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Original
Indoor tracking using unmanned aerial vehicles / Cardoni, Alessandro; Tarantini, Raffaele; Cimellaro, GIAN PAOLO. - ELETTRONICO. - 2:(2023), pp. 4632-4640. (Intervento presentato al convegno 9th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering tenutosi a Athens (Greece) nel 12-14 June 2023) [10.7712/120123.10746.22021].

Publisher:
National Technical University of Athens

Published
DOI:10.7712/120123.10746.22021

INDOOR TRACKING USING UNMANNED AERIAL VEHICLES

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Abstract

Search and rescue operations during emergencies are complex missions that put at risk the life of first responders. The main challenge is to detect the trapped and injured people inside buildings damaged by different hazards. With a tool showing on a map the number, location and health status of victims, first responders would be able to significantly reduce the evacuation time and save more lives. In this paper, an innovative real-time indoor localization system using Unmanned Aerial Vehicles (UAVs) is proposed. The system includes anchor nodes (antennas) that are mounted on three UAVs flying outside the building and can track the position of people wearing a smart bracelet (tags). The system allows measuring both the absolute and relative location between groups of nodes in 3D without relying on any fixed communication infrastructure that could fail because of the disruptive event. In addition, vital parameters such as heart rate and body temperature can be monitored for each victim and rescuer wearing the bracelet. Each UAV collects, processes, and transfers the data to a portable gateway. A software application with a graphical user interface was developed to display the real-time position of the UAVs and tags with a color-coded indication of the accuracy. Preliminary results of the on-field tests of the systems are presented and discussed.

Keywords: Indoor tracking, First responders, Emergency management, Search and rescue, Structural health monitoring.

1 INTRODUCTION

In order for search and rescue teams to operate more quickly and effectively in post-earthquake situations, localization and indoor tracking of rescuers and victims are crucial during disaster management. Despite the development of a number of indoor tracking systems over the years, localization and tracking remain difficult in emergency situations when power and telecommunications networks are frequently down. The biggest issue in these situations is finding the trapped and hurt persons inside the building that has been damaged by various hazards (e.g. fire, earthquake, flood, etc.). In addition, victims can be critically injured to call for assistance or be unconscious. Even while it is essential to lower the risk of deaths, current revolutionary technologies have not yet sufficiently addressed this problem.

Indoor tracking systems are generally classified according to signal type, measurement metrics, and dependency on pre-existing infrastructures [1]. 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. Rantakokko et al. (2011) [2] proposed a positioning system using multiple sensors such as GPS receivers. Inokuchi et al. [3] proposed a method that allows first responders to create an indoor/outdoor map using range scanners, GPS and Wi-Fi wearable devices. The system can detect obstacles with different confidence levels depending on different scenarios and environments. Another study was done by Li et al. (2014) [4] 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 them. Yoon et al. (2015) [5] presented a smartphone-based system for indoor emergency response assistance. The system includes both a victim positioning system, which uses Wi-Fi signals from a number of access points, and a victim assessment system, which is based on 3D acceleration changes by the status of a victim. Ultrawide band (UWB) is also a promising technology that has been investigated in this field of application. For instance, Grazzini et al. [6] tested an UWB radar for buried victim detection, while Sachs et al. [7] presented a system to detect breathing motion that can be used to find earthquake and avalanche survivors.

The main shortcomings of these tools are related to range of functioning, battery life, accuracy, costs, and durability of the materials that make it difficult to use them extensively. Moreover, despite having demonstrated good performances, such systems require a certain level of automation and technology integration which is usually too expensive to be applied to existing buildings. An innovative approach is the use of chemical sensors to detect breath and skin emitted metabolic tracers [8] as well as the deployment of robots [9, 10]. Even though tangible progress has been done towards the use of robots in dangerous places, there are still many challenges to overcome before robots can perform most of the routine tasks in emergency applications.

This article describes a new real-time indoor localization system of people inside buildings following catastrophic events (earthquake, fire, etc.). This system is proposed as a fast, reliable, and low-cost solution to optimize the rescue operations carried out by firefighters and any other operator in the emergency sector. The purpose is to create a link between the injured and/or victims and the rescue teams, allowing the latter to act quickly during emergency operations inside a building. It is based on the *ultra-wideband (UWB)* network and employs internal nodes (*tags*) in the form of wearable devices that can both detect biometric information and the indoor position as well as external nodes (*anchors*) in the form of drones with real-time localization sensors.

2 SYSTEM DESCRIPTION

The creation of technologies that can be utilized to enhance the emergency rescue procedure after a disaster has been made possible by recent developments and trends in *Internet of Things (IoT)* and wearable devices over the past ten years. In that regard, a prototype indoor tracking system using fixed anchor nodes inside the building was recently created, tested in pilot case studies, and granted patent protection. To detect the wearable tags, this system needs a pre-installed network of fixed sensors (*anchors*) inside the structure. The new aspect of this research is to install the permanent *anchors* (antennas) on moving *Unmanned Aerial Vehicles (UAVs)* that are flying outside the structures in order to get around this restriction. An example of two equipped drones is shown in Figure 1.

Figure 1 – Drones equipped with antennas

The system uses a *Wearable Sensor Network (WSN)* to track rescuers and victims inside buildings. The external temporary network is made up of a fleet of *UAVs* (*anchors*) outside the building, whilst the wearable devices are nodes (*tags*) of *WSN*. Anchors can communicate with the tags, gather their data, and transmit it to a data control center through long-range *Radio Frequency (RF)* module. The victims' indoor location and general state (dead/alive and conscious/unconscious) are included in the real-time data.

Due to a poor *Line of Sight (LOS)* to the *GPS* satellites, indoor *GPS* performance is inhibited. Instead, the suggested approach combines the use of swarm drones with a *Wireless Sensor Network (WSN)* to provide precise real-time indoor localization. The technology enables measuring the absolute and relative distance in three-dimensional space between clusters of nodes.

The choice of *Real-Time Localization System (RTLS)* fell on *Ultra-wideband (UWB)* technology. It offers a higher level of accuracy than other technologies, such as the well-known WiFi and passive *Radio Frequency Identification (RFID)*. Peer-to-peer fine ranging, which enables numerous applications based on the relative distance between two entities, is made possible by *UWB*. The system is capable of identifying target objects (*tags*) both inside and outside with respectable precision. This technology has the ability to spread the signal over enclosed areas like homes and public venues as well as through walls. The possibility of installing an antenna system on drones has been verified in such a way as to guarantee a good ratio between carrying capacity (*payload*) and flight duration, and the need for additional batteries to power the antennas.

The overall system architecture is shown in Figure 2, while the three main components of which the system architecture consists of are described in detail below.

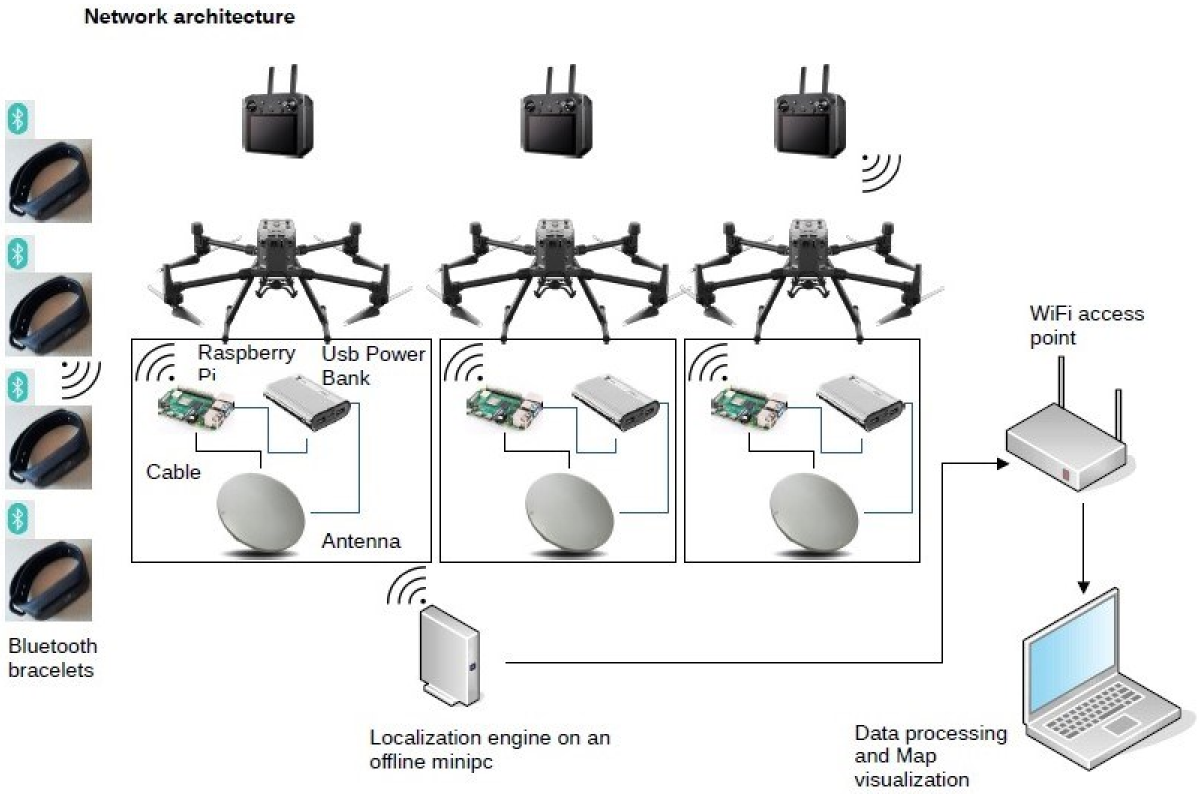

Figure 2 – Overall system architecture

2.1 Unmanned Aerial Vehicles (UAVs)

A swarm made up of three drones "*DJI MATRICE 300 RTK*" (Figure 3) has been used. It is the most recent commercial drone platform from DJI, it draws design cues from current aviation systems. It provides up to 55 minutes of flying time, powerful *AI* capabilities, 6 Directional sensing and positioning, and more. The brand-new *OcuSync Enterprise* provides triple-channel 1080p video and allows transmission up to 15 kilometers away. AES-256 encryption ensures safe data transmission, and real-time auto-switching between 2.4 GHz and 5.8 GHz allows for more stable flight in high-interference environments. To maximize flight safety and reliability, the *MATRIC300 RTK* platform has been developed with multiple system and sensor redundancies. The following redundancies and safety features are included: redundant obstacle sensor systems, dual flight control system sensors, redundant control signal connections, dual intelligent batteries, redundant transmission links, and three-propeller emergency landing.

Dual-vision and *Time-of-Flight (ToF)* sensors are present on all six sides of the aircraft to improve in-flight safety and aircraft stability. These sensors have a maximum detection range of up to 40 meters and allow the *DJI Pilot App* user to adjust the aircraft's sensing behavior. This six-direction sensing and positioning technology aids in maintaining the safety of the aircraft and the mission even in challenging operating circumstances. The operator can take control of the aircraft or payload (up to 2.7kg). As a result, there are more options for mission tactics and greater operational flexibility.

Figure 3 – DJI MATRICE 300 RTK

2.2 Anchors

A "*Quuppa Q35 Locator*" (Figure 4) antenna (*anchors*), based on the ultra-wideband technology, is mounted on each of the three drones flying outside the building. It is a *Radio frequency (RF)* transceiver using the 2.4 GHz frequencies, that enables the location and tracking of any object or person equipped with tags. Both indoor and outdoor environments are suitable for the *Q35*, making it possible an accurate tracking in even the most difficult circumstances. It has a high data throughput and a sub-meter accuracy.

Figure 4 – Quuppa Q35 Locator

2.3 Tags

Tags are mobile devices that are designed to be worn by the person being tracked. *Tags* gather data on the monitored person's biological state (heart rate and oximetry) as well as their distance from the *anchors*. The device conducts a trilateration and calculates the person's position based on the distance from the *anchors*. The *tags* use a rechargeable battery that can be powered by any device with a normal USB port.

The "*LandingSite eBand LS-B1*" tags (Figure 5) have been used. They are smart wearable devices which are fully compatible with the *Quuppa Intelligent Locating System*. Among the ordinary feature of general device in the market, the indoor localization, the date/time synchronization, the integrated heart rate sensor, the QR code identification, and the long battery life and rechargeable should be mentioned.

Figure 5 – LandingSite eBand LS-B1

3 APPLICATION AND RESULTS

The test has been conducted in the Airfield "Pegasus" (Busano, TO, Italy). *Tags* have been placed inside the hangar, while three equipped *UAVs* on the open field outside it. The application environment determines the system coverage (e.g. open space, obstacles, and so on). The performance of the system may be impacted by the existence of obstacles between the anchors and the tags, such as debris, walls, and metallic objects.

Figure 6 shows an aerial view of part of the airfield, with the base distribution of anchors and tags for the specific test.

The drones flight formation has had an equilateral triangle shape (ABC) with an edge of about 15m that has been maintained during the whole test. The *UAVs* swarm has been moved at different elevations (2m, 4m, 6m, 8m, 10m) and different distances from the opened hangar gate (2m, 6m, 10m). The triangle edge has been larger than the hangar gate (Figure 7). For these reason the drones BC have been shielded by the wall in the first meters from it.

A total of four tags has been placed in line and evenly spread, at about 2m from the opened hangar gate. Then, they have been moved into the interior of the hangar in five additional setups (4m, 6m, 8m, 10m, 12m). Tag n°1 was constantly sheltered by a wall and it had not a direct visibility of the drones. Tags n°2 and n°3, between 6m and 8m, were among two helicopters, simulating metal obstacles. While, tag n°4 was the one with a constant visibility of the drones.

Figure 6 – Aerial view: anchors and tags distribution for the specific test

Figure 7 – Hangar gate

In the following figures (Figure 8 - Figure 10) are shown the results of the conducted sensitivity analysis. They illustrate how a target variable (system accuracy related to each tag) is affected based on changes in other variables known as input variables (UAV elevation and tag-hangar gate distance). The sensitivity analysis has been conducted for 3 different UAVs BC-hangar gate distances (2m, 6m, 10m).

Four different tracking accuracy levels have been defined:

- 3 - Excellent (<1m)
- 2 - Good (<3m)
- 1 - Poor (>3m)
- 0 - Bad (Target not detected)

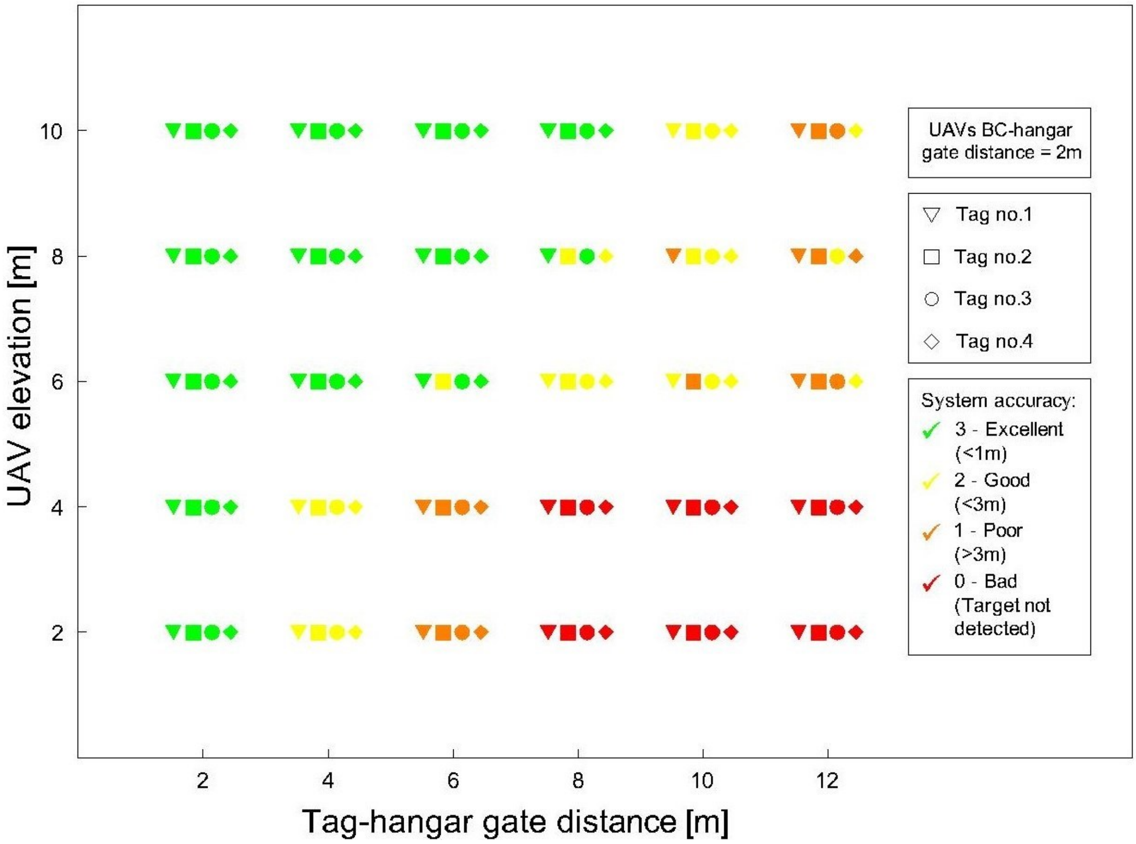

Figure 8 – System accuracy measurement: UAVs BC-hangar gate distance = 2m

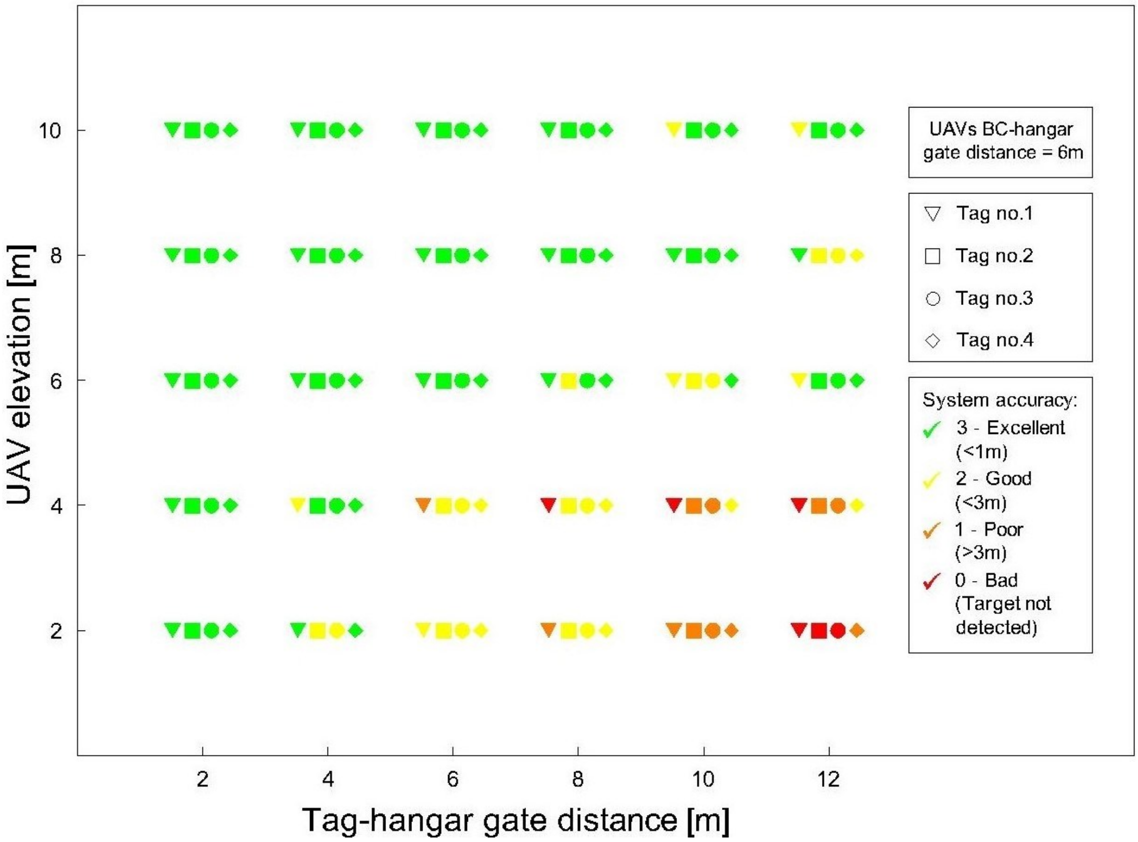

Figure 9 – System accuracy measurement: UAVs BC-hangar gate distance = 6m

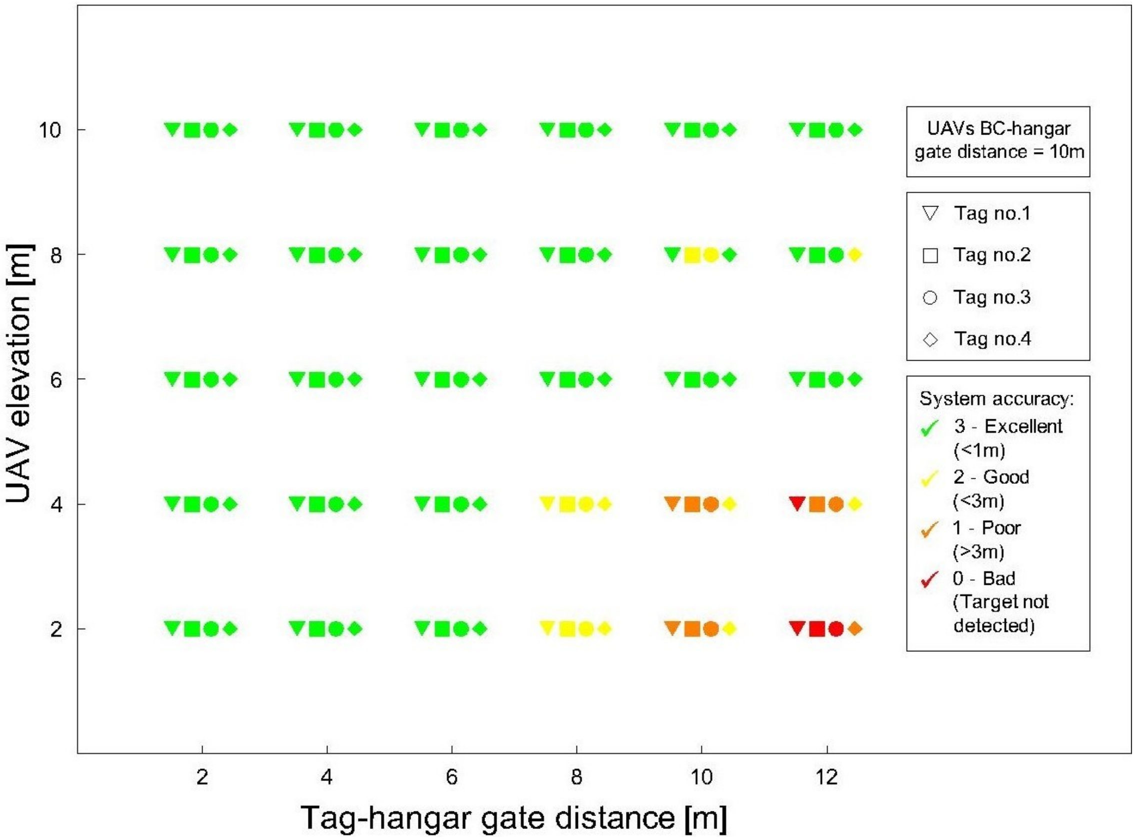

Figure 10 – System accuracy measurement: UAVs BC-hangar gate distance = 10m

All the three diagrams show that with increasing the UAVs elevation the system accuracy increase. This is due to the fact that the cone of signal increase too. As expected, increasing the tag-hangar gate distance the accuracy decreases until the complete not detection of tags. While, the behavior improves with the increasing of the UAVs BC-hangar distance. It is meaningful since in the first few meters the drones BC are covered by the walls in front of them.

4 CONCLUSION

The project outcome will be innovative with respect to the available technologies because:

- it allows indoor tracking without power and communication networks (WiFi, GPS, GPRS, etc.), that might not be available after a disaster.
- it allows data transfer related to vital parameters and tracking of both rescuers and victims at the same time.
- it does not require pre-installed fixed nodes (*anchors*) inside the building.

These features will allow the first responders to act quickly in searching and rescuing people even in building without an existing node network thank to the presence of a temporary outdoor network (*UAVs*).

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