1. IDENTIFICATION & SIGNIFICANCE OF THE OPPORTUNITY

This proposal will outline the possibility of attaching an Ultra WideBand Frequency (UWB) field to an **Unmanned Drone Neutralization System (UDNS)** for the detection and neutralization of enemy drones. Of all common sensor types, UWB tracking is the most promising approach as it provides precise location data with 10-centimeter accuracy. UWB's low energy consumption allows transmitters to be attached onto multiple drones, which enables coordinate flights to cover a wide radius. The cost of UWB sensors are comparable with other sensor types of similar capabilities. UWB sensors are detachable from the drones to allow for a more permanent placement, and are extremely light and compact. These transceivers can operate at a range of 200 meters, and work even in fog, rain, or dust.

Once an unauthorized drone has entered the UWB field, an interceptor drone will be launched to perform a takedown. The field will be set wide enough to be able to detect and neutralize enemy drones before they can inflict damage on friendly personnel and assets.

1.1 Background

The increasing availability of cheap, compact drones raise the probability of a drone related attack. Having the ability to quickly set up a perimeter that can detect and defend an incoming swarm is a valuable capability. Drones conjoined with UWB transceivers will create a Counter-Unmanned Aircraft System (C-UAS) perimeter that will provide accurate real time location of unauthorized drones. Attaching nets to friendly drones allows enemy drones to be disabled before they can inflict damage upon friendly personnel and equipment.

1.2 UWB Transceiver

In recent years UWB transceivers have slowly risen in popularity, with more and more designs coming out to support a higher range of frequencies. It has now reached a point where their size and power usage can be used commercially. The transceiver that will be used in Phase I is the DW1000 Single Chip Wireless Transceiver. These devices can transmit up to 290m in radius and support transmission through obstacles. They have a low power usage of 31mA when transmitting and 61mA when Receiving (decaWave). These chips can be held in a small case that also houses a rechargeable battery and a clip that allows the case to be attached to the drone. Having detachable sensors on the drones gives troops the ability to remove them from the drones and physically place then for a more permanent placement. Once the sensors are in place they can begin transmitting back to a central processing device where the data is interpreted and displayed as a type or radar.

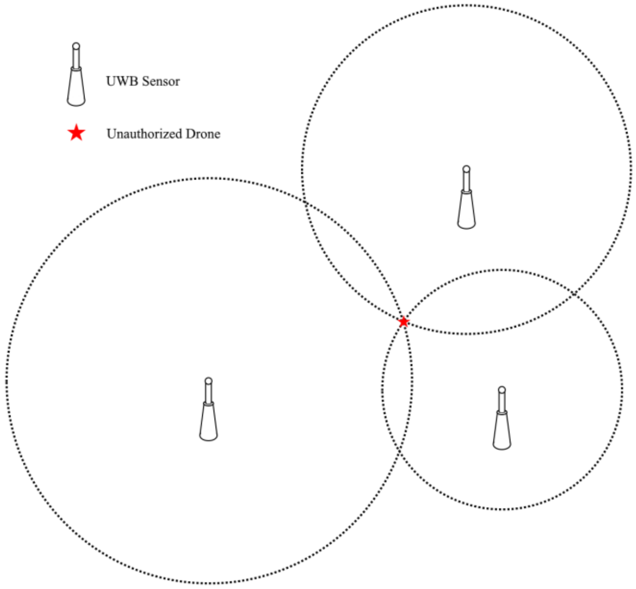
There are three main types of algorithms that can be used to track objects as they are in the field:

1. Angle of arrival(AOA) - These are algorithms that requires at least 2 sensors working to attempt to determine the location of an object between the sensors. This algorithm is not extremely accurate and will become even less so as the distance between sensors is increased. However, this algorithm can be used alongside other algorithms to make it more accurate (5).

2. Time of arrival(TOA) - These algorithms use the intersection of circles for 3 or more transmitters, as shown in Diagram 1. It uses the distance between the transmitters and the radius from the transmitter to the drone to get a location. This method of tracking has an estimated accuracy of 8.3 cm, which is accurate enough for drone takedown (4). This method works with as little as

DIAGRAM 1

Time of Arrival Algorithm



three sensors and increases in reliability as the number of sensors increases.

3. Time difference of arrival(TDoA) - These are algorithms similar to that of Time of arrival, but instead use the time difference of how long the signal takes to arrive at target location, rather than distance from sensor to target. These can be combined with the AOA algorithms to improve accuracy of object detection.

Most of the work done using the DW1000 has been in indoor environments, so extensive testing will be needed to determine its suitability in the field.

1.3 Parrot Bebop 2 Drone

The drones needed for this project have to be relatively cheap and reliable so that they can hold the UWB transceiver. The U.S. based company Parrot has a drone called the *Parrot Bebop 2* that could be modified to perform exactly as needed. A battery that supports up to a 25-minute flight time at up to 37 mph contains enough range to establish a UWB perimeter around a forward operating base. Once the drone has landed, it will enable the UWB sensor net and await further commands from the pilot. Operators can manually control the Bebop 2 within a 2km range using a Bebop Skycontroller 2 (2).

The physical design of the Bebop 2 also makes it ideal for modifying a hook meant for attaching and detaching the UWB transceiver. The underbelly of the drone is level which provides an area to attach the UWB transceiver box.

2. Phase I Technical Objectives

The goal of this proposal is to investigate the development of sensors that will be attached to the UDNS or work standalone to provide a field in which unauthorized drones are targeted upon entry then neutralized. The technical tasks needed to perform this research are as follows:

1. Begin testing of the DW1000 transceiver chips to gather data on different outdoor environments.
2. Start development of system architecture, testing different algorithms in similar settings to determine which is best suited for long range outdoor conditions.
3. Modification of the parrot drones so that they can carry an early implementation of the UWB sensors.
4. Program drones to fly to predetermined positions with UWB transceivers creating a temporary field.

3. Phase I Statement of Work

The Phase I statement of work will include the following tasks and timeframes for achieving the stated objectives:

3.1 Task I - Testing of DW1000 Single Chip Wireless Transceiver

This task will begin at project start and is expected to be completed within a two-month period. In this task extensive testing of the DW1000 chip will occur to ensure that it can work exactly as needed in several different obstructed conditions.

3.1.1 Indoor Testing. Setting up a basic indoor testing environment to ensure that the sensors work properly is the first priority. Bebop 2 drones will be flown through the indoor space to verify the system can track fast-moving objects of that size. This will take place inside a warehouse, smaller than the 200m goal set by the Army, to provide baseline data on their performance before moving the sensors outdoors.

3.1.2 Outdoor Testing. Moving the sensors to an outdoor test environment is the next step. The same tests from the indoor iteration will be used in the outdoor environment. A series of UWB sensors will be set over a 300m radius outdoor area and drones flown through the region. The two sets of data will be compared to ensure the sensors in a clear outdoor environment can still give precision feedback.

3.1.3 Conditions Testing. Finally, the sensors will be tested again in outdoor conditions with fog, rain and dust occluding normal vision.

3.2 Task II - Benchmarking / Programing of *Parrot Bebop 2* to fly

This task will be to assess the capabilities of the Bebop 2 under autonomous, semi-autonomous, and controlled flight. This will take place in one month after the UWP sensor has completed testing.

3.2.1 Carrying Capacity. Testing the flight capabilities of the *Bebop 2* is necessary to ensure that it can perform when weighed down by UWB sensor(s). If the drone is not able to fly effectively with sensor(s) on it, other drones will have to be used instead.

3.2.2 Hovering Stability. The hovering stability of these drones will also need to be benchmarked as the UWM sensors will have to remain very still to give accurate results. If the drone cannot hold the sensors steady, then the drone will be outfitted with stabilizers or replaced.

3.2.3 Programmability. Once the technical capability of the drones is confirmed, the drones will be programmed to fly into predetermined positions, hover there for a set amount of time, and returning back to their launch point.

3.3 Task III - Pair UWB Sensors with Autonomous Drones

Following the completion of Task II, for the next two months, the drones will be modified so that they can have a sensor attached securely and still be able to fly correctly.

3.3.1 UWB Attachment. The *Bebop 2* drone will be modified so a UWB sensor can be easily attached and detached at will. This will make it simple to replace or remove a sensor in case of damage to either it or the drone.

3.3.2 Integration Testing. Once the sensor is attached, additional testing will be required ensuring both the drone and sensor are still working effectively.

3.4 Task IV - Reporting

A report on technical progress will be submitted every month documenting all work done and research findings. If a change needs to be made to the drone type or the brand of chip used for the sensors the change will be noted in the technical progress report. Upon request from the program manager, a technical report can be drafted at any time between these monthly intervals. Daily informal communication between the principal investigator and the program director is expected.

Phase I Option:

If Phase II is approved, the time between Phase I and II will focus mainly on the development of a drone modified to take down unauthorized drones. This is accomplished by modifying one of the *Parrot Bebop 2* drones; because the drone will already be customized to hold a UWB sensor, it will be possible to develop a device to hold a large net that will clip into this existing hardpoint on the drone. The drone would then be tested to evaluate its flight capabilities. Work will then begin on pairing the takedown drone with the UWB sensors to fly the takedown drone to the location of the unauthorized drone. The programming and testing of this drone will carry over into Phase II.

4. Related Work

Ultra WideBand positioning has been rising in popularity over the years, mostly for indoor object tracking. A group at Oakland University did research into UWB tracking of mobile robots and were relatively successful. The group was able to use four UWB sensors and a combination of time-of-arrival algorithms and a fuzzy neighborhood filter to correctly track and predict the robots' movement. This research can be adapted to the tracking of high mobility drones over a larger distance. Through the experiments the group found solutions to the most common problems when tracking a robot using UWB. These solutions will be used in the UWB field that this project will create. The leader of the research group, Dr. Ka C. Cheok, who is not affiliated with this SBIR project, or with APDS, has publicly posted his contact information as: (248) 370-2232 and cheok@oakland.edu.

5. Relationship with Future Research and Development

This project will develop a smart system of drones that will fly out with UWB sensors and create a field with C-UAS capabilities that will detect intrusions into the protected airspace and task a takedown drone to disable incoming enemy drones. Phase I will allow for valuable testing on the overall capabilities of the UWB tracking in combinations with drones. It will also allow for any early problems to be addressed and be adapted while the project is still in early stages.

Upon funding of Phase II, development of the Phase I option will begin as described above. The Phase I option will provide an easy transition into Phase II. Phase II will continue with development and testing of the takedown drone and optimization of tracking algorithms in the sensor net.

6. Commercialization Strategy

There is a tremendous need in the market for an inexpensive and portable way to neutralize unwanted drones. The UDNS will provide a solution to this need that will start at only $4,100. The UDNS kits would contain 5 custom *Bebop 2* drones and 5 rechargeable UWB sensor packs that can be attached or detached from the drones at will. This would be sufficient to quickly protect a 300-meter radius area, such as an assembly area or temporary encampment. Multiple kits can be sold to protect progressively larger areas, and additional UWP sensors can be sold and installed to protect permanent positions such as forward operating bases or airports.

There are few other products on the market that offer the ability to stop unwanted drones and many of them still rely on human control to work. For example, the Battelle DroneDefender offers Counter-UAS abilities in the form of a large gun that uses remote control and GPS disruption (7). However, many of these existing products do not aid in the detection of unwanted drones, or offer a hands-free way of stopping them. The UDNS is able to be deployed and disable drones without a human operator controlling the takedown drone. This stops human error that can occur when using devices like the DroneDefender.

These kits would be valuable to any military base looking to secure a perimeter against unauthorized drones. The UDNS can also be taken out by troops that are securing possibly hostile locations. With over 800 military bases stationed in foreign countries these kits can be a very valuable asset in the protection of personnel and equipment on the bases (8). The total cost to outfit every overseas military base would cost $3.3 million. If the system prevents damage to even a single Apache helicopter it will have paid for itself. These kits could also be sold to airports as well. There have already been a number of accidental intrusions into restricted airspace in America. With terrorists beginning to realize the potential for drones, it will soon become critical for every airport in America to have C-UAS capabilities. If one UDNS system is sold to the 521 airports in America with air traffic control towers, this will represent sales of $2.2 million, which will again pay for itself if it even prevents a single major accident. With an estimate profit margin of 50%, this will represent a profit of $2.75 million to APDS.

7. Key Personnel

Bill Kerney

Principal Investigator

Education:
M.S., Computer Science, University of California at San Diego 2002.
B.S., Computer Science, University of California at San Diego 1999.

Background:
Bill Kerney has been President of Anodyne PDS, Inc. for fifteen years. APDS specializes in software development, evaluation, and professional development systems. Over the years, APDS has successfully worked on over fifty grants for federal, state, and local-level governments. Bill Kerney is concurrently head of the Computer Science Department at Clovis Community College in Fresno, California. He has worked as a professional software developer for twenty-five years. Two of these years were spent at Kaiser Electro-Optics, Inc. where he designed military grade AR and VR headsets for the Air Force and Army. Two more years were spent working on a Qualcomm project to conduct jam-resistant videoconferencing for all of the branches of the military.

Ezra Child

Project Manager

Background:
Ezra Child is a former United States Army Infantryman who participated in an Iraq tour from 2004 to 2005. After being given an honorable discharge, he now operates under the United States Air Force where he manages security, emergency management, and mission assurance programs. In addition to his military experience, Ezra has worked as a web developer with a focus on product marketing.

Zach DiFuria

Researcher / Microsoft Developer

Background:
Zach DiFuria is an AR developer who has spent the past two years developing AR applications for the Microsoft HoloLens. His first work was published as one of the initial apps on the Microsoft HoloLens store. He has performed private work for CART where he has developed AR applications that teach students how to operate heavy machinery in Product Development, Robotics, and Interactive Game Design labs.

Matt Mueller
Researcher / Microsoft Developer

Background:
Matt Mueller is a software developer who specializes in AR applications, database management, and web development. He has created a website and database for a non-profit company known as The R.A.D. Project. He has developed for the Microsoft HoloLens and published one of the initial applications on the Microsoft HoloLens store.

Danial Monastyrsky
Technical Analyst and Application Developer

Background:
Danial Monastyrsky for the past year has worked in a warehouse environment providing technical support on an on-call basis, and has developed a custom inventory to increase the workflow. Outside of the warehouse industry he has participated in many projects; including the development of an application for the University of California, San Francisco - Fresno Department of Medicine.

Christian Barrett
Application and System Developer

Background:
Christian Barrett is a real-time rendering engine developer who has spent the past year developing an interactive heads up display (HUD). Before that he worked in a team of developers creating intuitive applications.

8. Foreign Citizens

No foreign citizen(s) or entities are expected to participate on the Phase 1 section of this opportunity.

9. Facilities/Equipment

9.1 Facilities

Indoor testing will take place inside a warehouse in Fresno, CA. Outdoor testing will take place in a variety of outdoor environments in California, such as in open fields and in areas with forest and uneven terrain, to test the effectiveness of the system under different situations. Testing will also take place at night, in fog, in rain, and in high wind and dusty conditions.

9.2 Equipment

In order to set up a UWB field several UWB transceivers are required. The DW1000 Single Chip Wireless Transceiver is an optimal choice as its abilities fit what is needed to create an optimal field with C-UAS capabilities. These transceivers are very light and inexpensive, and can be easily linked to a central computer to send and receive information. The transceivers can be installed on a board inside a case with a battery pack creating a rechargeable sensor case.

The speed and accuracy of drones are able to get the sensors into position quickly and efficiently. A modified *Parrot Bebop 2* is an optimal choice, as it has a fully documented Software Development Kit (SDK). Six of these drones are required, four to set up the UWB field, one to serve as a takedown drone, and another to be the test unauthorized drone intruding into the field.

10. Subcontractors/Consultants

Phase I of this proposal does not anticipate any subcontractor(s) or consultant(s) are necessary to perform the required tasks.

11. Prior, Current, or Pending Support of Similar Proposals or Awards

No prior, current, or pending support for proposed work.

12. References

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