Wearable augmented reality in procedural tasks: Designing an interface used to deliver step-by-step instructions to support novice users in unfamiliar tasks.

by

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Abstract

Augmented reality is defined as a technology used to enhance the physical world by imposing virtual elements. This thesis paper is an observational case study of the impact of wearable augmented reality utilized by novice users to complete procedural tasks. The philosophy of this study is research through design with the intent to explore augmented reality technology and learn about the process of designing procedural instructions for wearable augmented reality. This research includes findings based on ARGOS (Augmented Reality Guidance and Operations System), a system built by a team at University of Baltimore for the NASA SUITS challenge (Spacesuit User Interface Technologies for Students). This study includes findings from design practices, research methods, user testing protocols, and overall implications.

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Chapter 1: Introduction

Introduction to Augmented Realty

Augmented reality, an immersive technology, transformed the traditional digital 2-D interaction into a 3-D virtual interface used to enhance real-world experiences. Augmented reality experience is described as computer graphics superimposed on to the external world (Ceruti et. al., 2018). Augmented reality systems provide an improved understanding of the real world by displaying additional information in virtual graphics. In chapter 1 of the book *Augmented Reality: Principles and Practice*, the authors Schmalstieg & Höllerer (2016) describe augumented reality experiences to connect direct, automatic, and actionable links between the physical world and virtual information. Wearable augmented reality enriches reality by displaying virtual components, resulting in the delivery of on-demand information available in physical environments.

An augmented reality system must include three criteria: the combination of real and virtual, interactive in real-time, and rendered in 3D (Azuma, 1997). Augmenting information can assist users during real-world tasks and enable individuals to learn and take action in real-time. Augmented information can provide guidance in industries such as navigation, training and maintenance, education, and medical (Schmalstieg & Höllerer, 2016, ch.1).

The NASA Microgravity University created an the SUITS Design Challenge, an initiative focused on challenging students to create an augmented reality interface that could support future spacesuits. The 2020 NASA SUITS Design Challenge, an Artemis

Student Challenge, is focused on building an augmented reality system for astronauts in the lunar mission Artemis. The University of Baltimore (UB) students entering the NASA SUITS challenge, consists of undergraduate students in the Applied Information Technology (AIT), Simulation and Game Design (SGD), and graduate (M.S) students in Interaction Design and Information Architecture (IDIA) programs.

ARGOS was usability tested at UB, with participants above the age of 18 with little experience using augmented reality. Originally inspired by NASA SUITS 2020 challenge, specifically for the lunar mission Artemis, the test scenario was modified to resemble a procedural task similar to space suit missions participants for participants without prior knowledge of the subject . This task was based off of lunar geological sampling, a common extravehicular (EVA) task. Each participant was tasked to interact with ARGOS for step-by-step instructions on how to sample geological material.

The philosophy of this study embodies research through design by the practice of an observational and exploratory approach. The design methodologies utilized in this research embodied design fiction, a technique describe by Mark Blythe (2018) as a conceptual prototype of a product or system that does not exist yet. This method is used to evaluate the design possibilities before committing time and resources to technological development. Tracing from Italian radical design of the 1960's, design fiction methods such as paper prototyping, sketches, speculative design, and simulations is now practiced in tech companies such as Google, Microsoft and Facebook in order to replicate and present the design concept as close as possible (Blythe, 2018). Design fiction was applied to designing the user interface of the system this project, Augmented Reality Guidance and Operations System (ARGOS), created by a team of UB students. As augmented reality is an emerging technology, many prototyping tools are limited, thus, design fiction was a necessary approach for prototyping user interface designs.

Problem Statement

This study is an observational case study of the phenomenon of the human ability to learn and complete unknown technical tasks in the physical world through wearable augmented reality. The focal point of the research documents the impact of how novice users perceive their experience using an augmented reality interface to assist with rock sample collecting, an unknown task to the user. Relative to wearable augmented reality, the objectives of this research are to answer the following questions:

1. Can wearable augmented reality assist novice users in completing an unfamiliar technical task?
2. What are the best practices for information architecture and design for procedural instructions in AR systems?

This thesis explores the impact of augmented reality to human cognition during the performance of a novice procedural task with no history of augmented reality assistance. The goal is to identify the potential opportunities and areas of improvement of applied augmented reality. The process of this research include design, usability testing, research methods, and synthesis of results.

Chapter 2: Literature Review

History

Schmalstieg & Höllerer (2016, ch. 1) cite the earliest application of physical world interpretation through a computer-generated system, created by Ivan Sutherland in the 1960s. Sutherland's program influenced alternative forms of interaction with computers. In 1968, he created "Sword of Damocles", the first head-mount-display (HMD) capable of tracking head orientation while displaying see-through optics that projected a simple wireframe room.

Figure 1. Sword of Damocles, the first head-mounted display built in 1968 by Ivan Sutherland (Schmalstieg & Höllerer, 2016, ch.1).

Caudell and Mitzel of Boeing first defined the term "augmented reality" in 1992 in their proposal of AR applications in the aerospace manufacturing domain. They hypothesized the use of heads-up display technology would improve manufacturing processes. Caudell and Mitzell (1992) describe a head-mounted tetherless goggle

(HUDset) that projects a “see-through” interface on to manufacturing pieces to assist and improve the performance of Boeing factory workers during the manufacturing and assembling tasks. Specifically, they discuss an AR system capable of projecting graphical objects to dynamically mark positions on aircraft machinery can improve the efficiency of workers.

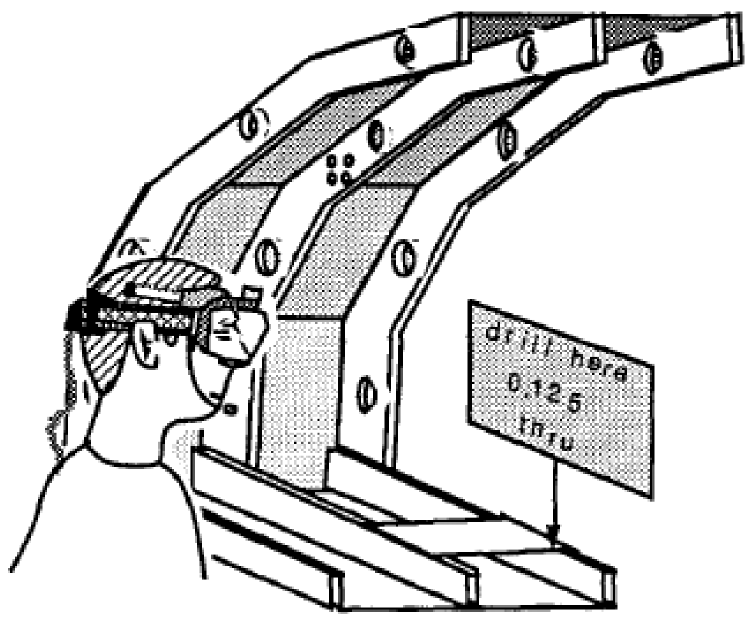


Figure 2. A sketch of the HUDset dynamically marking the area (Caudell & Mitzell, 1992).

Augmented Reality Hardware: Head-Mounted Display (HMD)

Today augmented reality manifests in different forms of visual displays including head-mounted displays, handheld displays, stationary displays, and project displays (Schmalstieg & Höllerer, 2016, ch.2). A head-mounted display (HMD) is a class of headwear commonly used for augmented and virtual reality experiences. This hardware supports multi-modal interactivity such as hand-tracking, eye-gaze, and voice command (Microsoft Hololens, (n.d); Magic Leap (n.d)).

An HMD includes a headset equipped with binocular or monocular goggles and a power pack that allows users to be hands-free (Microsoft Hololens, (n.d)). Tetherless HMDs allow workers to follow instructions on the virtual interface with free hands (Caudell & Mitzell,1992). A beneficial trait of HMD use includes the ability to accurately register 3D data and integrate most 3D-based algorithms that simulate the augmented experience (Garon, 2016). Additionally, Itoh & Klinker (2014) discover dynamic 3D eye position measurements using HMD eye-tracking system for re-calibration instead of manual calibration, which increases ease in use. Lastly, Caudell & Mitzell (1992) predicted the use of an ergonomically designed HMD provides convenience for regular use.

Optical and Video See-Through HMD

According to Rolland, et. al (1995), an optical-see-through HMD is visualized through transparent mirrors that reflect virtual graphics placed in front of the user's eyes, therefore combining virtual and physical scenery. Rolland, Holloway, & H. Fuchs (1995), define a optical see-through as a HMD that allows the user to see the real world through semi-transparent mirrored lenses that reflect the virtual components on to the users' eyes, resulting in a combination of virtual and physical views. Alternatively, a video see-through HMD uses video cameras mounted on to the headgear that projects video on to the real world (Rolland, et. al, 1995). Of the two, optical see-through HMD's are most used. Microsoft's HoloLens and Magic Leap One are today's most popular optical see-through AR headsets. Both devices integrate tracking/depth sensing, voice commands, hand gestures, and wireless capabilities, and offer remote control or hand-gesture interaction.

Augmented Reality Industries and Applications

Though the world of augmented reality is widely diverse and applicable to many domains. Augmented reality is utilized in a variety of industries including navigation, training and maintenance, education, and medical.

Navigation

Traditional navigational see-through HUD began in the 1920s and was primarily designed for pilots to display a heads-up display (HUD) of static metric information such as speed, gas, and torque (Schmalstieg & Höllerer, 2016, p.21). Examples of navigation AR include HUD displays projected on to car windshields and motorcycle helmet HMD. Today, geo-information technology is capable of predicting upcoming paths during in-car navigation in addition to registering virtual graphics of the predicted paths onto the real world (Bark, et. al, 2014). This capability allows virtual highlighted path/instructions displayed directly on the road. The HUD interface should not occlude the users' view, displays where to turn using a perspective view, provides advanced notice of upcoming turns without occluding the driver's view (Bark et. al, 2014).

Figure 3. Personal Navi interface with a virtual marker of the desired path (Bark et. al, 2014).

A common challenge of navigation-related AR is depth perception issues. Interpreting correlating virtual elements to spatial locations ahead can become difficult to comprehend at certain perspectives. In their research, Bark et. al (2014) prototyped a navigational AR HUD interface that projects images at accurate focal distances for proper motion parallax without the use of eye-tracking, to reduce visual fatigue by strategically placing the eye-box in a comfortable distance. Their AR system, Personal Navi, is a see-thru volumetric HUD, projected onto the windshield, that displays instructions directly on intersections to reduce cognitive load and ambiguity when driving. Personal Navi aids drivers to pinpoint turn locations earlier and keep their attention ahead for longer and is hypothesized to allow drivers to detect hazards sooner.

Training and Maintenance

Augmented reality is used as an educational medium for helping users understand how things work. For example, step-by-step instructions superimposed onto equipment can be easier to understand and result in more effective training, reduction in costs, and saving space by storing information electronically (Azuma,1997). Another technique used in the manufacturing world is ghost visualization. This technique shows the interior content of a real-world object by overlaying the interior image on top of the real-world element (Schmalstieg & Höllerer, 2016, p.17).

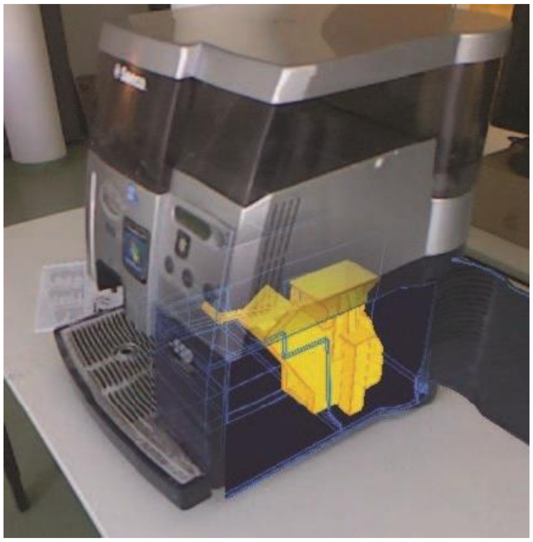


Figure 4. Ghost visualization technique (Schmalstieg & Höllerer, 2016, p.17).

In Sorko's (2019) study 'Augmented Reality in Training', it is stated, "interface competencies and the ability to solve abstract situational problems are gaining insignificance." It is evident that the working industry is advancing through digitization and is inevitably leading to a redesign of the work-process framework in the manufacturing industry to increase the flexibility of local, temporal, and content dimensions.

Training and maintenance careers require workers to have extensive knowledge of complex systems and errors that may occur in the assembly or operation of machines can be costly. AR HMD can be used to guide workers in this industry by projecting instructions on assembly or operational machines in real-time during their work. Workers are able to train on the job and gain competence during their daily tasks by providing step-by-step processes without causing serious damage (Sorko, 2019).

In Ceruti et. al (2018) study of augmented reality assistance in additive manufacturing technologies in aviation maintenance, AR is used to support operators in maintenance tasks in spare part production in aviation. Ceruti et. al (2018) discover AR assistance resulted in an increase in reliability and a reduction of workload and time required to complete tasks. In Sorko's (2019) study, 4 major sub-processes guided by AR were tested: warehouse removal, piston assembly, piston rod assembly, and cylinder assembly. Sorko et al. (2019) study states if a definitive process is established, the use of AR for training on the job and training near the job reduces costs and represents an innovative learning media.

Learning Environments

In the education environment, researchers believed that AR contains learning affordances that are beneficial in science, technology, engineering, and mathematics fields. In their literature review, Chen and Tsai (2013) identify two educationally beneficial AR domains: image-based and location-based. These domains contain significant affordances for science learning. Imaged-based AR is defined as a market-based system that registers labels on to real-world objects. The use of icons marking an environment helps students visualize engineering graphics and understand spatial concepts. Additionally, location-based uses global positioning systems (GPS) to identify the location and displays information on to the location in real-time.

Medical Industry

Augmented reality systems utilized in the medical field provides visualization and training aid for operations (Azuma, 1997). AR can show accurate visualization and depth perception for surgery and x-rays. As a result, medical industry AR is hypothesized to improve spatial perception in procedures (Wang et. al., 2017). Different mediums such as 3D projected hand-gesture based AR is noted to be beneficial because it will not contaminate the patient (Lopes, et al., 2017).

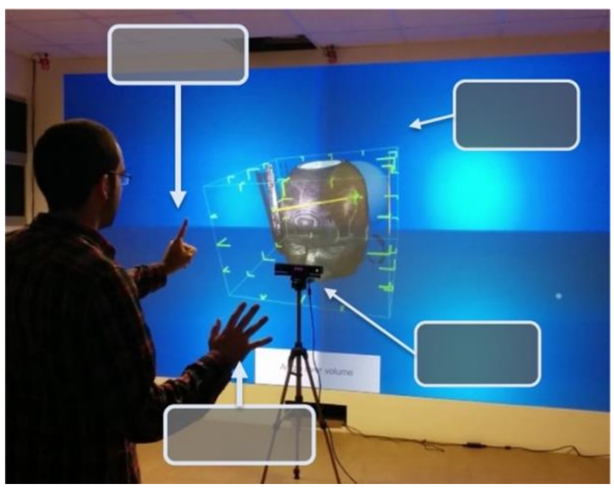


Figure 5. Touchless interaction system used for training biometric informatics (Lopes, et al., 2017).

Wang et. al (2009) categorizes three methods of medical AR visualization: video-based, see-through, and projection. Known to be the simplest approach, the video-based method uses captured videos by utilizing a camera superimposed on-to the real-world item using a transparent overlay. Wang Su et al. (2009) utilized this method when they created an augmented reality robot-assisted surgery. In the article, the surgeon was able to identify and track the kidney surface in real-time with applying intraoperative overlaid 3D models. To achieve accurate registration between the model and surgical recording, the system included image-based tracking technology to select fixed points of the kidney surface that augmented image-to-model registration. The see-through method uses a semi-transparent mirror in front of the user, allowing them to see directly through the mirror and the superimposed virtual elements on the physical element.

Lastly, the projection-based method uses a projector that displays virtual elements on the real-world scene. This method proves transparent mask and ghosting have the most accurate spatial perception, and though transparent overlay is the simplest method, it has the poorest spatial perception.

AR Design Principles and Guidelines

Cognitive Overload

In the world of AR design, a balance of virtual and real elements is essential for intuitive user experience. All components in an AR system should simulate a natural integration of virtual to physical worlds to allow users to comfortably interact with both environments. Doswell & Skinner's (2018) wearable augmented reality research states the primary challenge for HCI is identifying appropriate information presentation in order to stay within cognitive limitations. Thus, cognitive overload is a prominent challenge in the AR design space. Designers must consider the user's cognitive load when interacting with physical and virtual worlds simultaneously. When a large amount of data is presented, it is difficult for the user to comprehend the information they need while interacting with the real-world. Precautionary design and information hierarchy principles such as human-centered design methods, visual coherence, and depth perception should be prioritized to reduce cognitive load.

According to Dunser et. al (2007), user interface design strives to enable users to focus on primary tasks without the distraction of other virtual elements. The article states introducing new interactions, such as supernatural powers, requires users to learn how to interact with the interface instead of utilizing natural interactions. The additional non-automatic cognitive effort with the system can be counterproductive by overwhelming and distracting users. If the cognitive and perceptual load is too overwhelming, it is unlikely that AR will be a productive training aid.

Information filtering is categorized into knowledge-based and spatial filters. Knowledge-based categorizes information into an architecture based on hierarchy, and spatial filters are information presented based on distance. These techniques are used to reduce visual clutter and data-overload by limiting the amount of presented data by using filters to scale-down data density and limits interference with the user's field of view (Schmalstieg & Höllerer, 2016, p.265).

Human-Centered Design in Augmented Reality

Dunser et. al (2007) states design heuristics in the AR industry are still to be determined and recommend designers to utilize foundational HCI principles when drafting specific solutions to their individual problems. Certain human-centered design methods can be applicable to a variety of human-computer interfaces, including the augmented reality world. Generally, design heuristics and methodologies are universally applicable to all interactive platforms including virtual and augmented reality.

In his paper of standards for user-centered design and psychological implications of their application, Earthy (2001) defines human-centered design processes for interactive systems, originating from Norman and Draper (1986), as the following principles:

- Active involvement of users and a clear understanding of user and task requirements
- Allocate functions between users and technology
- Create iterations of design solutions (incremental progress)
- Ensure that the design is the result of a multidisciplinary input (user feedback)

MacNamara's (2017) study refers to Rosson & Carroll's (2002) Usability Engineering Gestalt Principles of Perceptual Organisation as a psychological explanation of human perception with particular reference to pattern recognition and how users subconsciously group entities together. There are seven main Principles of Perceptual Organisation; Proximity, Similarity, Continuity, Closure, Figure/Ground, Symmetry and Common Fate. These principles are widely practiced in user interface design in various interactive industries and human-computer interaction. MacNamara's (2017) experiment compared applications on the Oculus Rift with two interfaces, one that exhibited Gestalt Principles, and the other without, and concluded that Gestalt principles are transferable and beneficial for VR usability and suggests that cognitive workload can be reduced by using Gestalt guidelines.

Affordances

Dunser et. al (2007) describes the concept of affordance as an interaction metaphor that connects an inherent relationship of the user interface and the physical world, allowing the user to recognize instead of recall. This design principle invites the user to interact by presenting a familiar means of interaction and results in a low learning curve for the user. Pointon et. al, (2018) identify the use of cognitive affordances to guide users by providing cues on the best way to interact with an AR system.

Pointon et. al (2018) tested the concept of an affordance judgment, a term which derives from J. J. Gibson's theory of affordances. The affordance judgment is defined as "how humans perceive environments in terms of the action possibilities within that environment." (Pointon et. al, 2018). In their study, they used HoloLens to test if the user's perception of virtual affordances are similar to the perception of real-world features and concluded that affordance judgments are a useful way to evaluate user comprehension and discovered that when using affordances, virtual objects are perceived similarly to real objects in an AR system.

Visual Coherence, Calibration, Registration, and Depth Cues

AR design systems require harmony between virtual and environmental elements to create visually coherence for the user. Seamlessly embedding computer graphics into comprehensible proportions onto a real scene is an important element to consider when designing AR. In chapter 6 of *Augmented Reality: Principles and Practice,* Schmalstieg & Höllerer (2016) define spatial registration as the tracking system technique used to achieve a visually coherent AR experience. Another method of interaction design for visual coherence is utilizing a multi-local interface, an interface with the ability to place a virtual object in a different location on every display, allowing users to customize the location of virtual elements.

AR requires the alignment of the virtual elements on to a real scene to be comprehensible to the user, the registration of geometric and photometric elements must be calibrated. Photometric registration is the alignment of perceived brightness between virtual and physical elements, simulating how light travels between virtual and real objects. Dunser et. al (2007) identify registration errors or virtual-to-physical components is a contributor to the degeneration of user performance. All augmented reality systems must carefully calibrate all components including tracking system, display, and objects in the real world to the tracking system in order to ensure correct spatial registration (Schmalstieg & Höllerer, 2016, p. 56).

Depth cues are stimuli that allow humans to interpret three-dimensional structures in an environment (Goldstein, 2009, p.230). These cues are categorized as monocular, observation of a single image, and binocular, the observation of paired images. AR displays generally use a monocular view due to the see-through video mode. Based on Diaz, Walker, Szafir, & Szarfir's (2017) study of depth perception on augmented reality, the most important cues for influencing depth in augmented reality to the human eye include aerial perspective, shadows, surfacing models, billboarding, dimensionality, and surface texture. From this study, it was concluded that cast shadows were the most important cue for visual coherence between virtual and physical objects.

In a study of virtual texts read at a distance, Gupta (2004) discovered that text appeared blurriest to users as the experiment progressed due to eye fatigue from context-switching between virtual and real-world information. Gupta defines context-switching as the shift of attention between visual and mental attention altering from real-world and virtual information. Focal length affects the field of view and is recommended to develop virtual text displays as close as possible to real-world objects and with high resolution to reduce eye fatigue.

Learnability

In the realm of augmented reality user experience, prioritizing learnability is important. Designers should use familiar real-world interactions to create an intuitive user experience (Dunser et. al, 2007). An example of re-using everyday interaction is demonstrated in Magic Book, the interaction of flipping a page in a book requires the user to turn physical book pages in order to interact with the system. The user is already equipped with prior knowledge and is able to immediately interact with the system due to the affordance and familiarity of action.

Augmented Reality User Interactions

Due to the nature of augmented reality, a virtual enhancement of the real world, user interactions should reflect the human's common actions by using their senses. Real-world experiences are multimodal: audio, hand gestures, and eye contact are sensory interactions. Though there are no specific guidelines for designing user interactions, basic design principles and heuristics of HCI are applicable when designing interactions in an AR system (Duenser, Grasset, Seichter & Billinghurst, 2007). Because AR systems involve extensive user interaction, designers should focus on evaluating the usability of interaction experience by evaluating user goals.

Interaction Modalities

The term output modalities classify different approaches to presenting augmentation and interaction styles to the user (Scmalstieg & Höllerer, 2016, ch.8). Output modalities include augmentation placement, agile displays, and magic lenses. Augmentation placement refers to the placement of 2D content or virtual 3D objects relative to the head or body and environment. Agile displays are projected on to a physical surface that allows users to interact with the overlapped digital landscape. Lastly, the magic lense is a mode that allows users to browse and discover information that is placed in a focus area using a handheld device or HMD. Scmalstieg & Höllerer (2016) define input modalities as a classification of different methods of interaction from the user to the augmented display. These interactions include body tracking, hand gestures, touch, and physically based interfaces.

Hand Gesture Interaction

Gestural interaction such as posture and hand configurations is an important use of body tracking in AR. Lopes et al. (2017) tested a touchless interface controlled with hand gestures and body postures for interpreting medical volume data sets. They hypothesized a touchless augmented reality system can help train practitioners and improve spacial awareness in 3D volume over traditional 2D input devices. The adjustment to 3D will result in lesser attempts to achieve the desired orientation. The greatest limitation discovered in Lopes' et al. (2017) research was fatigue from consistently using hand gestures to navigate. Dunser, et. al (2007) recommends user interactions should require low physical effort. Designers should prioritize task completion by minimizing steps of interaction in order to reduce the likeliness of fatigue.

Voice Command Interaction

Voice commands are a mode of interaction that allows users to control the interface through language and speech. According to Ballard (2018), voice commands in AR are commonly used by technicians in the aerospace manufacturing industry. Boeing technicians use smart glasses and voice commands for guidance while assembling complex wiring harnesses. This enables technicians to perform hands-free and has resulted in a 25% improvement in productivity (Ballard, 2018). Microsoft highlighted best practices when using voice commands and recommends the following:

- Use concise commands
- Use simple vocabulary

- Make sure any action that can be taken by a speech command is non-destructive and can easily be undone
- Avoid similar sounding commands
- Maintain voice command consistency

Looking into the future, Ballard (2018) describes improving the system's ability to recognize the context of what the user is requesting as the next steps of advancing voice command.

Gaze and Commit

According to the article 'Gaze and Commit' from Microsoft (2019), eye-gazing is a primary form of targeting which allows users to interact and navigate through virtual elements by directing their gaze at the desired element. This action is similar to point and click interactions on the computer. Mahfoud & Lu (2016) explore gaze tracking in their study of visualizing scientific ensembles in vertically spread image stacks triggered by the user's attention using HoloLens. They discovered the greatest value of the gaze point is at close vicinity, and the value degrades at further distances. An issue highlighted in this study is determining the users' gaze point when focusing on a complex structure with multiple surfaces. Additionally, the gaze point is only able to focus on one element at a time. As a result, overlapping surfaces are harder to navigate through using gaze. The benefits of a large 3D rendering space for visualization are consequently addressed by the limitations of single gaze point interactions. Overall, Mahfoud & Lu (2016) conclude the benefits of eye-tracking devices are less intrusive and gaze-based interaction can provide intuitive operations for future mixed reality experiences.

Conclusion

Although the earliest signs of augmented reality date in the 1960s, today it is still known as technology in the early stages of development. Augmented reality is primarily used as a 3D virtual enhancement of the physical world experiences. Industries such as navigation, maintenance, education, and medical have shown the benefits of using augmented reality to guide and assist users during their real-world tasks, especially with tetherless HMD hardware. There are no definite design guidelines for designing AR, but it is advised to follow foundation HCI design principles and have awareness of cognitive overload. Lastly, multimodal interactivity is preferred because humans use multiple senses simultaneously when interacting with the physical environment, and augmented reality is designed to be an enhancement of the real world.

Chapter 3: Methodology

Overview

The methods utilized in this research are designed to discover the impact of wearable augmented reality used to aid users in completing an unfamiliar technical task and analyze the observations. The primary goal of this research is to observe how the user interacts with the digital interface and physical world and determine if the user performance is improved with wearable augmented reality assistance.

This study demonstrates a system developed by University of Baltimore, submitted to the NASA SUITS 2020 challenge (“NASA SUITS” n.d). The NASA SUITS 2020 project challenged students to create an augmented reality system capable of supporting astronauts in spacewalk missions. This initiative determines the criteria of the augmented reality system tested in this study. Altogether, this system is required to display an unobtrusive interface used and assist EVA operators during their space missions such as geologic sampling in the field.

The research and design strategies used to test University of Baltimore’s augmented reality system applied to geologic sampling are explained in this portion of the paper. The methodologies are designed to accomplish the following topics:

1. Observe the user’s ability to complete rock sampling without prior knowledge of the task with zero facilitator interference.
1. Learn about the user’s experience with the information architecture.
2. Learn about the user’s experience with interaction design.
3. Learn about the user's experience with visual design.

Materials

ARGOS System

The system employed for this study, Augmented Reality Guidance and Operations System (ARGOS), was developed for the NASA SUITS competition by a team of students at the University of Baltimore. ARGOS was the augmented reality interface designed to increase user performance and efficiently complete instructional based tasks by providing step-by-step instructions for their procedures. ARGOS is specifically designed to reduce cognitive load and aid completion of task while utilizing hand gesture and voice recognition for users to navigate through the interface

Magic Leap One

The Magic Leap One Augmented Reality Headset (ML1), an optical see-through headset, was utilized to render ARGOS (See figure 6). The ML1 is a tetherless headset that includes audio, hand gestures, and voice command functionality. For the usability test, two mild astigmatism-correction lenses of -3 diopters for each eye were available to support users with slight vision impairment. According to the Magic Leap portal (2019), the ML1 has a horizontal field of view (FOV) of 40 degrees, a vertical FOV of 30 degrees, and a diagonal FOV of 50 degrees.

Figure 6. Magic Leap 1 headset with tetherless battery

Test Equipment

The usability test, executed in an indoor facility, reflected a rock sampling test site, thus, requiring a variety of equipment. Shown in Figure 7-8, the materials used to simulate rock sampling consisted of excavation tools such as tools such as tongs, a rake, and container. Additionally, the sample site was staged with a shallow plastic container partially filled with sand and hidden rock samples.


Figures 7-8. Tools used for science sampling usability testing

Participants

Twelve adult volunteers within the ages of 20-45 participated in this study. All participants self-reported low to moderate technical skills and minimal experience with augmented reality. Due to vision impairment, one participant was unable to complete the test, resulting in a total of 11 participants evaluated in the analysis. Each participant was inexperienced with geologic sampling, nor did they have prior knowledge of the scenario before the test. Five participants self-reported minimal understanding of geologic sampling, and 6 participants self-reported no familiarity with the subject. Two participants reported moderate familiarity with wearable augmented reality while the majority of participants reported to be tech friendly with little to no experience with wearable augmented reality.

Table 1 displays the relevant user demographic characteristics of the diverse participants. Of 11 participants, the average age is 27.2 with a standard deviation of 7.9. 55% of the participants are male, and 45% are female. There are 9 different occupations and 7 different industries among the 11 participants. The reason for selecting a diverse demographic pool is to gather a variety of perspectives and unbiased feedback from novice users during their experience demonstrating ARGOS.

Table 1.

User Demographic Information

P	Age	Gender	Occupation	Industry	ARF	TF	GS
1A	24	F	Student	IT	1	5	No
1B	47	F	Admin Assistant	Education	1	2	No
1C	21	F	Student	Education	4	5	Yes
1D	33	M	IT Tech Support	Education	1	5	No
1E	20	M	Customer Service	Retail	1	5	Yes
2A	21	F	Server	Restaurant	2	5	No
2B	31	F	Graphic Designer	Communications	3	4	No
2C	24	M	Software Engineer	IT	5	5	Yes
2D	26	M	Systems Engineer	IT	1	5	Yes
2E	27	M	UI Programmer	Video Games	5	5	Yes
2F	25	M	Software Engineer	Tech	2	5	No

Notes: P= participant; AR = Familiarity with Augmented Reality; TF= Tech Friendly; GS = Familiarity with geologic sampling; AR and TF are rated from a scale to 1-5, 1 = least familiar, 5 = very familiar.

Research Design

Philosophy

This project is an observational case study of the phenomenon of the human ability to learn and complete unknown technical tasks in the physical world through wearable augmented reality. The focus is primarily on the interaction of humans and virtual elements containing information to enhance their perception of reality. This exploratory study focuses on the practice of applied foundational design principles and interaction design to wearable augmented reality. Additionally, data was gathered with research methods such as user interviews, user tests, data synthesis, and analysis from a diverse participant pool. The objective of the usability test is to observe user actions and document feedback relative to information architecture, visual design, interaction design, and overall experience. The information learned from the study is a contribution to research based on augmented reality assistance in technical tasks.

Interface Design

Designed with traditional visual and interaction design principles (MacNamara, 2017), the structure of the ARGOS interface is divided into the following categories: information architecture, visual interface design, and interaction design. The ARGOS UI is focused specifically to reduce cognitive load, aid completion of tasks, and enable user's productivity. The user's ability to comprehend virtual procedural instructions and real-world tasks can compromise situational awareness if too much information is displayed. It was important to consider the potentials of data overload and prioritize clarity in the structure of information architecture, visual design, and interaction design. Our team followed the system requirements provided by the NASA SUITS 2020 challenge. Below are NASA SUITS design challenge criteria:

- Display a digital interface that displays information in an unobtrusive way
- Conduct science sampling task at a designated geology site

- Display science sampling instructions
- Interact with sample bags, tongs, rake, and other miscellaneous lunar tools.
- Locate/navigate to the correct site
- Provide a unique method for taking field notes
- Take pictures of the excavation site and geology samples
- Collect and store samples

Information Architecture

Doswell & Skinner's (2018) wearable augmented reality research stated the primary challenge for HCI is identifying appropriate information presentation in order to avoid sensory overload. To mitigate cognitive overload, the structure of information hierarchy was formatted into a step-by-step sequence to provide the necessary amount of information. In this study, information architecture is defined as the flow of content in the given task and content design. The architecture of science sampling was divided into a step-by-step linear sequence, shown in Figure 9.

The instructions for rock sampling were divided into a series of steps and displayed in a virtual panel fixed to the left of the FOV. This widget is ARGOS's main UI component that displayed the step-by-step instructions. Pagination UI is included to provide the user context of where they are in the process. The architectural goal was to segment large tasks into smaller portions that contain concise and informative language. In order to fit in the field of view, it was important to use a minimal amount of text while communicating a clear
message.

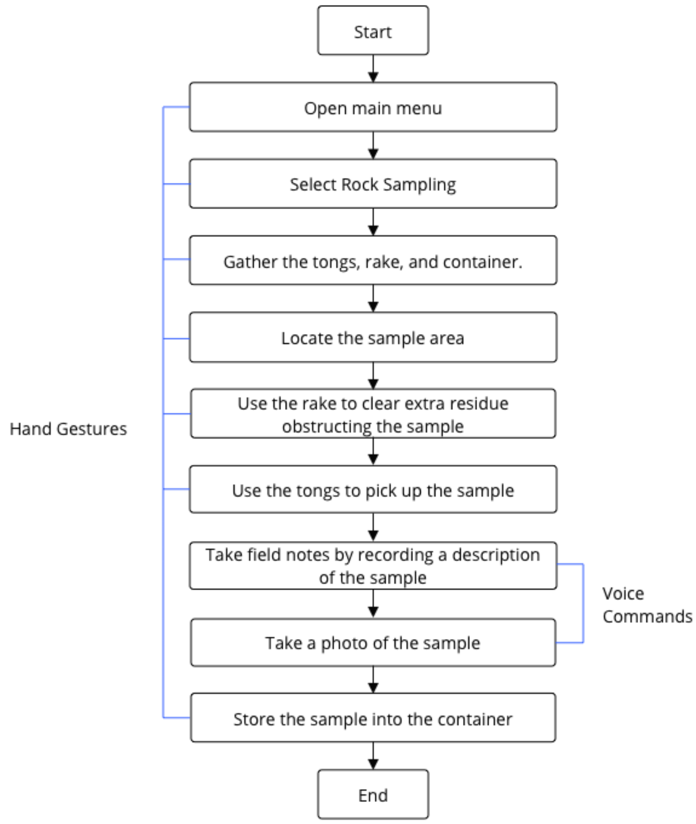


Figure 9. Science sampling user flow and interactions

Visual Design – Layout and Appearance

When designing visual elements of an augmented reality interface, accroding to Gordon (2020), it is best practice to utilize Nielson Norman group's 5 foundational design principles to create an intuitive design. These principles include scale, visual hierarchy, balance, contrast, and gestalt. Additionally, it is vital to recognize the user's ability to comprehend virtual elements in the physical world. It is most important to reduce the user's cognitive load and minimize heavy decision-making in an augmented reality experience. The highest visual design priority was minimizing obstruction of the real world with user interface components. In order to do so, balancing the scale, contrast, and color of the interface was imperative due to the changing physical world background.

Hierarchy of information was essential for the visual design because it provides visual direction and calls to action. In a scenario where an unknown technical task is to be accomplished, users who have never practiced this task will require prominent visibility and accessibility to the instructions. For ARGOS, the instructions menu and suit vital components are locked to the field of view to ensure its visibility.

Design Process

The HUD interface is designed to lock 2-dimensional virtual planes onto the user's field of view. The design process, shown in Figure 10, included the following steps: mapping the HUD concept in the 2D, exploring colors and transparency for legibility in high contrast environments, high-fidelity mock-ups, video mockups to visualize 3D space, and implementing the concepts into an interactive 3D prototype on the ML1.

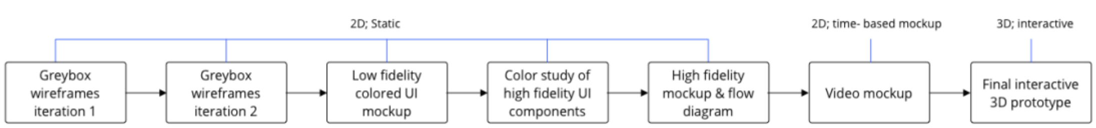


Figure 10. Flow diagram the ARGOS design process

The initial concepts of ARGOS were created as low-fidelity grey-box wireframes. The first iteration, shown in Figure 11, displays the primary interface that is locked onto the field of view and provides multiple options for the user to select. After re-evaluating the needs and concerns of the targeted user, I came to the realization that the interface resembled a digital/web experience, an experience allotting too many options at first view. Iteration one presented too many options which obtruded the field of view and could potentially overwhelm comprehension.

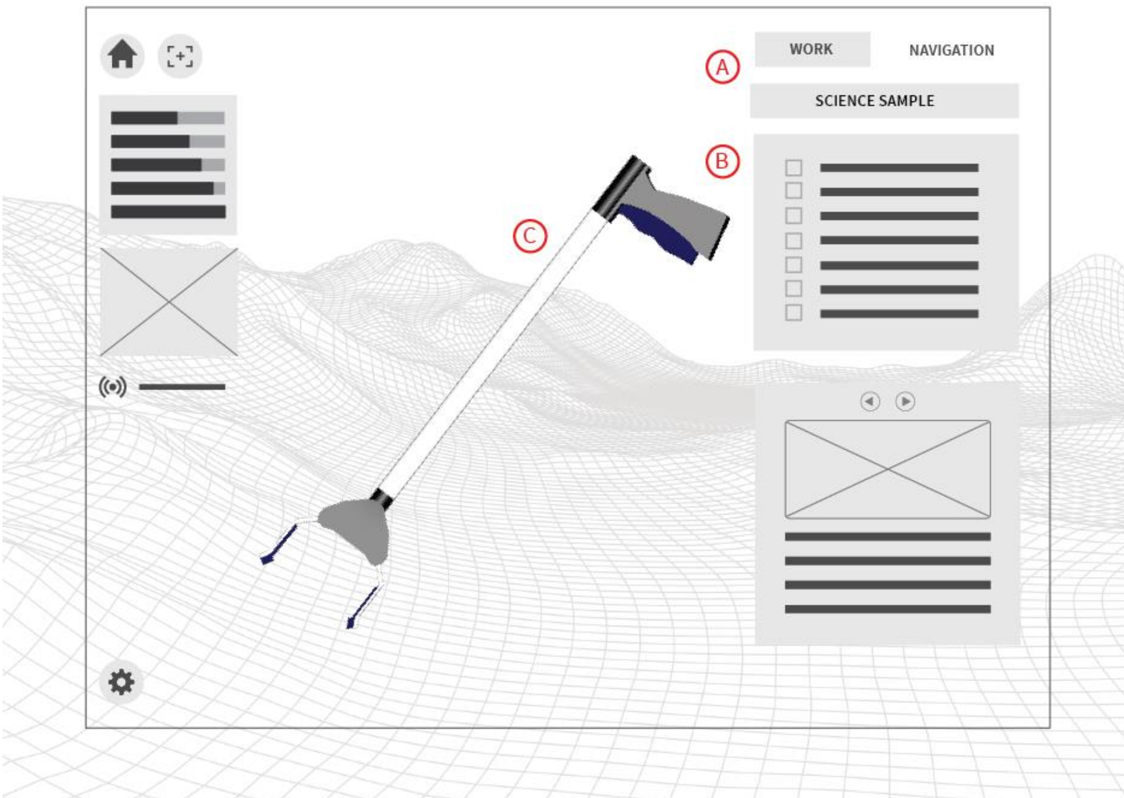
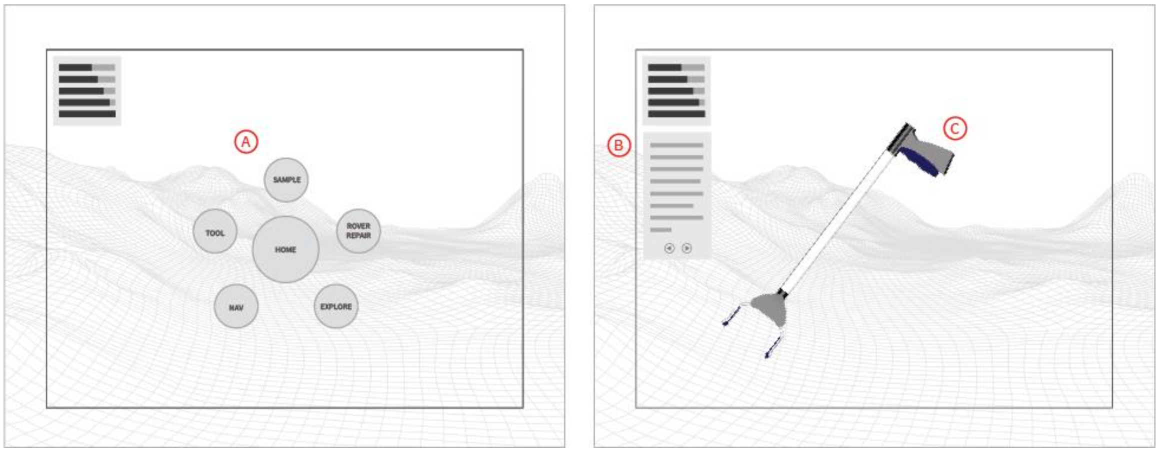


Figure 11: Iteration 1, grey box wire wireframe designed in Adobe Illustrator. (A) mode selection; (B) instruction menu; (C) 3D tool model.

This realization led to iteration two (see figures 12 and 13), an approach deconstructing iteration 1 into multiple steps that delivers information in a linear sequence. Iteration two is designed to help focus on the users’ needs one step at a time. Rather than presenting all options on the HUD interface, the user is required to select their desired task before moving forward. The wireframes of iteration 2 shown in Figures 12 and 13, shows the main menu where the user must select a task (Figure 12A), and the relative instruction panel (Figure 12B). This format improves the visibility of the field of view by reducing the amount of information presented in the interface.



Figures 12, 13. Iteration 2, grey box wire wireframe designed in Adobe Illustrator; (A) main menu mode selection; (B) instruction menu; (C) 3D tool model

After finalizing the usability flow in low fidelity wireframes, the next step was selecting colors and opacity values to use for the interface that is suitable for maintaining legibility on a real-world background. Colors were not required to comply with accessibility contrast rules because they are not applicable to NASA astronauts due to their screening. Additionally, it is important to consider the transparent digital interface is overlaid onto a changing environment, thus, the contrast consistently changes between interface and background. It was essential to select a specific color and transparency that was legible overlaid onto the real-world environment, a background that constantly varies in contrast and value. In order to analyze the comprehensibility of the components, I created a scale of 14 values between white and black to measure the legibility of high-fidelity ARGOS components on different contrasts, shown in Appendix A. Furthermore, shown in Figure 14, I placed the UI components on to a photo to test the comprehensibility in physical-world backgrounds.

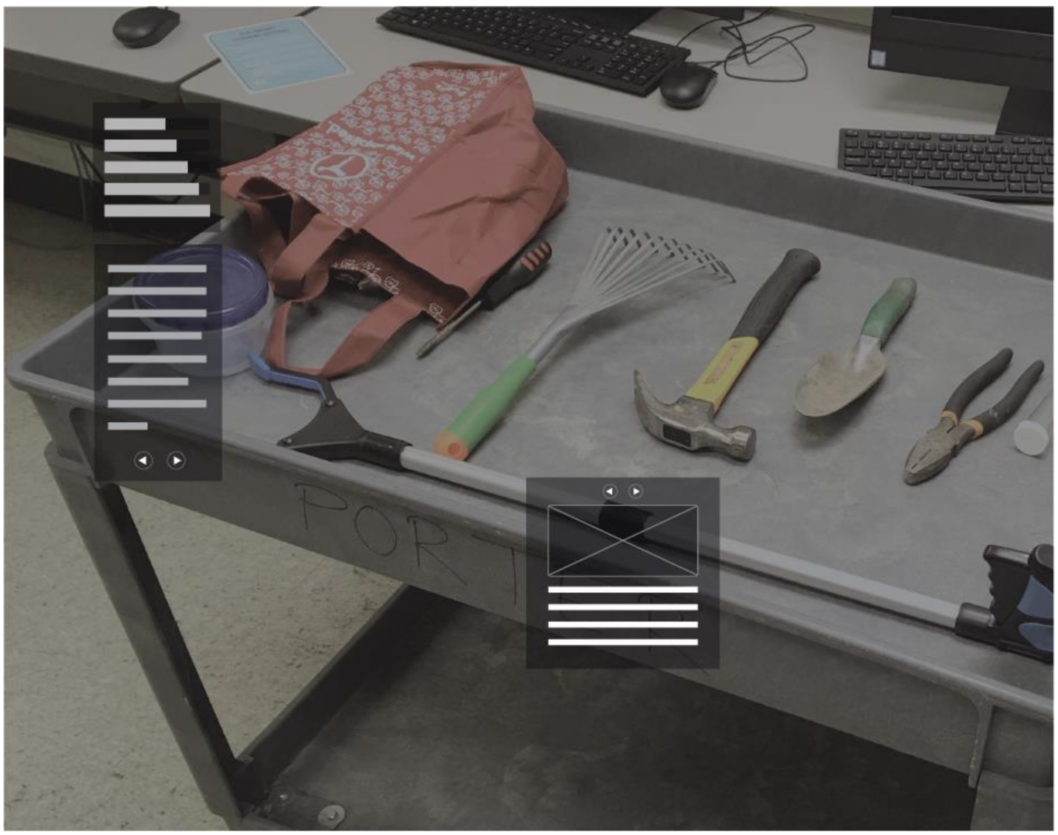


Figure 14. Iteration 2.1– Low fidelity mockup of colored components overlaid on a photo.

The interface components are placed and locked on to the left edge of the field of view, within the parameters of the 4:3 aspect ratio. Considering the depth and scale of the environment when overlaying virtual 2D panels on the real-world within the 4:3 ratio is important for perception issues. The main menu, suit vitals, and instruction menus are the interface components are locked onto the field of view to ensure the user's visibility. After the color and transparency were determined, I developed a high-fidelity 2D static mockup shown in Figure 15 to represent the interface to closest resemblance of the real experience. The high-fidelity interface design includes a virtual 2D panel placed into a field of view relative to the depth and scale of the physical environment, in a 4:3 aspect ratio.

The next step in the design process was to test the 2D user interface overlaid on a real-world moving background. This method captured the users' natural field of view with a consistently changing background. I utilized mobile AR tools to mock-up virtual elements placed in an environment. Below are the steps I followed to create a time-based AR mockup, shown in Figure 16:

1. For ARGOS, I utilized an app called Torch to place a virtual element into the environment. By doing so, I was able to test the legibility of the component at different angles.
2. Then, I recorded a video of panning the environment around the digital component in Torch.
3. Finally, I exported the video file into After Effects to overlay the instructional menu within 4:3 FOV markers, locked into the field of view. It is important to incorporate the correct 4:3 FOV in addition to peripheral space to ensure an accurate mockup of the user's experience. This method of prototyping ensured

visual elements such as transparency, font-size, and color are legible and non-obtrusive when in motion.

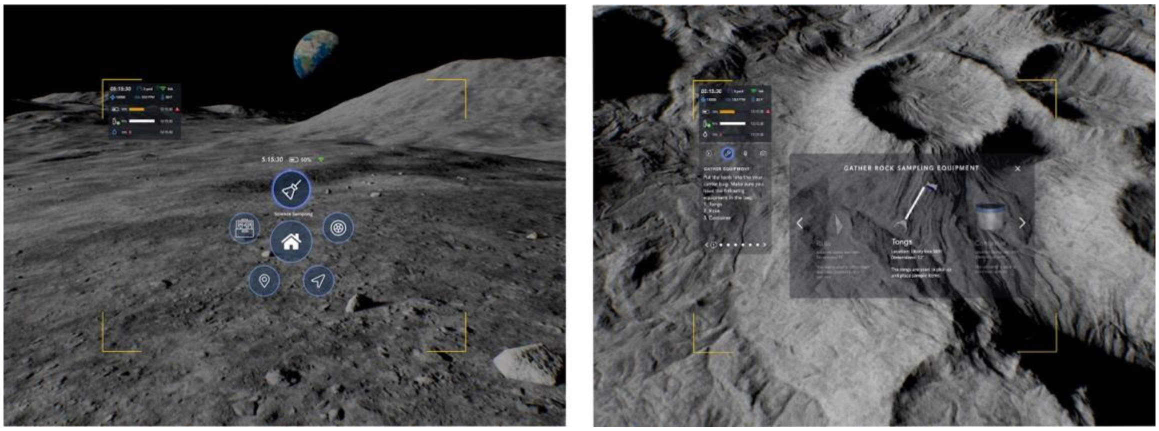


Figure 15. High-fidelity prototypes designed in sketch. The yellow corners indicate ML1 FOV parameters. (L) main menu mode selection; (R) instruction menu and toolkit

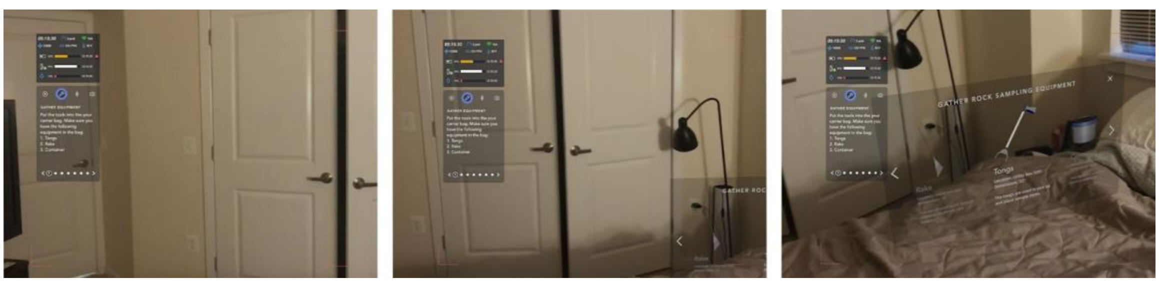


Figure 16. Series of screen captures of a video prototype designed with mobile AR tool TORCH and Adobe After Effects. Red corners indicate ML1 FOV (4:3 ratio).

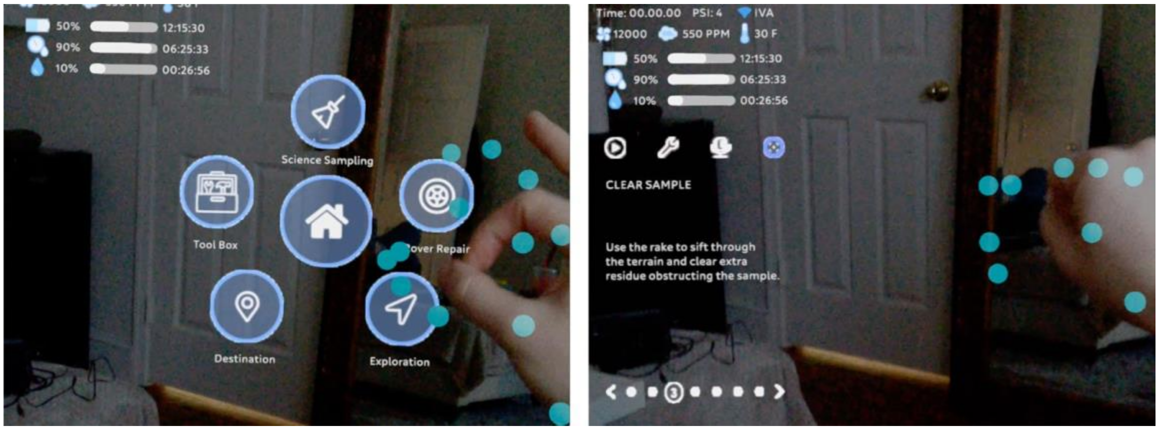


Figure 17. Final Prototype of the main menu (L), instruction menu(R). This image captures the ML1 FOV only, and excludes the peripheral space

Interaction Design

The built-in Magic Leap One system has the ability to recognize and interpret eight hand gestures. ARGOS leverages the ML1's capability of gesture-based interaction as the primary method of interaction. The hand gestures used in ARGOS follow real-world convention, the second recommendation in Jakob Nielson's 10 Usability Heuristics (Nielson, 1994). They are designed to match real world interactions that trigger information in a logical order. Furthermore, selection of minimal hand gestures can reduce the learning curve for novice users. As the human brain is only capable of retaining five to nine items in their working memory at one time (Miller, 1956), I limited the variety of gestures used in ARGOS's with the intent of establishing an intuitive gesture-based structure in order to avoid overwhelming the user. To mitigate the learning curve, ARGOS utilized four hand gestures to navigate through the system, shown in figure 18.

The second interaction ARGOS utilized was voice command for users to take photos and record field notes. Voice command instructions were included in the associative instruction menu. Each action required an opening and closing command. In order to take a photo, the user activates the system by saying "Hey Lumin, take a photo". By saying "Hey Lumin", the magic leap system activates and recognizes commands such as "take a photo". From there, the user commands the system to take the photo by saying "Take Photo." Similarly, to document field notes, the user activates the system by saying "Hey Lumin, record a video". To complete the recording, the user must say "Stop recording." The voice commands used simple and consistent vocabulary and were short and concise.

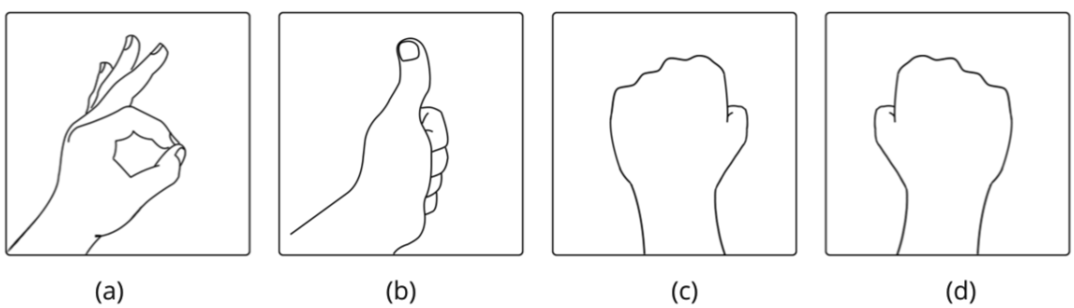


Figure 18. Hand Gestures for ARGOS (a) main menu; (b) confirm; (c) navigate back; (d) navigate forward

Protocol

Usability Testing Structure

This project was influenced by the NASA SUITS mission, inspired by the EVA operator tasks for the moon mission Artemis, which determined our user testing protocol.

The user testing scenario assigned to participants was rock sampling, an EVA astronaut task for planet missions. To validate our system, participants were tasked to a mission-based scenario in a controlled environment. This research test was designed to identify successes, failures, user comprehension, completion time, and feedback. The purpose of the test was to observe and learn how participants followed directions delivered through the augmented reality interface to complete a linear sequence of tasks. The documentation of this test included success scores, and observations of how the user interacted with the system.

The duration of the test was divided into two phases, with minimal variation. Phase 1 included a total of 6 participants with 5 successes and one failure, and phase 2 included a total of 6 successful participants . Both phases shared equivalent test structure, and research goal. The variation between the systems in each phase comprises iterations of the camera and recording function, which ultimately did not influence user performance. Phase 1 involved the “Wizard of Oz” approach, a design fiction method that requires participants to role play the voice command interaction in order to test the functionality before committing time and expenses to building it (Blythe, 2018). This was accomplished through role-play, as the facilitator narrates the system responses for camera and video functions. Phase 2 required no facilitator intervention and tested the technical prototype, where the ML1 system registered voice commands for camera and video.

Table 2.

User testing phase information

Phase	Participants	Variation
Phase 1	5 successful participants (Overall, 6 participants with 1 failure)	Wizard-of-Oz; Role-play voice command
Phase 2	6 participants	Technical prototype w/ built in voice interaction

Procedure

The usability test procedure shown in Figure 19, lasted approximately 30-40 minutes divided into three portions: ML1 demo, usability test, and exit interview. For each test, there were two facilitators and one participant. One facilitator guided the user for certain portions of the procedure and the second facilitator documented observations of the user's behaviors during the test, with zero interference.

Each participant was asked if they needed to adjust the headset with prescription lenses. Once the participant put on the ML1, the facilitator demonstrated the hand gestures needed to navigate through the system. After the hand gesture demo, the facilitator asked the user to open the main menu and instruct the user to say out-loud the menu option they would select. From here, the user was instructed to select Science sampling and encouraged to complete the rest of the instructions on their own. The facilitator only communicated with the participant to encourage think-aloud during the test. Minimal facilitator interference was practiced ensuring users were primarily utilizing ARGOS to accomplish their task.

After the participant completed the scenario, the facilitator interviewed the participant for approximately 15 minutes. The post-test interview highlighted qualitative feedback on the participant's experience and comprehension of the interface. These results were synthesized into affinity groups to highlight patterns across participant feedback.

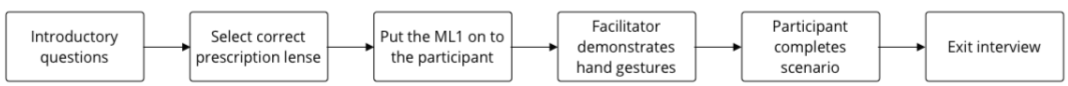


Figure 19. ARGOS Usability Testing Structure

Chapter 4: Results

Overview

In this section, the main observations were made during a two-phased usability tests of 11 participants. The usability test evaluates the average time of completion, success rate, common patterns across participants, and overall performance. The data collected is categorized into measurable results and observational results.

Usability Test Evaluation

Success Metrics

To measure success, I determined success criteria in pivotal points of the test that identified the systems usability. The criterion was scored with Jakob Nielson's usability metric (Nielson, 2001). Each participant will be prompted by the investigator to complete a task. For each task, they will be scored with a value of 0, .5, or 1 to determine their success rate. 0 is a failure, .5 is success after multiple attempts, and 1 is a success on the first or second try. I assessed each user's success by creating criteria that focus on each task in the scenario which determines if the participant understands the process. Below are the success criteria:

1. SC1 – Is the user able to pick the correct main menu item?
2. SC2 – Is the user able to gather the correct rock sampling tools?
3. SC3 – Participant can navigate to the test site
4. SC4 – Participant can use the rake to find find a rock sample
5. SC5 – Participant can pick up the sample using tongs
6. SC6 – Participant can use record field notes with voice command
7. SC7 – Participant can take a photo using voice command
8. SC8 – Participant can put the rock sample and close the container

Measured Results

The measurable results of this research are defined as success rate, completion time, and user interview responses, formatted as yes or no responses. These metrics provide an analysis of overall performance and experience which is ultimately used to identify areas of success and failures.

In Table 3, the percentage of success, and completion time are displayed. The total success rate for all participants was 87%, with an average completion time of 9:42, and a standard deviation of 5:01. In regard to completion time, it is imperative to consider the influence of the learning curve. The majority of the participants had minimal experience with augmented reality and lack an of familiarity with hand gesture interaction. Additionally, technical difficulties would occasionally arise due to the nature of the emerging technology and an early prototype. Examples of these interruptions include ML1 hand gesture interference where hand gestures were registered when not intended, and the inability to navigate back in certain moments.

Table 3.

Usability Testing Results

	CT	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	T
1A	7:30	0	.5	1	1	1	1	1	1	81%
1B	8:23	0	1	1	1	1	1	1	1	88%
1C	19:07	0	1	1	.5	1	1	.5	1	75%
1D	11:43	1	.5	1	1	1	1	1	1	89%
1E	9:02	1	.5	1	1	1	.5	1	1	88%
2A	13:05	1	.5	1	1	1	1	1	1	88%
2B	5:47	1	1	1	1	1	1	1	1	94%
2C	5:55	0	1	1	1	1	1	1	1	100%
2D	16:40	1	.5	1	.5	1	1	.5	.5	75%
2E	4:12	1	1	1	1	1	.5	1	1	94%
2F	4:38	1	1	1	1	1	1	1	1	88%
T	106:02	75%	88%	100%	88%	100%	88%	100%	88%	87%

Note: Completion time: n=11; SD=0:05:0; M=0:09:42; Observational results of user experience using success metrics, CT= completion time, 1A = Phase 1 Participant A, 2A = Phase 2 Participant A, SC1 = Success Criteria 1, T= Total.

Table 4 documents the user interview questions that involved a yes-or-no answer. The interview questions evaluate if participants felt educated after using ARGOS. Additionally, the interview includes feedback involving graphic interface and situational awareness in a mixed reality environment. After the test, all participants reported they learned how to take a rock sample. Below are the interview questions asked in yes or no format.

1. Do you feel like you learned how to take a rock sample?
2. Did you find this system helpful in completing your task?
3. Would you use AR to assist with a complex step-by-step task that you are unfamiliar with?
4. Did the digital interface ever visually interfere with your task?
5. Did you ever have any issues with interpreting the physical world and virtual elements?

Table 4.

User Interview Responses

Question	Yes	No
Q1	100%	0%
Q2	100%	0%
Q3	100%	0%
Q4	18%	82%
Q5	91%	9%

Key Observational Results

The examination of observational data is based on user behavior when interacting with ARGOS, and analysis of interview data is based on participant insights after the test. The information gathered from the results were synthesized into the following categories: information architecture, visual design, information architecture, and situational awareness.

Information architecture. In this study, information architecture is defined as the hierarchy of information and content design. The feedback targets the following components: main menu, instructions content, and pagination. Feedback from participants regarding information architecture is as follows:

Table 5.

Information Architecture Data

Observation	1. 36% of participants read through all instructions before starting the process. 2. 75% average success rate of selecting ‘science sample’ on the main menu
Interview	1. 72% of participants expressed positive feedback about the step-by-step content.

Interaction design. In this study, interaction design is defined as interactions such as hand gestures and voice command used by participants to complete their tasks. Feedback from participants regarding interaction design is as follows:

Table 6.

Data related to interaction design based on observation and interviews

Observation	1. 36% of participants struggled with balancing hand gestures and performing the real-world task. 2. 27% of participants held hand gestures after the system reacted.
Interview	1. 27% of participants mentioned ML1 registering hand gestures when they did not intend to interact with the system. 3. 45% of participants felt the voice interaction for camera and voice recording was intuitive

Visual Design. In this study, visual design is defined as UI components which includes layout, 3D models, color, and typography. Feedback from participants regarding visual design is shown in Table 7.

Table 7.

Visual Design Data

Observation	1. 100% of participants referred to the progress tracker when thinking aloud.
Interview	1. 27% of participants mentioned the progress tracker was useful. 2. 81% of participants believed the interface was not obtrusive. 3. 18% of participants reported the 3D models in the toolkit were helpful 4. 27% of participants reported difficulty reading text

Situational Awareness. Some participants expected the entire experience to be virtual and did not anticipate real-world interaction. Table 8 displays data on participant's situational awareness between the physical world and virtual elements.

Table 8.

Data related to the additional findings based on observation and interviews

Observation	1. 36% of participants showed difficulty transitioning awareness from virtual to the physical world in the first task
Interview	1. 9% of participants reported difficulty when orienting to AR

Chapter 5: Discussion, The Effect of Augmented Reality in Procedural Tasks

Interpretations

The findings from this research revealed patterns across participants highlighted by general areas of success and user pain points. This section presents the analysis of key results derived from usability testing observation and user interview feedback. The interpretations are based on common categories discovered in the results which include information architecture, interaction design, visual design, and situational awareness.

Information Architecture

Results related to information architecture revealed that users did not experience an over stimulus with the information presented in ARGOS and suggested more information would improve their experience. Although the majority of the participants reported appreciation for concise step-by-step information, other evidence shows the addition of more information such as a component that includes a library of hand gestures or feedback from the interface such as hover states may have improved the user's experience. This feedback identifies that users may have the cognitive bandwidth to utilize more information or interactive components. Based on the findings, it is safe to assume future iterations should continue to utilize the step-by-step delivery of information but have opportunity to emphasize the system by adding more information and/or components.

Some participants read the entire task before beginning the procedure. In table 5, four out of eleven participants skimmed through each instruction before beginning the process. This indicates a category of users who desire to be more informed of the process instead of committing to learning step-by-step. To address this finding, users may benefit from a summary of the task before beginning the procedure to give the user a better sense of the task ahead before beginning the procedure.

Concise and informative content is helpful in procedural tasks. When asked during the exit interview which element in the system was the most helpful, seven out of eleven users expressed positive feedback about the step-by-step instructions. One participant stated "The step-by-step instructions were very helpful. The content was simple, well written, and made it easy to get through the process". Information delivered in a segmented linear sequence was received well by the majority of participants. Additionally, the clarity of the copy of each instruction was favored.

Participants did not connect with science sampling on the main menu. In table 3, SC1, the lowest success rate pertained to the main menu, with a score of 75%. Some participants expected to select 'tools' because they believed they needed to collect tools before taking a sample. Other participants who selected the destination menu item assumed the first step was to navigate to the sample site. One can conclude the participants were uncertain about the initial task of the main menu. A potential cause for the uncertainty is the participant's prior knowledge of the rock sampling scenario. The participants were informed of the science sampling scenario before their test, resulting in prior knowledge of the task before the usability test. Additionally, other mode functions were not mentioned in the test, thus, the participants were unaware of other assistive modes on the menu. Consequently, the participants perceived they've already begun the rock-sampling experience. The participants were not informed that ARGOS is designed with multiple modes for other mission-based tasks non-relevant to geologic sampling.

Interaction Design

Interaction related results revealed that users experienced difficulty when using hand gestures for interaction while showing no signs of struggle when practicing voice commands. From an interaction design perspective, a potential cause for the issues with hand gestures is the interference of utilizing hand motions to execute physical tasks and use of hand gestures for controlling the AR system. Additionally, in this study, the logic of the application created issues in regards to hand recognition, as participants reported issues with the headset triggering hand-gestures when the participant did not intend to interact with the system.

Contradiction between hand gestures and real-world actions. Shown in table 6, four participants struggled with hand gestures while performing real-world tasks. These participants are right-hand dominant and struggled with alternating with system and real-world interactions. For instance, when participants used tongs to pick up the rock sample, they were unable to simultaneously hold the tongs and navigate to the next step and had to put down the tool in order to proceed. Operating the right-closed-fist hand gesture to navigate through instructions and perform physical tasks for right-hand dominant users were a contradiction that throttled the user's progress.

The ML1 registered hand gestures during physical-world action. In table 6, 27% of participants mentioned the system recognized hand gestures when they did not intend to interact with the system. For example, a participant who attempted to rake the sand in the sample site triggered the right closed-fist gesture, which resulted in moving forward one step. This issue is caused by the limitation of ML1 gesture mapping and is disruptive to the participant's productivity.

Voice interaction is intuitive. In table 3, the voice command success criteria (SC6 & SC7) resulted in a 100% success rate. One participant stated "I can see the application in something like this. It's really easy to take field notes. You don't have to stop and write down notes. It's hand's free, and the ease of use." Although voice command was largely successful, some participants desired to view the photo and voice recording file after they finished the task. This request may be a result of an uncertainty of completion in their action, and a desire for an opportunity to review their action for confirmation.

Visual Design

Overall, the visual design was received well, as nine participants expressed the visual interface design did not obtrude the FOV and were able to complete all tasks without visual interference. An area of improvement includes legibility issues of the instructions, as three participants reported difficulty reading the instructions. The cause could be due to scale, color contrast issues, or vision impairment. This portion includes the analysis of key observations relative to the visual design of ARGOS.

Pagination is helpful for tracking progress. All participants referred to the progress tracker when thinking aloud (see Figure 20). When the facilitator prompted users to think aloud, all participants referred to the pagination UI to describe the current step. One participant identified a connection between the pagination UI and the closed-fist hand gesture. The participant appreciated the UI feedback in the pagination component when using the closed fist hand gesture to navigate through each screen. This participant stated “The step tracker helped me understand where I am in the process. The fist gesture feels intuitive with the step tracker.” Participant 2C suggested increasing the visual prominence of the pagination UI by using active states for the active page for higher visibility. Overall, the majority of participants gravitated towards the use of the pagination UI.

Locked content can cause eye strain when reading instructions. Three participants expressed difficulty in legibility and placement in the UI. Participant 2B believed the eye strain was caused by poor peripheral vision and stated “I have a bad peripheral vision so having to look to the left was a bit exhausting. I wish I could have the menu placed in the center”. Participant 1E reported difficulty looking to the left side and stated, “Reading was a little difficult and the instructions. It started to hurt a little bit to look so far to the side”. This assessment highlights a lack of usability in the ARGOS design for individuals who have a sensitive vision or have fatigue when consistently gazing at location.

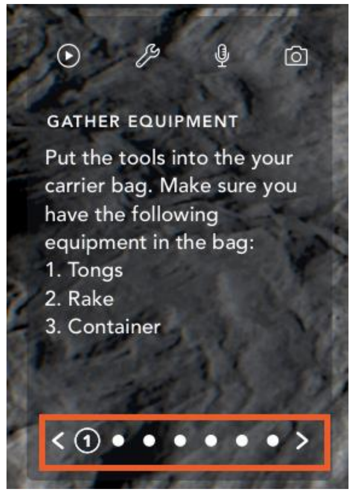


Figure 20. Pagination component located on the bottom of the instruction menu

Situational Awareness

Gupta's (2004) definition of context-switching in her study of visual perception in augmented reality, is stated as the shift of attention between visual and mental attention altering from real-world and virtual information. The results of this study revealed that users may have difficulty switching context between virtual elements and the physical world. Four participants did not anticipate completing the scenario in the real-world. When tasked to gather rock sampling tools, participants were unable to locate the tools because they assumed the tools would be virtual-based. One participant expected the sample site to also appear virtually and attempted to rake the floor instead of the sandbox. When participants came to the realization the instructions referred to the real world, it was apparent their demeanor changed and immediately understood how to complete the task. After this recognition, all participants understood the boundary between physical and virtual elements and were able to complete the scenario.

Summary

The significant pain points identified in this study include eye fatigue and hand gesture interference. Eye fatigue occurred when users consistently gazed in one direction, due to the instructions locked on to the field of view. Eye fatigue is a hindrance on usability for extended periods of time, especially when operating complex procedures. Furthermore, the ML1 registered hand gestures during physical tasks which caused the interface to change at undesired moments, resulting in a distraction for the participant. This situation is a technical limitation of ML1 that impedes usability when alternating virtual and physical interactions. Until the ML1 has advanced to be capable registering more complex gesture mappings, one can implement an alternate interaction such as voice command or eye gaze.

The usability test uncovered majority of participants relied mostly on the concise instructions and considered the ease in use when completing their tasks and as the greatest success. The most successful component described by the participants was the clarity and simplicity of the step-by-step instructions. Additionally, voice command resulted in a 100% success rate and participants expressed voice interaction as an intuitive feature. Finally, all participants expressed the benefits of displaying information on to the work environment and reported they would utilize augmented reality to assist with future technical tasks.

Implications

Based on the results, using augmented reality can amplify human perception and cognition when performing new procedural tasks. Once users calibrated to the augmented reality world, they began to work more productively. Below are the implications to further explain the significance of the research results.

Participants felt educated after the test. During the exit interview, 100% of the participants reported they felt that they learned how to take a rock sample. This result is evidence that integrating virtual information into the physical environment can increase learning and cognition. Once they learned how to navigate ARGOS and understood context switching, participants were able to complete tasks with no interference.

Participants desire more information and expect visual feedback. ARGOS was intentionally designed with minimal interactions and components, with the objective of reducing content and visual components to avoid overwhelming the user's cognition. Although the ARGOS UI was successful in conveying essential information, participant feedback reported a desire for more information and visual feedback. For example, the participants who flipped through all instructions before beginning the process may benefit from a summary or demonstration before the procedure.

Some participants suggested more visual feedback in the UI after completing an action because they felt uncertain about completing an action due to the lack of visual response. For instance, during the photo capture instruction, one participant suggested graphic guidelines around the perimeter of the photo area in order to informed of the boundaries. Another participant anticipated an option to view the photo after taking it to confirm the action completed. Providing visual guidelines and feedback can communicate completion of user action.

Participants are willing to utilize AR for complex procedural tasks. In the exit interview, participants were asked if they would use augmented reality to assist with advanced procedural tasks, such as changing a tire (Table 4, Q1). Although this study included a small sample size, all of the participants reported they would utilize a similar system for other complex tasks. The users expressed ARGOS enabled them to be more productive and complete their task more efficiently.

Hands-free capability increases productivity. When asked why they would use wearable augmented reality to assist with other step-by-step tasks, five participants communicated the hands-free experience was valuable because it reduces the amount of touch points, especially in comparison to traditional manuals. One participant stated, "It is easier to have AR instead of using your hands to grab your phone or other devices". This response was due to the visibility of information and minimal interaction. Another participant reported "Using my imagination, I can imagine working on my car now – I have to work with a book with papers that fly around with black and white paper. It would cut down on time, it's convenient. Hands-free is especially important because your hands are probably full of grease and handling a lot of tools. I find this immensely valuable." The augmenting of reality using relevant instructions enables users to focus on the real-world task.

On-demand delivery of information is valued. In the exit interview, four participants acknowledged the value of integrating instructions for each task. A participant stated "Yes. People don't have to work too hard. It would make everything easier because the information is right in front of you." This implies that wearable AR has potential to redesign the framework of common work practices by integrating data into the workflow. Participants valued the on-demand delivery of information and felt the immediate assistance improved their experience.

Recommendations

Research and designing ARGOS, the following topics should be considered when designing procedural instructions for augmented reality. These practical actions should be advised for future iterations of the HUD AR design.

Design Principles, Tools, and Methods

This project revealed the benefits of practicing traditional design heuristics and principles such as the Gestalt principles and Nielson's 10 usability heuristics. The Gestalt principles include: Proximity, Similarity, Continuity, Closure, Figure/Ground, Symmetry and Common Fate (MacNamara, 2017). Nielson's 10 usability heuristics are also recommended principles to follow (Nielson, 1994). The interaction design principles and heuristics are widely practiced in user interface design and are applicable to mixed reality experiences and provide guidance for designing intuitive user experiences across all platforms.

Design platforms are limited for prototyping HMD AR experience is a significant restriction when designing an AR HUD. Creating an interactive prototype for the ML1 headset is a prolonged effort due to the requirement of front-end implementation.

Utilizing traditional 2D design tools for prototyping low-fidelity wireframes provides an opportunity to visualize designs at a lower cost and greater efficiency.

Traditional prototyping tools such as Sketch, Photoshop, and After Effects are adequate resources for wireframing and prototyping a HUD augmented reality UI. Low fidelity wireframing and flow diagramming provide a global analysis of the user experience with minimal time contribution and low costs. This method allows for rapid iteration and is immensely valuable when testing basic interface designs before implementing components.

Although the virtual components in ARGOS resemble UI elements of the 2D world, the ARGOS UI is required to be legible in the physical world without overwhelming the user. When designing AR, virtual elements are overlaid onto the physical world, thus, the background constantly changes based on what area of the environment the user is viewing. The ML1 has a built-in overlay that slightly darkens and neutralizes contrast of the physical world, therefore increasing the legibility of the virtual components. It is recommended to place interface content such as text or icons at full opacity onto a transparent background container to increase legibility. Transparent backgrounds are preferred because opaque components block the physical world and can be obtrusive and overwhelming to the user. To test the legibility of the components in a static prototype, overlay the virtual elements on various background images. Based on the methods used for ARGOS, it is recommended to test the 2D user interface overlaid on a real-world moving background to simulate the users' natural field of view. Mobile AR tools are useful for mocking up virtual elements placed in an environment.

As augmented reality technology advances and is adopted in more practices, I anticipate prototyping tools will improve as well. I found methods were successful in designing a 2D heads up display interface for an AR HMD, and the overall transition from 2D resources to 3D is feasible but requires creative solutions to simulate an augmented reality UI. Because augmented reality is still in early development, there are limited means of prototyping. Therefore, there is creative freedom on prototyping methods. When prototyping, the priority is to visually simulate the AR experience in order to test the design principles and usability needs such as hierarchy, legibility, color, contrast, and proximity. Although the interactive design in wearable AR involves front-end coding, it is immensely valuable and efficient to utilize traditional methods of prototyping to test the digital interfaces' visual design.

Reduce Eyestrain

The results of this study revealed that users experienced fatigue when gazing at information locked on to the FOV. The instruction menu is locked and flushed to the left of the field of view, forcing users to consistently look to the left for more information. Implementing a multi-modal interaction option to the instruction menu instead of locked content could potentially alleviate eyestrain. For example, the user could have the option to unlock the instruction menu from the FOV and instead, place the element into the environment. The placement interaction would allow the user to view instructions in the designated physical location, thus, releasing the user's gaze to different locations.

Accessibility for Hand Dominance

Three participants were disrupted during their tasks due to conflicting use of their dominant hand for physical tasks and hand gesture-based navigation. Specifically, when using the tongs to pick up a sample, the participants needed to place the tool down in order to use their right hand to navigate to the next step. Pausing progress in the task in order to interact with the digital system can be perceived as inefficient. To address this issue, one can create a left-hand mode that reverses the hand gestures. Alternatively, the ML1 supports multi-modal interaction. Therefore, one could substitute hand-gesture interactions with voice command. Nonetheless, it is recommended to apply interactions that are accessible for users with different hand-dominances.

Mitigate the learning curve

It is imperative to consider the sensitivity of a novice user's situational awareness when using augmented reality. Beginners require time to adapt to a mixed reality experience and may need additional guidance of what to expect in the virtual or physical world. To reduce the impact of sensory overload, it is recommended to include a demonstration or tutorial of the system to prepare novice users.

ARGOS was designed to use minimal interactions to reduce the learning curve and avoid sensory overload. The simplicity of the interface was designed with the intention of building an intuitive system for all users. Minimizing the number of interactions can mitigate the learning curve. Based on participant feedback, ARGOS could be improved with providing more information to the interface. One participant suggested adding a virtual tutorial or tooltips in the UI to remind the user of what interactions they can use. This suggestion displays a need for additional training and guidance of interaction with the system. In certain situations, it may be beneficial to add UI components in order to provide guidance and confirmation in the experience.

Research through Design Fiction in Augmented Reality

Due to the minimal amount of research and guidelines for designing wearable augmented reality, the design methodology practiced in this exploratory study reflects research through design fiction. In *Research Fiction and Thought Experiments in Design,* Mark Blythe (2018) describes design fiction is the practice of designing representations of products that do not exist yet. The youth of augmented reality technology has a limitation when prototyping, thus, design fiction methods were applicable to designing ARGOS.

The design fiction technique influenced the design process of ARGOS and resulted in a conceptual prediction of the final product. Utilizing traditional 2D tools to design an augmented reality experience was beneficial because creating a 2D replica captured important elements of the end product. For example, although creating a mockup with a mobile AR tool is a video-based visual representation of the real experience, this 2D replica tests the validity of the interface based on design principles and usability heuristics such as hierarchy, balance, reduction of cognitive load, and consistency (Gordon, 2020; Nielson, 1994). In other instances, design fiction prototypes can also identify areas of improvement. It is recommended to use design fiction techniques to explore the augmented reality world because it allows designers to test a conceptual prototype without the additional time and expense of implementing into the headset system. This approach allows designers to explore if the design is feasible before seeking technological possibilities.

Chapter 6: Limitations & Conclusion

Limitations

It is imperative to understand this study as an exploration of recent growing technology. The wearable augmented reality industry is considered in the development phase in hardware, software, and design, resulting in constraints, When designing a digital interface for wearable augmented reality, one must be prepared to adapt to technical limitations such as interface prototyping and development.

This study was limited by hardware availability due to only one Magic Leap was available for the team. Consequentially, in order to experience the interactive design, one must implement the UI into the ML1 system. The limitation of one headset dedicated to UI design would constrain the software developers to progress. As a result, a set time was available for UI implementation, resulting in minimal iterations.

The inability to test an interactive prototype is limiting when designing an interface. Designers must resort to other means of prototyping and are unable to test a high-fidelity interactive experience without the headset and development. Two significant limitations were identified during development and testing: ML1 technology and vision impairment.

ML1 Hardware & Software Limitations

Although hand gesture recognition is considered one of the most substantial features of the ML1in the current AR headset industry, the variety of gestures available is limiting for interaction. The preferred way of designing an intuitive augmented reality requires interactions familiar to the real-world to limit the learning curve of a mixed reality experience (Dunser et. al, 2007).

Another limitation of this research includes complications when developing in MagicScript, the programming language used to build ARGOS. The process of developing and deploying the application was a significant issue. When using MagicScript, developers are unable to check the code before uploading to the ML1, resulting in a cumbersome process for deployment. Due to MagicScript's young and rapid changing framework, the development team faced challenges when implementing interface elements such as the UI placement feature, hover states in the main menu, and rendering image files.

It is common to encounter bugs due to the fragile framework, especially when MagicScript updates. The impact of ML1 updates can result in breaking the original code, which requires additional troubleshooting. It was common for the to encounter bugs that caused the system to break and ultimately crash. One developer expressed frustration with the need to frequently of reboot ML1 because the interface was unable to load. Due to the frequent bugs, a developer was required to stand by during testing to debug errors that may occur.

Similar to design limitations, developing augmented reality is limited because this technology in the experimental stages. Because the ML1 is an emerging technology, the developer community is small and the framework is new, resulting in a delay in answers when troubleshooting. Additionally, the development for ML1 was constrained to the functions that were available from the company. Troubleshooting was frequent and difficult to accomplish due to the limited resources and constant changes.

Vision Impairment

The ML1 headset used for testing included two mild prescriptions for users with near and far sight vision. Therefore, users with strong visual impairment without contact lenses may have struggled to complete the usability test. In the first phase of usability testing, a participant was unable to complete the usability task and was excluded from testing data. This limitation was discovered during testing. Each ML1 prescription lens set is costly, so an alternative to testing is screening users who do not have vision impairment.

Conclusion

The findings from this exploratory study prove the value of using an augmented HMD to assist beginner users in procedural tasks. This study contributes the findings related to information architecture, visual design, interaction design, and context-switching to the augmented reality industry. Additionally, this study contributes to the design fiction method of prototyping concepts for emerging technologies. These discoveries should be considered when designing a wearable augmented reality interface for procedural methods. It is encouraged to prototype by utilizing traditional prototyping tools in order to discover successes and failures in design with greater efficiency. It is safe to assume the ARGOS interface was successful in supporting novice users, as all participants reported they felt educated on how to collect rock samples. The results from this research affirm the effective use of Nielson's foundational design heuristics and Gestalt principles. Additional discoveries from this research that should be considered when designing a digital interface for wearable augmented reality experiences include spatial awareness, cognitive overload, and context switching. Future steps for advancing ARGOS involves integrating a complex task in order to stress-test the existing design by reason of all participants vocalized they would use an augmented reality system in the future for advanced procedural tasks.

This research has revealed an interest in using augmented reality HMD for procedural tasks. Wearable augmented reality is considered an emerging technology in an industry with room for advancement. Thus, the future of the augmented reality industry holds opportunities for hardware, software, and prototyping tools that may increase in availability. It is recommended that designers, developers, and researchers continue to iterate, experiment, and continue to contribute research findings as this technology progresses and increases in accessibility.

The phenomenon of augmenting reality through virtual elements to enhance the physical world is progression towards amplifying human perception and enabling human cognition. The addition of other emerging technologies such as include real-time comprehension and object recognition could contribute to enhancing reality. Real-time comprehension would allow the system to learn and adapt to the user's situation, and dynamically provide a solution to the existing task. These technologies are parallel to the enhancing user reality through data – real-time adaptive information integrated into the physical world to amplify human cognition. Ultimately, any advancement of augmented reality is designed to enhance the physical world to enable individuals to learn and take action.

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Appendix A: Title of Appendix

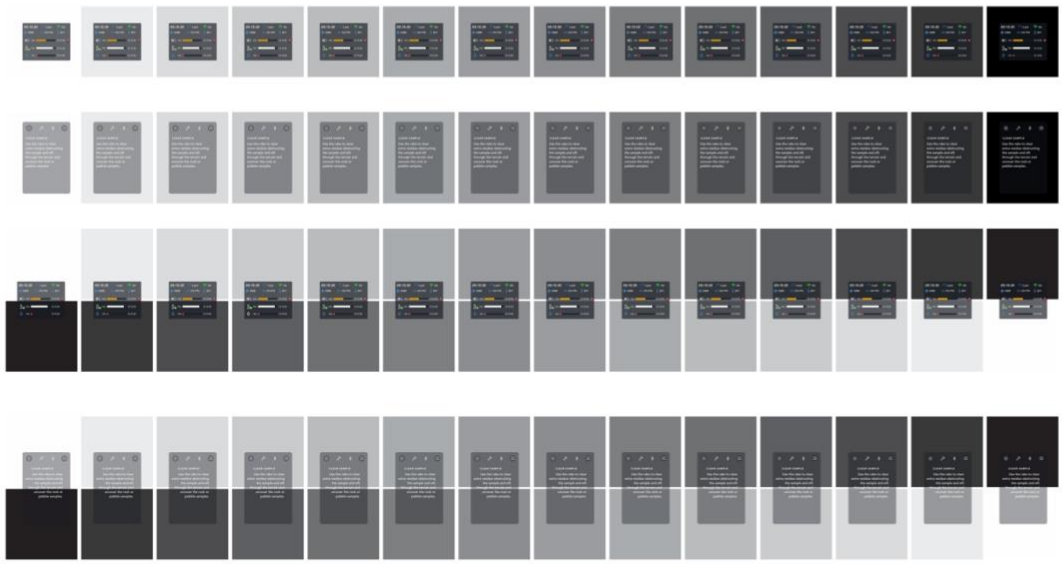

Figure 1. Color study of ARGOS UI components