Gemstone Program

University of Maryland

Proposal, Team ARM IT

Augmented and Virtual Reality in Relation to UAV Capabilities

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Honor Pledge:

We pledge on our honor that we have not given or received any unauthorized assistance on this assignment/examination.

February 17, 2016

Abstract - Search and rescue operations are challenging due to the limited time in which to the locate the subject, the hazards imposed on the rescuer and the difficulties of the non-local distribution of the full rescue team. Team ARM IT is developing a virtual and augmented reality interface that controls a mounted camera payload on an unmanned aerial vehicle through a head mounted display. This will allow rescuers to manipulate an unmanned aerial vehicle to assist search and rescue missions safely and effectively through telepresence and enhanced situational awareness. We plan to test our hypotheses by prototyping, testing, and refining individual components of the system through the use of flight simulation software and on-site testing. By providing a realistic sense of the UAV environment enhanced with relevant information, our project will reduce the danger to the rescuers and provide cognitively natural situational awareness.

I. Introduction

Team ARM IT plans to research how **virtual reality (VR)** and **augmented reality (AR)** technology can be incorporated into **unmanned aerial vehicles (UAV)** to aid the operator in Search and Rescue (SAR) operations. By utilizing this technology, the pilot will have greater control over what they can see from the UAV as well as have a more realistic sense of the UAV's environment. Relevant information can also be displayed on the video stream, which allows the operator to focus on searching for victims rather than monitoring the UAV itself. Overall, utilizing AR and VR technology within a **head mounted display (HMD)** will be beneficial to SAR UAV operators.

The questions that ARM IT intends to investigate are as follows: How can **stereoscopic vision** improve UAV operations? How does a VR and AR video feed affect operator visualization of a scene? How can a VR and AR interface improve on existing search rescue methods? The answers to these questions will provide a realistic sense of the UAV environment enhanced with relevant information. Thus our project will reduce the danger to the rescuers and provide cognitively natural situational awareness.

First and foremost, ARM IT’s first hypothesis posits that utilizing stereoscopic vision through an HMD will give the operator a greater sense of depth perception, resulting in better obstacle avoidance as well as a more natural view of the UAV’s surrounding area. Using this stereoscopic camera feed, the operator will be able to pilot the UAV with greater efficiency than they would be able to with a traditional UAV control setup.

The team’s second hypothesis proposes that a VR and AR video feed providing head-mounted control of a camera will allow greater control over the visualization of a particular scene. In traditional methods of UAV control, the camera is controlled by means of a joystick and provides only a monoscopic view of a particular scene. Incorporating VR and AR technology provides more information for the operator without the operator physically needing to be at the scene through the inclusion of stereoscopic vision and video feed overlays.

Finally, ARM IT hypothesizes that a VR and AR interface will greatly improve on existing search and rescue methods by allowing the operator more control over their vision and interpretation of a particular search and rescue scenario. With a VR and AR interface, the pilot will also be able to view relevant and real-time information as they control the vehicle, such as altitude, power remaining and distance from the operator. As a result of using VR and AR technology, ARM IT believes that conventional search and rescue methods will be improved and overall have a greater success rate.

II. Literature Review

A. Introduction

Team ARM IT is developing a new and advanced interface for piloting UAVs to assist in SAR operations. The objective of SAR is to locate subjects in disaster areas as quickly as possible. Disaster areas are treacherous environments, in which the sheer size and complexity of terrain pose a great challenge to SAR teams. The challenge is twofold: rescuers must place themselves in danger and locate subjects within the time constraint. In both of these situations, UAVs can significantly mitigate the risks of the SAR team and speed up SAR operations. With Team ARM IT's new interface based on VR and AR, rescuers can manipulate a UAV to execute SAR missions safely and effectively through telepresence.

B. UAV Capabilities

There are several ways in which UAVs overcome the difficulties of SAR. Complex terrain does not inhibit UAV navigation since the aircraft hovers above the area. In addition, the deployment of a UAV reduces any threats posed to either the rescuer or the victims, as the use of a UAV removes the operator from the scene, eliminating the risk of physical injury to the operator and the physical weight of the rescuer shifting rubble, thus avoiding further harm to the victim [1].

Any UAV that transmits video can aid in the location of missing persons, the assessment of a building's structural integrity, or the measurement of the extent of a forest or building fire. A survey of commercially available UAVs shows recurring characteristics between manufacturers [2-7]. Most manufacturers emphasize the "force multiplier" capability of these vehicles, which allows one or two operators to inspect larger areas of ground in a shorter time [2-7]. On average, small UAVs are 4-6 lbs and approximately 36” across. A majority of these systems are **multirotors**, which are UAVs with three or more long arms with a propeller (rotor) at each end. The flight time of these systems varies from 10 minutes to an upper range of 45-60 minutes depending on battery capacity and payload [2-7]. Many systems also advertise modular payloads which can be swapped out in different situations [2-7]. The payload capacity of this UAV size ranges from 200 to 1000 grams. In its simplest form, the UAV requires only a video camera, communication modules, and flight capability. However, the surveyed UAVs often additionally include infrared imaging, and have an operational range of 1-2 km without larger upgraded antenna setups. Other useful capabilities include thermal imaging, chemical detection, and network coverage extension to assist rescuers [8]. While costs prohibit the use of these sensors in this research project, future teams may consider their usefulness.

The two most common existing UAV control mechanisms are the tangible user interface, such as a joystick or wheel, and the graphical user interface [9]. Both these methods rely on sending and receiving information remotely to the aerial vehicle by using an onboard communication device [10].

Tangible interfaces are commonly used by both manned and unmanned aircrafts [10]. For manned aircrafts, a primary joystick controls the roll and pitch, a secondary joystick controls the thrust of the rotors, and a foot pedal controls the yaw. Larger UAVs, such as military or research vehicles, often use a setup similar to manned aircraft to accommodate pilots previously trained in manned aircraft [10]. Small UAVs, such as those used by hobbyists and videographers, use a radio control transmitter with two 2-axis joysticks. The most common control scheme maps pitch and roll control to the right stick and thrust and yaw to the left stick [9]. Other commonly used tangible interfaces include the gamepad and the remote, which are primarily used for video games [9]. The gamepad model is a variation of the joystick model, with a combination of buttons and small joysticks mapped to vehicle functions and directional commands. The remote, on the other hand, acts as an extension of the arm, allowing a user's gestures to control the system.

Graphical user interfaces (GUI) consist primarily of computer screens designed to provide the user with information regarding the UAV, such as data streams or control systems [11]. More specifically, a GUI can be a mobile device, such as a smartphone or tablet, or a computer, such as a laptop or desktop. Mobile devices in particular are popular for controlling recreational UAVs [9]. The benefits of mobile devices as control mechanisms are their portability, universality, and compatibility with various applications. The drawbacks, however, include the small size of the screen, the lack of processing power, and the lack of feedback from the controls. The last problem is of particular importance, especially when compared to tangible control mechanisms. Due to the mobile's touch screen features, the user loses tactile feedback received from a tangible mechanism's physical position of the control. This limitation presents a significant issue for creating more intuitive controls. On the other hand, in contrast to mobile devices, computers offer larger screens, more processing power, and more control options. However, in designing computer interfaces, these increasingly complex systems require a higher data transmission rate as more information is exchanged between the user and the UAV [11].

C. Monoscopic and Stereoscopic Vision

The objective of a search and rescue mission is essentially an object recognition problem. The human brain recognizes an object by first distinguishing the shape of the object and then profiling the object by searching for patterns that can be matched to a memory bank [12]. The first step, outlining the object, is done through visual cues such as contrast or depth perception. Depth perception is the phenomenon by which observers can distinguish the distance between layers of objects in their field of view (FOV). This increases environmental and situational awareness, which is highly desirable in SAR [13].

In humans, depth perception comes from a variety of both monocular cues, such as motion, perspective, and occlusion, and binocular cues, such as stereopsis [14, 15]. Stereopsis arises from the disparity between the two points of view caused by the distance between human eyes, called the **interpupillary distance (IPD)**. By processing two images taken from different angles, the human brain can focus on an object within the eyes' FOV and, through instantaneous implicit calculations, deduce the focal length. Thus, two image projections are used to create depth perception, achieving a 3D effect from 2D imaging [16]. Depth from monoscopic images or videos would only be attainable through the monoscopic cues, while stereoscopic videos provide both monoscopic and stereoscopic cues. A 2004 study used a Maximum Likelihood Model to show that the reliability and accuracy of depth perception increased when both stereoscopic and monoscopic cues were made available to the observer, as the brain processes and combines the cues in a statistically optimal fashion to make up for any errors [17]. Stereoscopy has also been shown to be a major factor in detecting an object camouflaged in an environment [18]. Therefore, utilizing stereopsis in search and rescue UAVs would increase the accuracy in the depth perception of the operator, which would in turn increase the chance for object or person recognition.

Stereopsis is attained through the recreation of a human's binocular vision using two image sensors or cameras. A binocular system similar to that of human eyes can be constructed by positioning two cameras adjacently and orienting their lenses toward an object. The image output of each camera will be relayed to each eye through the use of an HMD. The HMD will display the images taken by the camera on the left to the user's left eye and will display the images taken by the camera on the right to the user's right eye . The **interaxial distance (IAD)**, or the distance separating the centers of the two camera lenses, must closely match the user's IPD in order to mimic the user's optical system [14, 15].

Two methods exist in replicating the user's optical system. The first uses readymade stereoscopic cameras (two camera modules placed on one circuit board) which eases image processing as such systems output a single stereoscopic image (two images side-by-side). These systems, however, have fixed IAD since the cameras are locked onto the baseboard and consequently do not accommodate the variance in human IPD. As human IPD varies from 52mm to 78mm, it is worthwhile for the IAD of the cameras to be adjustable to account for this variance in users of the stereoscopic system [19]. The second method, as an alternative to fixed stereoscopic cameras, places two cameras purchased separately in a stereoscopic case that holds the two cameras adjacently. This would allow freedom to adjust the IAD to match a particular user's IPD. Naturally, a high resolution camera is desirable such that the user can view the environment with enough clarity to identify small details. The optimal resolution of the camera is determined by the HMD to be used.

D. *Augmented and Virtual Reality Interface*

According to Fox et al., VR is a “substitute reality” where people can interact with non-real environments and objects in an exclusively digital world [20]. While virtual environments have primarily been used for gaming and immersive simulations, AR overlays computer-generated graphics onto the real world [21]. AR enhances the real world as opposed to virtual reality, which replaces the real world. AR is primarily used to enhance human performance by adding critical information to the user’s view (e.g. an aircraft pilot’s heads up display) [21]. These displays not only provide additional information about a situation, but also allow the user to make real-time decisions.

The **Oculus Rift (Oculus)** will be the main VR platform utilized in this project. The platform was initially created as a VR gaming headset but has proven to have further applications within the bounds of VR [22]. It is an open-source project, and accordingly the System Developer's Kit (SDK) is completely free [22]. The Oculus is also compatible with the Unity and Unreal Engine gaming engines, and is most suited for the C++ programming language [23].

The major reason the Oculus was chosen for this project was for its commercial availability, relatively low cost, and open-source modification ability [23]. In addition, the Oculus provides a large range of developer's tools through its two readily available versions, the DK1 and DK2, which are internally very similar but have significant differences [22]. The DK2 ($350) features about twice the visual display power of the DK1 ($300) as well as positional tracking, which allows for more accurate registration of the user's head movements [22]. The HMD features a built-in gyroscope, accelerometer, and magnetometer which are able to read the yaw, pitch, and roll of the user's head and adjust the displayed image relative to the user's movements [22]. The DK2's additional positional tracking adds a fourth degree, allowing the user to lean in closer or further away from a point or peek around a wall. This added degree also reduces dizziness and confusion while using the headset [22]. The sampling and frame rates of the images are extremely high in order to reduce blurriness, double imagery, and "ghosting" of the image [22]. Oculus developers highlight the necessity of using correct distorting and calibrating values while displaying the image in order to mirror human vision [26].

However, the Oculus faces many drawbacks due to the inherent nature of VR technology, which can cause disorientation and strain on the part of the user [23]. For example, the Oculus has a high data draw of a 1920 x 1080 resolution and 75-hz refresh rate [23] and requires two cameras of resolution 1080 pixels by 1200 pixels in order to best synchronize image data to create stereoscopic vision and avoid **VR sickness** [14]. This resolution will require extremely high rates of data transmission between the **ground control system (GCS)** and the UAV. Unnatural degrees of motion, such as sudden acceleration or strafing side to side, also have to be restricted to avoid disorientation on the part of the user, which could affect the autopilot used for the UAV [23]. Latency in the displayed images can also contribute greatly to VR sickness; Oculus developers suggest maintaining the smallest amount of variance in the degree of latency as possible [23].

Search and rescue teleoperations can become challenging to navigate without a direct perception of the environment [27]. By using an HMD such as the Oculus to control a camera payload through head-tracking, situational awareness can be increased through a wider field of vision and the incorporation of depth perception [28]. Currently, two approaches exist to implement this method. The first is using a Free-Look Augmented Reality Display module to retrieve panoramic images taken from a spherical camera and to send these images to the HMD. The panoramic images are then stitched together and wrapped onto a sphere mesh, where images are split, one for each eye, to create a 3D image. However, this process is time consuming and any stitching errors that occur can cause disorientation, resulting in a trade-off between real-time data and image resolution [29]. The second method uses stereopsis, a process where two projections of an image are used to create depth perception, in which two stereo cameras can achieve a 3D effect from 2D imaging [28]. Head-tracking is achieved through the head teleoperation module, where the roll movement is used to control the camera. The angle of head orientation determines the degree that the image must roll in order for the projected images to match the user position. A drawback to this method is the lack of a pan or tilt movement with head-tracking, resulting in a loss of visual information. This function can be achieved by adding a pan and tilt mounting to the stereo cameras and by correlating the yaw and pitch movements to the panning and tilting of the camera [30]. By improving upon this method, high image resolution and decreased latency can be maintained while adding depth perception, which will increase situational awareness for operators.

By presenting information that the user cannot see, AR visual overlays can increase an operator's situational awareness, which is useful for UAV operations [31]. A user's perception can be enhanced when viewing the real environment through the highlighting elements of interest, such as key landmarks or flight information from sensors [32]. The combination of sensor imagery with visual overlays reduces a user's scanning time while integrating information from disparate sources, allowing the user to concentrate on the task at hand [32].

Several issues become prevalent with using AR displays in regards to view management, the spatial layout of 2D objects [33]. The quantity of extra-sensory information displayed becomes a problem, as large amounts of information can cause displays to become cluttered [31]. Cluttered displays, often the result of unnecessary information, have the potential to overwhelm users, impacting the user's ability to complete a task [34]. Another aspect of view management is objective readability. In a study done by Azuma et. al., it was discovered that human subjects were able to read AR labels fastest when the labels did not overlap, even if the placement was not ideal [33]. Thus, projected information must be appropriately arranged so that virtual objects do not intrude physical objects; otherwise, the overlapping of objects or the obscuring of background objects can cause objects to become impossible to read [33]. Lastly, cognitive tunneling causes another issue with AR displays and occurs when operators become so fixated on the 2D object from the overlay that they neglect to pay attention to the real environment [32]. Thus, the view management of the overlay in regards to positioning and visibility is extremely important in developing the AR display as unclear 2D objects may cause the user to become overloaded by the amount of visual information displayed. [33].

There are several view management strategies that can be applied in order to overcome AR display issues. Reducing the number of labels on the screen is one such strategy. The application of a filtering scheme, a system of prioritizing key information, so that information can be selected based on relevance to the task at hand, and unnecessary labels can be removed can remove clutter [35]. In addition to avoiding overlap between 2D objects, it is also important for the overlays to be placed so that it does not interfere with real world objects [35]. This can be avoided by placing 2D objects only in regions where there is less movement and interest. [35].

To increase objective readability, overlays should not have any excessive movements that may distract the user [35]. In regards to textual 2D objects, features such as size, contrast, and font can be used to differentiate it from real-time surroundings [33]. The location of the 2D object must also be considered; for example, when considering labels, the farther the label is away from the corresponding object, the longer it takes for the label to be read [33]. Other image enhancements can be used in order to improve visibility of overlays or highlight certain features, such as contrast, brightness, and transparency [31].

Several applications of AR displays have been used in previous research. One type of overlay that has been discussed is the virtual flag, which highlights key landmarks in the real environment using computer generated symbols [32]. The flag overlay is helpful during navigation due to its ability to pinpoint locations of interest and due to its simplicity which prevents cognitive tunneling [32]. One such project that uses the virtual flag incorporates an interface that is capable of identifying friendly, neutral, and hostile figures by recognizing icon shape and color [36]. It also offers an intuitive view of the operational environment that can identify landmarks, sun position, and other useful information about the surrounding environment [36]. This research also included development for a version for pilots, which provided real time information about the current flight space [36]. This technology could be modified for use in UAV control to identify points of interest for a search and rescue team, such as footprints or signs of habitation.

Another application of the AR display allows novice pilots to be able to learn controls and complete tasks in less time than using traditional methods. According to Goldiez et. al.'s comparison study on navigating mazes with AR assistance versus traditional methods, AR capabilities improved a subject's ability to navigate a maze with more transversal accuracy; however, the time required to complete the maze was not significantly improved ($p<0.05$) [21]. The results from this study would have been more significant with more training for the AR users and fewer glitches in the software. Overall, Goldiez et. al. conclude that AR shows promise in navigating through waypoints, but more research must be done before a significant correlation can be established [21]. A similar study conducted by Darken and Peterson also indicated some correlation and promise with respect to virtual reality guided interfaces improving navigation through waypoints [37]. This study aims to utilize an improved AR interface along with stereoscopic vision and useful flight information to improve the effectiveness of UAVs in search and rescue tasks.

Several studies have incorporated the Oculus with AR. These studies built their prototypes using the Unity engine, as it provides a flexible platform integrated with the Oculus [38, 39]. One method of creating the overlays takes advantage of Unity’s ability to live stream videos to textures [38] and the software library Oculus Virtual Reality. The library allows for two cameras to render any digital content created in Unity and to create textures from the video connection data. [38]. Another method connects Unity to an AR software library Metaio, where one external camera takes in the real environment and another camera is used for virtual projection. Virtual objects are then rendered as a layer above the camera plane, and the two layers (the external camera and the virtual overlay) are merged and rendered to the Oculus [39]. Both are possible avenues to be explored when creating an effective overlay for the interface being developed in this project.

E. Data Transmission

Any UAV operation involving a human operator requires data transmission, as operator commands or video feeds must be sent to and received from the UAV. Both these tasks require communication to be consistent, accurate, and with minimum delay in order for the operator to maintain control and prevent VR sickness. For these reasons, a UAV being teleoperated by a user using an HMD requires two-way communication with enough throughput to stream live video and less than 50ms total latency from user command to video response [40].

Wirelessly transmitting raw video at the resolution and frame rates desired for HMD use is infeasible because of its large data sizes. Therefore, the video must be compressed on the UAV before transmission and decompressed at the GCS after transmission. Data compression is the process of converting information from one format to another format which requires less bytes of data to store or transmit. The most effective video compression algorithms work by generating each frame of video by storing only a fraction of the frames as full images and storing the rest as a set of changes from the previous frame [41]. The frames stored as full images are called "key frames" because the rest of the frames are dependent on them. Current video compression software is capable of compressing and decompressing video in roughly 10 ms [42], which is well under the threshold for VR sickness [40].

Teleoperation can pose challenges for the operator due to various factors. Video image quality may degrade over increased distance, obstacles, and signal interferences, resulting in poor spatial awareness. In a study, Van Erp and Padmos recommended the speed of transmission or frame rate (FR) to be at least 10 Hz to avoid poor video quality [43]. However, for navigation and tracking purposes, Thropp and Chen suggested to use higher FRs such as 15-16 Hz for more stable results [40]. Latency also poses an issue to teleoperation. A MacKenzie and Ware study demonstrates that error rates are increased by 64% when the latency is increased from 8.3 to 225ms. Supportingly, latencies as short as 300-320 ms would also have a significant impact on the operator’s tracking and spatial awareness [43]. While other studies found that latency under 1s did not have any effect on the operator, but it did delay the operation. Besides delayed operations, latency can also cause VR sickness which is caused by the discrepancy between visual and sensory systems [43]. To minimize the problems caused by latency, a predictive display system is advised. Studies indicate that using predictive displays during teleoperation reduced the operation time by 17% [43].

F. Testing

The organization that is responsible for the safety of civil aviation is the **Federal Aviation Administration (FAA)**. The major roles of the FAA include regulating developing systems for air traffic control and navigation for civil and military aircraft, registering aircraft and recording documents reflecting the title of aircraft and issuing and enforcing regulations and minimum standards regarding the manufacturing, operation and maintenance of aircraft. [44] With the recent increase in popularity of both hobby and military use of **unmanned aerial systems (UAS)**, the FAA has created regulations specifically designed towards UASs and similar systems. In order to utilize a UAS for business purposes, the user must receive a **Certificate of Waiver or Authorization (COA)** from the Air Traffic Organization by submitting an online form for FAA approval. [45] This form covers a variety of topics, including but not limited to; aircraft model, operating altitudes, equipment on the vehicle, frequency usage, surveillance equipment, and flying locations. [46] Another option for receiving permission to fly a UAS is through the Special Airworthiness Certificate, which can be obtained by contacting the Air Certification Service located in Washington D.C. [47] This would allow the UAS to be flown for experimental purposes, specifically relating to testing new aircraft design concepts, new aircraft equipment, new aircraft installations and new aircraft operating techniques [48].

The physical capabilities of the UAV and of the camera payload can be determined through a series of tests devised by the National Institute of Standards and Technology (NIST). The first attribute tested based on NIST standards is aerial station keeping. This test will measure the UAV's ability to maintain its position while identifying a target in accordance with the NIST standards. The UAV must maintain a stand-off distance of two meters for twenty continuous seconds while identifying the target [49]. The targets are to be placed on a vertical wall, five meters apart forming a square with one target at the center [49]. The operator must identify each target twice, with the condition that they may not identify the same target twice in a row.

The last of the NIST standard tests will be exterior building reconnaissance, which evaluates the actual search capabilities of the UAV [49] and validates the UAV's camera payload control system. The UAV will be required to identify subjects in certain windows of a multi-story building, with optional targets on the roof of the building. The setup of this test is similar to the previous test.

G. Conclusion

The surveyed literature discusses current SAR specific UAV capabilities, the characteristics of monoscopic versus stereoscopic vision, the current standards of AR and VR interfaces, data transmission, and finally testing of the developed user interface. As UAVs are aerial vehicles that can be controlled from a distance, they offer unique advantages in managing search and rescue operations, such as reduced danger to searchers and increased search efficiency. Based on the relationship among all of the factors described in the literature, we propose the following hypotheses: stereoscopic vision will improve UAV operations, stereoscopic vision will significantly affect UAV operator visualization, and that a AR and VR interface will improve upon existing search and rescue methods. These hypotheses agree with the team's goals and supports the concept of the system the team wishes to create. By utilizing stereoscopic vision to improve UAV operation and operator visualization, the team will be able to create a UAV system that allows search and rescue operators to locate victims more easily and efficiently while reducing the risk to human lives.

III. Methodology

A. Introduction

Team ARM IT proposes to develop an AR and VR interface to control the sensory payload of a UAV. Team ARM IT's research will be divided into three components and corresponding subteams: payload, platform, and GCS. The payload component will provide high-resolution stereoscopic vision for the UAV operator. The UAV platform will act as a navigation and transportation unit, allowing the operator to remotely interact with the environment. The GCS will consist of the VR user interface that controls the payload and displays the information from the platform on a HMD. This interface will be built to display on an Oculus VR headset.

Mixed methodologies will be utilized to design, build, and test a prototype. The prototype will be assessed quantitatively against current SAR methods outlined by the NIST. Variables to be analyzed will include course time completion, which will be measured by the time it takes for operators to use the interface to navigate the UAV, and search time per area, which will be measured by the time it takes to search a certain amount of ground. UAV operators will be able to decrease completion times of SAR operations through this VR interface that implements head tracking to control stereoscopic cameras on a UAV.

The research questions that will be answered over the course of this project are:

1. How does stereoscopic vision improve UAV operations?
2. How does utilizing VR as the delivery method for the video feed from the sensory payload affect how the operator visualizes the search and rescue environment?
3. How does a VR interface that controls a sensory payload of a UAV in order to conduct search and rescue improve on pre-existing search and rescue methods?

B. *Payload*

The payload of the UAV consists of the camera setup, batteries, transmission (Tx), and reception (Rx) equipment. Each component will be carefully selected based on the product's specifications and mission requirements.

Two GoPro HERO4 Black cameras will be used to simulate a single stereoscopic camera. The camera was chosen for its high definition 1080p resolution at 120 frames per second (FPS). The resolution and framerate of the camera is necessary to match the resolution of the Oculus, and to combat the effects of VR sickness [26, 50]. This allows for a clear video stream from the UAV to the HMD, which is required in SAR situations to distinguish environmental features [51]. Stereoscopic vision will be achieved by positioning the two cameras adjacently on the UAV and then transmitting the two video feeds from the cameras to the HMD. The IAD, or the distance separating the centers of the two cameras, must closely match the user's IPD, or the distance between the user's pupils, in order to mimic stereoscopic vision. As human IPD varies from 52mm to 78mm, the IAD of the cameras will be adjusted to account for this variance [19]. With the user in the **Frankfurt plane**, the distance between the subject's **supraorbital foramen** will be measured using calipers, preferably **anthropometric**, positioned parallel to the ground. The camera spacing will then be physically changed before flight to match the distance measured by the calipers. The cameras will be mounted on a 3-axis brushless **gimbal**, allowing the cameras rotational freedom to pan, tilt, and roll to match the user's head movements. A gimbal will be purchased as well as a 3D Dual GoPro mount. The two cameras will then be mounted on the dual mount, which will then be mounted on the gimbal.

A video downlink is needed to transmit the video from the camera system to the GCS. This can be accomplished by using a Tx/Rx radio communication device. Such communication devices which utilize the 5.8 GHz frequency are light, small, economical, and efficient and therefore commonly used for video Tx systems on UAVs [52]. These devices will be connected to a power source, the video output from the cameras, and finally antennae to transmit data to the GCS. A **circularly polarized antenna** will be used on the payload to account for maneuverability of the UAV and a **helical antenna** will be used on the GCS to allow greater signal strength and range, especially in **non-line-of-sight (NLOS)** situations [53, 54]. Depending on the team's analysis of how far the UAV should be able to fly away from the user, the team will purchase radio antennae of sufficient strength to permit such long distance flight. When making this analysis, the team will consider the amount of video and sensory data that must be quickly and reliably sent to the user on the ground, as well as the control data that must be sent to the UAV. The calculations for what setup would be necessary to transmit such a volume of data are complex, and an expert on electronic data transmission will be contacted to ensure that these calculations are correct. In the spring of 2016, after the team has obtained experience using the Oculus and the camera system, the team will obtain these communication devices to integrate the two systems.

Once a communication device has been chosen, the next step is to use the device to begin sending video data from the camera payload to the Oculus interface. The team will turn on the camera payload and manually rotate it to test for working video transmission between the two systems. If portable power sources become available, the team will test the quality of video feed at varying distances by transmitting data and moving the cameras steadily farther away. The team will then reevaluate the choice of antennae and reposition them, upgrade them, or make other adjustments as needed. Finally, the angle of the two cameras on the payload will be calibrated in order to ensure proper and natural stereoscopic vision.

Two separate rechargeable battery packs will be used to power the gimbal motors and transmission equipment since the two have different input voltage requirements. Purchase of the cameras includes rechargeable batteries, so a power supply for them is not needed. Gimbals generally require an input voltage of around 12 V. Transmission equipment on the UAV has an input voltage range from 6 to 25V. Two 11.1V 3s Lithium-ion polymer (LiPo) battery packs will be used due to their high storage capacity to weight ratio. The transmission equipment and power components will be assembled according to Figure 1.

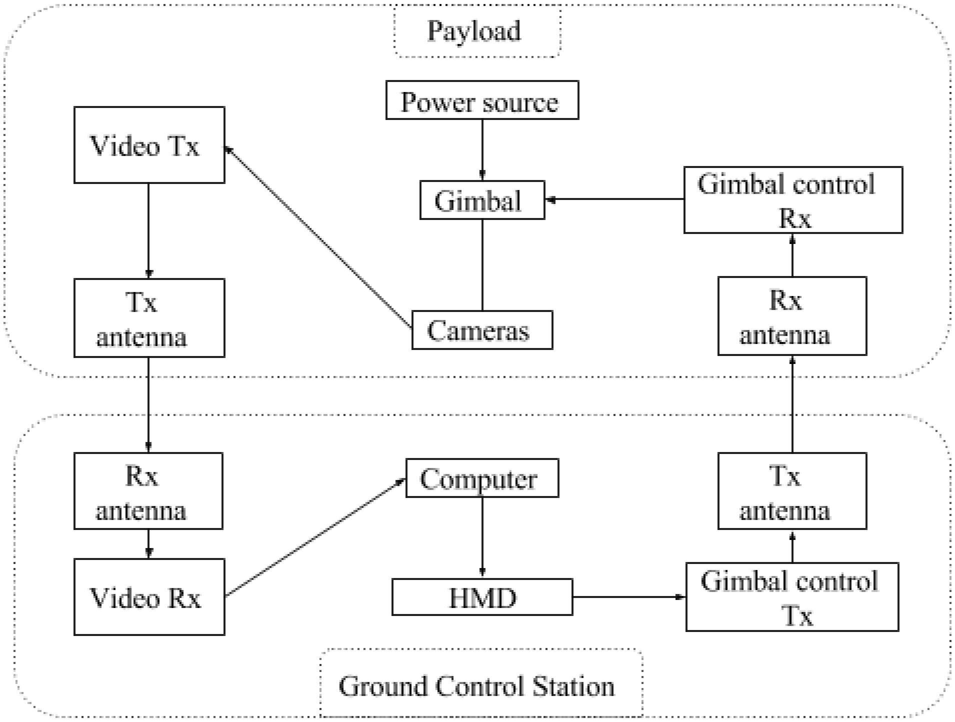

Figure 1 - Transmission and Power Diagram

A summary of estimated prices and weights is given in Appendix A.

After assembling the camera setup and transmission equipment on the UAV, communication will be established between the cameras and the HMD. The reception of this data as well as displaying this video data on the HMD screens will be discussed in the next section.

C. *Ground Control System (GCS)*

The GCS for this project consists of the Oculus VR display, the computer, the controls for the aircraft, and the communication equipment. The user of this system will control the aircraft from ground control and will receive video feed and data from the aircraft using the Oculus. This section will discuss the process for assembling and testing the GCS.

The Oculus requires a computer with certain hardware specifications. For the consumer release version of the Oculus, which will be released in Q1 of 2016, the minimum computer hardware requirements are very high. The consumer version requires a NVIDIA GTX 970 or AMD 290 graphics card, an Intel i5-4590 processor, 8GB of RAM, two USB 3.0 ports, and Windows 7 or higher [50]. While most of these requirements are reasonable for a modern computer, the requirements for the processor and especially the graphics card are quite strict. As such, the team will either need to purchase or build a computer that will meet these requirements or else the Oculus experience will be suboptimal.

In order to navigate the UAV, control the cameras, and take the camera's output and correctly display it onto the HMD overlay, the team will need to utilize open source libraries that contain the necessary code and functions to allow the UAV, cameras and HMD to function properly. There are many open source libraries to consider, such as **Robot Operating System (ROS)**. ROS deals with communication with sensors and is referred to as middleware, because it acts like a middleman between a robot and the controller [55]. ROS also deals with diagnostics, robot geometry, and mapping of the robot's surroundings.

Another library to consider is **OpenCV**, which is the world's leading open source computer vision and machine learning software library [56]. OpenCV can be used in C/C++, MATLAB, Java, and Python and is compatible with different operating systems such as Windows, Linux, Mac OS, iOS, and Android. OpenCV has many algorithms pertaining to video which can be used to detect and identify objects and humans. This library would be used to process the camera data and overlays, and would aid in outputting this information to the HMD. The team needs to learn how to incorporate these libraries and any others that might be used into their code as well as know how to utilize them to achieve the desired outcome of the project.

Other code found during research includes an open source program on Github created by a team from the Norwegian University of Science and Technology with a similar but smaller scale goal to control a camera payload on a UAV using an HMD [57]. This is similar to what ARM IT plans to do, in that they control a camera using the gimbal outputs from a VR headset. This code will be evaluated in order to determine whether it can be applied towards Team ARM IT's research. If the code is found to be insufficient, further research will be conducted on head tracking algorithms.

A crucial step in the progression of Team ARM IT's research is obtaining the HMD itself, which will be a version of the Oculus. The team will be ordering the consumer release version of the Oculus once it is released in the first quarter of 2016. The team will utilize the Oculus SDK, which is the development software that allows people to interact with all elements of the Rift and create programs supported by the device [58]. The beta version of SDK is offered for free on the Oculus website, with the current version being 0.7 [59]. The first release version of the kit is being distributed in November 2015 [59]. The SDK will allow the team to access data from the head tracking sensors which can then to be used to control the cameras on the UAV. The team will also use the SDK to output the virtual reality (VR) overlay to the device.

The team intends to use head tracking to give the user the ability to intuitively change camera orientation by moving their head. To accomplish this task, the system needs to gather data on the position of the user's head, convert it into a form the camera gimbal can use, and transmit it to the payload. The Oculus has built-in capabilities to measure the pitch, roll, and yaw of the user's head which satisfy the need to gather data. The Oculus outputs this positional data in the form of three axis vectors, which is the same form needed by the camera gimbal. Although the Oculus does produce data in the format the gimbal uses, there may still need to be a conversion if the Oculus and the gimbal use different angle units. Once the data has the right format and units, it can be sent to the payload through the ground control station's transmitter. The UAV’s navigation control system will be discussed later in the Platform section.

The team needs to reach a final consensus on what information should be included in the VR overlay before it is implemented. Some options the team currently wants to include on the VR interface include a compass, altitude, signal strength, and battery life. Each of these aspects is essential to ensure the user is well informed about the state of the aircraft. If time and money permits, speed and direction, outside communications, an infrared sensor, and more advanced **global positioning system (GPS)** capabilities could also be included in the overlay. More advanced GPS services could aid the user in understanding the location of the aircraft and possibly tell the user where they have already searched. In order to implement each of these options, the corresponding sensor would need to be purchased and equipped onto the UAV, and the data from that sensor sent to the GCS. A panel of information will be designed and programmed to include this information. This panel will then be overlaid on the video feed from the camera payload, so that the user can view both the information panel and the video feed at the same time.

D. Platform

To test the payload under realistic conditions, a suitable UAV platform is required. The platform will need to accommodate the weight of the payload, navigate a complex environment, and maintain stability for use by a novice operator. For these reasons, a multirotor-type airframe will be chosen for this project over a fixed wing-type airframe. A multirotor-type airframe can stop, hover, and move in all directions below the stall speed of a similar weight and size fixed wing airframe, which relies on forward motion to generate lift. This allows the UAV to maneuver in more complex and confined environments than fixed wing alternatives. Multirotor-type airframes also allow independent movement in all three spatial axes, giving intuitive control to an operator using a HMD streaming video from the perspective of the UAV by translating inputs from the user directly to the movement of the airframe. The ability of a multirotor UAV to hover will also allow for test flights in smaller indoor environments, enabling more efficient testing.

To determine which frames, motors, rotors, electronic speed controls, batteries, and autopilot will be used to construct the multirotor test platform, the mass and size of the payload must first be determined. The size of the payload will determine the minimum size of airframe that can be used, based on physically attaching the payload. From there, combinations of airframes, motors, rotors, and batteries will be analyzed using manufacturer specifications and the intended flight time to determine which of those components should be used. Electronic speed controls that can handle more current than the motors can draw will then be obtained (to maintain a safety margin). Finally, an autopilot will be chosen (if it has not already been chosen in an earlier stage of the process) based on its compatibility with the payload, ground control station, and other pertinent hardware or software. The initial testing configuration is expected to be finalized by Spring 2017.

Once the final testing configuration of the vehicle is known, an application for a COA from the FAA will be completed and sent through the appropriate faculty at the University of Maryland. The COA will, if approved, allow for outdoor research testing of the vehicle under

FAA regulations [45], which will be conducted at the closest safe testing area, Free State Aeromodelers (6050 Van Dusen Rd, Laurel, MD 20707).

To control the UAV, several control methods will be tested to determine which method provides the most intuitive control to a novice operator. These control methods will include, but are not limited to, standard commercially available dual-stick radio controllers, other commercially available joysticks, **Oculus Touch** controllers, and **Leap Motion**. To test these control methods, volunteers will fly the platform through an obstacle course in a modified consumer UAV flight simulator (such as the "FPV Freerider" Unity engine-based multirotor simulator [60]) that will allow for minimum risk integrated testing. This simulator will be modified to display the view from a simulated UAV on the Oculus. The simulator will take input from the Oculus and one of the control methods mentioned earlier in this paragraph to operate the simulated UAV in a manner similar to the expected platform. Multiple SAR scenarios will be modeled in the simulator, and each volunteer will fly each scenario once. The control method will be different for each volunteer, allowing for an assessment of the effectiveness of each method. Performance of each control method will be evaluated based on the time of completion for each trial, with lower completion times being optimal, and user feedback from a qualitative survey. The anticipated results of this test are physical control schemes (joysticks and physical controllers such as Oculus Touch) outperforming intangible controls such as the Leap Motion.

E. Testing

Testing will be an ongoing process during this project and will be divided into several distinct phases. After completing initial testing in the payload, ground control, and platform, the team will test the prototype against SAR standards from NIST.

The finished UAV will be different from current SAR UAVs in a variety of ways. The primary modification will be the inclusion of stereoscopic vision, adding depth perception to the HMD visual displays. This feature will allow for better control of the UAV by allowing the operator to gauge distances and maneuver the UAV more precisely. Overlay displays will be added to the foreground of the HMD visual display to add additional information (i.e. airspeed, geographical location, altitude). By incorporating this feature into the HMD processes, an optimal user interface will be produced allowing users to access real-time data in the most efficient manner possible.

Data will be collected that corresponds to the standards set by NIST for **small unmanned aerial systems (sUAS)**. Standards are given by size of the UAV in terms of lateral clearance. Preliminary testing will be conducted via flight simulations to validate vision payload systems. It will consist of ten trials per operator, randomizing the vision experienced first either monoscopic or stereoscopic, labeled only version 1 and version 2. There will be five set target locations and the order in which the operator is searching for them is to be randomized. The operators will be controlling both the flight of the simulated UAV and the vision payload system on the UAV. In compliance with the Institutional Review Board (IRB) standards, optional surveys will be conducted before and after the participants complete the trials. Before they begin, subjects will be asked if they have any experience with the operation of UAV, and, if so, how extensive their experience is in terms of flight time hours.

Experience Level	**Hours of Flight Time**
New	0
Beginner	1 - 10
Advanced	> 10

Participants will be sorted into three categories based on their amount of flight time: new, beginner, and advanced. After the participants complete the test, another survey will be conducted using a comparative scale. The results will be analyzed using the **Wilcoxon-Mann-Whitney** statistical test, which will show whether there is a statistically significant difference between the times collected for monoscopic and stereoscopic trials. Quantitative data will be collected, including simulation completion time and the number of people located.

Attribute testing will be conducted at the Maryland Fire and Rescue Institute, and will determine the capabilities of the UAV in a search and rescue function. The operators for these tests will be selected from the team by a random number generator selecting three team members. The first attribute tested based on NIST standards will be aerial station keeping. This test will measure the UAV's ability to maintain its position while identifying a target in accordance with the NIST standards. The UAV must maintain a stand-off distance of two meters for twenty continuous seconds while identifying the target [49]. The targets are to be placed on a vertical wall, five meters apart forming a square with one target at the center [49]. The operator must identify each target twice, with the condition that they may not identify the same target twice in a row. The confounding variables for this test will be the operator's experience level and the outside conditions. Wind will play a large role in how well the UAV is able to maintain its station.

After testing aerial station keeping, the second test will be aerial endurance of the UAV. This test will measure the UAV's ability to maintain flight under adverse conditions [49]. For this test the UAV will be tethered to the ground in an outdoor testing location and will simulate flight conditions, such as multiple turns in windy conditions and high speed maneuvers, until the battery level reaches fifty percent. At this level of battery charge, a UAV in the field would return to the operator for recharging. This process will be repeated for a total of ten trials and the total time will be averaged to give the endurance and range of the UAV. Possible confounding variables include the simulated flight path and the simulated conditions. In order to minimize the effect of these variables, each flight path will be simulated twice in order to get a more accurate value for the endurance of the UAV.

The last of the NIST standard tests will be exterior building recon, which evaluates the actual search capabilities of the UAV [49]. The UAV will be required to identify subjects in certain windows of a multi-story building, with optional targets on the roof of the building. This test will be conducted at the Maryland Fire Research Institute. The targets will be placed in both open and shut windows, with some flush mounted to the window and some two meters inside the window. This test will prove the ability of our UAV to perform in an urban setting. The time it takes to identify all of the targets will be recorded. It is expected that the operator of our UAV to be able to find the targets faster than the existing baseline of times for this test. Possible confounding variables include wind and light variation, operator inconsistency, and communication fidelity. Light variation and communication fidelity will most affect the ability to identify the targets, as the operator will largely rely on the video transmission for the search.

F. *Anticipated Results*

The anticipated results upon completion of the VR interface are a user preference for the stereoscopic vision and for faster completion times of the course when using stereoscopic vision in order to determine that the finalized product can improve SAR operations. While SAR teleoperations reduce danger as the UAV can be controlled from a distance, they are challenging without direct perception of the environment. These anticipated results will be an important contribution to the research field as the VR interface increases situational awareness for UAV operators by providing wider field of vision and depth perception. In addition, the interface will include overlays to supplement flight information related to SAR tasks to the operators.

IV. Conclusion

UAVs used in tandem with VR and AR technology offer unique advantages in managing SAR operations. UAVs allow for a more efficient and rapid search while keeping the operator out of harm's way, and VR and AR technology allows for an operator to have a more realistic and in-depth view of the environment in order to easily find points of interest.

In this paper, the team has discussed the costs and benefits of various UAV models, of various user interfaces, and of modern VR technologies. Additionally, the team has explored alternative methods of interacting with a remote UAV. Several methods exist for controlling a UAV, ranging from a physical control to a graphical interface. Additionally, numerous options exist for communicating with the UAV at a distance, often with a trade-off of improved reception for more power consumption. The preferred method of controlling a UAV is through a combination of stereoscopic camera inputs linked to the HMD and an AR interface overlaid onto the video feed. Through an intelligent combination of these features, the efficiency and ease of using UAVs in search and rescue situations can be improved.

The payload, GCS, and platform are used in tandem to incorporate VR and AR into UAV controls. The payload component will be accomplished by obtaining stereoscopic vision from two cameras, building the camera platform, and transmitting video feed to the HMD. After completion of the payload, development of the platform will begin by selecting a UAV based on the weight of the sensory payload. The GCS focuses on the development of the Oculus as a control mechanism through head tracking to control the camera payload. Once the head tracking mechanism is ascertained, communications will be established in order to receive video feed and data from the UAV as well as the development of VR overlays. Finally, after assembling all three components, the finalized product will be tested to see if UAV capabilities have improved in regards to speed of searching an area. To do so, the UAV will be tested against NIST standards. Additional testing will occur through timed trials and surveys for the completion of a course with monoscopic versus stereoscopic vision. Qualitative analysis will be conducted through the surveys, where users will be asked their UAV expertise level and which vision system they preferred. Quantitative analysis is conducted by comparing the completion times of the course and determining if a certain vision produces faster completion times.

The results of this research could greatly impact how SAR operations are conducted. The VR/AR interface can increase SAR success rates by decreasing the cost in human resources and search time while reducing injuries to both searchers and victims. In the future, the project results could be used in high risk SAR operations to find lost individuals quickly and safely.

V. Appendices

Appendix A
Summary of Estimated Prices and Weights of Payload Items

Item	Estimated Price (USD)	Estimated Weight (g)
GoPro HERO3+ (x2)	1000	300
3-axis gimbal	800	300
ESC	500	50
Tx module	300	60
LiPo Batteries (x2)	100	60
CP antenna (x4)	80	40
Total	2780	810

Appendix B
Summary of Estimated Prices of Platform Items

Item	Estimated Price (USD)
Autopilot	1000
UAV w/ propulsion system and Batteries	3000
Charging Equipment	350
Control Methods	2000
Total	6350

Appendix C
Initial Timeline

Quarter	Tasks
August 2015	Literature Review Methodology Obtain lab UAV Determine computer requirements Obtain NVIDIA graphics card Complete lab safety training Experiment with stereoscopic vision (ZED)
October 2015	Obtain COA Obtain RC control Work on HMD overlay content Complete research proposal draft Begin finding experts to guide research Create budget outlook Determine flight simulation software
December 2015	Apply for grants Capture and display video from cameras Work on HMD overlay content
February 2016	Apply for grants Defend thesis proposal Obtain Oculus Learn to use Oculus Obtain communication hardware Assembly Tx, Rx, and power components Prepare for Undergraduate Research Day Autopilot tuning Image processing/recognition Experiment with head tracking Obtain video feed from cameras
April 2016	Decide on HMD overlay content Output head tracking data Transmit Video

	Develop flight simulation Begin subsystem testing Revise budget Revise literature review Revise methodology Submit IRB paperwork
June 2016	Decide whether to use IR Decide UAV frame Obtain project UAV Continue with image processing/recognition Evaluate cameras effect on operator efficiency (stereoscopic vs monoscopic vision) Design camera platform Refine overlay content
August 2016	Continue with image processing/recognition Integrate HMD w/ GCS software Build camera platform and gimbal system Test camera platform Continue testing Develop thesis outline
October 2016	Find experts to guide research Refine overlay content Complete flight simulation Continue flight testing Present at Junior Colloquia Obtain approval for NIST and MFRI testing
December 2016	Grant applications Object identification tests (with camera payload system)
February 2017	Complete flight simulation testing Prepare for Undergraduate Research Day Begin initial draft of senior thesis Obtain feedback, revise draft (chapters 1-3 of thesis)

April 2017	NIST testing MFRI testing Analyze data Evaluate system improvements
June 2017	Integrate payload with autopilot Integrate HMD with autopilot
August 2017	Complete all testing Find and invite experts to Thesis Conference Draft presentation for Thesis Conference Finish data analysis Finish system evaluations Present at non-Gemstone professional conferences Revise thesis draft
December 2017	Revise thesis
February 2018	Update website Practice for Thesis Conference (rehearsal) Present and defend research at Thesis Conference Submit final team thesis Attend Gemstone citation ceremony

VII. Index Terms

Anthropometry - Measurement of a human individual.

Augmented Reality (AR) - Additional computer-generated information such as graphics or GPS data is projected and integrated onto the real-world environment of the user.

Certificate of Authorization (COA) - A form that states that the Federal Aviation Administration permits the group to fly a certain kind of drone in a certain situation.

Circularly polarized antenna - A communication device, transmitting in two dimensions with a 90 degree phase shift, to avoid lapses in data transmission due to the orientation of the aircraft.

Federal Aviation Administration (FAA) - A United States government agency that regulates flight over United States airspace.

Frankfurt plane - A standard anatomical position in which a subject's head is positioned parallel to the ground.

Gimbal - A pivot support device that allows the rotation of cameras about a single axis, while keeping the cameras in a fixed and stable position.

Global Positioning System (GPS) - A method of tracking an object using communication with satellites orbiting the earth.

Graphical User Interface (GUI) - A type of interface that allows users to interact with an electronic device through visual indicators such as icons.

Ground Control System (GCS) - The equipment that will be placed with the user on the ground. In this case it includes the Oculus headset, the computer, and communication equipment.

Head Mounted Display (HMD) - A form of user interface consisting of a computer screen fitted onto a helmet, to be worn by the user. The Oculus is an example of this.

Helical antenna - A communication device in the shape of a corkscrew, which extends transmission range and strength in the direction it is facing.

Interaxial Distance (IAD) - Distance between left and right camera.

Interpupillary Distance (IPD) - Distance between the center of pupils from each eye.

Leap Motion - A sensor that detects hand and finger movements and uses them as input.

Multirotor - A small rotary-wing UAV with 3 or more rotors.

Non-line-of-sight (NLOS) - A path that is obstructed between the location of the signal transmitter and the signal receiver.

Oculus Rift (Oculus) - A virtual reality headset developed by the company Oculus VR.

Oculus Touch - Pair of wireless controllers that can track the movement of the user's hands.

OpenCV - open source computer vision and machine learning software library.

Robot Operating System (ROS) - A set of software that aids the user in controlling robots and hardware.

Software Development Kit (SDK) - A computer program that enables the user to build and design new programs. These programs are generally specialized towards a specific language and output device.

Stereoscopic Vision - Using two fields of vision to view an image.

Small Unmanned Aerial System (sUAS) - An unmanned aircraft weighing 4.4 pounds or less.

Supraorbital Foramen - An anatomically defined position on the skull, above the eye.

Unmanned Aerial Systems (UAS) - An unmanned aircraft and its associated elements, including the ground-based controller and system of communication.

Unmanned Aerial Vehicle (UAV) - A flying robot controlled either autonomously or from a distance.

Virtual Reality (VR) - A “substitute reality” where people can interact with non-real environments and objects in an exclusively digital world [C1].

Virtual Reality Sickness (VR Sickness) - A type of motion sickness caused by the video displayed in a VR environment being of insufficient quality or frames per second.

Wilcoxon-Mann-Whitney statistical test - A variation of a t-test in which the null hypothesis tested assumes dependent variables for two populations are equal.

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