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RESEARCH ARTICLE

Bluetooth Low Energy for Close Detection in Search and Rescue Missions With Robotic Platforms: An Experimental Evaluation

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ABSTRACT In the field of rescue robotics, data collection about the environment and efficient communications are fundamental for the success of search and rescue missions. Digitalization provides new ways of detecting and localizing potential victims via the wireless devices carried by the users. Nowadays, the number of personal Bluetooth low energy wearables in use (smartbands, smartwatches, earbuds…) increases constantly, being a yet-to-be-exploited personal radio frequency beacon in the case of an emergency, where the user may not be localized and unconscious. In this paper, the results of experimental tests of a Bluetooth low energy based detection system ported by terrestrial and aerial robots are provided, in order to test the feasibility of such system for the localization of the victims in unknown complex disaster areas. The results show that the tested devices can be reliably detected up to 15 meters away when using transmission power values typical of a smartphone, while being able to detect even lightly burdened devices. These results support the idea of developing an algorithm for the delimitation of areas of interest for the search and rescue groups, influencing the routes followed by the robot with the objective of exploring the detected devices area in the search of victims.

INDEX TERMS Analytical models, bluetooth, rescue robots, signal detection, 5G mobile communication.

I. INTRODUCTION

The large amount and diversity of data that can be collected during a search and rescue (SAR) operation must provide information that can be used for risk interpretation and prioritization. In today's era of Big Data, there are several methods, based on risk indexes, to assess the consequences of certain natural phenomena [1]. When an emergency must be handled to in a catastrophic scenario, there is a need for data to asses the situation. However, the problem is sometimes to deal with too much, not-so-relevant, data that may confuse rescuers with alerts which makes the use of available resources inefficient. Data acquisition can be done through wireless sensor networks (WSN), established in the areas of interest during a first phase of ground survey; or through the use of SAR agents (human and robotic) that act as carriers of

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IoT (Internet of Things) devices to capture information from the environment, while performing their SAR tasks [2]. The inclusion of unmanned ground and aerial vehicles, such as drones, and even ground and aerial robots facilitates SAR tasks, reduce the occupational stress that places human agents at higher risk of mental illness [3], and speeds up the process of finding a victim. Thus, it is essential to provide real-time information on the environment in which SAR agents must operate. This information can be used to generate alerts with higher priority than others, evaluate potential risks (PR), detect potential victims (PV), and to obtain datasets [4] that help the leaders of these SAR teams to learn from previous experiences and thus make a continuous improvement to increase the efficiency of the future operations of their SAR teams. Robots must act autonomously when possible or be tele-operated to locations hostile to human rescuers. In this regard, visualization sensors such as stereo, high-resolution cameras, LiDARs (Laser Imaging, Detection, and Ranging), thermal [5], hyperspectral cameras [6], or ground penetrating radar [7], [8], [9], [10] can be of great help for victim detection. In addition, signal capturing devices from the robot's immediate environment are also often used. For instance, microphones to detect audio, scanners to detect radio signals of certain frequencies and low power WSN to establish some point of interest according to a physical magnitude throughout the area of operations [11].

In this context, Bluetooth low energy (BLE) is a successful technology implemented in a wide variety of technological devices with a promising prediction in terms of growth for the upcoming years. Following the Bluetooth Market Update of 2021 [12], close to 4.5 billion Bluetooth devices were shipped that year, with a prediction of more than 6 annual billion devices to be shipped by 2025. From those 6 billion devices, more than 600 million will be Bluetooth earbuds or hearing devices, and the number of shipped smartwatches and smartbands is expected to rise up to 260 million devices. Additional to those, the projected 2 billion platform devices (smartphones, tablets, PCs...) establish Bluetooth as a hugely extended technology of extreme potential to its application to victim detection, far more adopted than other short and mid-range radio-technologies such as UWB and RFID [13], [14] as well as cellular technologies such as 5G [15]. Moreover, due to the personal nature of these wearable devices (earbuds, smartwatches...) that have a high chance of remaining close to its owner in any scenario. Although BLE beacons and other related positioning technologies are available, this article aims to provide results for detection and localization of the victims in any kind of scenario, whether rural or urban, without modifying the program of the devices the user is carrying or having to force the inclusion of a locator device in the victim.

Regarding the localization of BLE devices, the amount of research is extensive when applied in indoor spaces where the area or building is structured and known in advance. The number of articles focused on the field of outdoor localization is, however, reduced, due to the various problems encountered outdoors (usually much larger areas, greater number of obstacles, vegetation...) And finally, when talking about victim detection in unknown outdoor spaces for SAR missions, this number of articles decreases significantly. Besides, the fact of working in unknown spaces eliminates the possibility of applying multiple error reduction techniques, such as fingerprinting, turning the localization problem specially challenging.

In this way, the contribution of this article is double. First, a novel BLE victim detection architecture for robotic platforms to be implemented in the robotic agents of emergency response teams (both in ground and aerial agents) is presented. Secondly, experimental results on detection of BLE devices from ground and air, with devices both in line of sight (LoS) and buried in different positions of a realistic experimentation scenario, are provided. Here, the mentioned architecture allows cooperation in victim localization of aerial and ground robots, having the advantage that it does not require any modification of the devices held by the victim, being able to detect any advertising device as is. The provided experimental results come from a realistic experimentation scenario with multiple elements that can affect detection and localization, like dense vegetation or the deployment of multiple emergency response teams in the area, with the interference associated to their typical equipment.

The structure of the article is as follows: in Section I an introduction on common victim detections methods, followed by the advantages of using BLE, and the aim of this work, is provided. After this brief introduction, Section II revises the related literature to sum up the state of the art of BLE localization in emergency situations. Following in Section III, the proposed system is presented before sharing the experimental results obtained in a real scenario in Section IV. Finally, the gathered results are analyzed mentioning the extracted conclusions in Section V.

II. RELATED WORKS

Time-critical applications, such as SAR ones, can highly benefit by using unmanned aerial vehicles (UAVs) or UAV-swarms with a flying network attached to determine the PV's location [16]. Some cluttered scenarios, such as lush forests, make it difficult for drones to move without colliding. This prompts new developments to give drones the ability to sense the environment and plan a locally optimal trajectory [17]. Another important point to look for PVs concerns the formation flight [18], [19], [20] of UAVs, when they operate as a cluster, where the preferred shape can adaptively change according to task requirements. The UAV size and its payload limit is a handicap in the SAR context since they are directly related with flight time and manoeuvrability. In this respect, the use of lightweight 5G sensors is of interest to be able to transmit data requiring high bandwidth and low latencies [21]. Among the missions of UAVs and unmanned ground vehicles (UGVs) is to act as robotic platforms as a means of transport to bring a mobile network infrastructure to places where they do not exist. A flying network for emergencies is proposed in [16], where UAVs act as WiFi Access Points (AP), always ready to capture any signals from clients (usually smartphones carried by the PVs). However, there is a big dependence of the positioning error on the number of received signals and on the relative accuracy of distance measurement. In addition, the exclusive reliance on received signal strength indicator (RSSI) for localization is often too imprecise, although it is often a good complement to other localization techniques. Lighter drones are also included in SAR operations to locate and evaluate the health state of the PVs. Most of the works found in the literature using drones for SAR operations are based on simulations but they show the relation between gathering as many data (radio signals or images) as possible and the speed of the drones (when operating as PV signal scouts). Therefore, the speed is conditioned not only by the flight plan established or the maximum surveying altitude, but also for the data quality required. Thus, the mobility of agents who carry sensors to acquire information from their environment is crucial both in the case of unmanned vehicles and SAR dogs [22], [23].

Finally, other works focus on autonomous drone motion planning and object finding system under object detection uncertainty for outdoor environments [24].

The potential of wireless connected devices for localization was reckoned long time ago. Among those suitable for victim detection, BLE is the technology with the greatest spread among personal devices [25], since then, BLE localization has been extensively studied. From detection, to precise localization and identification, research on this field continues to expand, developing new hardware and techniques to obtain more precision. Among the works on the field of localization via BLE, several studies like [26], [27], [28], [29], [30], [31] work in indoor spaces applying a wide range of localization techniques to improve the accuracy of the estimation; although none of these works go outside and most of the methods applied like mapping [27] and fingerprinting [28], [29], [31], [32] require previous knowledge of the terrain. The only exception here is [30], where trilateration and other techniques are used that are suitable for outdoors unknown terrain.

Other works, although less common, that focus on outdoor environments can be found, like [33], where BLE beacons are used in a previously deployed Wireless Mesh Network (WMN) throughout an outdoor area to allow a moving device to receive their signals and trilaterate its position through RSSI. This case is the most closely related to the case we are interested in, but in our unknown emergency scenario we do not have access to a previously deployed BLE WMN. Another example of BLE outdoor localization is [34], where the position of cattle is tracked through BLE devices attached to the cows. In this case outdoor fingerprinting is applied, since the pasture is a delimited area. This approach cannot be applied in an emergency scenario that could take place in unknown environments. As these, multiple outdoor examples where special BLE beacons are attached to to-detect entities (like workers of a construction site) can be found, but none of the reported cases try to localize the non-modified BLE personal devices of a victim taking into account the restrictions of an emergency scenario.

About studies on BLE localization in emergency scenarios, there are some works focused on localization of human victims that port a BLE device (BLE+SAR), like [35], where a drone with a BLE detector or a smartphone scan the area looking for a reported victim. This implementation is particularly interesting because all registered smartphones can work as scanners by executing a background routine, but the victim device must have been previously registered in a database and its lost/injured state reported to the operator in order to initiate SAR protocols. Other works like [36] make use of BLE localization through RSSI to keep track of already found injured victims, not focusing on the initial localization step of such victims.

As seen, there have been no reported trials on detection and localization of victims in unknown outdoor emergency scenarios where the victims' devices are not previously known, logged in a database or equipped with on purpose engineered BLE devices. It is here where this article focuses its objective, implementing and testing the capabilities of a BLE victim detection system added to SAR robots, terrestrial and aerial, that will scan the emergency area looking for BLE devices and recording the RSSI of the received signal, as well as all the information received regarding the device nature. Here, the implemented system is exposed, and real measures are taken during the annual event organised by the Chair of Emergencies, Security and Disasters and the University of Malaga, in which activities involving SAR missions are carried out with the participation of various rescue and emergency forces, the XV Conferences on Emergencies, Security and Disasters (CESD) [37]. This event takes place in a complex outdoor scenario adjacent to the campus area [38], full of vegetation and wrecked vehicles that can interfere with the BLE signals, as well as the response teams communication systems that work using nearby bands.

III. PROPOSED SYSTEM

In this section, the devised BLE detection system is presented. The hardware used is based on the well-known ESP32 microcontroller, which has both BLE and WiFi capabilities. A group of nodes has been configured as BLE transmitters with a transmission power of 9 dBm (Bluetooth class A), so as to emulate potential victims (PVs) in the context of SAR missions. Figure 1 shows a generic set up, where victim detection from the sky (by UAVs) and from the ground (by UGVs) has been considered using BLE scanners. The UGVs are sent to an area of interest, being tele-operated or moving autonomously. The UAVs are tele-operated by a remote pilot who should try to fly over the same terrain to explore. In both cases, the waypoints are available in a remote control and coordination center (RCCC) to be processed. This way the PV detections can be paired with the GPS location, which is taken with differential corrections. For a practical implementation, in real time, an MQTT broker has

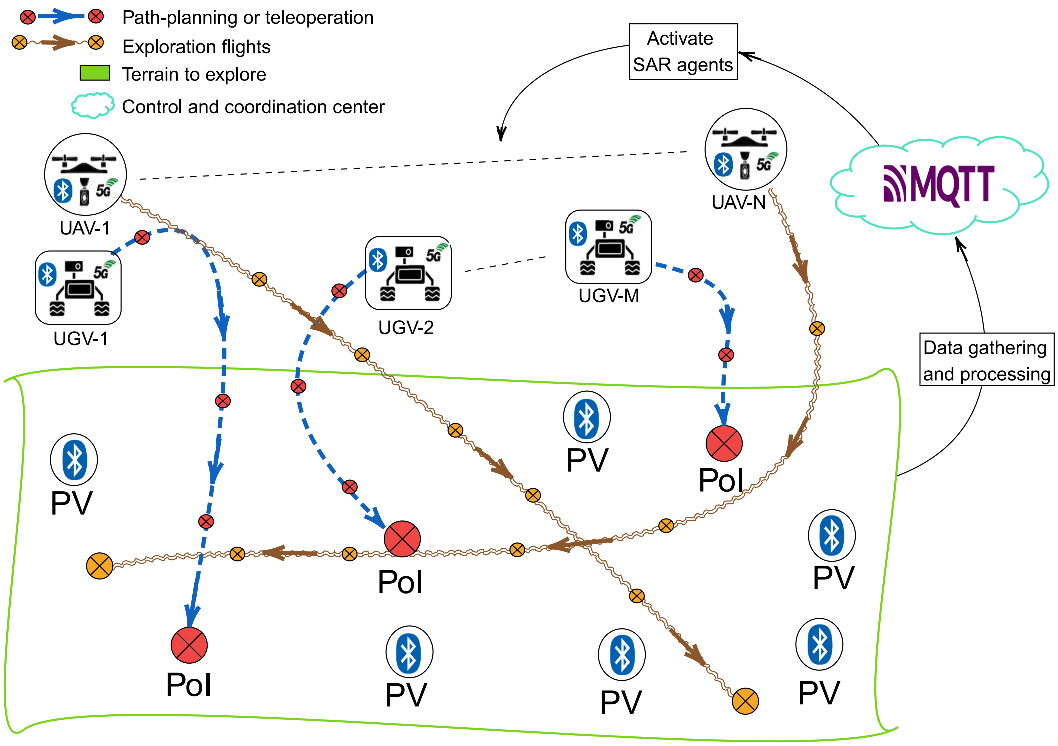

FIGURE 1. General set up of the proposed system to detect PVs using BLE.

to be available in the cloud. Each robot has an MQTT client who publishes the information to the RCCC. To do this, all the SAR robotic agents should have Internet connectivity; 5G preferably in order to have low latencies in the robot control side. Finally, the RCCC could activate SAR agents to specific PoI using a SAR Feedback Information System (FIS) connected to the same MQTT broker [2], as can be done with other technologies such as LoRa [39]. Since both the position of the robot and the detection of the MACs of the BLE devices in the robot's environment would be available in real time, the MQTT broker would have all the necessary information to activate other agents to the new area of interest. This way, the generic set up proposed enables the detection of victims and facilitates their location by sending in new agents, which could also be human or canine.

However, the main goal of this paper is to establish an experimental evaluation of a communication architecture for BLE detection in SAR missions with robotics platforms via the generic setup devices and the MQTT broker. The aim is to achieve a first approach to the set up presented in the Figure 2.

BLE transmitter nodes are deployed in the terrain to be explored. The UGV performs a planned movement towards areas of interest in order to detect transmissions from the BLE nodes, i.e., PVs. For this purpose, it carries two BLE scanners. The first one is based on the ESP32, configured only as a BLE scanner and with a scanning periodicity of 10 seconds. In addition, the UGV also carries a Meshlium scanner (Libelium), in order to obtain real-time measurements and to compare a purpose-built commercial scanner with a low-cost one. The Meshlium scanner is connected to a 5G router (terminal of a 5G pilot network provided by Vodafone), thus being able to synchronise its local database with an external database with low extra latencies. This external database is hosted on a web server, which in turn is linked to a Matlab script in which the measurements are processed. To do the same with the signals perceived from the scanner based on ESP32 on board the UGV, the data is stored in an internal memory (micro SD card). Thus, the comparison of data gathered by both BLE scanners is done after the tests.

In addition, the UGV path waypoints are sent in real time to a Message Queue Telemetry Transport (MQTT) broker hosted on local server linked to the aforementioned 5G pilot network. For this purpose, an MQTT client is used in a LabVIEW program, installed on the UGV's on-board PC. This client publishes the waypoints (latitude, longitude and altitude) obtained with a differential GPS with Real Time Kinematic (RTK) corrections, used for the terrestrial robot. In this way, the position of the UGV (with an error of a few centimeters) can be combined with the detections made from the two on-board BLE scanners.

In the case of the UAV (DJI Matrice 600), it also carries a battery-powered ESP32-based scanner. The data is stored on its micro SD card too. Flight data is extracted from the Remotely Piloted Aircraft System (RPAS), and processed

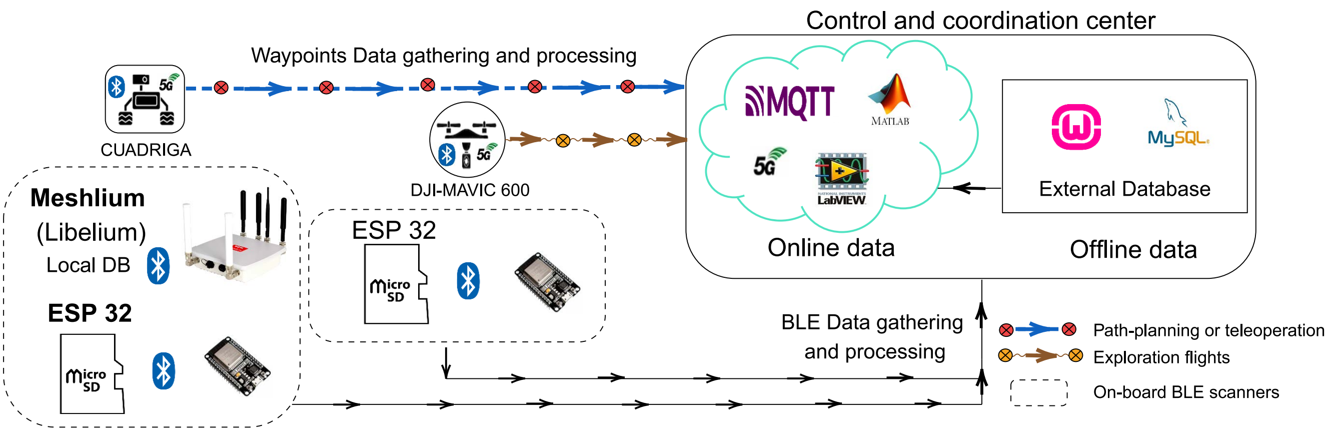

FIGURE 2. BLE scanning and detection mobile system architecture.

after the flights. The tracking of the UAV is also quite accurate, as the UAV is equipped with three GPS antennas, providing precise positioning, given by up to 18 satellites. According to the manufacturer (DJI), it has a horizontal accuracy of 1.5 m, and a vertical accuracy of 0.5 m.

IV. EXPERIMENTAL RESULTS

The BLE-based victim detection system presented in this work has been tested and evaluated in the context of a series of realistic SAR experiments, carried out in an area of experimentation in new technologies for emergencies (AENTE) [40], with an extension of 90000 m^2 (see Figure 3). The zone belongs to University of Málaga and is used every year in the CESD, where realistic SAR exercises are designed and implemented in collaboration with firefighters, police, medical and military units. The terrain profile is quite irregular and has areas covered by dense vegetation, due to the existence of a close stream.

This experimental part has been implemented in two different cases. First, certain preliminary realistic experiments have been designed to test the BLE-based sensing system in a controlled manner. Second, the system has been included in a more realistic exercise with SAR missions during the XV CESD, where the context was a fire drill with mock victims.

In both cases, several BLE transmitter nodes have been deployed at fixed locations in the AENTE. In addition, some SAR robotic agents carried BLE scanners to detect the transmissions while performing other tasks. Several flights have been conducted with a UAV (DJI Matrice 600 Pro), which carries a BLE scanner (based on ESP32) and a camera to detect and search for potential victims (PVs), respectively. In parallel, a UGV (Cuadriga) moves over the ground, carrying a BLE scanner based on ESP32 too, but also a Meshlium Scanner (Libelium [41]), in order to support the detection of victims from the ground. Cuadriga's task is to move tele-operated or autonomously throughout the AENTE, capturing information from their environment. To do this, a path planner establishes its route according to a destination set by an operator located at a control center or due to the trigger of some event detected (with higher or lower priority) in some area of interest. The purpose of this paper is not to explain the importance of a strategic planner in SAR tasks, neither how it works [42], [43], but this resource developed and implemented by the Robotics and Mechatronics Lab [2] will be used, just like it would be in a realistic scenario.

In this work, the path followed by the BLE scanner-carrying robot has not been planned with prior knowledge of where the PVs are. For that, Cuadriga scans the rough zone, while performing path planning in the operation area (the one overflown by the UAV shown in Figure 9), which has natural and artificial characteristics that allow testing of the BLE detection system in a realistic outdoor environment. In some cases it is difficult to detect victims from the ground via BLE, thus the use of UAVs is justified in this type of missions.

A. PRELIMINARY EXPERIMENTS

The exercises carried out during the testing session prior to the CESD are presented. A configuration has been made with the BLE transmitter nodes (Figure 3) or PVs very far apart, in order to transmit from very distant points, and located in very different environments (with more or less vegetation, hidden or with high visibility). In all cases, the BLE nodes have a direct line of sight to the sky. In these preliminary sessions, the entire AENTE was unused by others, so that there was no interference from other equipment or mobile obstacles for Cuadriga making the system testing easier. Moreover, the direction of movement of unmanned vehicles has been added. For the particular case of Cuadriga, certain black circles have been established indicating the time at which it detected a PV at a greater distance from it during its route. In addition, the end of every path has been marked (see Figure 3).

The execution of the exercise is as follows. A UAV is tele-operated performing three exploration flights (F1, F2 and F3) around the AENTE, carrying a BLE scanner. Throughout this area, four static locations have been established to place a set of five BLE transmitters, which emulate the PVs, and which have been identified with the labels BE, BF, BG and BH, as well as another commercial

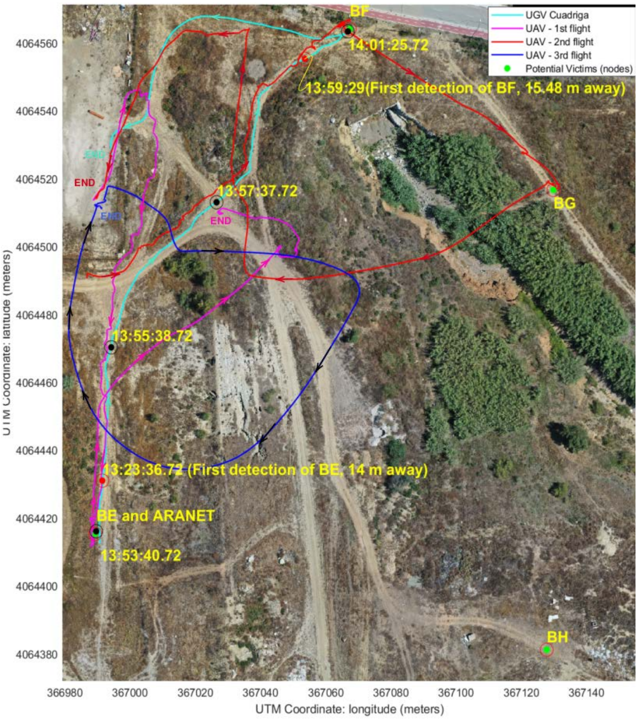

FIGURE 3. AENTE and paths for UAV and UGV (testing session).

BLE transmitter, identified by the name Aranet. This fifth BLE transmitter node was included since its transmission power was lower than the rest of transmitters, so it would add interesting information on detection of BLE devices of lesser transmission power. As it is seen, its position will be the same as the BE transmitter. In addition, Cuadriga followed an autonomous path towards two of the positions where the BLE nodes (BE and BG) were located. The first path autonomously followed ends at the location of the BE and Aranet BLE nodes. Once Cuadriga reaches the final waypoint of this first path, the UAV starts its first flight towards that position and remains static over the UGV (Figure 4) in order to record data on the SD connected to its ESP32 scanner. In this way, it is possible to compare the readings received from the UGV and from the UAV, both located at the same point, although at different heights, with respect to the position of the BLE nodes. The UAV was kept flying over the Cuadriga endpoint for a few seconds at an altitude of two meters.

Figure 3 shows the deployed BLE nodes and the routes followed by the UAV and the UGV, including their orientation and the end of their respective paths during the testing session (Figure 4). Figures 5 and 6 show the node detections by the Meshlium and the ESP32 scanners on board Cuadriga, respectively. Finally, in Figure 7, the results provided by the ESP32 scanner installed in the UAV are shown.

Figures 5, 6 and 7 show that the system has detected all possible victims (emulated by the five BLE transmitters used) except for the BH node, as the UAV does not fly close over its area, and the UGV does not approach it either. In fact, the F2 and F3 remain 120 m away from this node, flying at too high

FIGURE 4. UAV and UGV looking for potential victims (position of BLE nodes labeled BE and Aranet).

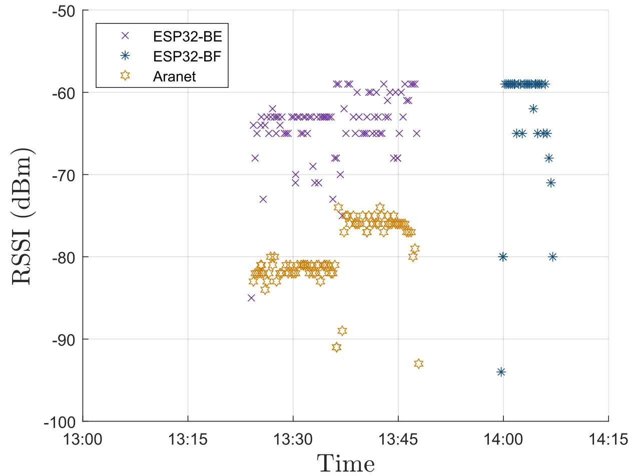

FIGURE 5. RSSI values obtained from the Meshlium scanner embarked on Cuadriga (testing session).

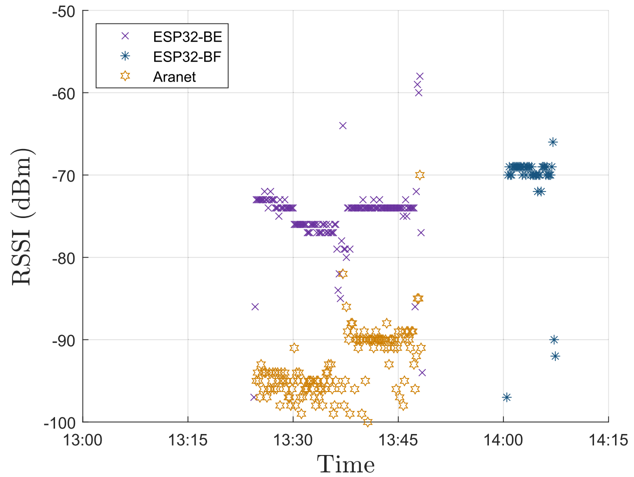

FIGURE 6. RSSI values obtained from the ESP32 scanner embarked on Cuadriga (testing session).

a speed. Therefore, slower flights and more complete sweeps of the area are required to serve all the PVs.

From the UGV perspective, both BE and BF BLE nodes were detected while traversing the path shown in Figure 3.

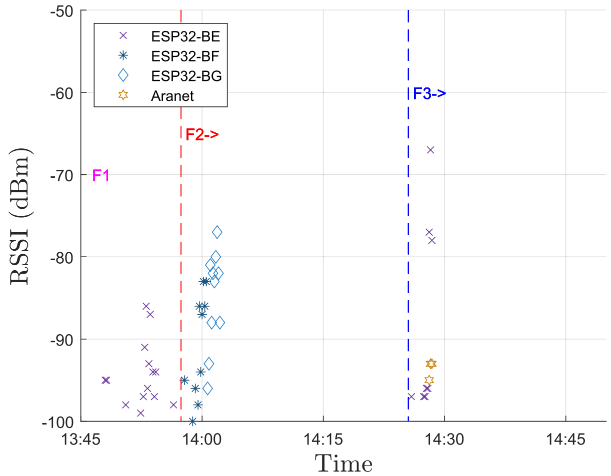

FIGURE 7. RSSI values obtained from the ESP32 scanner embarked on UAV (testing session).

FIGURE 8. Tunnel entrance with wrecked vehicles.

First it moved down towards the BE and Aranet BLE nodes, the first detection occurs at 13:23:36, 14 m away from the BLE nodes, then it reached the node, remained there for several minutes, and lastly it went up towards the BF node. The first detection of BF takes place at 13:59:29, from a distance of 15.48 m. After this, Cuadriga finished its path to reach the end point seen in Figure 3.

Focusing now on the UAV results, three flights were carried out, whose results are all chronologically represented in 7. During the first one, only the BE node was detected while it remained at its original position just before the UGV started its path towards BF. Following this flight, the second one started, reaching the locations of BF and BG. In this case the UAV remained in place for a while, hovering over the BLE nodes and lowering its altitude (hence the increment of the RSSI by several dBm). During the last flight (F3), as a final check, the BE and Aranet BLE nodes were moved to the take-off site, and they were detected.

This preliminary experiments led to the decision of only embarking the ESP32 scanner on the following experiments. This was due to the fact that the ESP32 scanner provided many more detections, although with a lower RSSI, while being more portable and more power efficient than the Meshlium.

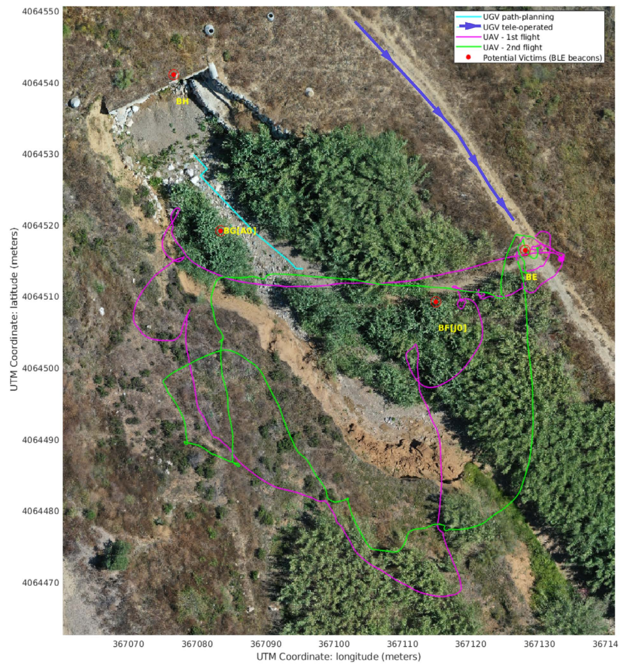

FIGURE 9. Paths for the UAV and UGV (CESD 2021).

FIGURE 10. Both flights' orientations and home positions according (DJI Flight Log Viewer).

TABLE 1. PV detections from the robotic platforms during both experimental workshops: the testing session (TS) and the CESD. Dash symbols indicate that BLE nodes were not used in the workshop.

Robotic platform and workshop		Victim detections for each BLE node							
		BD	BE	BF	BG	BH	A0	J0	Aranet
UGV (ESP32)	TS	-	140	42	0	0	-	-	136
	CESD	71	60	70	30	0	16	48	-
UGV (Meshlium)	TS	-	92	32	0	0	-	-	92
UAV (ESP32)	TS	-	23	11	10	0	-	-	3
	CESD	87	57	36	10	2	16	1	-

B. DEPLOYMENT OF THE SYSTEM DURING CESD2021

This realistic experiment was carried out with a different configuration, where the BLE nodes were placed in a more hidden area of operation susceptible to interference. The context was a fire with car wrecks and victims scattered in the area of a stream, covered by a lot of vegetation. The simulated disaster area was prepared at a tunnel entrance (Figure 8), in a depression of the ground where there is a gully, with negative altitude for the UAV flight, which always measures its altitude from the take-off site. The position

FIGURE 11. **UAV finding a victim (BE).**

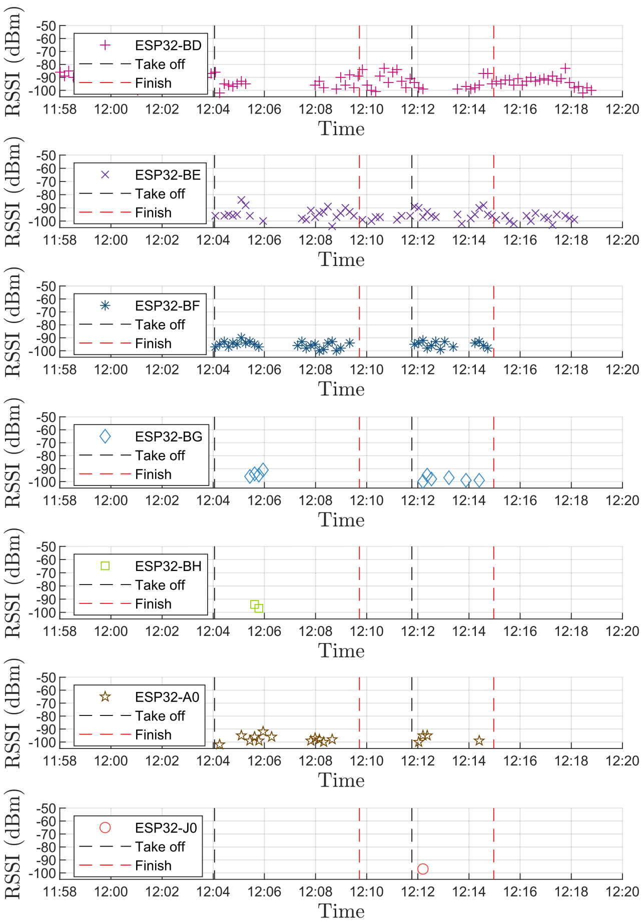

FIGURE 12. **RSSI values obtained from the ESP32 scanner embarked on the UAV (CESD 2021).**

of the BLE nodes that emulated the PVs can be seen in Figure 9. In addition, this figure shows the two exploration flights performed by the UAV carrying the BLE ESP32-based scanner, detailed in Figure 10, as well as the path followed by Cuadriga autonomously. It should be noted that the UGV was tele-operated to the PVs area, close to the tunnel, as the terrain

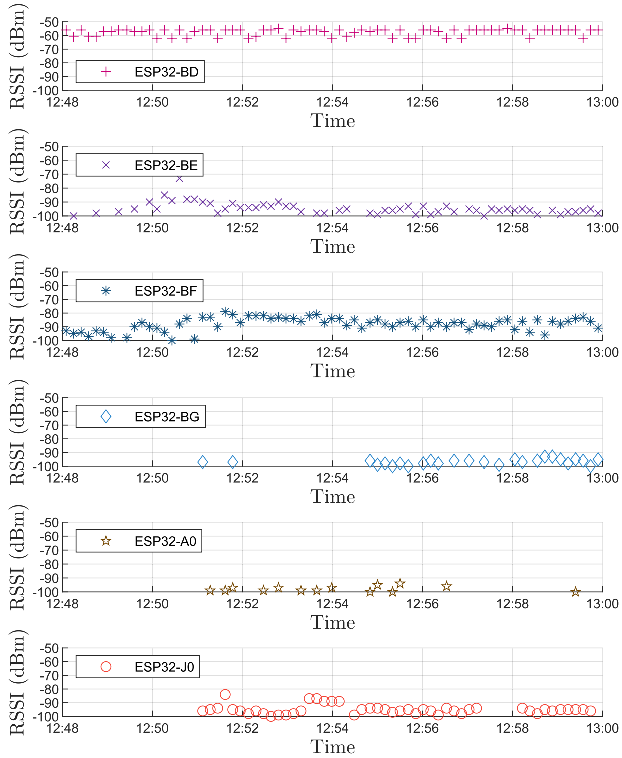

FIGURE 13. **RSSI values obtained from the ESP32 scanner embarked on Cuadriga (CESD 2021).**

was too full of vegetation to ensure the proper functioning of the planned movement. In the figure, only Cuadriga's descent to the area has been indicated, so as not to blur the image.

Figure 11 shows an instant of the exercise, in which the UAV locates with its camera one of the BLE nodes, and positions itself statically over it, recording measurements on the SD of its ESP32 scanner.

The execution of the exercise is as follows. A UAV is tele-operated performing two exploration flights (F1 and F2) around the operation area, carrying an ESP32 BLE scanner. The UAV has other tasks that are not part of this work (such as real-time tessellation or publishing images via ROS from an on-board smartphone via 5G). These two flights are used to detect PVs. Throughout this area, four static locations have been established to place a set of six BLE transmitters, which emulate the PVs, and which have been identified with the labels BE, BF, BG and BH (located inside the tunnel on a rubble pile), as well as two half-buried BLE nodes (A0 and J0). In addition, Cuadriga performed another path in a controlled area near the entrance of the tunnel to detect PVs in the area using the ESP32-based BLE scanner it packs. Since the Meshlium scanner did not provide sufficient robustness, detecting a smaller number of signals than the ESP32 scanner in the previous tests, it was decided to rely on this low-cost scanner, which is also the one carried by the UAV, for the detection of PVs.

A transmitter node (BD) was on-board Cuadriga in order to detect Cuadriga from the UAV. The results can be seen in Figures 12 and 13. In the former, the time of the UAV take-offs and landings have been marked.

Finally, Table 1 summarizes the PV detections in both experimental workshops.

V. CONCLUSION

This paper has presented the experimental results of the implementation and testing of a BLE detection system on a UGV and a UAV deployed at the AENTE of the University of Malaga, during the CESD 2021, in the context of a fire in which isolated victims had to be detected. The proposed system is intended to serve as a complement for locating potential victims, composed by BLE scanners and tested through a set of transmitter BLE nodes deployed around a wide and diverse area in order to emulate the PVs.

As can be seen in the results presented in Figures 12 and 13, and Table 1, all the devices were detected by the robots as they moved through the area, even those that were under the cover of dense dust, light debris or vegetation (nodes A0 and J0). Such nodes would not be visible from the aerial view of the area and may not be sufficiently conspicuous to promote the search by other more exhaustive methods. In fact, the UAV and UGV systems complement each other, the UGV can provide more detections in order to estimate the distance to the victim, while the UAV while the UAV allows faster preliminary terrain reconnaissance. This allows covering wider areas, being able to detect even the semi-buried devices as mentioned. It should be noticed that the BH node located inside the tunnel was only detected by the UAV (Figure 12), since its height improved the line of sight towards the device, thus demonstrating the complementary effect of a dual ground and airborne approach.

In addition, this system has the advantage over previous cases that it does not require the use of any specific application or hardware by the victim to carry out the detection, as the devices used are of general use and only require that the BLE versions of the scanners and devices are compatible and active, increasing the range of action in terms of detectable hardware spectrum.

However, the speed of the UAV must be adequate. Neither too high, since it would not have time to scan the BLE signal at the right time (given the periodicity of the scanning), nor too low, since UAVs still have a very limited battery, having to make landings and takeoffs to replace the batteries.

In conclusion, the effectiveness of the cooperative system consisting of a UAV and a UGV in detecting BLE nodes has been demonstrated, making it a search complement for SAR missions.

As future lines of development, an efficient way of filtering useful portable devices from irrelevant ones should be pursued. The goal of this would be to determine which devices have a high chance of being carried by a victim. Lastly, an improvement of the system to allow real-time BLE data collection and visualization taking advantage of the new characteristics of 5G, such as latency slice, should also be implemented to instantly provide this data to the rescue team. In this sense, the information from the BLE detections could be used to perform the path-planning and demarcate the areas of interest when a BLE device has been detected. In this paper, it has been presented a generic set up for this future implementation where the PV detections could help to move all the robotic agents autonomously.

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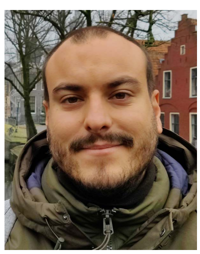

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