

A Novel Drone-based Search and Rescue System using Bluetooth Low Energy Technology

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Abstract-Drones are widely known for their mobility and ease of use and represent a significant technological breakthrough with various applications. In this paper, a novel inexpensive Search and Rescue (SAR)-based approach for application in indoor environments is presented. The usage of Bluetooth Low Energy (BLE) has been evaluated with respect to other technologies and a conceptual view of the complete setup has been presented. Besides the cost of the drone and the locator devices, the other hardware is relatively inexpensive costing only a fraction of a US dollar. The system is believed to cover a wide area in a small-time frame ranging a few minutes, for instance, a 3600m² surface area could be scanned in less than 5 minutes. The system is tested by attaching a BLE device in the payload to evaluate the presence of target beacons. Potential upgrades in the system are also proposed, including design modifications for outdoor use and the application in locating missing objects. This system can confidently replace search parties dealing with missing children in public places or venues, with minimal human interaction while bearing the potential for complete automation.

Keywords-BLE; wearable electronics; UAVs; localization

I. INTRODUCTION

During the last decade, the usage of Unmanned Aerial Vehicles (UAVs) has risen exponentially [1]. It is estimated that the global market share of multi-rotor drones is expected to reach \$36.9 billion by 2022 from \$6.8 billion in 2016 [2]. Drones are directly or indirectly used as an effective tool in agriculture, industrial maintenance, logistics, military, entertainment, and traffic control [3, 4]. In most of the aforementioned applications, drones have proven to be an effective replacement of the existing technologies, mainly in terms of cost maintenance, time, training, and automation. One of the most significant applications of UAVs lies in the domain of Search and Rescue (SAR)-based missions. Usually, such operations are performed in conventional matters, which are time consuming and costly [5]. For example, a successful 19-day rescue operation in July 2020 to locate two hikers lost in New Zealand cost the New Zealand authorities over 80k NZD (\$57.8k) [6]. Using an autonomous UAV would potentially cut the cost and time of a SAR operation by 70% in comparison with classic operations [7]. Typically, drone-based SAR operations are carried out manually by continuously monitoring live transmitted broadcast imagery through technologies, such

as the First-Person View (FPV). Some advances in the automation of the search process have been implemented which involve AI-based protocols to identify pre-trained objects or shapes, or face recognition. In confined places, such as events held at parks, theatres, or concerts, parents or guardians that lose their children usually seek the assistance of a dedicated lost child office to locate them. The proposed UAV system can potentially help in such cases or in similar cases regarding elder patients (e.g. patients with Alzheimer's or autism). The search process in these cases can often be costly and time consuming or may involve the risk of a child/patient leaving the dedicated event area [8].

This paper discusses a novel inexpensive approach of utilizing multirotor drones as a SAR tool whereby it scans passive pre-defined passive receivers. This device overcomes the characteristic challenges of events being held in large venues, allowing object/person finding applications. Potential future upgrades for transforming the system to form a completely autonomous decision support system tool for event management may even be possible. Moreover, these developments may be uploaded to upgrade the system for open space usage with certain limitations.

II. EXISTING TECHNOLOGY

There are various existing drone-based SAR applications and these attempts have been featured to be utilized in various types of technologies as described in the existing literature. Table I enlists some common technologies used in a typical SAR operation.

As shown in Table I, most of the technologies are focused on searching wireless radio activities emitted by target mobile phones. However, usually minors and individuals with special needs are not expected to carry mobile phones, therefore technology dependent on mobile phones may be difficult to implement in such cases. Other technologies achieve this task by different means which include live streaming footage, QR codes, or audio signals. Cellular network-based systems received enormous attention when it comes to SAR application due to the increased network coverage and enhanced communication capabilities, including the rapid expansion of 5G networks [16, 17].

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TABLE I. SELECTED EXISTING SAR DRONE-BASED APPLICATIONS

Product	Technology	Features	Drawbacks	Ref.
AltiGator	IR thermal imaging	Manual inspection of live footage.	Manual inspection requires additional human power, thermal cameras can be expensive.	[9]
Intelligent drone navigation for SAR operations	Computer vision	QR codes are used for indoor localization.	Uses GPS for localization, difficult to operate indoors	[10]
SARDO	Mobile network and IR cameras	Locates a mobile phone in 3 minutes in an open field.	Mobile network-based solution, requires a phone carried by the target	[11]
SLAM	3D map generation from stitching still images	Compares movement between two frames of the images.	Images are difficult to be evaluated in crowded environments	[12]
MOBNET	Mobile phones	Searches for mobile phones, signal of trapped people.	Mobile network-based solution, requires a phone carried by the target	[13]
GuideLoc	Wireless signals from mobile phones	Localization system uses target guiding technology based on region division.	Mobile network-based solution, requires a phone carried by the target	[14]
Audio-based SAR with a drone	Drone-embedded sound source localization	Estimates the Time Difference Of Arrival (TDOA) of sound waves in a microphone pair in addition to the angle of arrival.	Difficult to operate in crowded environments due to various sources of sound	[15]

The possibility of utilizing electronic ID tags, such as Bluetooth Low Energy (BLE) devices has been explored. We believe that featuring such inexpensive tags will make the task less complex and more achievable comparing to the methods proposed in Table I.

III. CONCEPT AND METHODOLOGY

The concept of the design is to re-design the drone payload in order to be able to carry the required electronics and means of communication for accurate identification of the ID tags. In order to design the system appropriately, various elements of the design have been investigated.

A. ID Tags

The ID tags are an important element of the process of development since they act as the primary point of communication. Tags should communicate with the host once close proximity is detected, and may be operated actively or passively. They should feature reliable operation, rapid response, inexpensive price tag, reasonable energy consumption, lightweight arrangement, and acceptable communication range. If the total weight of those tags is low, they can be manufactured as wearable electronics. The recent advances in the development of short to medium range wireless technologies provided multiple options for the UAV designed in this study. There are various communication protocols meeting the aforementioned criteria, which are enlisted in Table II [18, 19]. Referring to Table II, it can be seen that the BLE technology features have low cost, low weight, moderate communication range, and relatively low energy consumption. Conventional Bluetooth has stable connection, reasonable price, and moderate IPv6 communication energy overhead with a slow data transfer rate. As the name suggests, BLE is designed to optimize power consumption compared to the classic Bluetooth, while maintaining a similar protocol stack profile. Usually BLE devices are powered by a single coin battery that lasts up to two years. It was found that BLE consumes very little energy compared to competing low-energy communication technology, such as ZigBee [20]. It uses a 2.4GHz ISM Band with 2MHz channel spacing, and is governed by IEEE 802.11 and IEEE 802.15 standard protocols

[21]. The low energy operation of BLE is achieved by the potential trade off of the following features:

- Communication channels: Instead of using multiple channels for discovery or connections, only 3 broadcasting channels would be used.
- Memory: Only a few bytes are featured with BLE, while additional memory would require additional hardware, increasing the chances of current leakage.
- Data packets: BLE sends shorter data packets which results in fewer calibration iterations drawing less leakage current.
- Sleep time: Classic Bluetooth takes over 100ms for waking from sleep, transmitting a data packet, and then going to sleep mode, while BLE performs this process 15 times faster. This will reduce scanning time for BLE saving more battery, especially if small data segments are broadcast.

TABLE II. EXISTING SAR DRONE-BASED TECHNOLOGIES

Technology	Cost	Weight	Range	Energy consumption
Radio Frequency Identification (RFID)	Very low	Low	Read range of 100m, unidirectional	Passive
Near Field Communication (NFC)	Very low	Low	10cm, bidirectional	Very low or passive
Bluetooth	Medium	Low	100m (class dependent), bidirectional	Medium (class dependent)
BLE	Low	Low	10-50m, bidirectional	Very low
Wifi	High	High	100m	High
ZigBee	Moderate	Low	10-20m	Low

BLE operates in star network topology where the nodes can be configured as slaves connected to a single master, or a master connected to multiple slaves. The master scans the designated channels to search for slave devices. Once a device is discovered, synchronous connection is established between them resulting in the change of state of activity mode from 'sleep' to 'wake up'. Another option would be to set the slave devices to sleep mode by default to save energy [22].

B. Data Transmission and Positioning

Data are transmitted in BLE using two service profiles, namely Find Me Profile (FMP) and Proximity Profile (PXP), which take into consideration the slave/master (target/locator) positions. As the name suggests, FMP makes the localization of devices a significantly straightforward process. The target seeks the search command broadcast by the locator. Once the message is delivered, the target device is triggered, usually in the form of an audio signal or other alert mechanisms. On the other hand, PXP detects any drop in the connection with the target or initiates a connection with a different locator. This profile is effective only if a connection is initiated. Other available protocols found in the domain of consumer-based electronics include the iBeacon which operates between pre-programmed manufacturer's devices.

In terms of internal hardware arrangements in BLE devices, one point to consider is the directionality of their chip antennas, which are characterized by non-isotropic radiation. This is significantly challenging to mitigate due to the size of the additional antenna. There are various fundamental concepts when considering the positioning of BLE devices. The simplest approach of positioning is determining if both the target and the locator are within the radio coverage range, while providing a binary decision about their presence within that range [23]. In order to determine the distance between devices in free space, the following equation that relates distance (d) and the Received Signal Strength Indicator (RSSI) was utilized.

$$d = 20(\text{RSSI} + \alpha) \quad (1)$$

where α is an offset based on the maximum RSSI of the locator. The equation could also be used to determine the lateration based on multiple locators. Unlike outdoors, the indoor environment usually exhibits multipath effect due to the presence of obstacles that may vary in form and arrangement. This significantly worsens the approximation taken into consideration in (1). However, the utilization of the Time-of-Flight (ToF) approach has proven to produce more accurate results in indoor locations. Unfortunately, ToF estimation requires additional electronics (e.g. oscillators) which increase power consumption and cost. It is also important to note that since the locator is fixed in a moving station (i.e. drone), the angulation process may be ignored. In the same context, it is highly challenging to utilize fingerprinting which identifies the pre-recorded target RSSI values of both the target and locator, since they tend to exhibit continuous change in their locations.

C. Locator Movement and Beacon Analysis

One of the most challenging issues when attempting to locate the target in indoor environments is the multipath propagation effect. This issue can worsen if several devices are available in a confined space and moving objects are present. Usually, no accurate RSSI model in case of indoor environments is available and a rather simplistic way of estimation involves the use of ToF values. Therefore, a worst-case scenario should be taken into consideration when planning such a system. In some commercial applications, such as the iBeacon, it is recommended that the advertising signal intervals should be set below 100ms, when the tag is operated by a coin cell battery for maximizing the battery life to a few months. In

addition, when the intervals are set just below 1000ms the battery may last up to 3 years [23].

BLE devices continuously broadcast their data packets with a unique identifier known as the Universally Unique Identifier (UUID). This UUID acts as a network MAC address for the manufactured chipset and consists of 128-bits, with a 48-bit mandatory advertiser address. For BLE target finder, an open-source program, Raspberry Pi 3 BLE sniffer was used [24]. This code allows the detection of various compatible devices from different manufacturers, with all data being analyzed in a dedicated dashboard. While initiating the software, a signal search interval of 200ms was set. The advertising signal interval was set to 500ms, so that the target could operate confidently using a coin cell battery for one full year. In Figure 1, we see the Raspberry Pi (locator) attached to a drone payload for locating advertising channels.

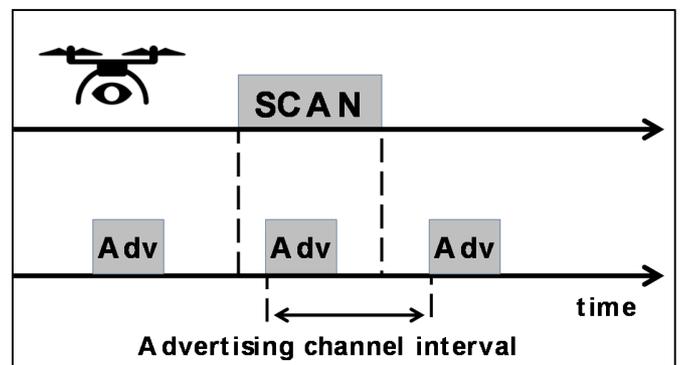


Fig. 1. Basic arrangement of target localization with scan and synchronization with the advertising beacons.

IV. EXPERIMENTAL SETUP AND ROUTE PLANNER

For route estimation purposes, the maximum Bluetooth coverage radius was assumed to be 10m. To ensure that all targets in the designated search zone are discoverable and that their discoverability is enhanced, the detection range was reduced to 5m. Moreover, the drone should fly in intervals whereby the movement was paused for 1000ms for each 5m flown. This interval of inactivity ensures that the locator exhibited at least 4 iterations of advertising signals broadcast by the target. For doubling the chances of discovery, each drone's vertical/horizontal straight parallel route should have a separation of <5m. Raw experimental data are shown in Table III.

TABLE III. RAW EXPERIMENTAL DATA

AGL	Flight duration		Wind speed
	Route length	Stop mode	
5m	Vertical movement: 12×55m = 660m Horizontal lines: 11×5m = 55m Total route: 715m	1000ms every 5m flown	0m/s (indoor)

For demonstration purposes, the exhibition hall Dhahran Expo, located in Dhahran, Saudi Arabia and covering a surface

area of 3600m^2 ($60\text{m}\times 60\text{m}$), was chosen [25]. To estimate the planned route, an open-source code named Reinforcement Learning for Autonomous navigation for UAVs [26] was used. This code was designed to implement reinforcement learning algorithms for autonomous navigation of drones in indoor environments. Figure 2 shows the exhibition hall and the planned route using predefined hall edges. The total horizontal route of the drone was $60\text{m}\times 12\text{m}=720\text{m}^2$, with an additional $5\text{m}\times 11\text{m}=55\text{m}^2$ surface area of horizontal connecting lines, which makes the total route approximately around 775m^2 . Considering the average speed of the drone to be 6.7ms^{-1} (15mph), the total area can be covered in around 115s, with an additional 1s per 5m taken into consideration. It would take a total of 227s to completely evaluate the whole area of 3600m^2 .

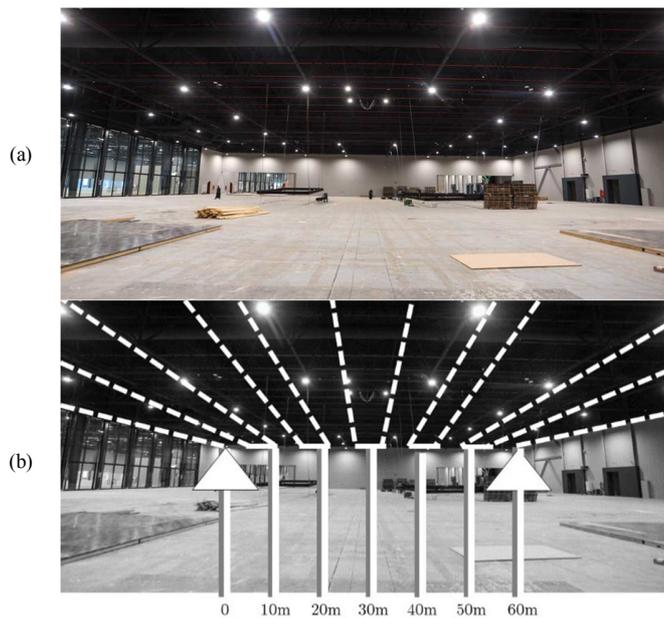


Fig. 2. (a) A raw image of hall #3 in Dhahran Expo, Dhahran, Saudi Arabia. (b) Raw image processed using planned routing with the aid of open-source code named Reinforcement Learning for Autonomous navigation for UAVs. The triangle on the left-hand side demonstrates the drone's starting point, while the triangle on the right is suggestive of the end point of the flight. The dashed lines demonstrate the main path of vertical movement, and the solid lines represent the path of the horizontal flight.

A. Accuracy and Operationality

In order to ensure the maximum accuracy of the system, repeated movements may be performed. Once the target is located, the movement of the drone is locked around this area, while it continuously performs search operations in its proximity. If the connection drops, the drone should potentially move in a spiral path to reconnect with the target. The RSSI value could be taken into consideration when determining the static positioning of the drone. The proposed model was validated by using a BLE device as a target moving backward and forward from the host. The signal loss was evaluated to ensure scan signal being continuously broadcast within the expected Bluetooth range.

B. Potential Applications

The technological development reported in this study may be used in applications involved in locating objects or persons in halls or exhibitions. This development is easy to implement, since the BLE target devices require inexpensive hardware. BLE devices could come in different forms, such as wristbands, keychains, tags, pins, each costing less than one US dollar. Therefore, the tool shows promising potential for commercialization. One potential upgrade of this application would be its outdoors potential use. In that case, uploading a suggested route plan with details of streets or landmarks may be pertinent. A swarm drone technology may be applied to cover a wider area.

V. CONCLUSIONS

A BLE-based SAR system with indoor applications was proposed which potentially could be applied to locate lost individuals. The proposed BLE-based, cell-battery powered device has a year-long operational durability, and bears relatively inexpensive electronic tags in convenient packaging such as a wristband or a keychain. The drone is able to scan an indoor area of 3600m^2 with high accuracy in just below 5 minutes. This time can be further minimized with tradeoff with battery lifetime. This system can be used for additional purposes such as event management and enhanced localization capability based on beacons from target or high-density spots based on attendees' mobile signals. Dedicated AI-based software was utilized in order to estimate the UAV route. This system could be upgraded for outdoor operations using swarm technology.

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