Using Unmanned Aerial Vehicles (UAVs) in Locating Wandering Patients with Dementia

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***Abstract*— This paper presents findings from three experiments involving the use of Unmanned Aerial Vehicles (UAVs) for the purpose of locating a wandering person whose behavior resembles the behavior of a wandering patient with dementia. Additionally, it presents research review on the use of UVs in locating wandering eprsons with dementia. The characteristics of this critical form of wandering--or eloping—are discussed. By using test subjects simulating individual lost patients with dementia, along with current Search and Rescue (SAR) operational methods, experiments were performed employing drones to find the wandering persons. The algorithm used to determine the drone paths is based on the analysis of incidents analyzed in the literature from the International Search and Rescue Incident Database (ISRID) which contains thousands of international and national police records on lost persons. The experiments revealed that UAVs, if used with the pre-determined path, could expedite the search process thus improving the survivability of the lost person. The paper considers the time needed to detect the person, duration of the complete mission, the differential longitude and latitude analysis from an Initial Planning Point (IPP), the time taken to find the test subject and the battery life of the drone. Challenges and recommendations are presented to inform future experiments.**

Keywords—UAV, Wandering, Dementia, Search, Rescue, Path, Algorithms, Computational Public Safety

I. Introduction

The causes of wandering behavior in people with dementia are inadequately-understood. However, the effects of wandering are problematic worldwide. Wanderers are at risk when they enter unknown and possibly unsafe environments, while caregivers are left to worry and search. It is little wonder that wandering is a major reason for extended care facility admission. Even these facilities face the challenge of wandering as dementia patients, on occasion, "elope" [1].

There are several technologies that could help in tracking an eloping patient's movements. Wearable technology depends on GPS tracking which may then be connected to an emergency alerting system that could provide caregivers and/or emergency first responders information about the location of the patient. However, tracking depends on whether patients have the tracking devices on or not. If they don't have it, dozens of first responders may be deployed to conduct an organized search.

More efficient search methods are necessary to facilitate this search process to reduce the cost of search while finding patients as fast or faster than traditional ground search techniques might allow. We are looking into the use of UAVs to assist in the process of searching.

The challenges associated with predicting how patients wander are compounded by variations in the patients themselves. Dementia can affect a person at any stage of their adulthood; This is one form of Alzheimer disease and its severity varies from one person to another; thus, the wandering patterns vary. Our testing process described in this paper is the initial step to support the development of a theoretical foundation for algorithms that predict the probable paths of wandering patients in order to search for them quickly using drones.

It is envisioned that our practical experimentation, as well as in-depth analysis of the available data, will establish benchmarks for the algorithms' design. Finally, based on direct communication with expert ground search and rescue (GSAR) practitioners, more in-depth research will eventually support GSAR teams in finding lost people faster and more safely.

Section I of this paper lists the characteristics of the critical form of wandering and eloping associated with patients with dementia. Section II discusses previous work on the use of UAVs in SAR Operations. In Section III we present the methodology used to perform three experiments conducted to find a wandering person who exhibiting known behaviors similar to an eloping patient with dementia. Results are discussed. Section IV presents the conclusion and future work.

II. Related Work

A. Characteristics of Wandering Patients with Dementia

Many reasons motivate people to elope. Some intentionally and some unintentionally. Anyone with cognitive impairment may be at risk of wandering [2] [3]. Patients with dementia may start wandering at any stage of the illness. They may also experience a wide variety of changes in their mental state and behavioral skills. They may experience problems with spoken language, body movement, decision-making and recognizing common entities [4].

According to [5] "six out of ten people with dementia will wander" (p.1) and 20% of the wanderers will suffer an injury if they are not found within 24 hours [3]. The wanderer may go out to reach a specific destination that could also be imaginary, or simply leave because something upsets them. Because dementia may not effect over-learned skills, wanderers may use any type of transportation including public transportation, driving themselves in vehicles or simply walking. However, [4] states that they will most likely use public transit in urban areas.

Patients with dementia may experience a visual reduction in their peripheral vision, which creates what is called tunnel vision. It drives the wandering dementia patient to keep moving straight until they no longer can. Patients with more severe dementia symptoms may travel shorter distances and wander randomly. In these cases, they tend to exit searching for a former favourite place—perhaps their former residence [4]. Additional factors that may trigger wandering include an expressed desire to go home even when the patient is at home, they may ask about past or current family and friends, show signs of restlessness and find it challenging to locate the bedroom or the bathroom [6]. However, there is no way to know if the person will wander and no specific dementia stage in which there is a higher likelihood for the person to wander; it could happen anytime and anywhere [2].

[7] examined incidences, risk factors, and consequences from dementia-related police missing-person reports. They investigated incident reports in a UK policing region with a population of 2.1 million over four years and searched reports for one complete year. 281 incidents were investigated where data included information about age, time of the day the person went missing, gender, the location they wandered from, time of the year, the number of hours spent missing and what form they used to walk away. Risks increased as people aged and were in a domestic setting. The majority of cases, people remained unharmed with the percentage of those experiencing harm increasing as the duration of their wandering increased. More people were lost in the daytime than the nighttime and in the warmer months of the year than the colder ones. Additionally, the more restrictions and precautions taken, the lower the percentage of incidents. They also found that wanderers mainly went walking, some used public transportation and some drove cars. Further studies are needed to relate the ad hoc medical information reported by first responders in these incidents to verified medical records after examination by a qualified practitioner. In addition, it would be useful to investigate larger data sets with a focus on home settings, behavior and preferences as well as how the caregiver strategy in keeping the patient safe could influence these incidents.

An investigation carried out by [3] using incident records of search operations carried out in mostly rural areas by the Virginia Department of Emergency Services revealed that patients with dementia were found closer to the location they left than the other elderly. They were found mostly beside creeks and/or dense bushes with a mean distance of 0.9 km. This finding must still be corroborated through the analysis of a more extensive data set. However, the median distance of 0.8 km will likely not change for a larger dataset. Patients found within 24 hours were likely to survive with some injuries--mainly hypothermia and/or dehydration. Incident reports do not contain detailed information about the medical condition of the patient [7] [3]. The selected dataset of n=297 records included data on wandering people between the age of 40 and 90. The data collected included age, sex, race, time and date the wanderer was last seen, type of location where last seen, straight line distance from wanderer last seen location to where found, and the time they were located. In addition, reports contain the search technique that actually succeeded in locating the patient, the description of the environment where the wanderer was located, and a brief summary of their medical condition. The classification of the cases in these reports depended solely on the input of the caregivers and were not corroborated by medical experts. From these incidents, 42 were identified as being possible patients with dementia. In urban environments, wanderers, walk along roads, will not respond to shouts (as they don't know that they are lost), they will not leave clues and will not try to gain anyone's attention unless they do so inadvertently by wearing odd attire. For these reasons, wanderers are hard to detect. Issuing alerts similar to AMBER alerts may help in identifying a wanderer in a busy urban area [8]. The dataset in [3] was later added to a larger dataset in the ISRID which combines over 40 databases starting in 2008. [9] conducted interviews with caregivers and family members about the challenges faced in keeping those exhibiting wandering behavior safe. They concluded that there are conflicting needs and ethical views that could affect how a caregiver protects a wandering patient, thus the need to develop technology tools with design approaches that adapt to distinct and varied requirements is an important consideration.

B. Algorithms for Object Tracking Using UAVs

[10] analyzed spatial traversals of patients with dementia in nursing homes. The movements were classified as direct, random, pacing and lapping. [11] proposed a classification-wandering algorithm, which focuses on pacing and lapping patterns as an indicator of a wandering movement. Additionally, along with this algorithm, [12] proposed mobile wandering software framework in a later study to detect real-time movement through the use of a mobile phone that could predict

space traversal behaviors in a patient with dementia. This framework works within integrated circuit monitoring tags. The study, while beneficial in detecting movement patterns, is limited to indoor movements which are usually not the cause of eloping and wandering episodes. [13] proposed a stream-based wandering monitoring system to detect wandering behavior in the elderly. Again, by identifying pacing and lapping movements, the system analyzes travel patterns in real-time using GPS data preprocessing. The GPS signal along with the patient's heart rate are detected through a mobile phone and a sensor attached to the wanderer's body. The system is designed to transmit a signal to a wandering detecting service. They constructed a wandering methodology by applying a wandering detection algorithm that processes the GPS data, identifying loop patterns and generating notifications through the use of a web-based wandering management application. The application could be used by caregivers to detect real-time location, heart-rate, geo-fencing and location history.

[14] explained that the use of drones supported rural and urban policing as well as military activities. Using infrared radiation and thermal imagery could be utilized to detect specific targets. For example, drones can transmit data back to computer systems including facial recognition, skin colour and other personal data. However, the aerial infrared imagery transforms human targets into forms that cannot easily be used to identify specific individuals. [15] experimented detecting wildlife using UAVs using a prediction model, computer vision and thermal imaging. They used a predictive algorithm in an app on an iPhone that was connected to the UAV via Bluetooth. To determine the direction of a ground target they used Kalman filter and Markov logic prediction algorithms. A Kalman filter can be used to detect objects that are continually changing. The method does not require large amounts of memory as it only saves the previous state and is an optimal estimator for a sizable class of problems using few conceptual tools [16] [17].

[18] presented the real-time estimation of position and velocity of a UAV in an indoor environment. The authors used a modified Kalman filter to calculate the localization of the UAV through the use the time difference of arrival method. The mathematical calculations to calculate time difference of arrival is presented. Then, the Kalman filter is modified to capture the nonlinear process of tracking and localization taking into account drifting which is one of the significant weaknesses of applying Kalman filter. The authors integrated wireless communication and ranging methodology in a single chip. The chip includes a kit to measure the distances between two nodes in a wireless sensor network which can work as Real-Time Location Systems (RTLS). This distance is calculated based on Symmetrical Double-Sided Two Way Ranging (SDS-TWR) technique which measures roundtrip time and eliminates the need to coordinate clocks.

There are various challenges in using UAVs in the people detecting task. First, many popular UAVs are limited in the amount of sensors and computation they can carry—severely limiting their flight time due to the extra weight [19]. Most non-commercial UAVs can carry less than a kilogram of equipment, so adding cameras, sensors, lenses and communication equipment degrades UAV performance and precludes adding additional equipment that might be required to achieve accurate detection like zoom lenses. Second, the mechanical vibrations can affect the quality of images taken by the UAV. Third, the computing power available on a UAV is limited therefore on-board processing may be impossible—slowing the generation of results. Finally, with their lightweight, often porous construction, UAVs can be affected by the weather conditions like precipitation, high winds and extreme cold effect many aspect of operations including battery life, the ability to station-keep and, sometimes, the ability to fly at all. Further, [20] and many regulators around the world have introduced restrictions that can severely limit how drones can be employed. These restrictions were of particular concern during our experimentation. Explicitly, they warn of using a drone close to a moving vehicle and populated areas—often the prime search location for wandering individuals.

III. Methodology and Discussion

Our research team conducted three field experiments on three different occasions. The experiments were based on the calculations and conclusions reported in [4] on cases for lost persons with dementia (n=1061). The main characteristics of the wandering behavior of this group are that they do not turn around and keep moving in a straight line due to the tunnel vision in the elderly eyes [22] but may go back and forth when facing an obstacle. They may attempt to go back to a former familiar place and they will keep walking until they are physically blocked. In addition, wandering people with dementia are attracted to water and normally do not wander far from a road.

All experiments were set up with an initial planning point; this point resembles the point where a person was last seen by an eyewitness or could be the last known point which is identified by strong evidence. Testing locations were selected from flat expanses which combine the characteristics of temperate and dry conditions. As stated in [4], data from the ISRID indicates that 95% of search incidents involved people who traveled between 7.3 to 7.9 miles. The tests were performed by the use of drone using the quartile distance statistics from the ISRID as reported in [4]. It is formed as a 'bulls-eye' divided into the 25%, 50%, 75%, and 95% probability circles [4] [23]. The distance ring model then serves as a baseline for all the test. All experiments were set up with an initial planning point (IPP) and expected "Find Location" which is location the person was found in the ISRID; for example, it could be structure, a water stream or road [4]. Figure 1 presents the IPP, the find location and potential hot spots that could be an obstacle in the road. Each test subject was provided with instruction concerning the known wandering behavior of people with dementia and were provided with a rough direction to travel in by the test coordinator. UAV pilots participating in our experiments were provided with a search algorithm by the test coordinator and asked to follow its guidance while searching for the test subjects with their UAVs. The test subjects and the pilots did not communicate after receiving their instructions.

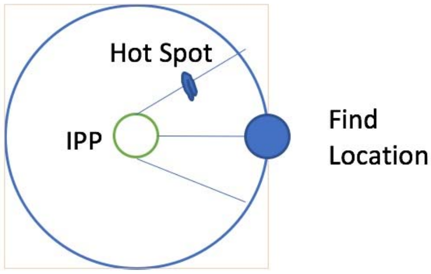

Fig. 1. Diagram indicating IPP, Find Location and areas of potential obsticales (hot sposts).

A. The First Experiment

Our first experiment was conducted during the ASTM International Standards Committee meeting on Homeland Security Applications during a response robot evaluation exercise held around the City of Hamilton, Ontario with police officers familiar with SAR operations acting as observers [21]. In this experiment, three drones were used to conduct three complete tests. Two tests were successful in finding the wandering person and one failed.

The test subject was given the following direction from the search coordinator: move straight ahead, walk south downhill and walk until stuck then move back on forth and stop.

The pilot was instructed to fly the UAV from the Initial Planning Point (IPP) which is assumed to be the initial point of last seen (IPS). As reported from the ISRID data for lost people with dementia in [4], we used the median distance of 0.8 km. The span of the UAV camera lens reaches 84 degrees which clearly includes both the 50% and 95% probabilities of a find. Three different attempts to find the wanderer are listed below:

- The first attempt was completed using a DGI Mavic Drone with a camera feed displayed on a mobile phone. The drones' weight is 743 grams including including battery and propellers. Its maximum velocity is 22.4 mph with an operational flight of 5000m above sea level and 28mm (35 format equivalent) lens is used with a Field of View (FOV) of 78.8 degrees. Initially, the test subject was not able to head down hill towards the South as there were electrical wires and it was dangerous to fly around these cables. Adapting to the terrain, the test coordinator instructed the test subject to employ a small road in their wandering using observed behavior from the recorded data of wanderers in an urban environment. After nearly 10 minutes the pilot was unable to find the test subject using the Mavic and the test was stopped. The primary challenge was the unclear picture on the small mobile device with the display's clarity further reduced due to the sun's reflection. In addition, the drone had sustained some damage on its camera mount from previous experimentation which caused problems that were insurmountable in this test.
- The second attempt was made by a more sophisticated advanced drone used by the police search team employing an Aeryon Labs Ranger drone. The pilot followed the same instructions and was able to locate the test subject in less than 7 minutes. The challenge with this attempt was that the video was not entirely recorded and none of the data of the search was stored. However, using a larger screen and a better camera provided a clearer image of the test subject. Figure 1 illustrates the complete search path.
- The third attempt was completed by another pilot flying a drone designed and constructed by IMR Systems. The test subject was successfully located in 6:02 minutes. A final test was performed to find other wanderers using a thermal camera to detect body heat. This search was also successful in locating the wanderer. We were not able to collect coordinates or metadata during this experiment due to a malfunction of the drone and the lack of complete route tracking by the drone. However, this experiment provided us with information about the requirements of the overall setup of a drone as well as the challenges to avoid in future experiments involving problems with recording, directions, and the drone itself.

B. The Second Experiment

The second experiment was conducted in an open urban park. The flat field search space was used again as in the first experiment. The test subject was instructed to follow similar directions as in the first experiment. However, they were asked to record their route using their mobile phone so that a Find Location and details could be determined concerning their exact path. The drone used for this experiment was a DJI Phantom 4 Pro. For the purposes of the experiment, only a few of the UAV's features were employed since they were determined to provide the most accurate search data. The hardware features relevant to this experiment are:

- Drone weight (including battery and propellers) is 1388 grams.
- Maximum velocity of the drone is 45 mph
- Operational flight is 6000m above sea level.
- 24mm (35 format equivalent) lens is used with a FOV of 84 degrees.

Fig. 2. Experiment 1: The complete route of the second attempt. Time to locate the test person was less than 7 minutes.

Unfortunately, as we started the experiment the drone was not able to fly outside a certain limit. The reason maybe because of flying regulations around the area. New apps for many drones are now programmed to recognize no-fly zones in parks. "Parks

Canada states that it limits the use of all flying objects, including both used for leisure and training drones in national parks [21]. However, this may not be the case as we were able to fly the drone normally in the same area as listed in experiment 3 below, the problem might have been in the app software DJI Go 4 app (v4.1.5).

To mitigate this challenge, we used a different app just to be able to perform the experiment. The app used was PIX4D (v.2.2.0) using the free flight option. We were able to record the flight path and we obtained the real path from the mobile device carried by the test subject. Figure 3 provides an illustration of the path. Figure 4 shows the path recorded on the mobile device. In Figure 3 the test subject was asked to mimic the behavior of the wandering person with dementia as they approached an obstacle. That behavior is shown by the back and forth pacing movement in the route. The test subject was found in 10 min.

Fig. 3. Experiment 2: Path recorded on mobile of the test subject.

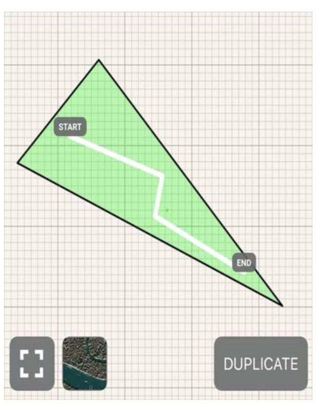

Fig. 4. Experiment 2: Path recorded on the iPhone app.

C. *The Third Experiment*

The third experiment was carried out in the same park as experiment 2. We used the same DJI Phantom 4 Pro which was controlled through the DJI Go 4 app (v4.1.5) on an iPhone 5s to make use of many of the software's features and to record the flight data. The DJI Phantom was set to 'Sport' mode to cut down on flight time and increase the chances of finding the target location. Sport mode allowed for increased flight maneuver as well as speed which ultimately reduced the flight time of the drone. The battery for the drone used is a 6000 mAh Lipo 2S battery, which allows for up to 30 minutes of flight time; however, the drone flew missions of approximately 5-7 minutes.

The 8.8mm/24mm (35mm format equivalent) lens was used with a FOV of 84 degrees. However, the effective video formatting allowed for a forward and backward horizontal 60 degree FOV and vertical of + and - 27 degree FOV. The video footage was recorded in H.265 C4K: 4096 x 2160 at 30 fps and 100Mbps onto a 64 GB micro USB located onto the drone. Although the live video streaming to the controller was high quality and lag free, once the video files were transferred from the micro USB card to a computer the video quality was falling behind. This was caused because of the H.265 codec. Lagging was removed once the video files were converted to a lower quality.

We performed four test flights. For all the tests, we recorded the longitude and latitude for every second of the flight. We then calculated the differential value of each and plotted the outcome as shown in Figure 5 and 6 for one of the tests. From the four tests, three were considered a success in terms of finding the wandering person and the fourth is considered a failure as we were not able to locate the wanderers within the parameters we set. The figures illustrate the differential longitude from IPP, the differential latitude from IPP, and the time it took to focus on the wanderer. This factor is crucial as it provides confirmed detection of the target and presented as the time between the large yellow dots in Figures 5 and 6 below.

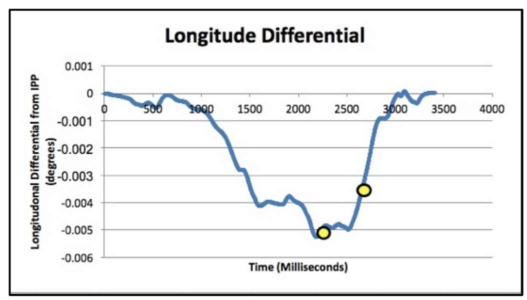

Fig. 5. Experiment 3: Longitude Differential and the time for the flight. Test 2 success in locating the wandering person.

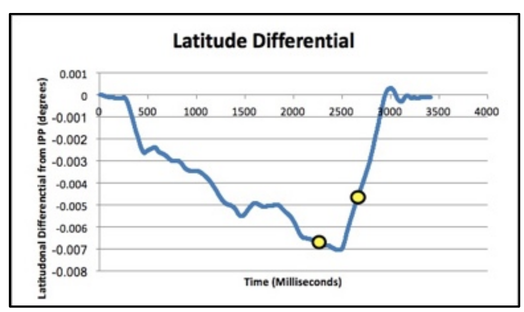

Fig. 6. Experiment 3: Latitude Differential and the time for the flight. Test 2 success in locating the wandering person.

Table I provides information about the time it took to find the test person, the duration in which the drone focused on the person and captured a picture to confirm the identity of the wander and the duration of the entire flight from and to the IPP. On average, it took about 3.4 minutes to find the test person. It worth noting that in test 2, we were able to locate a moving person and with a close focus on him it was revealed that it is not our test person that we are looking for. This highlights the importance of the use of UAVs in SAR operations. Based on the ISRID data, [4] reported that survivability of the lost person is higher when it is located within 24 hours, so the faster we find the wanderer, the higher their survivability. Additionally, [23] reported that the price of rescue missions has increased over several years, therefore the faster we find the wanderer, the less resources are used—allowing those resources to be used elsewhere.

TABLE I. RESULTS OF FLIGHT TESTS FROM EXPERIMENT 3

Parametar	Test 1 (Fail)	Test 2 (Success)	Test 3 (Success)	Test 4 (Success)
Total Flight Time (minutes)	7:58	5:59	8:41	5:34
Total Flight Distance (meters)	2530.9	2429.7	3026.7	2029.5
Duration to find the person (minutes)	NA	3:43	4:48	2:30
Duration focusing on target (seconds)	NA	41	101	78

Battery life is an essential parameter in the search process. As the time passes in the search, the drone may need to be returned to base either to replace the battery or to deploy another drone ready to start where the first drone stopped in order to complete the search. Therefore, monitoring battery usage as well as the longitude and latitude differential is critical for effective search operations regardless of the eventual search outcome. Table II lists the percentage of battery usage for the four tests when finding the target and for the complete mission.

TABLE II. RESULTS OF BATTERY LIFE FROM EXPERIMENT 3

Parameter	Test 1 (Fail)	Test 2 (Success)	Test 3 (Success)	Test 4 (Success)
Battery % at find location	NA	86%	81%	88%
Battery % at the end of the mission	24%	76%	66%	76%

IV. CONCLUSION AND FUTURE WORK

The use of UAVs, if used with a pre-determined path based on an algorithmic approach to analyzing wanderer behavior, can expedite the search process thus enhancing the survivability of a lost person. Knowing the behavioral patterns of lost people with dementia is important in determining the search path as they inform the parameters of the search. Using UAVs to locate wandering persons can prove much faster and more efficient than standard ground searches. Even with average battery life, a drone could reach planned locations faster, eliminating ground more quickly.

Our findings support the need to develop a model that could be transformed and technically implemented to automate the search process using UAVs based on underlying algorithms. Future work will create simulations to test the algorithm(s) for finding people with dementia via UAV search and then develop software that can be used to automate the search process. Furthermore, these simulations could be used to train first responders and SAR teams through game-based learning. The primary challenge in this study will remain ones of validation and will eventually require tests performed during actual incidents involving wandering patients with dementia.

The deployment of UAVs is an emerging area as the drone market is quickly expanding and their presence is becoming ubiquitous. UAVs have the potential to offer solutions in a wide range of applications, such as SAR and disaster management, among others. Our experiments will continue and seek to add to the body of knowledge that support the more efficient and effective use of drones within the field of computational public safety.

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