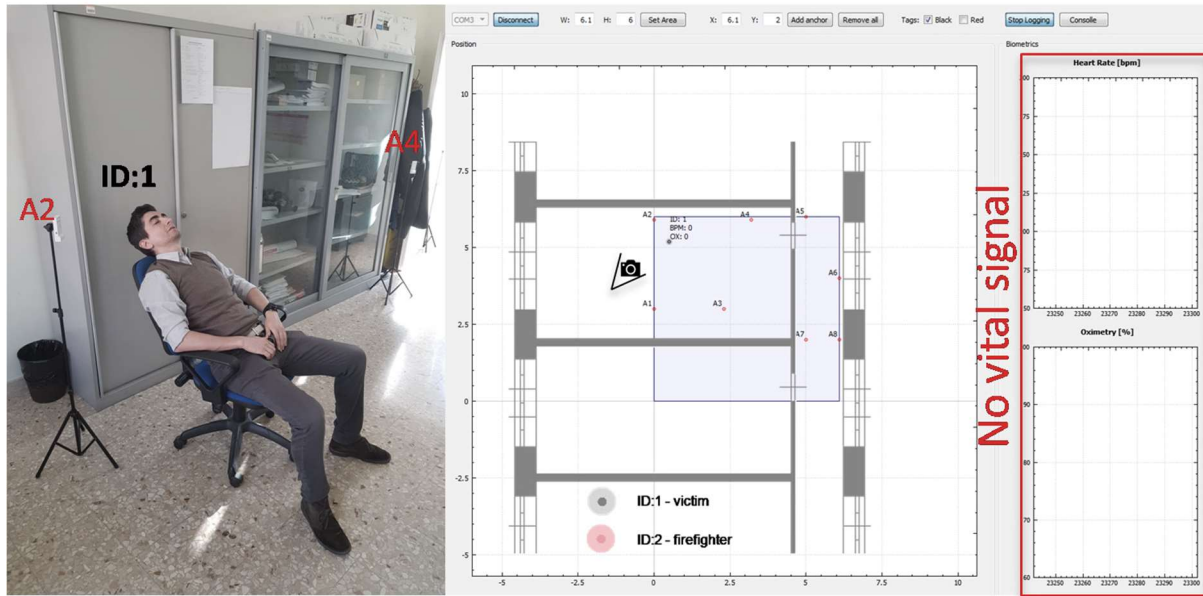


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Figure 17. Victim Localization (Tag ID:1) inside the building.

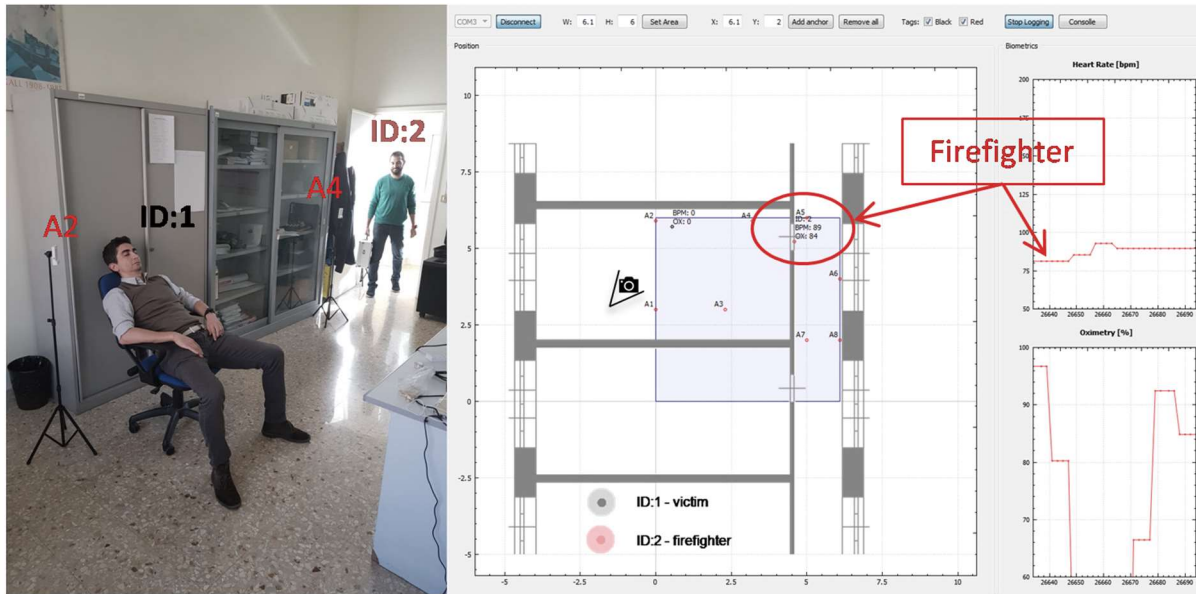
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Figure 18. Victim localization and vital signal visualization.

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Figure 19. Search and emergency rescue procedure.

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CONCLUSIONS

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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

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443 the large amount of constraints in post-earthquake emergency interventions. The system is able
444 to continuously evaluate the position and vital signals of mobile users in both indoor and
445 outdoor environments. In order to assess the feasibility of the proposed technology, two
446 experimental tests for indoor tracking and emergency rescue have been performed. Different
447 conditions such as different configuration of Anchors, the presence of obstacles like walls and
448 metal objects, have been considered. The results confirm the effectiveness of the proposed
449 system and they are very promising both in terms of position accuracy (average accuracy of 50
450 cm) and system robustness. Future work will focus on extensive performance evaluation and
451 optimization of the overall system, especially in terms of independency on the pre-installed
452 structure.

453

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