Unmanned Aerial Vehicle Search and Rescue: Augmentation with Crowdsourced Imagery and Radio Frequency Technologies

April 22, 2016

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Abstract—Unmanned Aerial Vehicle (UAV) Augmentation of AMBER Alert searches is evaluated for two possible capabilities. The first experiment evaluates the efficacy of providing Full Motion Video (FMV) from a UAV to a crowd via a streaming website and the second checks the capability of a UAV to connect to the missing device via RF. There are two distinct problems: 1. Can a UAV provide FMV of sufficient resolution to enable a group of volunteers to detect and identify a unique individual from streaming video? 2. Can a UAV connect to a device with missing victim using Radio Frequency (RF) technology? This project is aimed at providing a solution to these problems, and building a strong foundation for future developments. The paper illustrates successful implementation of the project in providing real-time video for crowd-sourcing and near-accurate location tracking of a remote device for the chosen use cases. The results obtained from this project indicate considerable potential for the use of these technologies in search and rescue operations such as AMBER Alerts.

Keywords—UAV, AMBER Alert, FMV, Wi-Fi, XBee, Edison

I. PROBLEM OVERVIEW SETTING

America’s Missing: Broadcast Emergency Alert (AMBER) system, named after AMBER Hagerman, and originally deployed in Texas, is a cooperative effort between law enforcement, telecommunications providers, and citizens aimed at helping recover children and missing persons [1]. While credited with hundreds of “successful recoveries”, multiple studies indicate the effectiveness and correlation to successful recoveries depend more on the intent of the abductor rather than the use of the AMBER Alert system for assistance and recovery. Regardless of a positive correlation between successful recoveries and use of the AMBER Alert, this project evaluates the possibility of using two additional platforms on an Unmanned Aerial Vehicle (UAV) to help augment search and rescue operations in the critical time-sensitive search for AMBER Alert victims.

This research is unique in using localized crowd-sourced full motion video (FMV) analysis to aid in AMBER Alert recoveries. This research would also, apparently, be the first attempt to study Wi-Fi/ZigBee technologies as a means of remote tracking and location of children or adults. There are two components: can a UAV effectively provide FMV to crowd sourced “analysts” to help aid in AMBER alert recoveries? Can a UAV simultaneously detect the missing device with the help of Wi-Fi/ZigBee technology?

If UAV augmented AMBER Alert search and rescue operations using crowd-sourced FMV is effective for tipping and locating a person or vehicle in the open, it could be a significant tool in future AMBER Alert search operations. If the use of Wi-Fi/ZigBee technologies for detection of a missing victim is effective, the same technology can be used at many more complex rescue operations.

Research indicates that there is a “golden hour” during which missing children can be recovered alive. In that research Hanfland, Keppel and Weis discovered that “91% of victims abducted were dead within 24hrs” [1]. Their analysis indicated that 74% were dead within three hours, which helps narrow a critical timeframe for a search to within 3 hours. While this data indicates there is a positive correlation to the timeliness of recovery and outcome, other research indicates the primary dependent variable for successful recovery is actually the motive of the abductor [2]. Not surprisingly, the identity and

AMBER Alert - UAV 1
familial relationship of the abductor also had a positive correlation to outcome in an AMBER Alert abductions.

It is assumed that the optimal time, during which a search and recovery system can aid in the search effort will be 3 hours from the last reported sighting. It is also assumed that the optimal outcome in child recovery cases is the rapid recovery of the victim, as the motivation of the abductor and other factors are independent of search efforts regardless of platforms and technology used. In addition to time constraints, research described in the Department of Justice (DOJ) AMBER Alert best practices indicates a strong relationship between the victim’s last known location and the site of initial kidnapping, which indicates access to the last known location and mobility are desirable characteristics for an effective search technology.

This project tries to combine a UAV with FMV and Wi-Fi technologies to aid the AMBER Alert system. We aim to assist the AMBER Alert system in finding or locating the victim within the first three hours.

II. RESEARCH QUESTION

Research Question: Can a UAV coupled with FMV and Wi-Fi/ZigBee technologies help to identify and rescue AMBER Alert victims?

A. Sub-Problem 1: Can video imagery be distributed from a UAV at sufficient resolution for detection of a suspect, victim, and/or vehicle through crowd-sourced analysis?

First, can off-the-shelf video from a UAV be captured on a UAV and distributed to the ground? The objective is to identify the missing victim as soon as possible. Therefore, the received video should have enough resolution to identify objects present in the video.

Second, we need to select a suitable platform for the distribution of UAV video. To link the AMBER alerts with the video received, we need a medium like a website where we can distribute the video to public. The public can then go to this website, select an appropriate AMBER Alert, and get the relevant video.

B. Sub-Problem 2: Can a UAV or mobile “search” vehicle connect via RF to a “missing” device, receive data and locate the missing device?

First, what data can be sent/beaconed from the “missing” device? When the UAV connects to the missing device, the data stored in that device points to the locations the device has been through. So, the missing device should be able to store the Wi-Fi Basic Service Set Identification (BSSID) addresses.

Second, can there be a suitable connection range for the 802.11 Wi-Fi link between the “missing” device and the “search” device? For the AMBER alert search and rescue scenario, the range required to demonstrate the feasibility of Wi-Fi is assumed to be 100m using a 5dBi antenna on the search device and a chip-based antenna on the missing device. If a search device passes within 100m of the missing device, the missing device will connect to the known network and transfer the detected BSSIDs. However, for this to be a feasible solution, several search devices would have to be employed to cover a search area. Wi-Fi signal propagation is unfavorably affected by line-of-sight obstructions such as walls or windows, with some building materials drastically reducing line of sight range. Testing of this problem will be focused on demonstrating field-tested range instead of studying or optimizing the range because it is apparent that Wi-Fi is not the optimum solution for the RF link between the search and missing devices.

Third, if the Wi-Fi range is a limiting factor, then what other power conservative technology can be used to form the link between the search and missing device?

Fourth, can the entire system be made mobile? Can the system be small enough that the missing device is obscured in clothing?

III. LITERATURE REVIEW

A. Flight Considerations

Operating a UAV will require careful deconfliction with a myriad of local and federal regulations. Public use UAVs are governed by a dual set of rules (at the time of writing) that restrict the use of UAV systems. House Resolution 658-62 establishes the guidelines for UAV use and mandates further Federal Aviation Administration (FAA) regulation, which has not yet occurred [4]. In order to avoid FAA approved “type certification” of our UAV, flight testing was conducted under the provisions of a model aircraft. Using model aircraft provisions, we were restricted to operating a registered recreational UAV with a gross weight of 24.9 kg (55lbs) and we would need to operate outside of 9.26 km (5 nautical miles) from a controlled airport. Encroachment into the tower controlled airspace class E or above could be possible with prior coordination with the owner of a control tower [4].

Operations for testing under the recreational provisions are significantly more user-friendly than Public Aircraft Operations (PAO) under which some state entities and universities can operate. PAO aircraft are limited to 2 kg (4.4lbs) or less and would generally allow for faster type certification if the aircraft exceeded 2 kg, as states can apply for this type of expedited clarification [5].

After determining a legal and safe flying altitude, it would be possible to employ a number of search algorithms to cover the terrain. There are currently search mechanisms, which enable visualization of what UAV cameras can “see” as described in research published at the 2010 International Conference on Human-Robot Interaction [6].
B. Full Motion Video

A UAV augmented with an FMV camera is used to stream real-time video to a website, it would offload significant workload from high demand assets and possibly allow for more simultaneous (timely) analysis of aerial imagery and submission of helpful tips by the public, that is, public tipping. Commercial off-the-shelf (COTS) technology providing High-Definition (HD) video for identification of people wearing certain clothing and vehicles is available in the market.

In military operations, Intelligence, Surveillance, and Reconnaissance (ISR) features are being employed into airborne vehicles as a support for warfare in urban areas [7]. It is relatively difficult to achieve visual clarity for Full Motion Videos in urban areas. Rural abductions or children missing in the wilderness could benefit from aerial detection using autonomous infrared person detection, even from lower resolution imagery; however, that technology appears unsuited for direct application in urban searches [7]. A method of using HD FMV Electro-optical/Infrared (EO/IR) sensors in avionics system architectures has been proposed in [7]. It proposes a solution that increases a warfighter’s ability in recognizing objects and their smaller details using COTS technology.

The National Geospatial-Intelligence Agency (NGA) has provided engineers and systems architects with the Motion Imagery Standards Board (MISB) as guidelines to achieve best visual clarity from integrating HD FMV sensors into avionics systems [8]. MISB provides a set of guidelines to avionic system architects to handle compression, various file formats, or signal formats, compression and decompression techniques [8]. Video compression may be necessary due to bandwidth limitations that arise while uploading the HD FMV to a website. The resultant compression cannot reduce resolution below the threshold necessary for detection of vehicles and persons by the crowd/end-user. The above solution must be tested for effective motion imagery analysis that yields unique keywords for public tipping.

A unique clothing and vehicle identifier should be provided to volunteers to determine if they can detect a person or vehicle in the streaming video. Video National Imagery Interpretability Rating Scale (Video NIIRS) rates the airborne motion imagery for visual quality. Quality refers to the interpretability and intelligence value of the recorded video [8]. The Video-NIIRS compares and analyzes the differences in resolution, sampling rate (frame-rate), scene complexity, and human activity or behavior [8]. Motion Imagery provides techniques to perform analysis on the video when a specific object of interest is defined. The object is identified based on its morphology. Based on factors such as frame rate and sampling rate, the motion imagery can identify a certain type of movement or track the object. This method uses a continuous stream of images to analyze the behavior of the object and predict the next action. These techniques are employed by military, air, naval forces and security for motion imagery analysis [8] for help in wars. The application of Video-NIIRS for crowdsourcing appears to be understudied.

Geo-referencing systems were demonstrated in military applications for reorganizing data files [9]. These systems add a footprint of the geographic location along with time stamps to later view as single frames or as group frames based on their geo-reference or time-stamps [9]. Geo-reference on the video feed would be primary and the most accurate way to correlate tips for AMBER alert searches when FMV is crowdsourced.

Lockheed Martin, Harris Broadcast Communications, and NetApp have jointly developed a fully integrated FMV architecture [10]. The architecture provides a solution that performs immediate processing, exploitation and dissemination (PED) to securely store FMVs for later archiving and performing analysis by tools. The system can tag videos with keywords or graphics [10]. It allows the user to have automated alerts set up that send notifications in case any new relevant content is uploaded. The system has a technique to overcome bandwidth problems while transmitting videos. The FMV video system can manage and process multiple videos simultaneously with the help of secure storage solutions. It can perform analysis for a particular time frame while comparing multiple videos recorded by different sensors.

These COTS FMV systems, when incorporated with an unmanned aerial vehicle may be directly applicable to the research question being evaluated in this project. FMV can be used to analyze the content intelligently for possible tips on the geographic location and traits of the abductor.

C. Wi-Fi Technology

Tracking user location using Raspberry Pi and Wi-Fi technology was analyzed in a research on Wi-FiPi [11] to track people at mass events. Wi-FiPi scans the packets sent out by user’s mobile at multiple locations. This method enables tracking thousands of people simultaneously at a concert or mass event. The devices of each user are identified by the Media Access Control (MAC) address of the device’s Wi-Fi interface. AMBER Alert rescue operations implemented by this project uses a similar research idea of augmenting Raspberry Pi device with Wi-Fi technology for victim tracking.

Raspberry Pi’s small size, lower power requirements, and greater range make it more effective than other systems evaluated for testing purpose. Raspberry Pi can be used as a Wireless Sensor Node for monitoring and tracking systems [12]. Raspberry Pi acts as a small independent computer capable of running Linux operating system. The device is also cheap, and programmable for custom requirements. Raspberry Pi and Intel Edison were used in a research that involved processing images captured by UAV [13]. In “Wi-Fi GPS based Combined positioning Algorithm”, the authors proposed a positioning system that combines GPS and Wi-Fi system to calculate the location of a person [14]. The paper discussed an
algorithm to find the accurate location of a person using Signal Strength measurements of Wi-Fi and at least four GPS solutions obtained from satellites. The algorithm achieved a positioning accuracy of 100 meters with two satellites and two Access Points. The algorithm achieved a position accuracy of 5 meters with four or more satellites.

The project is not novel in the concept of combining Raspberry Pi with Intel Edison for geolocation tracking. However, the research idea to help recover AMBER Alert victims within the critical time frame by combining UAV, FMV and RF technologies is novelty of the project.

IV. COMPONENTS AND METHODOLOGY

A. Sub-Problem 1: Can video imagery be distributed from a UAV at sufficient resolution for detection of a suspect, victim, and/or vehicle through crowd-sourced analysis?

Many suitable camera options were researched to record the video from the UAV. The choices of the camera were narrowed down to a Sony 700TVL and a Go Pro Hero 2 due to the size of the platform and the ease of integration with the platform. The specifications of both the cameras are given below in Table 1 and Table 2. Flight testing was performed with a quadcopter UAV, an ImmersionRC vortex 285, for each camera in consideration. A survey was conducted in which the recorded videos were shown to participants and their opinion was asked for the quality of the video. The video quality was also tested by asking the participants if they could identify the objects and people in the video.

Test 1: Sony 700TVL
The Sony 700TVL camera was lightweight and was a stock camera on the drone used for testing. The video was being transmitted using a 5.8 GHz transmitter on the drone to a pair of goggles, the feed from which was being transmitted and recorded on a laptop. The streamed or transmitted video had a lag of less than one second, which was acceptable as per the project requirements.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sony 700TVL Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Viewing Angle</td>
<td>101.8° to 27.4°</td>
</tr>
<tr>
<td>Resolution</td>
<td>800 x 640</td>
</tr>
<tr>
<td>Weight</td>
<td>119 Grams</td>
</tr>
<tr>
<td>Dimensions</td>
<td>3 x 3 x 3 Inches</td>
</tr>
</tbody>
</table>

Table 1: Sony 700TVL Specifications

Test 2: Go Pro Hero 2
The Go Pro Hero 2 camera was slightly heavier and larger in dimensions than the Sony camera, but was acceptable for the purpose of the project, as it could be mounted on the drone used for testing. It was stable on the drone and transmission was seamless. The maximum altitude attained during the flight was 397 feet. The method of transmitting video was similar to the Test 1 setup. Rewiring of the cables on the drone was required for connecting the Go Pro to the onboard video transmitter.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Go Pro Hero 2 Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Viewing Angle</td>
<td>170° to 90°</td>
</tr>
<tr>
<td>Resolution</td>
<td>11 MP (720p)</td>
</tr>
<tr>
<td>Weight</td>
<td>189 Grams</td>
</tr>
<tr>
<td>Dimensions</td>
<td>3.8 x 2.2 x 2 Inches</td>
</tr>
</tbody>
</table>

Table 2: Go Pro Hero 2

For the distribution of video on a public platform, a website was developed. This website was hosted on the campus network for demonstration purposes. The features of the website included details of the AMBER alert, location tracking on Google maps and crowd-sourcing video feed. The website had its own MySQL database on a Red Hat Linux server using a 64-bit Fedora Linux as OS. The website code was primarily built using PHP and HTML5, and it was developed to have a structured layered security model. The layout of the website is discussed further in the next section.

B. Sub-Problem 2: Can a UAV or mobile “search” vehicle connect via RF to a “missing” device, receive data and locate the missing device?

Initially, this project intended to evaluate RFID technology for the geolocation component of the problem. The objective was to locate the missing device by moving a search vehicle such as a UAV to optimize the Received Signal Strength Indicator (RSSI) from a “missing” RFID device.
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geolocation

geolocation

from the perspective that only

one search device with only one antenna

was needed.

The missing device collected BSSIDs and relayed them when a

connection to a search device was established. This allowed the

missing device to keep a log of BSSIDs, which, when queried

by the search device, provided a track log of the previous

locations of the missing device. Upon connection with the

“search” vehicle, the stored BSSIDs were transferred from the

missing device to the search device. The search device then

queried the Google Maps Geolocation Application Program

Interface (API), which returned latitude and longitude

information stored for the detected BSSIDs. In the event the

missing device was separated from the missing person, this

track log could be valuable in determining travel direction and

time correlating previous positions.

Additionally, selection of Wi-Fi positioning would allow for a

second use case whereby the missing device could connect to

known Wi-Fi networks and upload the detected BSSID log to a

server or email the log to an account. This second use case has

the added benefit of being more autonomous in that it

eliminates the need for a search device; however, this type of

technology would be essentially “always on” and could be

suitably replaced by a mobile 4G system or GPS, which would

not be a novel application of technology. Consequently, this

project focused on the first use case where the missing device

sends data to a remote search device, which can then geolocate

the missing device.

This project attempts to demonstrate a connection between the

search and missing device via 802.11. This was accomplished

by hosting a Wi-Fi hotspot on the search device and

programming the missing device to connect to the known

search device network when within range. The link had to work

in both line of sight, and when obscured by vehicles and

buildings. Further, the connection had to be established and

sufficiently fast for file transfer from the missing device to the

search device before movement of either resulted in link

termination.

Other techniques considered include triangulating the missing

device via Time Difference of Arrival (TDOA) or Frequency

Difference of Arrival (FDOA). These techniques could still be

applied to the modified problem statement using 802.11 or

802.15.4. However, if the missing device can detect 802.11

signals and receive BSSIDs, geolocation from a single search

device is possible. Wi-Fi Positioning is thus preferable to RFID

tag TDOA or FDOA geolocation from the perspective that only

one search device with only one antenna

was needed.

Table 3: Test Scenarios

<table>
<thead>
<tr>
<th>Device Name</th>
<th>Series</th>
<th>Range</th>
<th>Frequency</th>
<th>Tx Power</th>
<th>Power Consumption</th>
<th>Protocol</th>
<th>Data Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>XBee 1mW Chip Antenna</td>
<td>1</td>
<td>300 ft</td>
<td>2.4 GHz</td>
<td>1 mW</td>
<td>50mA @ 3.3v</td>
<td>802.15.4</td>
<td>250 kbps</td>
</tr>
<tr>
<td>XBee Pro 63mW Wire Antenna</td>
<td>28</td>
<td>1 mile</td>
<td>2.4 GHz</td>
<td>63 mW</td>
<td>295mA @ 3.3v</td>
<td>ZigBee Mesh</td>
<td>250 kbps</td>
</tr>
<tr>
<td>XBee Pro 60mW Wire Antenna</td>
<td>1</td>
<td>1 mile</td>
<td>2.4 GHz</td>
<td>60mW</td>
<td>215mA @ 3.3v</td>
<td>802.15.4</td>
<td>250 kbps</td>
</tr>
<tr>
<td>XBee Pro 900 U.Fl (900 MHz)</td>
<td>1</td>
<td>6 miles</td>
<td>900 MHz</td>
<td>50mW</td>
<td>210mA @ 3.3v</td>
<td>Multi-Point</td>
<td>156 kbps</td>
</tr>
<tr>
<td>XBee Pro 900 XSC Wire</td>
<td>38</td>
<td>28 miles</td>
<td>900 MHz</td>
<td>250mW</td>
<td>215mA @ 3.3v</td>
<td>Multi-Point</td>
<td>10 kbps</td>
</tr>
</tbody>
</table>

Tabel 4. XBee Characteristics

Factors such as lack of access to a UAV better than the one used

for flight testing, and a pilot to fly that UAV forced the project
to evaluate the scenarios indicated above. However, results

from placing a small form factor search device on a UAV are

expected to be better than surface search due to line-of-sight

improvements and lack of surface/other vehicle interference.

Preliminary research indicated Wi-Fi range would be

insufficient for a search device to missing device pairing

without deploying several search devices. The problem

does not become as complex as the geographic area for search

increases. So, the use of XBees was evaluated to complete the link

between the search and missing devices. XBee technology is

standardized, so, demonstration of the technique on the cost

effective 2.4 GHz XBee should directly scale to the longer

range yet more expensive 900 MHz models. While the 900

MHz XBee models were not evaluated in this project,

compensating for the increased transmission power

requirements would necessitate providing a larger capacity

power source than our demonstration model. Multiple versions

of the XBee were sufficient to fulfill the search-missing device

link as indicated in Table 4. Each device can connect through a

standard set of pins, leads, or third-party devices to a small

computing platform like the Intel Edison.

V. VIDEO TESTING AND WEBSITE

A. Video Testing:

The flight testing videos from both the cameras were shown to

the participants in the survey that was conducted. For the Sony

700TVL camera, the video was reviewed by a total of five

individuals chosen to represent a random crowd with varied

intellectual capabilities, and all of them reached a consensus

that the video was poor or low quality. The snapshot of the

flight testing is shown in Figure 1. Further, they were asked if

any objects of interest (suspect car, vicinity, houses, and

people) were identifiable; a majority agreed that only large

structures such as roads or houses could be identified. In
For the Go Pro Hero 2 test, the participants viewed the video and agreed that the video from Go Pro Hero 2 was better in quality than the video from Sony TVL 700 and four participants out of five said it was high-resolution video. When asked to elaborate on what they meant by high quality in the subsequent question, they reached a consensus that they could identify smaller objects of interest such as cars and certain people, in addition to the houses and other structures from the Sony test video. The snapshot of the flight testing is shown in Figure 2. The survey results are shown as a chart in Figure 3.

In conclusion, this video can be used for testing without an imminent need to switch to a higher quality camera. However, video quality for these off-the-shelf devices is sufficient only for detecting the presence of a person and not distinguishing between individuals. In the event of an actual, AMBER Alert this quality of video would likely only be sufficient for situational awareness instead of identifying a victim in the open and urban environment.
The login page is exclusive for the administrators of the website. This page allows the admin to add and update details on the database. The admin account is secured by a login username and password. The password has been saved to the database table after strong hashing. This helps in securing the website from unauthorized users. Figure 6 shows a snapshot of the admin page.

The website also has information security layers implemented on it. The website uses Secure Socket Layer (SSL) encryption for more secure data transfers. The website code prevents simple cross-site scripting attacks and SQL injection.

VI. GEOLOCATION RESULTS

Several combinations of equipment was considered for the Wi-Fi positioning service aspect of the project. Initially, Eye-fi Secure Digital cards were considered as they are both lightweight, concealable and theoretically could be made to report collected BSSIDs through firmware modification. Combinations of the Arduino boards, breakout boards, and shields, as well as several SparkFun devices was also considered to be used for implementation.

A. Initial Setup – Iteration 1:

Search Device: Raspberry Pi;
Missing Device: Raspberry Pi;
Data Transfer: Wi-Fi

Two Raspberry Pi were setup with Raspbian OS and were configured to act as either the search device or the missing device. The Raspberry Pi acting as the search device (search-pi) was configured to act as a Wi-Fi Hotspot, hosting its own access point - “AmberAerial” and a DHCP server to lease out IPs to the Raspberry Pi acting as the missing device (missing-pi). This configuration was implemented by installing 'hostapd' and the ‘isc-dhcp-server’ packages as explained on Adafruit and Dave Conroy’s tutorials [16][17][18]. A Python script was implemented on the missing-pi to collect BSSIDs, store them and transfer that data to the search-pi over the hotspot created by the search-pi – “AmberAerial”. The search-pi was running a python script to parse the data received and then query the data against Google Geolocation Database to find the latitude and longitude coordinates and also a reverse geocode/look-up, which provided the address corresponding to the returned coordinates.

B. Results - Iteration 2:

Search Device: Raspberry Pi;
Missing Device: Intel Edison;
Data Transfer: Wi-Fi

The Edison was chosen for size, battery life, cost and flexibility of Linux operating system.

The Edison’s in-built Yocto Linux operating system was replaced with a Debian variant ‘ubilinux’ to improve the compatibility with the script that was created in Python on a Raspberry Pi in the Iteration 1.

The Edison was designated as the missing device and the Raspberry Pi was designated as the search device. The Raspberry Pi with associated battery pack was sufficiently small and lightweight that it could easily be carried or attached to a 300mm frame UAV. While UAVs were not used in testing this sub-problem, consideration was given for equipment size and portability to allow for realistic employment on a UAV.

The Raspberry Pi was configured to host a Wi-Fi hotspot with a 5dBi off-the-shelf Wi-Fi adapter. The Intel Edison was configured to operate from an attached SparkFun Battery block, which includes a 400mAh 3.7-volt lithium polymer battery.

During the first several tests, the Raspberry Pi had unobstructed line-of-sight to the Edison. After initial testing, the Edison was placed in a coat pocket of a team member, acting as a victim, who walked into a business and waited, while a test vehicle containing the Raspberry Pi drove in the surrounding parking
lot. Initial testing was complicated by a minor design flaw in the SparkFun Battery Block for the Intel Edison. The battery contactors had solder points on the reverse side of the board, which would short when placed on the base block due to the proximity of a micro USB receptacle as shown in Figure 7. This problem was rectified by adding small pieces of electrical tape to prevent shorting during movement or handling of the Edison. Subsequent research revealed the problem and solution are already documented by SparkFun.

A program was executed on the Edison to collect detected BSSIDs, and transfer the detected BSSIDs via secure copy to the Raspberry Pi every minute. The Raspberry Pi would then look for the BSSID file and execute queries for the detected BSSIDs and determine the location of the missing device on a five-minute interval. The BSSIDs would be appended to the file on the search device to help reduce bandwidth usage and connection time between the missing device and the search device. This configuration also allowed for a log of detected BSSIDs to be maintained on the search device should it be in contact with the missing device long enough to build a history.

This test scenario successfully demonstrated that the missing device could be located to a reported accuracy of 47 meters as determined by the Google Locational Database. Analysis of the 176 collected BSSID files indicated a mode of 47 meters precision. Three outliers were identified with precision in excess of 92.7 km. Reverse geocoding revealed detected locations in Dallas, Texas while the testing was conducted near Denver, Colorado.

Results of testing in scenario one were favorable for reducing the search area for a missing device and presumably the associated victim in an AMBER Alert. In Figure 8, the residential location, and the returned range of accuracy estimated by Google Maps was 47m. The actual distance to the test device was 60m. However, in Figure 9 the missing device was contained within the Google estimated accuracy range, which averaged 67m.

One possible cause for the three exceedingly inaccurate locational returns is a corrupted BSSID. The Google Maps Geolocation API can return a large precision response when no known BSSIDs are detected. In this event, the browser IP can be passed for geolocation. However, in our test conditions, the browser is not used for the query, so a more likely error source is a BSSID that has not been geographically correlated in the Google database. The outlier locations were preceded, followed by and bisected with BSSID location results that correlated to the actual testing position. Consequently, the outliers could be easily identified and ignored, if necessary. We were able to reduce the Circular Error Probable by excluding the mobile hotspots or Wi-Fi tethered devices from the Edison’s BSSID detection. It is likely that mobile devices, used as Wi-Fi hotspots, can introduce errors in the process as the physical device location may no longer match the geographic location.
stored for the BSSID in the Google Database. An Android mobile phone, used in the project and operating as a hotspot had disabled location services for the device. Consequently, the Google database had not correlated this Wi-Fi hotspot to a geographic location with GPS or cell ID. Forcing the query to ignore the BSSID of this device resulted in eliminating the outlier position results.

During this phase of testing, the two devices were connected to each other via Wi-Fi link, which was considered an iterative step to refine the procedures before range could be increased with the XBee modules.

C. Results: Iteration 2:

- Search Device: Raspberry Pi;
- Missing Device: Intel Edison;
- Data Transfer: XBee

This iteration was focused on improving the link range between the search device and the missing device. XBee modules were configured to identify each other as peers with a common Personal Area Network Identifier (PAN ID). The XBee modules were connected to the Edison and the Raspberry Pi (missing-XBee and search-XBee) using a mini-USB cable. Python modules, pyserial and XBee, were used to program ‘send’ and ‘receive’ scripts. The Intel Edison collected BSSIDs and stored them every minute, then used the missing-XBee to transfer the data to the search-XBee.

The Raspberry Pi would parse and reconstruct the data, and then query the Google Maps Geolocation Database using the Google API as in Iteration 1 and 2. Non-Line-of-Sight (Non-LOS) and Line-of-Sight (LOS) testing was performed for range analysis.

The connection protocol between the search device and missing device does not influence the position accuracy, it merely increases the communication distance between the search and missing devices.

The XBee link helped increase detection range significantly. During urban testing, the search device and missing device were obscured from LOS by a typical residence with fiber glass insulation, wood frame, and vinyl siding. The device antennas were not optimized for orientation or elevation, and the mobile device was carried in a backpack. The maximum detection range attained during urban testing was 147 meters. In addition to houses obstructing LOS, trees, fences and ground reflections were likely contributing factors to reducing the link range.

The XBee link was also tested for an unobstructed line of sight range. In the unobstructed scenario, the XBee antennas were not optimized for orientation or elevation. The mobile device was again concealed in a backpack. This LOS testing resulted in a maximum detection range of 592 meters.

As expected, there was no significant difference in returned position accuracy between the neighborhood and open field testing locations. In the open field, the average accuracy obtained from the Google Maps Geolocation query was exactly 60 meters with an average of 40 BSSIDs detected during each minute. In the urban environment, the Edison was detecting an average of 20 BSSIDs, likely restricted by LOS obstruction and reflections. In urban testing, the average accuracy returned from Google Maps Geolocation was 58 meters.

VII. CONCLUSION

The video testing conducted in this experiment revealed a general inadequacy of the two cameras tested. Using either the Sony or Go Pro cameras, identifying structures was possible but differentiating between individuals based off size and clothing was not possible. Consequently, the team does not believe either camera is suitable for AMBER alert augmentation beyond the benefits gained in situational awareness.

Wireless positioning and geolocation results from the missing device were sufficient to narrow the search radius for an AMBER alert scenario. The approximate 60-meter accuracy of derived position is likely sufficient to isolate the missing device to a few homes in a neighborhood. However, increased detection range between the missing device and search device would need to be achieved in order to significantly contribute to AMBER alert search operations. Replacing the XBee Series 1, 2.4GHz modules used in this experiment with XBee 900 MHz modules should be considered for a significant range increase.

VIII. FUTURE ITERATIONS AND IMPROVEMENTS

Integrated testing of video and the Wi-Fi positioning system onboard a UAV would be the ideal next step in testing. The search device is sufficiently small and lightweight that even with a dedicated battery it could easily fit on a small-medium frame quadcopter UAV.

The next step in testing would be then to place the search device on a UAV, collect the detected BSSID file from the missing device, query the Google Database to obtain a location, then pass the location to the flight controller onboard the UAV. Several types of UAV flight controllers utilize Linux operating systems and some devices utilize the Intel Edison as the flight controller. GPS integration in UAVs is well established and passing GPS coordinates as a fly-to-waypoint in a GPS augmented flight controller would be a straightforward task.

The Intel Edison as tested with the battery block weighed 26 grams. During testing, the battery life of the Intel Edison was measured at two hours and five minutes. An additional battery was obtained that would extend the battery life of the Edison to beyond 12 hours. The upgraded battery added 20 grams of weight to the missing device. With solar charging, the Edison could conceivably operate for a day or more as the battery block
circuitry will allow charging of the attached battery at 500mA. Incorporating deep sleep and further power savings methods could enable the Edison to run for even longer periods between charges.

Further development should be considered for forcing the Edison to connect to open networks and known prevalent networks that use capture portals for Wi-Fi such as AT&T Wi-Fi hotspots and Starbucks Wi-Fi hotspots. In this scenario, the Edison could connect to a known network and upload or email the BSSID list to a search team thereby eliminating the need for a search device. Similarly, the derived location data could be uploaded to a UAV, which could then fly to the detected location and provide video footage to investigators or the public via the developed website.

Use of multiple UAVs to form a mesh network could significantly help in better and faster search operations. Algorithms for area triangulation and coordination between UAVs could be developed for increased efficiency and performance.

ACKNOWLEDGEMENTS

This project could not have been implemented successfully without the help and guidance of Dr. David Reed, University of Colorado Boulder, and Mr. Peter Smyth, Cable Television Laboratories, Inc. We would also like to thank Prof. Joe McManus, University of Colorado Boulder and Mr. Timm McShane, SparkFun Electronics for their valuable inputs in the implementation of the project.

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