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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.

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1 INTRODUCTION

Natural and man-made disasters such as earthquakes, floodings, fires are often responsible of disproportionate human and economic losses. The main challenge in these situations is finding trapped and injured people inside damaged buildings. Localization and indoor tracking systems of first responders and victims would allow for safer and more rapid search and rescue operations.

Indoor tracking systems are generally classified according to signal type, measurement metrics, and dependency on existing infrastructure [1]. Several applications adopting different types of techniques, such as infrared, Bluetooth, WiFi, Radio Frequency Identification (RFID), Ultrawide 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 multiple access points, and a victim assessment system based on 3D acceleration changes by the status of a victim. UWB has shown solid performance 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, they require a certain level of automation and technology integration which is usually expensive to install into existing buildings. Innovative approaches are 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 environments, there are still many challenges to overcome before robots can perform most of the routine tasks during emergencies.

This article describes a new real-time indoor localization system of people following catastrophic events (e.g., earthquakes, fires, 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 injured and/or unconscious occupants of damaged buildings and rescue teams, for faster and more efficient rescue operations. The system consists of three unmanned aerial vehicles (UAVs) equipped with UWB antennas (anchors) flying outside a building and are used to track the position of wearable devices (tags). The UAVs are placed in a predefined configuration based on the geometry of the building. Then they are moved simultaneously at different elevations to scan all the floor levels. The system was tested on-field on a case study to evaluate its performance. The results of these preliminary tests are presented and discussed in this work. Sensitivities analyses were carried out to evaluate the precision of the indoor tracking varying the UAV elevation, their distance from the building, and the distance of occupants from the UAVs.

2 DESCRIPTION OF THE PROPOSED INDOOR TRACKING SYSTEM

The new aspect of this research is to install the needed infrastructure for the real-time indoor tracking on UAVs that are flying outside the structures. This represents a cheaper and more reliable solution since it does not depend on any existing fixed infrastructure that might fail during the disruptive event.

The technology chosen for the localization system is based on UWB, which offers a higher level of accuracy than other technologies, such as WiFi and passive radio frequency identification. The technology allows measuring the absolute position of the wearable devices (tags) in three dimensions and the relative distance between them. The system can identify tags both outdoor and indoor providing an indication of the level of accuracy. Obviously, the presence of walls and internal partitions has an impact on the system precision. Nonetheless, the proposed technology is promising, and drones can be strategically positioned in configurations that maximize the signal strength. For instance, they can be placed closer to transparent and thin elements such as windows and openings. The possibility of installing UWB antennas on drones has been verified to guarantee a good compromise between payload, flight duration, and power consumption. Indeed, power banks needed to be mounted onboard to power the antennas and the transmission module. The transmission module is a Raspberry Pi, which gathers the data about the tags collected by the antennas and sends it to a localization engine implemented on a mini pc. The data can then be processed and visualized on a map from a laptop. The map shows the indoor location and health state (e.g., dead/alive and conscious/unconscious) depending on the data collected by the wearable devices.

Figure 1 shows the system architecture, while a picture of fully equipped UAVs is shown in in Figure 2. In the next subsections more details about the main components of the system are provided.

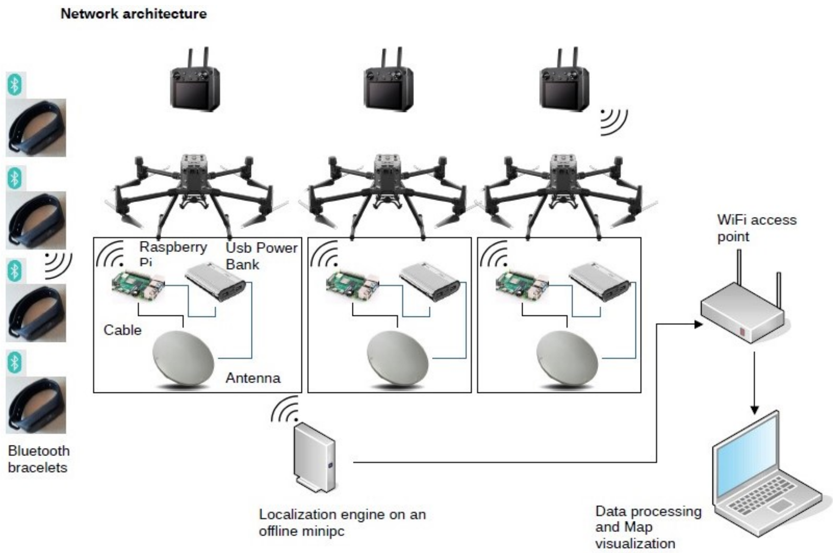

Figure 1: System architecture.

Figure 2: UAVs equipped with antenna, Raspberry Pi, and power bank.

2.1 Unmanned Aerial Vehicles (UAVs)

A swarm of three drones “DJI MATRICE 300 RTK” (Figure 3) was used to deploy the tracking system. It is the most recent commercial drone platform from DJI that draws design cues from complex aviation systems. It provides up to 55 minutes of flying time, powerful AI capabilities, 6 Directional sensing and positioning, and more. 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. It has a maximum payload of 2.7 kg, which was almost reached as the weight of the mounted components is about 2 kg.

Figure 3: DJI MATRICE 300 RTK.

2.2 Tracking antennas

A "Quuppa Q35 Locator" (Figure 4) antenna, is mounted on each of the three UAVs. It is a transceiver operating at 2.4 GHz, 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 Wearable devices

Tags are mobile devices that are designed to be worn by the person being tracked. Tags gather data on the monitored person's location and vital parameters (e.g., heart rate). 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 USB port. The "LandingSite eBand LS-B1" tags were selected (Figure 5). They are smart wearable devices fully compatible with the Quuppa Locator. Their main features are indoor localization, date/time synchronization, integrated heart rate sensor, QR code identification, and long-lasting battery.

Figure 5: LandingSite eBand LS-B1.

3 CASE STUDY AND SYSTEM PERFORMANCE

On field testing has been conducted in the hangar of the airfield "Pegasus" (Busano, Italy). Tags have been placed inside the hangar, while three equipped UAVs on the open field outside it. The objective of the tests was to evaluate the system performance considering the effects of case study specific characteristics and three variables, namely the UAV elevation, their distance from the building, and the distance of occupants from the UAVs. The environment and building's characteristics may have a significant impact on the system coverage. For instance, material and thickness of the obstacles standing between the anchors and the tags can alter the accuracy of the indoor tracking.

Figure 6 shows an aerial view of the airfield and a scheme of the positioning of the UAVs, indicated by the letters A, B, C, and the tags (1, 2, 3, 4). The flight formation was an equilateral triangle shape (ABC) with a side of 15m that was fixed during all the tests. The UAVs were then moved at different elevations (2m, 4m, 6m, 8m, 10m) for three distances from the hangar entrance (2m, 6m, 10m). Since the hangar gate is only about 6m, this means that UAVs B and C were shielded by the hangar walls and gate (Figure 7).

Figure 6: Aerial view of the testing site showing a scheme of the UAVs and tag positioning.

Figure 7: View of the test building.

Four people were provided with tags and asked to walk from the gate towards the opposite wall of the hangar. Their position and vital parameters were continuously monitored and recorded in real time. For visualization purposes, the results obtained for six distances from the hangar gate are reported, i.e., 2m, 4m, 6m, 8m, 10m, 12m. Tag no. 1 was constantly shielded by a wall and never had direct visibility with the three UAVs. Tags no. 2 and no. 3, while moving towards the center of the building, were separated by helicopters, simulating metal obstacles. Tag no. 4 was the only one to keep constant visibility of the drones.

Figures 8-10 show the results of the sensitivity analyses. They show the accuracy of the indoor position of each tag varying the UAV elevation and the distance between tags and hangar gate when the UAVs B and C are at a distance of 2m, 6m, 10m from the hangar. The position accuracy was categorized into four levels: 0 - Bad (Target not detected), 1 - Poor (>3m), 2 - Good (<3m), 3 - Excellent (<1m).

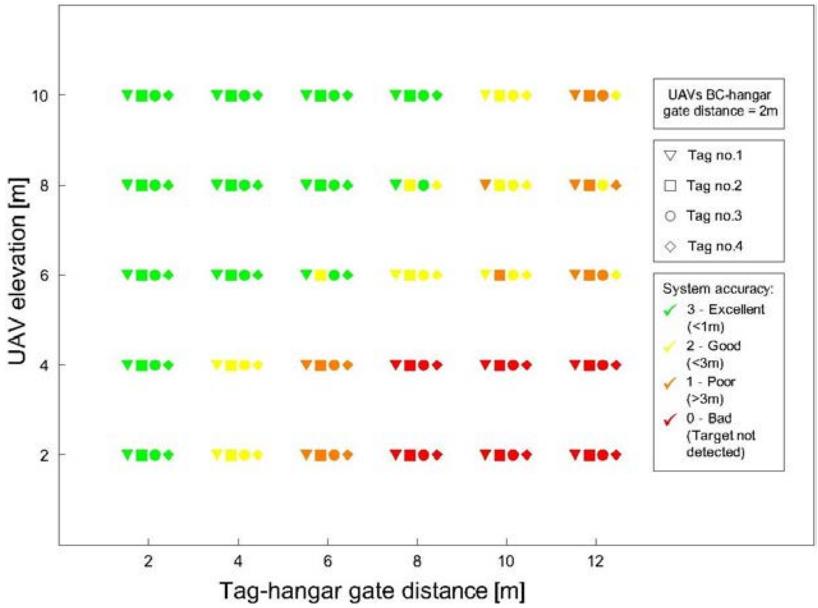

Figure 8: Indoor position accuracy for a distance UAVs BC-hangar gate = 2m.

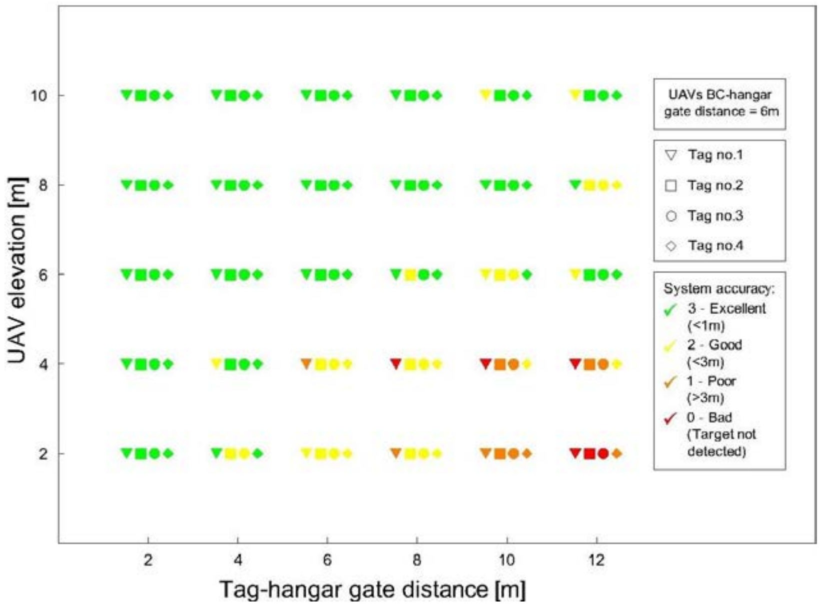

Figure 9: Indoor position accuracy for a distance UAVs BC-hangar gate = 6m.

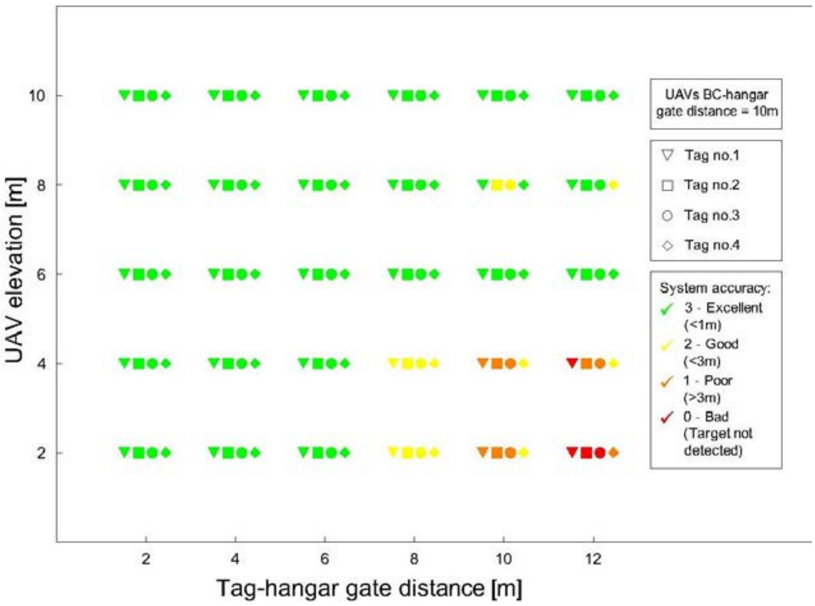

Figure 10: Indoor position accuracy for a distance UAVs BC-hangar gate = 10m.

The graphs show that increasing the UAVs elevation has a positive effect on the system accuracy. This is due to the fact that the area covered by the antennas increases with the elevation. As expected, increasing the tag-hangar gate distance the indoor tracking accuracy decreases until the tags are no longer detected. On the other hand, the performance improves by increasing the distance between the UAVs BC and the hangar. This means that when the UAVs are too close to the walls the signal suffers from reflection and interference phenomena.

4 CONCLUSIONS

This work presented an innovative system that can be used during emergencies to track the presence of injured and unconscious people inside damaged buildings. It is also intended to be used to monitor and guide first responders in search and rescue operations. The main components of the system are UWB antennas mounted on UAVs that are deployed outside a building to detect the position and vital parameters of the people inside. This data is collected by simple wearable devices and transferred to a positioning engine. Information about position and health status can be visualized on a map from a laptop connected to an access point.

The proposed technology for real time indoor tracking using UAVs showed promising results and is innovative compared to other technologies because: (i) it does not rely on power and telecommunication networks (WiFi, GPS, GPRS, etc.), that might not be available after a disaster; (ii) it allows data transfer related to vital parameters and tracking of both rescuers and victims in real time; (iii) it does not require pre-installed fixed nodes (anchors) in the buildings. These features would allow first responders to act more rapidly and in safer conditions during search and rescue operations.

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REFERENCES

[1] Bastos, A. S., Vieira, V., and Apolinário Jr, A. L. *Indoor location systems in emergency scenarios-A Survey*. Proceedings of the annual conference on Brazilian Symposium on Information Systems: Information Systems: A Computer Socio-Technical Perspective, 34.

[2] Rantakokko, J., Rydell, J., Strömbäck, P., Händel, P., Callmer, J., Törnqvist, D., Gustafsson, F., Jobs, M., and Grudén, M. 2011. *Accurate and reliable soldier and first responder indoor positioning: multisensor systems and cooperative localization*. IEEE Wireless Communications, 18(2), 10-18.

[3] Inokuchi, M., Higuchi, T., Yamaguchi, H., & Higashino, T. (2012, November). *Autonomous recognition of emergency site by wearable sensors.* In 2012 IEEE International Conference on Green Computing and Communications (pp. 400-409). IEEE.

[4] Liu, H., Gan, Y., Yang, J., Sidhom, S., Wang, Y., Chen, Y., and Ye, F. *Push the limit of WiFi based localization for smartphones.* Proceedings of the 18th annual international conference on Mobile computing and networking, 305-316.

[5] Yoon, H., Shiftehfar, R., Cho, S., Spencer Jr, B. F., Nelson, M. E., and Agha, G. 2015. *Victim localization and assessment system for emergency responders.* Journal of Computing in Civil Engineering, 30(2), 04015011.

[6] Grazzini, G., Pieraccini, M., Parrini, F., Spinetti, A., Macaluso, G., Dei, D., & Atzeni, C. (2010, June). *An ultra-wideband high-dynamic range GPR for detecting buried people after collapse of buildings.* In Proceedings of the XIII Internarional Conference on Ground Penetrating Radar (pp. 1-6). IEEE.

[7] Sachs, J., Helbig, M., Herrmann, R., Kmec, M., Schilling, K., & Zaikov, E. (2014). *Remote vital sign detection for rescue, security, and medical care by ultra-wideband pseudo-noise radar.* Ad Hoc Networks, 13, 42-53.

[8] Güntner, A. T., Pineau, N. J., Mochalski, P., Wiesenhofer, H., Agapiou, A., Mayhew, C. A., & Pratsinis, S. E. (2018). *Sniffing entrapped humans with sensor arrays.* Analytical chemistry, 90(8), 4940-4945.

[9] Kruijff, G. J. M., Pirri, F., Gianni, M., Papadakis, P., Pizzoli, M., Sinha, A., ... & Priori, F. (2012, November). *Rescue robots at earthquake-hit Mirandola, Italy: A field report.* In 2012 IEEE international symposium on safety, security, and rescue robotics (SSRR) (pp. 1-8). IEEE.

[10] Trevelyan, J., Hamel, W. R., & Kang, S. C. (2016). *Robotics in hazardous applications.* In Springer handbook of robotics (pp. 1521-1548). Springer, Cham.

[11] Cimellaro GP, Domaneschi M, Zamani Noori A. *Improving post-earthquake emergency response using indoor tracking.* Earthquake Spectra. 2020;36(3):1208-1230. doi:10.1177/8755293020911163