1. IDENTIFICATION AND SIGNIFICANCE OF THE OPPORTUNITY

The objective of this proposal is to identify the benefits of implementing cost-effective, reliable, and repeatable Augmented Reality (AR) assistance to eliminate unproductive business practices in the warehouse environment. AR in conjunction with RFID-enabled containers is expected to become the new standard for workers in warehouses, raising productivity to new highs. The capabilities of AR will improve these technicians' accuracy, efficiency, and safety levels (1). Many companies have already started the transition to AR+RFID warehousing, proving that demand for this technology is already rising. This proposal will build upon existing AR technology to create a new state of the art AR device called the **Optical Micro Navigation Infrared Sensor (OMNIS)** for both the Defense Logistics Agency (DLA) and commercial warehousing entities. Examination of old AR devices will provide a baseline for the cutting-edge AR device this project will produce in Phase II.

Current AR devices can be compared to the first generations of personal computers: they are sub-par proofs-of-concept with ample room for improvement. Most current devices have unsatisfactory features, such as headsets weighing over 1.3 lbs, poor ergonomics, short battery life, and fields of view (FOV) below 35°. The industry has made much progress in recent years, but still lacks the capability for commercialization success (2).

This project will thoroughly test the two most promising AR headsets on the market, and investigate what it will take to modify them to make a cutting edge AR headset for logistics purposes. These tests will take place in Phase I and will be used in Phase II to build the best AR headset possible for the warehouse environment.

1.1 Modern AR Devices

Modern AR devices such as the Microsoft HoloLens show promise in eliminating the problems described above by using new technology to provide the users with a lightweight device that can show up to 70° in their FOV (3). This new technology, named *Waveguides with Extended Field of View*, takes incident light and inserts it into a input-coupler where it splits the images and distributes it across the lens for a wider FOV (3) than any other battery operated AR device on the market.

Many businesses and government agencies across the United States have been integrating the HoloLens into everyday work. As of March 2016, the National Aeronautics and Space Administration (NASA) has begun using the HoloLens to develop an application named ProtoSpace (4). ProtoSpace allows NASA scientists and engineers to step foot onto a virtually displayed Mars. This provides geolocation data for engineers to better understand the terrain around the rover. Also, the new Mars 2020 Rover is currently being assembled using HoloLens technology. Engineers are able to take three-dimensional Computer-Aided Design (CAD) images on computers, and translate these diagrams to AR, providing the engineers a faster assembly process (4). Engineering and construction company CDM Smith in Boston Massachusetts has applied the HoloLens to their entire product life cycle. All workflow is now required to pass through a HoloLens inspection in order to accurately obtain safety information before a structure is physically built (4).

The HoloLens, unlike most AR devices, uses an Inertial Measuring Unit (IMU) to track the attitude and location of the device (5) in conjunction with WiFi, four "environment understanding" cameras, and a depth-sensing camera. While IMUs are traditionally placed on large aeronautical products, miniaturized IMUs can provide accurate data collection without needing to be tethered to a large device (6). Most modern smartphones carry these mini IMUs that can provide accurate orientation up to ± 0.3° (7). It is imperative that any AR device constructed must be built with no more than this amount of error.

Like most portable headsets, the HoloLens lacks long-lasting battery life. The average employee will need a device which can work for up to 10 hours per day. The HoloLens, however, lasts for only 2 to 3 hours on a full charge, using its internal 3,200 mAh battery (8). Users typically overcome this by attaching a battery pack. Battery packs such as the *Poweradd 2nd Gen Pilot 2GS 10,000mAh Power Bank* triple the battery life, while adding 2 oz to the weight of the unit, in a compact form factor (9).

The Microsoft HoloLens's main competitor within the AR market is the Meta 2 (10). What the Meta 2 lacks in portability, it makes up for with computational power. Both the HoloLens and Meta 2 use a process called Simultaneous Localization and Mapping (SLAM) to provide spatial mapping for holograms to sit on (11). The Meta 2 has the ability to save more map data due to its 9 foot extension cable that hooks into a local PC. This allows for more data to be processed, but limits maneuverability and range (11). Wide lenses have also been mounted on the headset due to its reliance on the local PC to process and display graphics (11). The combination of its unique SLAM architecture and extended lenses allow these spatial mappings to be displayed up to 90° FOV in real time.

The Meta 2 development team is a major supporter of free and open source software (FOSS). With the release of their software development kit (SDK), most of the source code on the device is free for developers to use and change. The SDK provides documentation on all components of the device for public modifications (12). If APDS chooses the Meta 2 over the HoloLens, it can be quickly edited for this proposals specifications. Instead of reverse engineering many built-in components, researchers on this proposal will have a much faster time gathering relevant information needed for the success of this project.

By using headsets with an IMU and SLAM, a headset can conduct "spatial mapping" which allows the headset to understand what the world looks like in 3D around it. Unlike most AR devices that simply function as heads-up displays, headsets like the HoloLens and Meta 2 can identify objects in the physical space around the user and attach 3D graphics to them. As the user moves his head, the graphics will hover in place over the real world objects. This will greatly improve the usefulness of an AR headset, as it will allow the software to, for example, highlight the specific crate on a shelf that a certain item is in, to show the contents of boxes directly over them, and have the words can travel with the crates as they move. This will allow warehouse workers to be more productive than when using systems that use non-SLAM headsets like Google Glasses or the Intel Vaunt glasses. Diagram 1 shows how a SLAM-enabled AR device can overlay 3D objects over real life objects.

DIAGRAM 1. Demonstration of SLAM AR

Photo Credit: Microsoft HoloLens promotional materials

For this reason, we will limit consideration of headsets to SLAM-enabled ones.

1.2 Modern AR Devices - External Components

Infrared (IR) sensors are crucial to the development and success of these devices as they have a lightweight and low latency ability to scan and track rooms providing for the optimal AR experience (13). However, a recent study (14) done by the UCLA Institution of Electrical and Electronic Engineers (IEEE) performed a series of tests on an IR device called a "micromouse." These tests studied the effects the sun had on infrared technology. The results showed IR sensors in the sun behaved erratically and unreliably, making them too unreliable to use. All modern AR devices that use IR sensors have this fundamental flaw where they perform poorly in sunlight (14). This means a better sensing technology, such as Light Radar (Lidar), is needed.

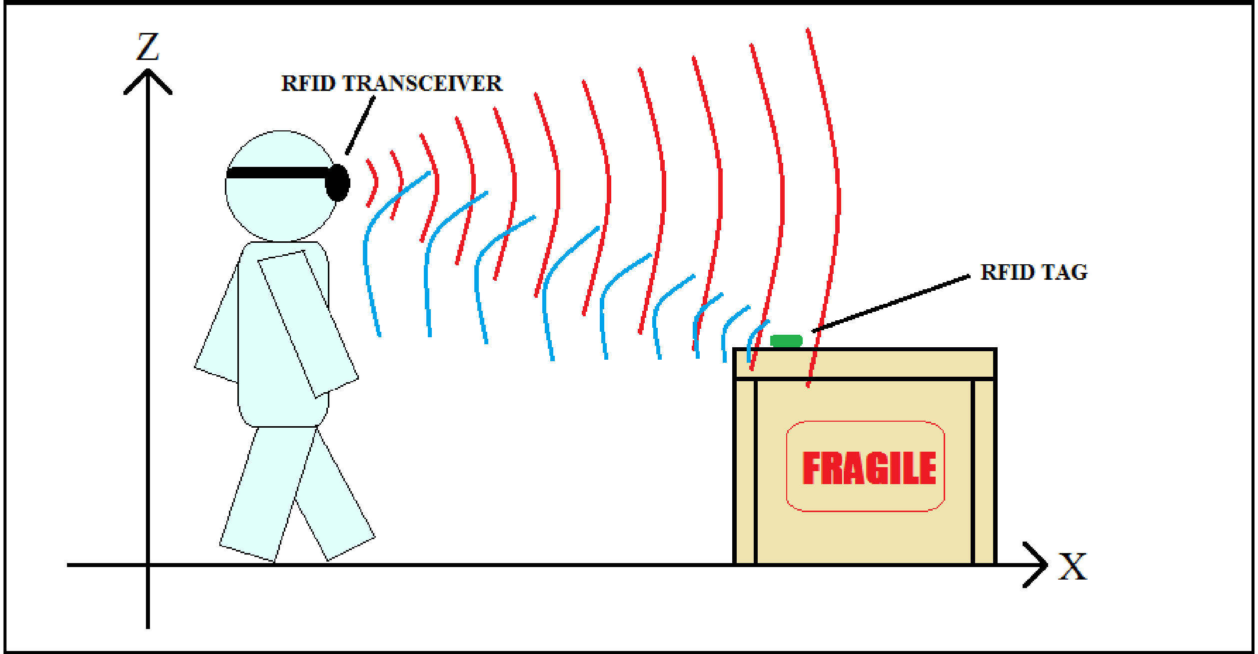
Lidar sensors would be a significant upgrade for AR devices. Most AR developers avoid this tracking technology not because of accuracy, but because of cost. There have been improvements in Lidar since the development of first-generation AR devices that have boosted the quality of the sensors (15). Boston Dynamics has begun outfitting their robotic products with Lidar sensors to provide optimal tracking for autonomous robots (16). We will study the cost and effectiveness of Lidar tracker sensors on AR headsets, and the ease of incorporating them into SLAM mechanisms.

AR headsets are also in need of fine precision hand-tracking sensors in order to interact with three-dimensional holograms in the AR space. Manus Virtual Reality (VR) gloves bridge this gap by providing a new, accurate set of internal trackers. NASA has begun to adopt these gloves in conjunction with their AR and VR training programs to provide a better experience for their workers (17).

New tracking advancements using radio-frequency identification (RFID) tags have revolutionized the robotics industry. By attaching small RFID tags to objects, transceivers now have the power to track objects with 99% accuracy up to 30 feet (18). An RFID tag produces a detectable wave from up to 300 feet, though at reduced accuracy (18). We will study a system in which the long range signal will help guide workers closer to the object(s) and, once within 30 feet, the OMNIS will pinpoint the location of the item. Mixing RFID with modern AR technology has the potential to save technicians many hours searching through warehouses trying to find a lost crate.

Diagram 2 shows how an OMNIS paired with a RFID transceiver communicates with an RFID tag to pinpoint its location and information.

DIAGRAM 2. RFID SCANNING



2. Phase I Technical Objectives

The goal of this proposal is for **Anodyne Professional Development Systems (APDS)** to investigate the development of a safe, practical, and cost-effective “OMNIS” device to eliminate unproductive business practices using Augmented Reality technology. The technical tasks needed to perform this research are as follows:

1. Compare current commercial AR devices and external sensors to document current hardware limitations for expectations for future progress.
2. Begin testing proprietary and nonproprietary AR software. Tests performed on this software include, but are not limited to, latency, security, portability, and support for an intuitive real-time interface.
3. Customize industrial grade equipment to test feasibility of integration with the OMNIS.
4. Break down total time to perform work-related tasks using traditional methods, and comparing the data with AR supported methods.
5. Report findings and recommend an AR headset and external sensors for Phase II.

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 - Hardware Benchmarking

At project start, the project manager will acquire a set of AR headsets, external sensors, and testing equipment. APDS will then begin the hardware benchmarking phase. Over the course of two months, ratings will be generated for each of the hardware components based on durability, ergonomics, and ease of modification.

3.1.1 Durability tests will include a device’s response to minor impacts and scratching. Lenses will be tested using a Mohs Hardness Kit to determine the likelihood of a scratch appearing. If a device’s lenses are found to be prone to scratching additional research will determine the viability of upgrading the lenses to a stronger material, or providing a scratch-resistant coating. Impact tests will examine both normal wear and tear and the drop-resistance of a device inside its case. Upon the discovery of a fragile case, a cost-effective and more durable alternative will be determined.

3.1.2 Ergonomic tests will rate the comfortability and practicality of wearing the OMNIS for an entire work day. Individuals shall use each gadget for a full 10-hour shift, with a one hour lunch break in the middle of the shift. A survey will be administered immediately following completion asking the individuals to assess the ergonomic characteristics of the device, including long term comfort and usability. A poorly rated product will be modified and returned to the individuals for re-evaluation.

3.1.3 Ease of modification will determine if a product can be efficiently modified within the timeframe of this project to prevent unforeseen future cost overruns and delays. Each of the headsets will be disassembled, and the components will have their underlying characteristics identified. This includes ability to replace or upgrade the battery pack, the speed of charging system, adjusting the intraocular distance on eyeglasses, and so forth. External components such as gloves and RFID tags will be separately tested and rated on how difficult it will be to incorporate them with the AR headsets. Multiple brands of RFID tags will be examined to test both strength and precision capabilities.

3.2 Task II - Software Benchmarking

Following hardware tests, the next month and a half will be spent benchmarking software on the AR headsets. Benchmarking will rate software products on their latency, security, portability, and user interfaces.

3.2.1 All proprietary and nonproprietary AR software will benchmarked to test whether the latency is too great for AR use. Tests will mainly be conducted on real-time rendering engines such as the Unity and Unreal engines. The latency (in milliseconds) between input and response and the frames per second (FPS) will be the main qualifiers in this benchmark. Anything below 9 FPS or greater than 100ms latency will be considered unusable, 10 to 19 FPS and between 50 to 100ms will be considered average, and 20 or higher FPS and < 50ms latency will be deemed ideal. If these engines are deemed too slow to run the necessary applications, the possibility of building a custom engine will be researched.

3.2.2 Any software used or designed must be vetted to make sure no cybersecurity issues are present. APDS will search through databases of known exploits, such as CERT, to see if the software is vulnerable before integrating it into a solution. If the software contains unresolvable security vulnerabilities, it will be automatically removed from contention.

3.2.3 Software used in the development of an OMNIS must be flexible and able to run on the machine. Installation testing will determine whether certain software can be applied to the new device. Any software that restricts itself from being installed on a custom AR headset will not be used for the final product.

3.2.4 The software must allow for a real-time graphical interface that allows for easy interaction with AR holograms. This means the displayed information must be intuitive and easy to learn. Test will be administered on many different age groups. For older individuals not well versed in technology a design plan will be drafted to accommodate for the skill gap.

3.2.5. APDS HoloLens developers will integrate the output of RFID sensors into the augmented reality space, superimposing the location of RFID tags onto the view of the users.

3.3 Task III - Warehouse Testing

After APDS researches the AR hardware and software, the team will move testing to a 500-shelving unit electronics warehouse facility that has agreed to allow APDS access for the project. Over the next two months this testing location will provide the necessary space and equipment to test the AR headsets in conjunction with external sensors such as RFID technology.

3.3.1 Construction of the warehouse test environment includes placing RFID tags on every object of interest. A range of RFID tags will be installed on many different objects to test the strength and accuracy of the different devices. Detailed pictures and diagrams of the warehouse will be drafted to provide accurate distance measurements for reporting purposes. Every few weeks the layout of the warehouse will be changed in order to continually generate valid test data.

3.3.2 APDS will then determine the employee efficiency gains from using AR headsets with RFID tags. This test will be conducted by randomizing the storage layout of the facility and then having the warehouse employees conduct their regular business. The employees will be divided into an experimental group using AR headsets and a control group that does not. Based on results from related work, APDS expects to see at least a 20% gain in workplace efficiency from using the headsets (19).

3.3.3 APDS will integrate a safety helmet with an AR headset for worker safety. The effectiveness of the design will then be tested against common hazardous scenarios such as falling crates and metal bar impacts. If there are any issues with safety the problem will be documented, and potential solutions explored.

3.3 Task IV - Reporting

A report on technical progress will be submitted every month documenting all recent findings and future expectations. Daily communication between the principal investigator, the program director, and the team is expected, with progress tracked and reported on each milestone as the grant progresses.

4. Related Work

Matthew Hodge, an Interactive Game Design instructor at the Center for Advanced Research and Technology (CART) in California, has led a team of designers in creating new, educational AR applications. These training programs have assisted students enrolled in the Robotics, Product Development, and Interactive Game Design labs by providing AR training through the Microsoft HoloLens. Students learn to operate heavy machinery through interactive life-size 3D holographic models. The simulations include descriptions for the machinery, step by step instructions, hazard warning alerts, and a custom Heads-Up Display which all help guide the progression of student learning. This work led to a 20% increase in productivity, and an overall reduction in total accidents within the workshop. Zach DiFuria and Matt Mueller, two of the researchers on this Phase I proposal, were the lead developers of this product. Development occurred from January 10th, 2017 to September 14th, 2017. Matthew Hodge can be contacted at (559) 248-7400 on business days from 8:00 am to 4:00 pm PST (20).

5. Relationship with Future Research and Development

This project will develop an AR headset that will improve users' efficiency, safety, effectiveness. The Phase I effort will provide helpful inside for the creation and design for the Phase II device. Phase I will investigate external and internal sensors, ergonomics, and practically of an AR headset in order to prevent unwanted problems during the creation the Phase II final product.

Upon funding of the Phase II proposal, this project will seek permits to test Phase II equipment at DLA sites. Requests will be submitted within the first two months of Phase II funding. Expected testing at these locations will commence during the latter half of the Phase II effort.

6. Commercialization Strategy

There was a 6.3% increase in demand for warehouse storage and logistics facilities in 2016. Costs of operations are expected to rise 2.7% every year over the next several years (21). The average employee in the warehouse industry makes $19.1 dollars an hour and works 41.2 hours a week. An OMNIS with external sensors will have an estimated cost of $8,940 dollars. If it makes an employee 20% more productive then it will save the company $114.61 dollars per week. This provides the company that purchases one of these OMNIS a Return on Investment (ROI) in approximately 54 weeks, or slightly less than one year.

In order for an OMNIS to be working at maximum efficiency, objects such as crates and machines will need to be RFID-tagged so the system knows the location of all objects in the facility. This price is dependent on how large the facility is. Current estimates put the price per square foot of converting a facility at $2.64/sqft (22). An average major shipping warehouse contains 200,000 square feet of storage space (22). Therefore, it will cost an average of $528,000 to convert a warehouse to an AR and RFID storage facility.

APDS plans on selling these AR headsets and RFID storage technology in waves. Selling in waves provides quality control to prevent any minor overlooked technical mishaps from occurring. This also allows APDS to negotiate with product manufacturing companies should high demand occur. The waves are predicted to have six to eight-month cycles between each shipment. After three to four waves APDS plans on converting to a deliver upon purchase business model for all private companies.

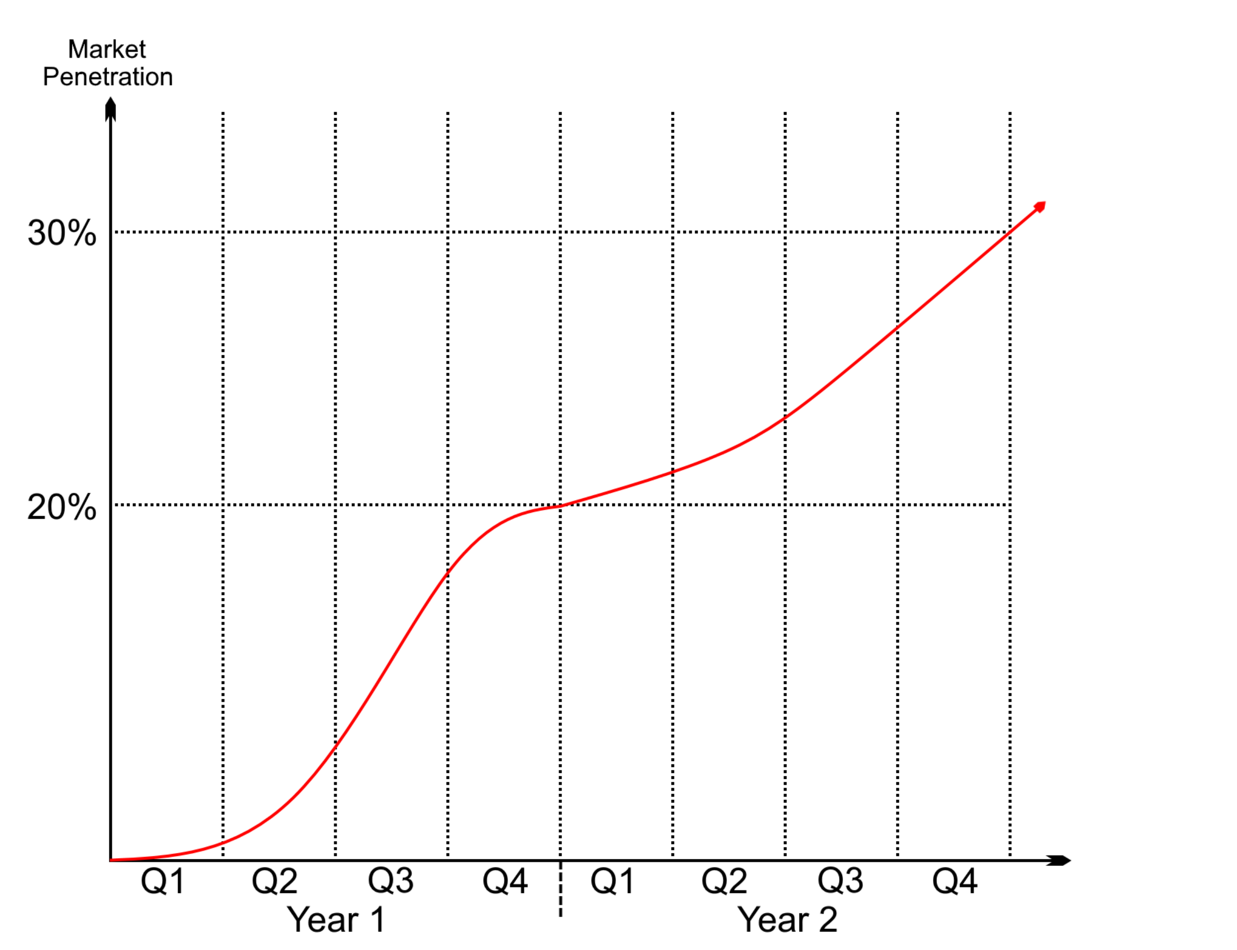
These OMNIS will be first be sold to DLA storage facilities. The OMNIS will be marketed as an extension of the worker's natural capabilities, to boost productivity, not as a replacement for workers.

Success with the DLA's first wave of units will prove to private enterprises that there is a substantial profit to be made by using this new technology. Ideally, a warehouse will purchase one OMNIS for every active floor employee. A training course detailing the handling, care, and functions of each OMNIS is imperative for its commercial success. An online training program will be provided for free with each sale. APDS will alternatively sell in-person training courses for companies that prefer that means of receiving professional development.

APDS' target is to deliver new OMNIS devices and external sensors to 20% of the private shipping and warehouse industry in the first year of Phase III after the delivery waves to DLA has finished. Over 350,000 people work on the floor of warehouses, locating and moving items. If APDS sells to only 1 in 10 (10%) of workers in 20% of the warehouses in America, that represents sales of 7,000 units. At an estimated cost of $8,940 per unit, this will represent sales of slightly over 62.5 million dollars. With an estimated marginal profit of $4,000 per unit, this will translate into total profits of 28 million dollars at the end of the first year of commercialization. With successful results and an aggressive marketing campaign, market penetration is estimated to rise to 30% at the end of the second year of commercialization, representing profits of 42 million dollars on 94 million dollars of sales.

Diagram 3 displays the quantitative estimates that will be achieved during the first two years after the initial DLA waves are completed.

DIAGRAM 3. COMMERCIALIZATION FORECAST



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. He has worked as a professional software developer for twenty-three years. Two of these years were spent at Kaiser Electro-Optics, Inc. where he wrote software for military-grade AR and VR headsets for the Air Force and Army. Two other years were spent working on a Qualcomm project to create a jam-resistant videoconferencing system for all branches of the military. He has also developed a virtual reality online classroom for education and training purposes, that has sold well over the years. Mr. Kerney is concurrently the head of Computer Science at Clovis Community College in Fresno, California.

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 receiving 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. He was one of the first developers to publish an application on the Microsoft HoloLens store. Mr. DiFuria has also performed private work for CART where he has developed AR applications that teach students how to operate heavy machinery in the 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 with Zach DiFuria.

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 system to improve its workflow. He has experience building and disassembling hardware devices such as the HoloLens. He is also an software developer who has taught classes on app development for mobile systems and has successfully finished many software projects, such as a Unity app for the UC San Francisco School of Medicine. Unity is the base software package used in the Microsoft HoloLens.

Christian Barrett
Application and System Developer

Background:
Christian Barrett is a real-time rendering engine developer who specializes in designing and implementing heads up displays (HUD) in Unity. He has worked with a team of developers to deliver new, intuitive applications for the AR market.

8. Foreign Citizens

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

9. Facilities/Equipment

In order to obtain a competitive market edge, testing of Phase I AR gadgets will need to occur at a facility which provides challenges that a final product would endure.

9.1 Facilities

In order to achieve accurate, reliable data, testing will occur within a warehouse which operates similarly to a distribution center. APDS has already contacted an electronics warehouse and reserved a space for research and development of such AR products (23). Scanners and tracking devices will be mounted onto shelves, pallet racks, and industrial machinery. This facility will help assist with the transportation and storage of all equipment needed for testing. A fixed experiment location provides a quality-controlled environment to make sure any and all products tested here are accurately measured and recorded.

9.2 Equipment

A variety of AR products are needed to conduct the evaluation efforts in Phase I. Necessary devices include a Microsoft HoloLens and Meta 2 Development Kits, in conjunction with Manus VR gloves, hard hats, and external batteries. These devices and components will be tested at the warehouse to provide accurate information on latency, effectiveness, modifiability, and safety. RFID tags and sensors will be purchased in bulk and tags will be applied to crates throughout the test warehouse. The researchers on this program will write code to integrate the RFID location data into the AR space, and test to see how much this improves productivity of warehouse workers using the headsets.

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.

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