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October 11, 2014
Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia, V5A 1S6

Re: ENSC 440/305W Capstone Project: Functional Specifications for the Augmented Reality Telepresence (ART) System

Dear Dr. Rawicz,

Pandora Vision is thrilled to submit the "*Functional Specifications for the ART System*" as part of the documentation required for our Capstone project. The goal of the ART system is to provide a sense of physical presence to the user while monitoring a remote location.

The enclosed document provides all necessary information corresponding to the functional specifications of the ART system. The document discusses details of the system's general functionality, usability, reliability, and safety for both proof-of-concept and production phases of the development. The requirements listed in each section highlight our design goals. Hence, the listed requirements will serve as a guide for our team to conduct research, development and testing.

Pandora Vision endeavors eliminating physical presence in hazardous environments by developing the ART system. We are excited to share the functional specifications of our system with you. Should you have any questions regarding this document, please contact me at rraizada@sfu.ca. We look forward to working under your guidance.

Sincerely,

Rashika Raizada
Chief Executive Officer
Pandora Vision
Enclosed: Proposal for an Augmented Reality Telepresence (ART)

Pandora Vision

Augmented Reality Telepresence

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Table of Contents

Executive Summary

Advancements in industrialization and robotics have driven research into working with robots using virtual reality as a means of communication. In manufacturing plants, in order to perform maintenance duties or monitor operations, employees are required to step into hazardous environments. In British Columbia between 2008 and 2012, there has been over 3000 serious injury claims caused by human presence in the manufacturing sector [5]. As an example, human exposure to lead can cause lead poisoning leading to reproductive problems [2]. There are numerous situations where machinery [1], atmosphere, temperature, chemicals, and other operating conditions create hazardous environments in which human exposure is dangerous. Avoiding the physical presence in such circumstances will help mitigate various risks to an employee.

At Pandora Vision we recognize the necessity for a plausible, cost-effective solution to addresses human safety related problems that currently exist in manufacturing plants. In the pursuit of addressing the solution, we aim to develop the ART system. The ART system is a device consisting of two main sub-systems, the head-controlled stereoscopic camera (HCSC) system and the control system. The two subsystems communicate together to create virtual human presence. In the proof-of-concept model, we aim to develop the following:

- Mimicking the movement of the user's head by the HCSC system
- Communication between the HCSC system and the control system
- Maneuvering the HCSC by a head mounted display
- Real-time video feedback of the remote location received from the HCSC and displayed by the head mounted display

The functionality outlined above is enough to achieve virtual human presence in hazardous environments. Human operators can monitor processes or machinery from a remote location (a "base station") using a head mounted display (HMD). Development and unit testing of components for each system will begin and progress concurrently. Integration and system functionality tests will also occur in parallel to system development. Test cycles will be performed on the system to ensure that it meets all the specified requirements mentioned in the remainder of this document.

The functional requirements specified below are a set of requirements corresponding to each module within the system, which must be met as a means of proof-of-concept, prototype, or final production model. Safety, standards, usability, reliability and environmental requirements are included to put the user at ease, knowing that these concerns have been accounted for prior to development. Pandora Vision has created a dynamic project timeline to meet the functional specifications mentioned in this document within a two-month time frame. This document provides a full list of functional requirements to be followed closely to reach a deliverable proof-of-concept model of the ART system.

List of Figures

Glossary

Telepresence: refers to a set of technologies which allow a person to feel as if they were present, to give the appearance of being present, or to have an effect, via tele-robotics, at a place other than their true location.

Two degrees of freedom: A degree of freedom of a physical system refers to a (typically real) parameter that is necessary to characterize the state of a physical system. Two degrees of freedom referred to in this document is specifically referring to rotating around the yaw and pitch axes.

Yaw: Defined as the sideways movement of the head.

Pitch: Defined as the vertical movement of the head.

Virtual Reality: is a computer-simulated environment that can simulate physical presence in places in the real world or imagined worlds.

Augmented Reality: is a live direct or indirect view of a physical, real-world environment whose elements are augmented (or supplemented) by computer-generated sensory input such as sound, video, graphics or GPS data

Virtual Reality Device: is a device capable of measuring and providing information on head orientation and movement and is able to display two images representing the left and right eye of a human being.

Head mounted display: Head mounted display and virtual reality device are used interchangeably through this document

Category 5 cable enhanced: A cable used to connect a computer to a computer network

WiFi: any wireless local area network product that is based on the IEEE 802.11 standards [18]

Acronyms

VR: Virtual Reality

ART: Augmented Reality Telepresence

HCSC: Head Controlled Stereoscopic Camera

cmd: Command

HMD: Head mounted display

HDMI: High-Definition Multimedia Interface

USB: Universal Serial Bus

Cat5e: Category 5 cable enhanced

UDP: User Datagram Protocol

1 Introduction

The ART system is designed to minimize physical presence of human beings in hazardous environments such as the prohibited area of an operating manufacturing robot [1]. A sense of telepresence is provided by the ART system, as a result of a camera system mounted in the location of interest and controlled by the user's head movement sitting in another, safer, location. The user in turn views the images generated by the camera system through a VR device to provide not only a 3D, but also physical presence experience as shown in figure 1.

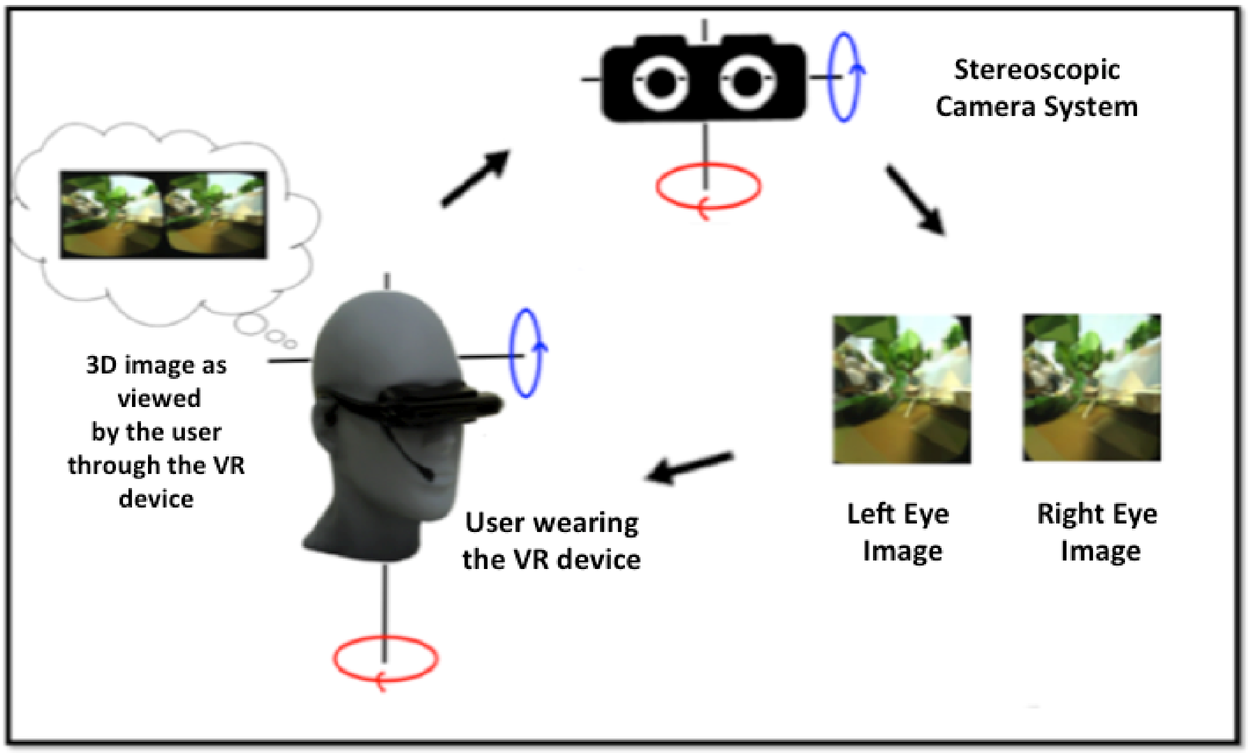

Figure 1: High-level demonstration of the ART system [9] [11][12]

1.1 Scope

The functional specification document has defined the functional requirements that the ART system must adhere to. This document clearly differentiates the prototype functional requirements from those of the final product ones.

1.2 Intended Audience

The functional specification documentation is to be used by all the members of Pandora Vision during the design and development of the ART system. This specification document will also be referenced for creating testing plans for the ART system.

1.3 Classification

In order to identify the functional requirements and priority corresponding to each functional requirement, we have used the following notation:

[**R-n-p**]: Functional requirement

where ***R*** denotes the functional requirement, ***n*** specifies the functional requirement number, and ***p*** indicates the priority of the requirement. For the purpose of this document, there are three levels of priority corresponding to each functional requirement.

A. High priority, Proof-of-concept
B. Medium priority, Prototype model
C. Low priority, Final production model of the system

2 System Requirements

The requirements of the ART system are defined in this section.

2.1 System Overview

The figure 2 below illustrates the behaviour of the ART system. The VR Device sends head orientation data to the control system. The control system redirects the data to the HCSC that uses the corresponding orientation data to orient the cameras accordingly. The HCSC then sends the updated image data back to the control system, which forwards the image data to the user. The user views the image as a stereoscopic 3D image. The flowchart shown on the next page describes the functionality of the ART system as expected from the user's perspective.

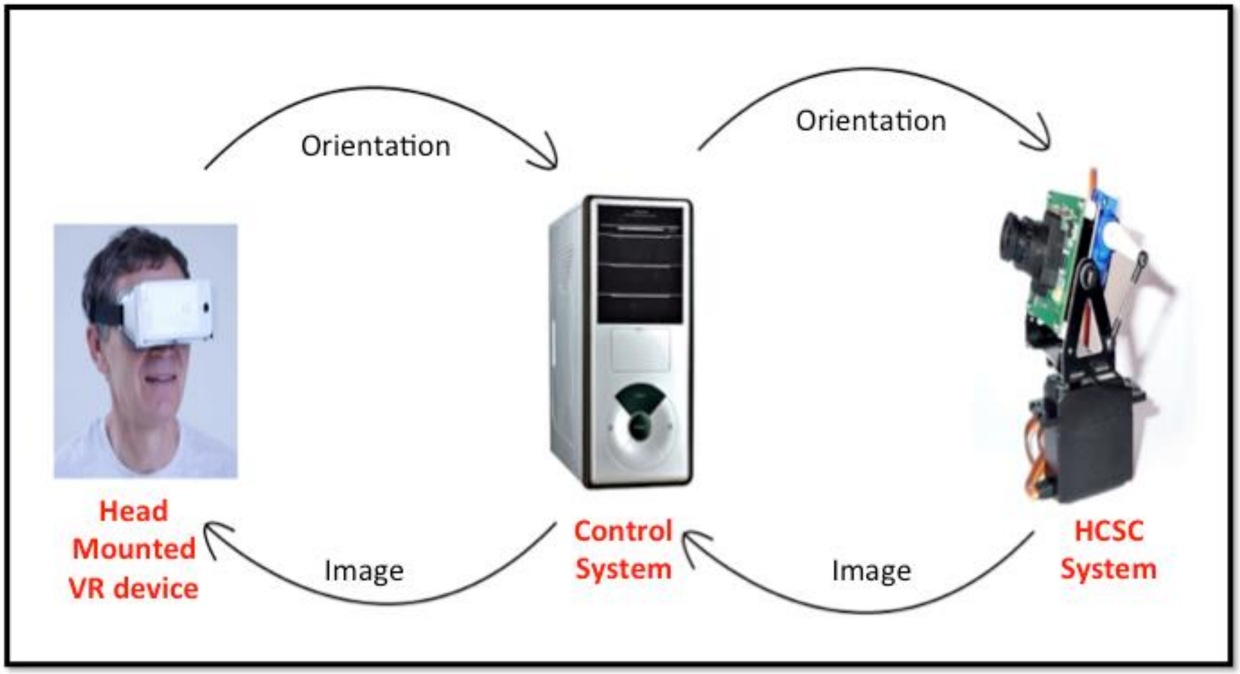

Figure 2: ART System Overview [15][16][17]

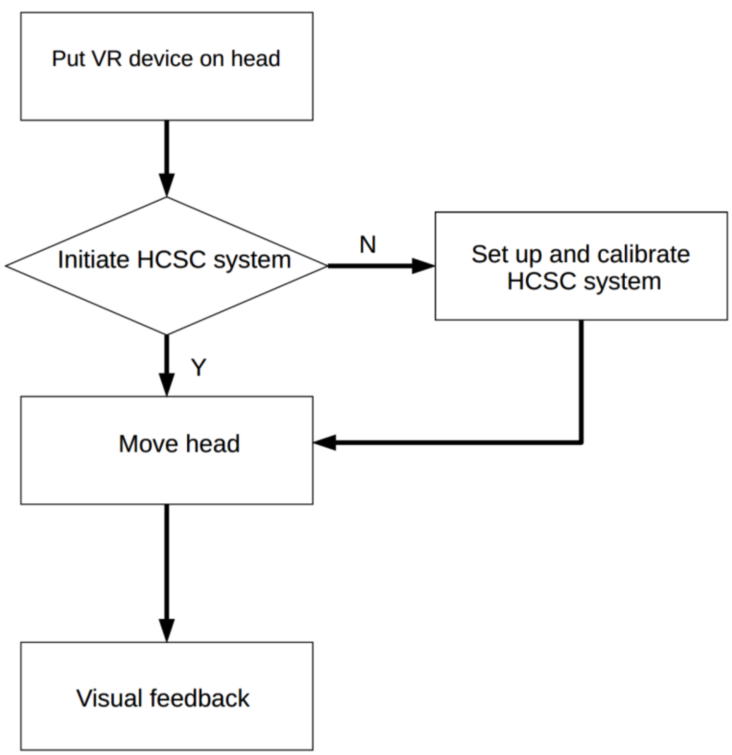

Figure 3: Expected Functionality from User's Perspective

2.2 Overall Requirements

2.2.1 General Requirements

[R-1-C] The device must have minimal training time to use
[R-2-B] The device must be robust
[R-3-C] The device shall be easy to assemble and maintain
[R-4-C] The components of the device must be easily available
[R-5-B] The total cost of the device must be less than $500
[R-6-C] The system should be operable using any VR enabled device
[R-7-C] The system will operate with less than 150ms or less motion latency [10]

2.2.2 Performance Requirements

[R-8-A] The device must follow the head movement of the user along both yaw and pitch axes
[R-9-C] The device must not restrict the motion of the person
[R-10-A] The device must be capable of collecting two images simultaneously for stereoscopic vision
[R-11-C] The device must perform in real time
[R-12-B] The device must be capable of refreshing visual information at a minimum rate of 60 frames per second [8]
[R-13-C] The subsystem of the device must communicate wirelessly

2.2.3 Physical Requirements

[R-14-B] The device must be balanced when assembled
[R-15-B] The wires must be color-coded in the system circuitry

2.2.4 Safety Requirements

[R-16-A] The system must be carefully grounded
[R-17-C] All electronics for the device must be enclosed
[R-18-B] All circuitry within system should be organized, no loose wires
[R-19-B] The system circuitry must be stable
[R-20-B] The wires must be soldered properly

2.2.5 Standards Requirements

[R-21-B] The device shall conform to IEC 61508 standards [3]
[R-22-B] The device shall conform to CSA/UL 60950-1 standards [4]
[R-23-B] Any device used within the system must adhere to North American standard IEC 60906-2 [20]

2.2.6 Environmental Requirements

[R-24-B] The system should operate normally in room temperature
[R-25-B] The system should work normally in ambient humidity and pressure conditions
[R-26-C] The system should not get altered by light interferences
[R-27-C] The system shall not get altered by vibration interferences

2.2.7 Reliability Requirements

[R-28-C] The device must be capable of 24 hours continuous operation
[R-29-C] The system must have a minimum lifetime of 5 years

2.3 Head-Controlled Stereoscopic Camera (HCSC) System

The HCSC sub-system is responsible for receiving the user's head orientation and transmitting the captured images to the control system. It consists of two cameras, a mount system comprising of servomotors and brackets, and two microcontrollers. The HCSC is the most important aspect of the ART system, as the HCSC must accurately mimic the user's head orientation with minimal latency.

2.3.1 General Requirements

[R-30-B] The system must be able to operate in remote areas
[R-31-C] The system must conform to the requirements of any Virtual Reality (VR) enabled device currently present in the market
[R-32-A] The system is able to transmit video to a PC
[R-33-A] The system must update its orientation with new orientation data
[R-34-A] Each camera's size is not greater than 25mm by 20mm by 9mm [13]

2.3.2 Performance Requirements

[R-35-A] The cameras must support a real time video feed at 720p at 60 frames per second (fps) [13]
[R-36-A] The mount system must rotate in the yaw axis
[R-37-A] The mount must rotate in the pitch axis
[R-38-A] The mount's acceleration should be controlled by the user's head movement.
[R-39-C] The system must provide a real time video feed at 1080p resolution and 60 frames per second (fps) [13].

2.3.3 Physical Requirements

[R-40-A] Maximum weight of the system is 5.0kg
[R-41-A] The system height should not exceed 50cm

[R-42-B] Cables and equipment must be stable such that they are not affected upon system movements

[R-43-C] The system cabling must be insulated and have no jumper cables

[R-44-B] The cameras must be mounted robustly on the camera mount system

[R-45-B] The camera mount system must be able to withstand the weight of the cameras

2.3.4 Safety Requirements

[R-46-A] The system should not release harmful materials to its surroundings

[R-47-A] The System must not create electrical discharge or sparks

[R-48-A] The System must not combust spontaneously

[R-49-B] All electronics in the system will be contained inside of an enclosure

[R-50-C] All electronics will be of waterproof material

[R-51-C] The system includes ventilation for electronics equipment to prevent overheating of systems

2.3.5 Standards Requirements

[R-52-B] The cameras conform the ISO/IEC 14496 standard for video coding [19]

[R-53-B] Data transmission should be completed using the UDP network protocol adhering to standard RFC 768 [7]

[R-54-B] All electronics related to system including circuitry, cables and wiring, and cables should be compliant with the CSA Canadian Electrical code in regards to safety

[R-55-A] The system will follow Oculus VR Best Practices Guide [8]

2.3.6 Electrical Requirements

[R-56-B] The servo motors of the camera mount must be carefully grounded

[R-57-B] The servo motors must be connected to the microcontroller via bread boards to eliminate erratic behavior while downloading code on the microcontroller [14]

[R-58-B] The servo motors must operate at a voltage of either 3.3V or 5V [14]

2.3.7 Mechanical Requirements

[R-59-B] The servo motors of the mount system must have 180 rotation

[R-60-A] The mount must be capable of 180 degree rotation in both the yaw and pitch axes

[R-61-C] The mount must provide smooth motion

2.3.8 Environmental Requirements

[R-62-C] The system must be able to operate in the temperature range of -10^{o}C to 40^{o}C

[R-63-C] The system must be able to operate in relative 100% humidity

[R-64-C] The System must be able to work in varying pressure conditions

2.4 Control System

The Control system consists of a computer and a VR device. The computer is responsible for receiving head orientation from the VR device and sending the information to the Head-Controlled Stereoscopic Camera (HCSC) System. The VR device is responsible for displaying visual feedback to the user.

2.4.1 General Requirements

[R-65-A] The system must be capable of receiving head orientation from VR device through a 10ft USB

[R-66-A] The system must be able to send information to HCSC system through 10ft USB

[R-67-A] The system must be capable of receiving video from HCSC system through 10ft USB

[R-68-A] The system must be able to send video to VR device through HDMI

[R-69-C] Data transmission should be completed using the UDP network protocol adhering to standard RFC 768 [7]

[R-70-A] The VR device will display independent images for the left and right eyes

[R-71-A] The VR device will prevent the user from seeing their surroundings

[R-72-A] The VR device will provide the user information on how much further the camera can rotate

[R-73-A] The VR device will display to the user when the camera cannot rotate any further

[R-74-A] The VR device will adjust to different head sizes

[R-75-A] The VR device will orientation will only update after the user changes the orientation of the VR device

2.4.2 Performance Requirements

[R-76-A] The system must be able to create a side-by-side placed video clip from two videos

[R-77-A] The system must have a server set up, listening to VR device and HCSC system

[R-78-C] The system will display the left and right frames produced by the HCSC at t_0 at the same time

[R-79-C] The system must be able to send information to HCSC system through Cat5e

[R-80-C] The system must be able to send information to HCSC system WiFi

[R-81-C] The system must be capable of receiving video from HCSC system through Cat5e

[R-82-C] The system must be capable of receiving video from HCSC system through WiFi

[R-83-C] The system must be able to send video to VR device through Cat5e

[R-84-C] The system must be able to send video to VR device WiFi

[R-85-C] The system must be capable of receiving head orientation from the VR device using WiFi

[R-86-C] The VR Device's frame rate must match the frame rate output by the software

[R-87-B] The system will prioritize frame rate over camera resolution

2.4.3 Physical Requirements

[R-88-A] The VR Device must have accelerometer and must be mounted on the user's head
[R-89-B] The VR Device must be adjustable for different head sizes
[R-90-B] The VR Device must have a maximum weight of 0.5 Kg
[R-91-B] The VR Device's must have a display to completely cover the users eyes

2.4.4 Safety and Standards Requirements

[R-92-A] The device must not cause harmful interferences
[R-93-A] The device must be electrically insulated from the user
[R-94-A] The distance between the cameras should be constant to reduce eyestrain and avoid perceptual anomalies
[R-95-A] The system will remove any zoom effects as zoom effects can cause dizziness [8]
[R-96-A] The system will follow Oculus VR Best Practices Guide [8]

2.4.5 Electrical Requirements

[R-97-A] The device must operate at a voltage value of 5V
[R-98-A] The device must have a power consumption less than 300W
[R-99-A] The VR Device will have an independent power source

2.5 User Application Requirements

If smartphone is used as VR device, user application developed by Pandora Vision must be installed. The user application provides visual feedback from control system to users. The user application displays two video clips side-by-side for user's left and right eye respectively. User's head position and movement are collected and sent to control system using user application.

2.5.1 General Requirements

[R-100-A] The application must be able to collect accelerometer and gyroscope data
[R-101-A] The application must be able to convert motion sensor raw data to yaw and pitch
[R-102-A] The application must be capable of sending information to control system through USB
[R-103-C] The application must be capable of sending information to control system through WiFi
[R-104-A] The application must be capable of receiving video clip from control system through USB
[R-105-C] The application must be capable of receiving video clip from control system through WiFi

2.5.2 Performance Requirements

[R-106-A] The application must be able to play at least 720P video
[R-107-C] The application shall support playing 1080P video
[R-108-B] The application must play the video at 60 frames per second (FPS)

2.5.3 Safety Requirements and Standards Requirements

[R-109-A] The application conform IEC 61508 standards [3]

2.5.4 User Interface (UI) Requirements

[R-110-C] The application must fit within 1/3 of the users viewing area
[R-111-C] The application must have a user-friendly interface
[R-112-C] The application must have an interface to calibrate HCSC system directly
[R-113-C] The application must be 3D and sit approximately 2-3 meters away from the viewer
[R-114-C] The user should not swivel their eyes to see the UI

2.5.5 Software Requirements

[R-115-A] The application must be compatible with Android 4.4
[R-116-C] The application must be compatible with IOS8 or above

2.6 User Documentation

[R-117-C] User documentation will include a website with general support information and user manual written in English
[R-118-C] User documentation will be written for an audience of minimal knowledge of data communication and robotics
[R-119-C] User documentation will be provided in multiple languages, French, German, Spanish, Traditional Chinese, Simplified Chinese, and Japanese to satisfy product language requirements for international markets
[R-120-C] An installation guide for technicians and vendors shall be created

3 Sustainability Considerations

The objective of Pandora Vision is to eliminate the need of physical presence in hazardous situations, reducing the risk of injuries imposed on humans. In order to guarantee the safety of the user. Additional measures must be taken to ensure that the design itself does not impose any harm or danger to the user or the surrounding environment. The following are major concerns that arise in satisfying the above requirement:

1. During operation, the VR device does not cause any harm to the user upon wearing the VR device and using it to control the HCSC system.

2. The HCSC system does not produce any harmful effects to the surroundings such as any toxic, radiation, electromagnetic, or electrostatic effects.

It is also important to consider sustainability aspects of the ART system during the development process of both the prototype model and the final production model. Upon dismantling of the system, many of the components and parts that have been incorporated, such as the raspberry pi, can be reused or recycled for other purposes. The complete system includes raspberry pi microcontrollers, camera module boards, a VR device, servo motors, cables, LEDs, and breadboards. In terms of the production model, the cradle-to-cradle design approach will be used for mass manufacturing and the appropriate certifications will be acquired [6].

4 System Test Plan

The ART system will be iteratively tested as each component and subsystem is completed. Testing each component for basic functionality will ensure that each component meets the basic requirements before integrating into the larger system. As the proof-of-concept approaches completion we will begin to conduct user-based trials of the ART system. Testing methodologies will be outlined which an emphasis on the proof-of-concept requirements. More detailed testing procedures will be developed in the designing and implementation stages.

All rotatable parts have rotational requirements dictating the physical range of motion of the part. The rotational requirements will be tested before the component has been assembled to verify the expected range of motion. Once the component has been assembled, the part will be tested to ensure that the component can rotate the full range of motion with the additional load. Once the entire system is completed the rotational parts will be tested again to determine the responsiveness of the system.

The control system will be tested with a head mounted display verifying that the output of the control system matches the head orientation of the user. Once the data communication software has been completed between the control system and the HCSC, a test will be completed verifying that orientation data from the head mounted display is being correctly sent and received.

The expected use of the product that a typical user would experience to use the ART system is defined as the general use case:

1. User connects a head mounted display to their control system
2. User starts ART software
3. User puts on a head mounted display
4. If the orientation is incorrect the user resets the orientation of the camera

5. While user is wearing the head mounted display, the uses the ART system by turning their head

The responsiveness of the system will be broken down into two different categories, responsiveness of the video and responsiveness of the movement. The responsiveness of movement will be tested by rapidly moving back and forth the head mounted displays. The responsiveness of the images will be tested by moving a constant image across the display and viewing the image on the head mounted display. If significant latency is found in either case more time will be spent adjusting the algorithms used to draw the images and the performance retested.

Requirements for operational safety and error handling will be simulated and the response of the system will be observed.

5 Conclusion

The requirements listed in this document demonstrate the functional specifications of the ART system. The requirements establish the capabilities of the system including performance, safety, standards, and usability. The proof-of-concept serves to provide a functional identity and ensure each component functions accordingly before it is integrated into the system. The prototype model aims to integrate the individual components and meet the specified requirements to develop a working model of the ART system. The final production model is the end goal to produce the ideal model which complements the prototype in terms of meeting the requirements and the standards provided in this document, but also contains added features and it is a product that can the end-user can use.

Pandora Vision is targeting a delivery deadline of December 1st of 2014 for the proof-of-concept and the prototype model of the ART system.

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