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November 6, 2014

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Re: ENSC Design Specifications for the ART system, a telepresence system

Dear Dr. Rawicz,

Please find a copy of the design specifications for Pandora Vision's augmented reality telepresence (ART) system, enclosed in this document. Pandora Vision aims at developing a sense of presence for the user in situations where real presence is hazardous.

The enclosed document provides design details that all the members of Pandora vision have developed to achieve a prototype of the ART system. The document also provides high level system designs and block diagrams to highlight the technical details necessary for building the ART system. A functional test plan is also included in the appendix of the document to test and build a working prototype of the ART system.

The Pandora Vision team is excited about sharing the design details of the ART system with you. Should you have any questions or concerns about the design details, please contact us at rraizada@sfu.ca.

Rashika

Rashika Raizada
Chief Executive Officer
Pandora Vision
Enclosed: Design Specifications for Augmented Reality Telepresence (ART) system

Pandora Vision

Augmented Reality Telepresence

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Issued date: *November 6, 2014*

Revision: *1.2*

Abstract

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, individuals are required to step into hazardous environments. Avoiding the physical presence in such environments will help mitigate various risks to an employee.

The prototype for the ART system consists of 3 subsystems: HCSC system, control system, and VR device. All the subsystems are designed and implemented as independent modules complying with the other subsystems. The HCSC system operates in a remote location and captures and transmits images to the VR device. The VR device provides a 3D stereoscopic view of the remote location where the HCSC is located to the user. The VR device also provides the head orientation data of the user to the HCSC system so that the camera's orientations mimic the user's head. The control system provides the software for data transmission and processing.

Testing of the prototype will take place independently for the modules to catch anomalies at early stages and ensure a reliable foundation of the system. Testing of the integrated system will then be carried out to ensure compliance and functionality requirements are met.

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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 rotation of the user's head.

Pitch: Defined as the vertical rotation of the user's 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

Raspberry Pi-breadboard shelf: two raspberry pi units and a breadboard mounted parallel to one another, giving the appearance of a three-floor shelf

List of Acronyms

ART**:** Augmented Reality Telepresence
GPIO: General purpose input output
RPi: Raspberry pi
HCSC: Head-Controlled Stereoscopic Camera
HMD: Head-mounted display
VR: Virtual reality

CSI: Camera Serial Interface
GUI: Graphical User Interface
PWM: Pulse Width Modulator
FFMPEG: Fast Forward Moving Pictures Expert Group
IPC: Inter-Process Communication
UDP: User Datagram Protocol
TCP: Transmission Control Protocol
FOV: Field of View
2D: two-dimensional
3D: three-dimensional

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]. The ART system provides a sense of telepresence by allowing the user to control a remote camera. Figure 1 below illustrates the high level functionality of the ART system.

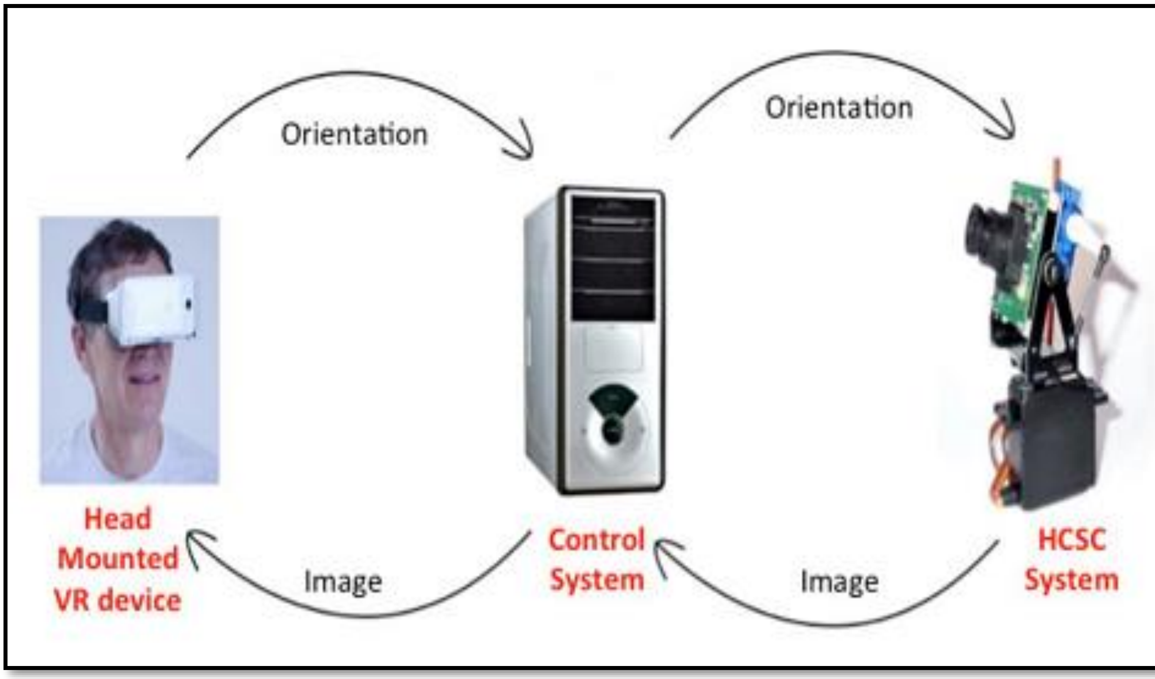

Figure 1: ART System User Experience [2] [3] [4]

A VR device is worn by the user and sends head orientation data to the control system. In response, the control system orients the stereoscopic cameras of the Head-Controlled Stereoscopic Camera (HCSC) system placed at a remote location. The images collected by the HCSC system are passed on to the control system to be processed before forwarding to the VR device.

1.1 Scope

This documentation describes the design specifications for ART system, including the design approaches and possible justifications. The design specifications correspond to the functional requirements listed in function specification document of ART system. Explanation will be presented for each design approach as well as any design modifications. This design specifications document focuses on proof-of-concept model but may still involves prototype and final product model.

1.2 Intended Audience

The Design Specification document is created to be used by the Pandora Vision team during the development and testing phases of the ART system. The engineers are required to refer to this document, ensuring that the ART system meets all the functional requirements by successfully completing the test plans.

2 System Specifications

2.1 System Overview

The ART system consists of a VR device, a control system and a HCSC system. The control system and the HCSC system are placed in two different locations from each other. The user uses the VR device in the same location as the control system and has direct physical and constant access to the control system. The HCSC system is located at a remote location, possibly hazardous for physical human presence.

Figure 2 below shows the interaction between various components of the HCSC and the control system.

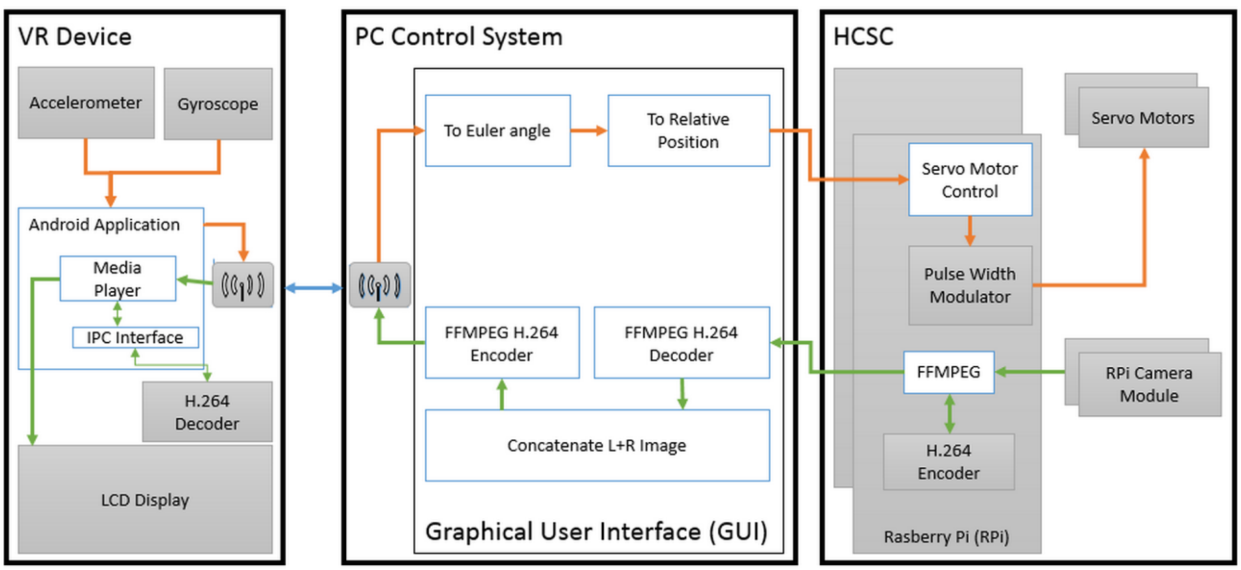

Figure 2: Block level diagram of the ART system

The ART system consists of a VR device, a PC, and a Graphical User Interface (GUI). The control system is responsible for sending the user's head orientation to the HCSC and receiving the images captured by the HCSC. The gyroscope in the VR device is used to collect the head orientation of the user and transmit it to the PC. The PC prepares the orientation data before sending it to the HCSC system. Moreover, the PC is also responsible for processing the images received from the HCSC system before sending it to the VR device. The GUI resides on the PC and enables the user to control the ART system.

The HCSC system is responsible for receiving head orientation data from the control system and sending the captured images to the control system. The HCSC system contains the camera mount and two Raspberry Pi (RPi). The RPi is used to control the servo motors. In addition, the RPi transmits images captured by the cameras to the control system.

2.2 System Design

Figure 3: Inputs based ART system block diagram below provides a generalized data path from Figure 2: Block level diagram of the ART system, the perspective of the inputs to the system to the output of the system.

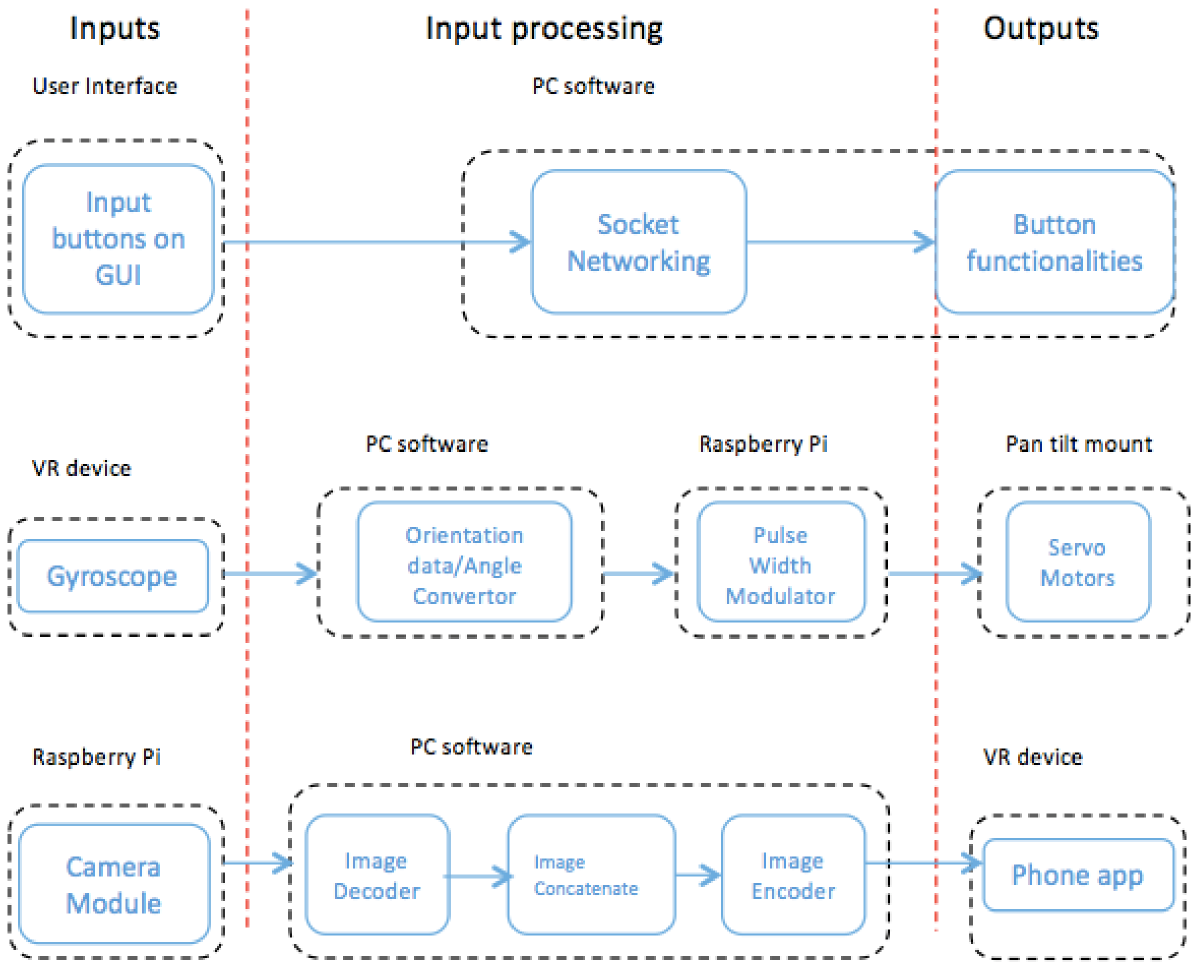

Figure 3: Inputs based ART system block diagram

The Figure 3 above describes the three inputs to the ART system and their corresponding outputs. The first input is from the user through the Graphical User Interface (GUI) that is created to enable the user to control the ART system operations. The GUI starts the ART system operations through network communication, which is initialized on the PC. The second input to the ART system is the head orientation data that is collected by the gyroscope of the VR device, which is mounted on the user's head. The orientation data is converted to angular format using the software on the PC, which then controls the servo motors of the pan tilt mount of the HCSC system using the pulse width modulation. The third input to the ART system as shown in Figure 3 is the image input through the Raspberry Pi camera module. The images collected are then decoded and concatenated before encoding them to send to the phone app for user viewing.

3 Head Controlled Stereoscopic Camera (HCSC) System

The HCSC system consists of two RPi B+ model computers, two RPi camera board modules, two HS-422 servo motors, two Cat5e Ethernet cables, two power supplies, and a battery pack.

Figure 1 illustrates the relative appearance of the HCSC system. The HCSC system is constructed by placing the two RPi units on a pan tilt mount, and the two camera modules are connected to the RPi units via Camera Serial Interface (CSI) cables. The camera modules will be fixed to a surface to prevent unintended movement in their positions. The servo motors will be configured to enables rotation along the yaw and pitch axes. Lastly, the Cat5e cables are connected to the RPi units on one end, and to the control system on the other end.

In the prototype model of the HCSC system, separate power supplies will be used to provide power to each RPi, and the battery pack will power the servo motors. For the production model, the goal is to design a circuit which has the capability to power both the RPi units and the servomotors, as outlined in the electrical requirements in section 2.3.6 of the functional specifications document of the ART system.

3.1 Raspberry Pi

A RPi is a credit card-sized computer on a single board containing a CPU, a SD card slot, and ports. Ports enable the RPi to communicate with external devices, peripherals, and hardware. Figure 4 below represents a RPi B+ model, displaying the board and its features. There are no major changes between the B and the B+ model of the RPi, with the exception of the 20 additional General Purpose Input Output (GPIO) pin connectors and two extra USB 2.0 ports, and a microSD card slot instead of the SD card slot.

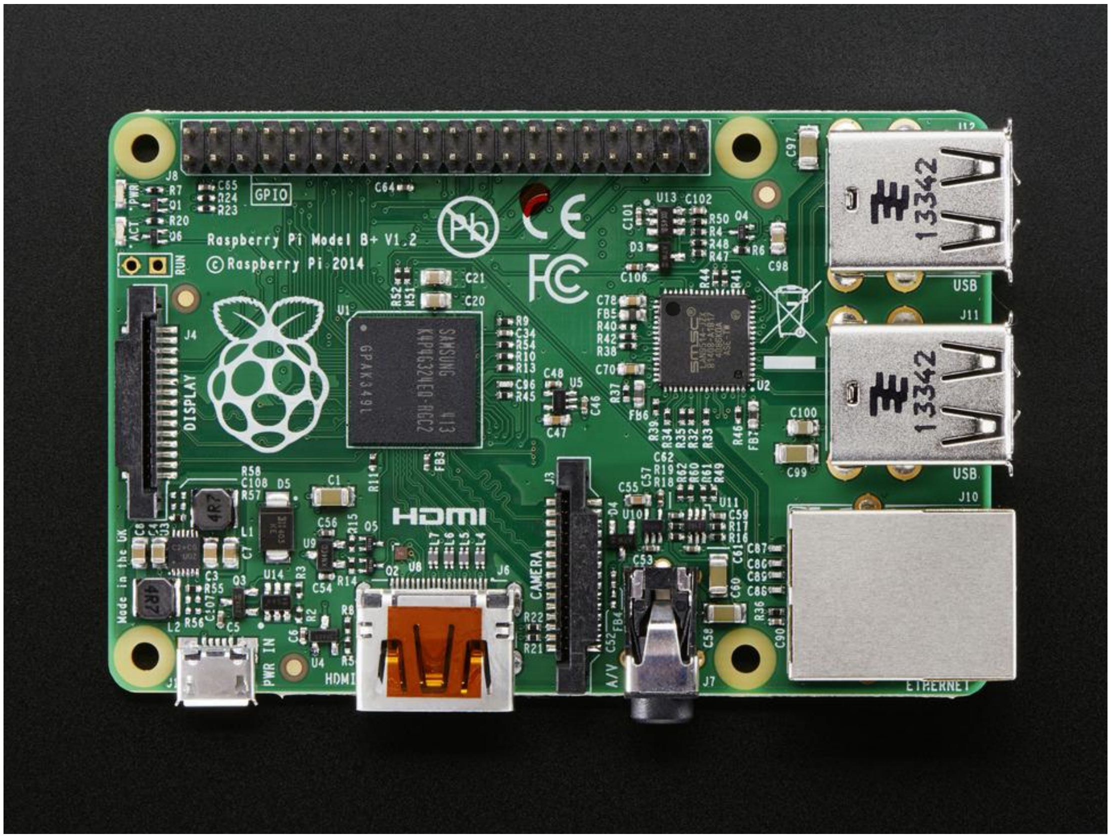

Figure 4: RPi B+ Model [5]

Table 1 below illustrates relevant specifications of the RPi B+ model. Note that the resolution features of the RPi meets the performance requirement 2.3.2 [R-35-A] from the functional specifications

Table 1: Specifications of the RPi B+ Model [5] [6]

Chip	Broadcom BCM2835 SoC
Core Architecture	ARM11
CPU	700 MHz Low Power Arm 1176UZFS Applications Processor
GPU	Dual Core VideoCore IV Multimedia Core-Processor
Memory	512 MB SDRAM
Operating System	Boots from Micro SD Card, running a version of the Linux operating system
Dimensions	85mm x 56mm x 17mm
Power	Micro USB socket, GPIO header 5V, 2A
Size	85.60 mm × 56 mm (3.370 in × 2.205 in)
Weight	45g

Table 2 below outlines the ports that are available on the RPi model.

Table 2: Connectors of the RPi B+ Model [5] [6]

Ethernet	10/100 BaseT Ethernet socket
Video Output	HDMI
Audio Output	3.5mm jack, HDMI
USB	4 x USB 2.0 connector
GPIO connector	40-pin 2.54mm expansion header
Camera connector	15-pin MIPI CSI
Display connector	Display Serial Interface (DSI) 15 way flat cable connector (2 data lanes and a clock lane)
Memory card slot	SDIO

Comparing a range of micro-controllers (such as Arduino Udoo and Banana Pi), the RPi contained a few advantages for the application of capturing a video feed. The RPi comprises of a hardware implemented H.264 hardware encoder and the license allows us to use it freely for image and video compression [7]. Therefore, the Rpi was selected to meet the 2.3.5 standards requirements from the functional specifications.

Another advantage of using a RPi is the ability to communicate with external hardware or devices using the General Purpose Input and Output (GPIO) pins. For the purpose of this project, GPIO pins of the RPi can be used to forward and receive head-orientation data from the head-mounted display, meeting the general requirement 2.3.1 [R-33-A]. In addition, the GPIO pins can control the servo motors of the HCSC system using the Pulse Width Modulator (PWM). The RPi has a single PWM located at pin #12 of the GPIO which is used to control servo motors, making it difficult to control two servo motors simultaneously.

3.2 Raspberry Pi Camera Module

The RPi camera module was chosen as a tool to obtain a video feed to be forwarded to the control system. The camera board module is an Omnivision, 1/4" colour CMOS QSXGA image sensor camera, designed to interact with the RPi directly [8]. Figure 5 below represents a RPi camera module connected to a RPi via a Camera Serial Interface (CSI) cable.

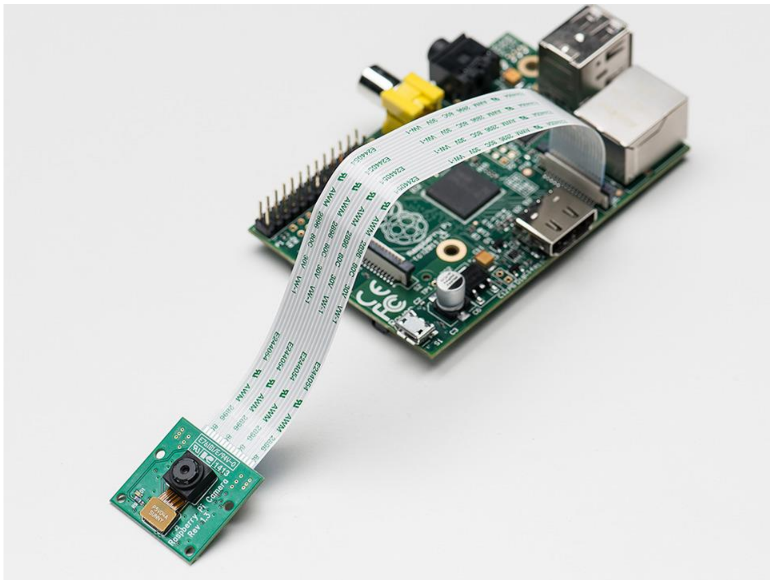

Figure 5: RPi Camera Module Board connected to a RPi (B-Model) via a CSI cable [5]

Table 3 below illustrates notable performance and physical specifications of the RPi camera modules which make it the ideal choice of camera for the design of the HCSC system. The camera module's small physical features and high resolution capabilities are highly desired for the implementation of the ART system and its intended use of applications, meeting the physical requirement 2.3.3 [R-40-A] of the functional specifications. The default resolution of the camera modules is 1920 x 1080 with a bit-rate of 17 MBs that gives files of 115 MB per minute [9].

Table 3: RPi Physical and Resolution Specifications [10]

Camera Module	Size (mm x mm x mm)	Weight (g)	Field of View (inches)	Still Image Capture Resolution	Video Capture Resolution		
					@90 fps	@60 fps	@30 fps
RPi Camera Module	25x20x9	~ 3.00	194 (wide) 195(distance)	5 MP (2592x1944)	640x480p	720p, 640x480p	1080 HD, 1080p

The camera module is connected to the RPi by means of a CSI, a 15-pin ribbon cable that allows for transfer of extremely high data rates, meeting the 2.3.2 Performance Requirements in the functional specifications. The ability to capture a live video feed, transfer data at high rates in addition to simplified communication with the RPi were desirable aspects in the design considerations for video capture. Furthermore, using a camera module along with a RPi guarantees compatibility to use the H.264 hardware encoder of the RPi.

As revealed in the previous section, there is only a single CSI cable available on a RPi. Due to meeting the performance requirement 2.2.2- [R-10-A] to output a stereoscopic video feed, two camera modules along with two RPi units are required to achieve stereoscopic images. Capturing two video feeds from the camera modules and transferring the data from the RPi to the control system is an intermediate step to obtain a 3D video feed (discussed in section 5.1).

The distance between the centers of the lenses of the two cameras is approximately 6 cm, which is the average inter-pupillary distance. The inter-pupillary distance is defined as the distance between the centers of the pupils of the two eyes of a human, and is measured to be at an average of 6 cm [11]. Measurements and details regarding inter-pupillary distance are provided in section 3.4.

3.3 HS-422 Servo motors

The HS-422 servo motor is the device responsible for rotating the HCSC along the yaw and pitch axes. A brief comparison of the specifications of different servo motors is highlighted in Table 4.

Table 4: Comparison of servo motor specifications [12] [13] [14]

Servo Motor	Speed (sec/60)	Torque (Kg-cm)	Size (mm)	w/Mount	Price (USD)
HS-311	0.19	3.7	40 x 20 x 37	No	$7.99
HS-422	0.16	4.1	41 x 20 x 37	Yes	$9.99
HS-485HB	0.22	4.8	41 x 20 x 38	No	$16.99

The HS-422 is met was selected between the HS-311, HS-422, and HS-485, as each model meets the mechanical requirement 2.3.7 [R-60-A] in the functional specifications. The HS-422 is similar in specifications with both HS-311 and HS-485 servo motors as increasing torque results in increase of their respective prices. More importantly, the HS-422 could be optionally bundled with custom designed parts to assemble a mount, reducing the cost significantly and meeting the general requirement 2.2.1 [R-5-B].

Figure 6 shows the HS-422 servo motor has a range of motion of 180°, meeting the HCSC prototypes' range of motion. For the production model, a servo motor with a higher range of motion is used so that the user could completely rotate 360°, enhancing user experience of the ART system.

The controlling pulse signal and the correlated angle is described in Figure 6.

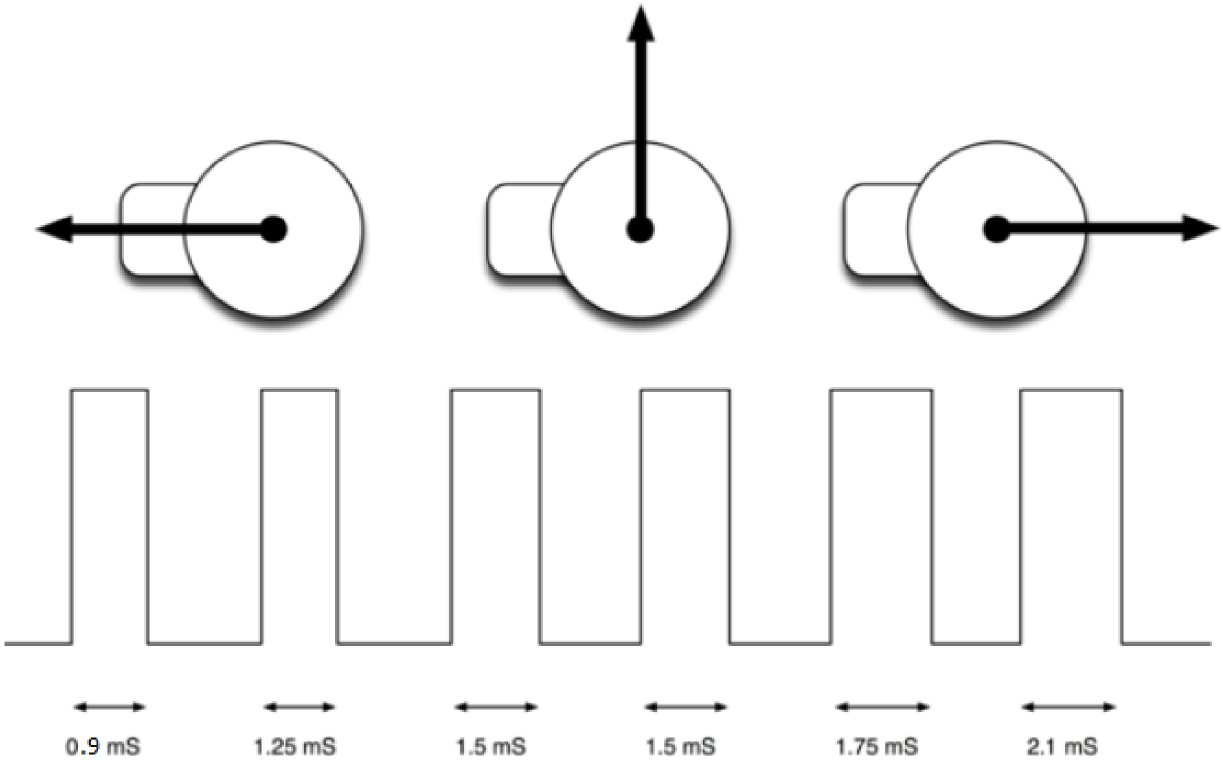

Figure 6: Range of motion of the HS-422 motor [15] [16]

The servo motor accepts a square wave signal which causes the servo motor to rotate to the specified angle. The servo motor measures the signal over a duration of 20 milliseconds (mS) and depending on how long the signal has been high the servo motor will adjust the angle of the motor. For 0°, a signal must stay high for 0.9 mS out of the 20 mS duration. To rotate to 180° the signal must stay high for 2.1 mS.

The servo motors must be controlled using the RPi general purpose input output (GPIO) pins. To control the HCSC along the yaw axis, the hardware pulse width modulator (PWM) correlating to the RPi GPIO pin #12 will be accessed and utilized to generate the expected signals used by the HS-422 servo motor. Since the RPi has only one hardware PWM located at pin #12, the second RPi will be used to control the pitch axes. The servo motor test circuit to the RPi is depicted in Figure 7.

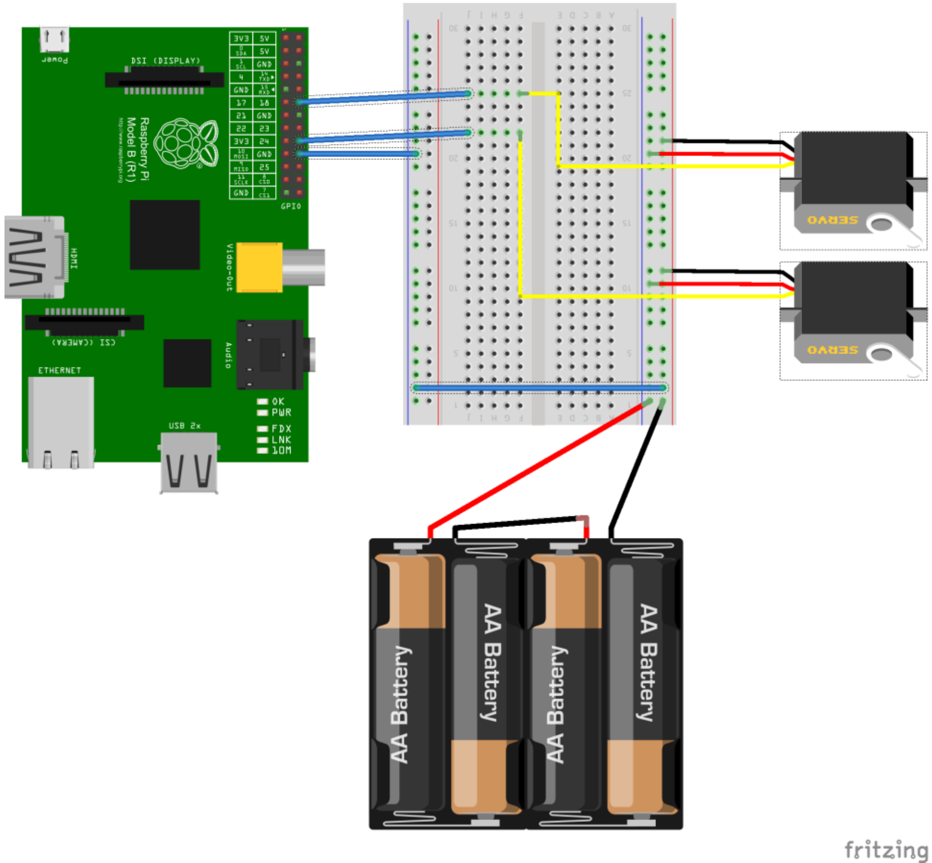

Figure 7: HS-422 servo motor test circuit

While operating (rotating without a load), the HS-422 servo motor draws 150 mA of current. The 150 mA of current is too high for the RPi GPIO pins and it can damage the CPU when the current exceeds 18 mA. Thus, the servo motors will have a separate power source to draw from. Since the current is drawn by the servo motor when the motor requires the extra current, no safety resistor has been added.

3.4 Mechanical Design

The HCSC system is configured to hold the two RPi units as well as a pan tilt system holding two cameras. The pan tilt mount is capable of holding a maximum of 3.3 kg of mass in order to achieve the desired range of motion. The pan tilt system consists of two servo motors, a metallic bracket and an extender component as shown in Figure 10. The pan tilt system can hold the 2 cameras as well as a metallic moving component (bracket and extender attachment) since it can handle a maximum mass of 3.3 kg which meets the physical requirement 2.3.3[R-40-A]. The extender attachment and the bracket are components responsible for spacing the cameras at an inter-pupillary distance. Various inter-pupillary distances are shown in Table 5.

Table 5: Inter-pupillary distances of human eyes [11]

Data set	Inter-pupillary distance (mm)
Adult male 95th percentile	70
Adult male 5th percentile	55
Adult female 95th percentile	65
Adult female 5th percentile	53
Average Adults	54 to 68

The inter-pupillary distance for the ART system was chosen to be approximately 60 mm as it is a whole number that is the average of the 95th percentile of adult male and female inter-pupillary distances. An inter-pupillary distance of 60 mm lies in the range of an average adult's inter-pupillary distance.

The base of the HCSC system is designed to be 150 mm X 140 mm to fit all the components. The pan tilt mount is the highest point of the HCSC system. The pan tilt system is 56 mm high at rest, meeting the physical requirement 2.3.3[R-41-A]. Figure 8 shows a sketch of the top view of the prototype model detailing all the chosen dimensions.

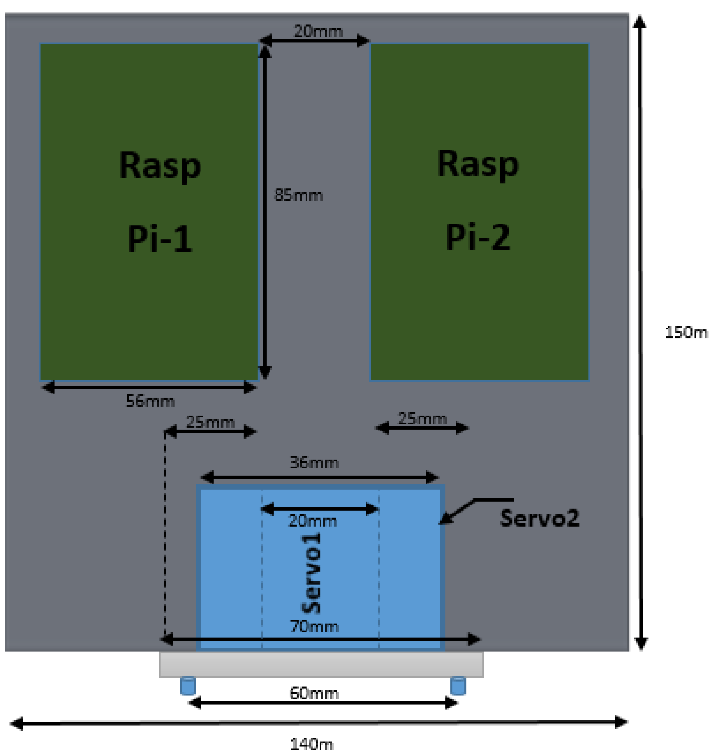

Figure 8: 2D sketch of the Top view of the HCSC system

Cameras are mounted robustly at average inter-pupillary distance of adult humans of 60 mm to meet the physical requirement 2.3.3[R-44-B]. The base of the HCSC system is designed to be of an insulating material to meet safety requirement 2.3.4[R-47-A]. All the components of the HCSC system will be firmly mounted onto the base of the HCSC system to meet physical requirement 2.3.3[R-42-B]. Figure 9, shows a trimetric view of the 3D Solid works model.

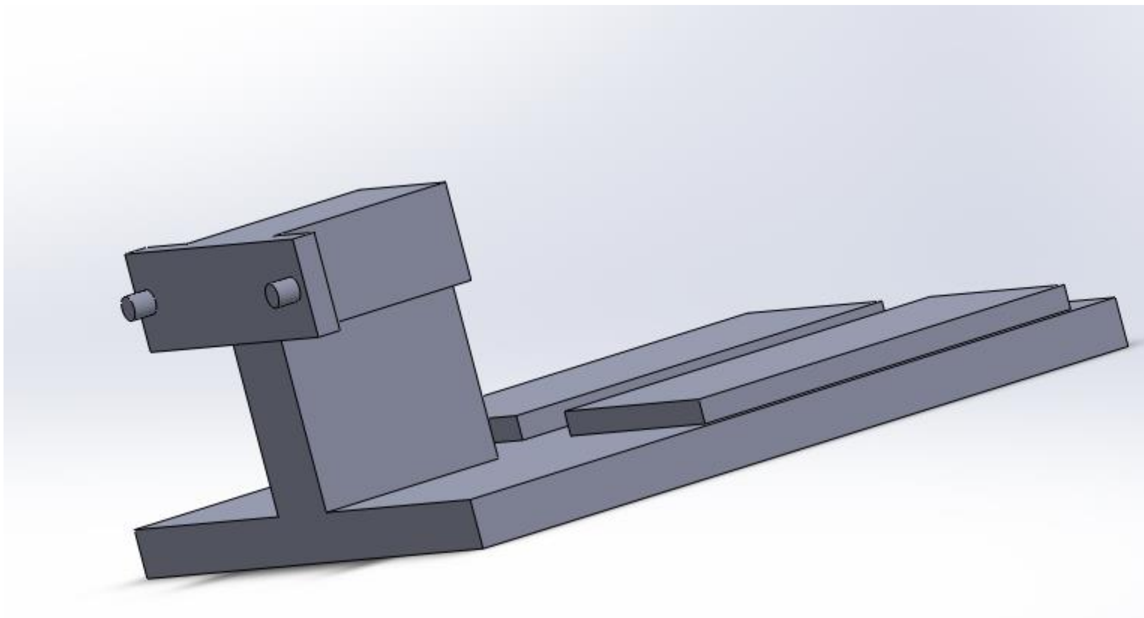

Figure 9: A trimetric view of the HCSC system design in solid works

The two servo motors are mounted onto the HCSC system's base to mimic head movement in the yaw and pitch axes, meeting performance requirements 2.3.2[R-36-A] and [R-37-A]. The bottom servo motor provides motion in the yaw axis. The second servo motor, mounted on top of the first one, provides motion along the pitch axis.

Upon testing the system for connections between servo motors and raspberry pi as well as between raspberry pi and bread board and PC, another design- a 3-floor design seemed to be a better choice. Figure 10 shows all the components of design 2.

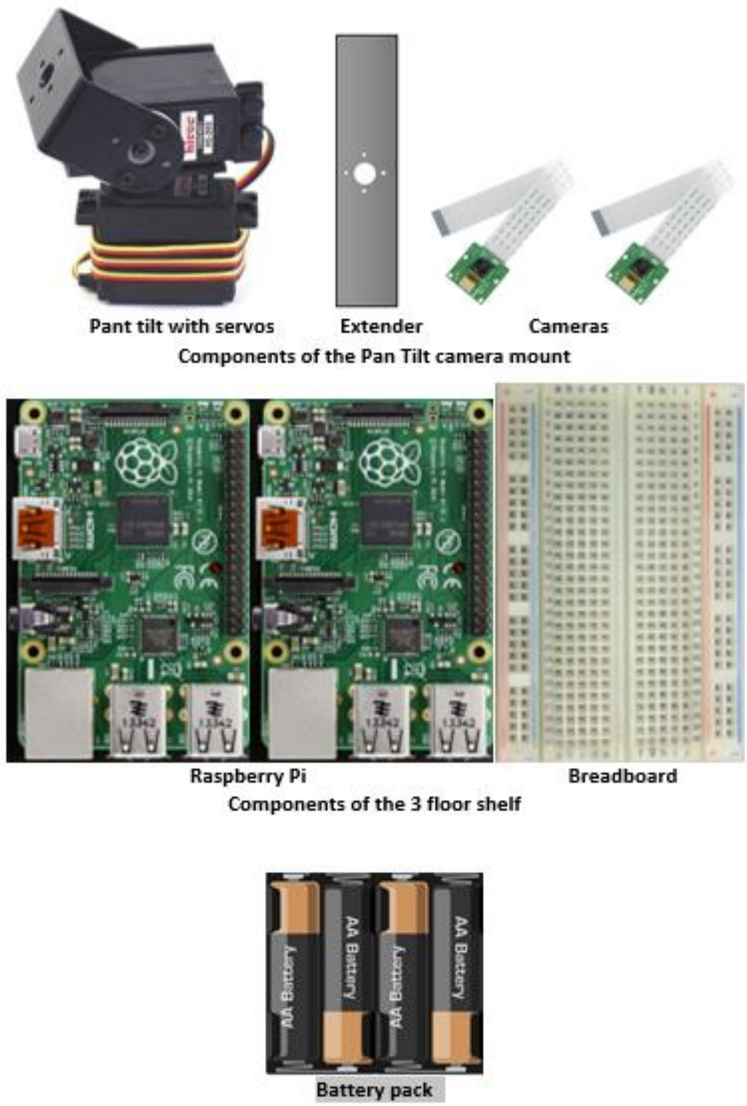

Figure 10: Components that are mounted on Design 2 of HCSC

The components of design 2 are different from design 1 in that design 2 includes bread board and a battery pack. Design 2 carefully considered all the connections to and from the HCSC system. Figure 11 shows a 2D sketch of the design.

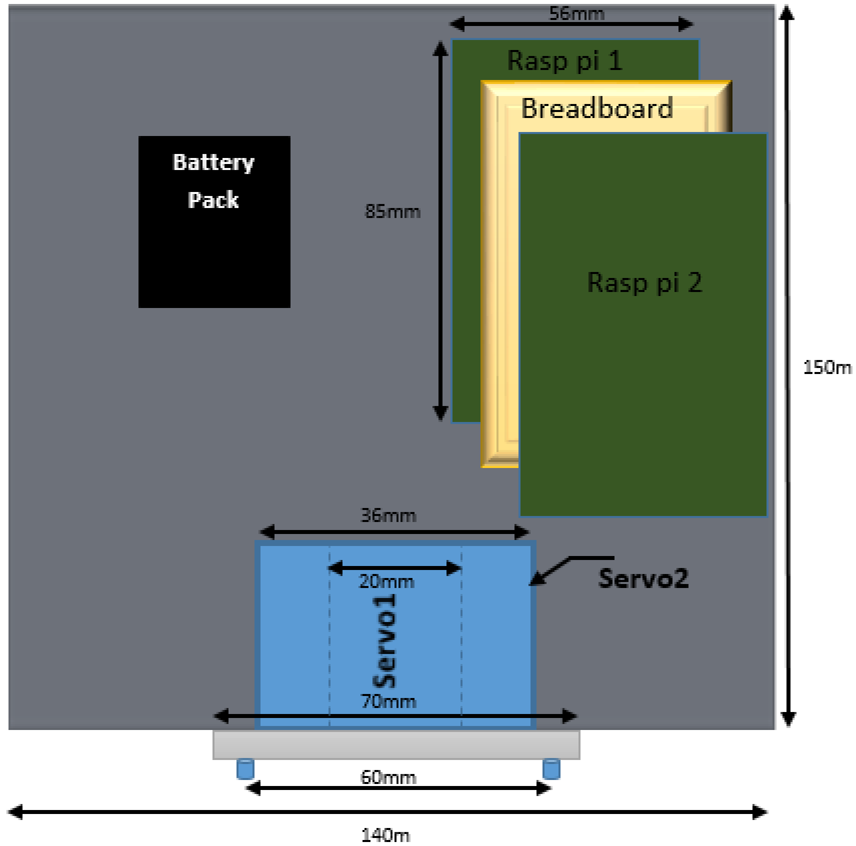

Figure 11: 2D sketch of 3 floor design (Design2)

The two raspberry pi units are placed parallel to each other rather than beside each other. In addition, the breadboard is placed in between the two raspberry pi units. The servo motor cable will connect to the breadboard which in turn will have cables connecting to the raspberry pi mounted above it, as can be seen in the figure. A battery pack will be enclosed and placed on the left side of the three floor "raspberry pi-breadboard shelf." 70 mm clearance will be provided between the pan tilt mount and the "raspberry pi-breadboard shelf". This distance is chosen to be almost half of the lengths of the CSI ribbon (150 mm) that is used to connect the cameras to the RPi units. The chosen distance allows bending and fixing the CSI ribbon on HCSC system's base.

3.5 H.264 Encoder/Decoder

The software that was chosen to capture and encode video from the two camera modules of the RPi is Fast Forward Moving Pictures Expert Group (FFMPEG). FFMPEG is the leading framework for multimedia containing libraries that are able to decode, encode, mux, de-mux, transcode, stream, filter, and play just any format that currently exists. In fact, FFMPEG supports the most obsolete and the most cutting edge formats that have ever existed or currently exist. Additionally, it is an open source code and also a free software. FFMPEG can also support most open and proprietary standards of protocols. Due to the capabilities mentioned above, and it's compatibility with both Windows and Linux environments, FFMPEG was chosen as the software that is used to capture images from and feed to the control system to meet the general requirement 2.3.1 [R-32-A]. [17]

4 Control System

4.1 Graphical User Interface

A GUI has been implemented to control the ART system. The GUI will reside on a PC, providing communication between the HCSC system, and the VR device in the control system.

4.2 Front-end Implementation Details

The GUI is implemented using Swing which is an open source GUI widget toolkit for Java [18]. To implement the front-end of the GUI in Java using swing, the package javax.swing is required [19]. All the labels are defined as JLabel while buttons are defined using JButton on the page known as JFrame in java swing [19]. The back-end software in the GUI will be responsible for processing and forwarding image data received from the HCSC system to the VR device. The software will also receive head orientation data from the VR device and forward the data to the HCSC system to control the HCSC orientation. Figure 12 illustrates the basic design of the GUI for the ART system

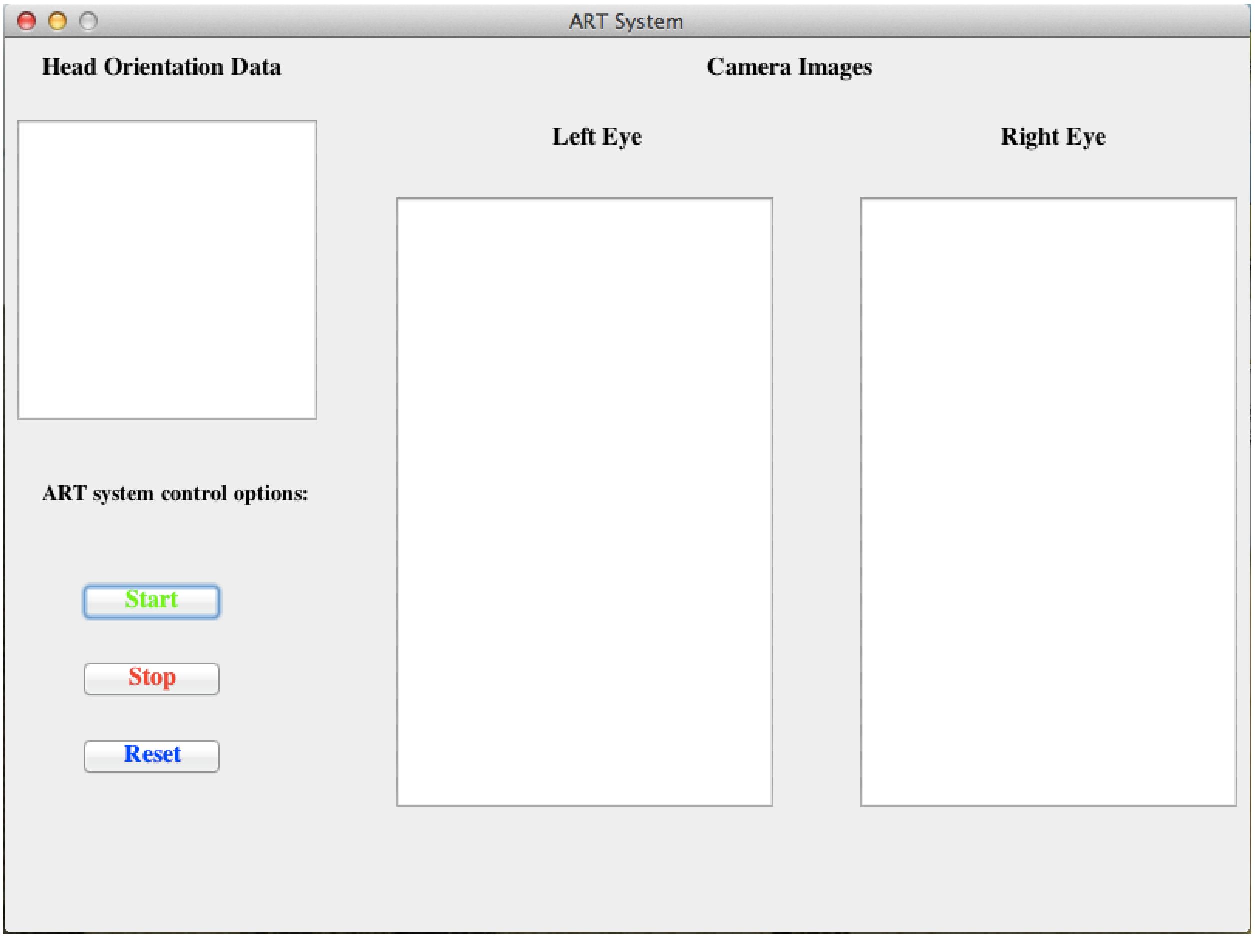

Figure 12: GUI design for the ART system

The head orientation data collected from the VR device will be shown in the area below the "Head Orientation Data" label while the images collected by the cameras will be shown in the empty boxes "Left Eye" and "Right Eye" labels in real time. The basic functionality of the GUI buttons is explained in Table 6 below.

Table 6: Designed button functionality of the GUI

Button	Functionality
Start	The start button will trigger a timer that will give the user enough time to wear the VR device after pressing the Start button before the ART system starts collecting data. This button will make the cameras align in the origin position while assuming the user's current orientation is the origin with respect to the cameras. The start button will then enable the ART system to collect head orientation data and camera images accordingly.
Stop	The stop button will instruct the ART system to stop collecting data.
Reset	The reset button will reset the camera positions in HCSC system to origin while assuming the user orientation as the origin in the control system.

Note: The origin position of both the HCSC and VR device are initially set to provide a relative movement with respect to each other [R-8-A].

From Table 6 above, algorithms are outlined for each button in the following sections.

4.2.1 Start Button

Upon a user-generated event, the software must proceed through a sequence of steps before the PC is able to begin the transfer of images and head orientation data between the HCSC system and VR device. The procedure is outlined in Figure 13

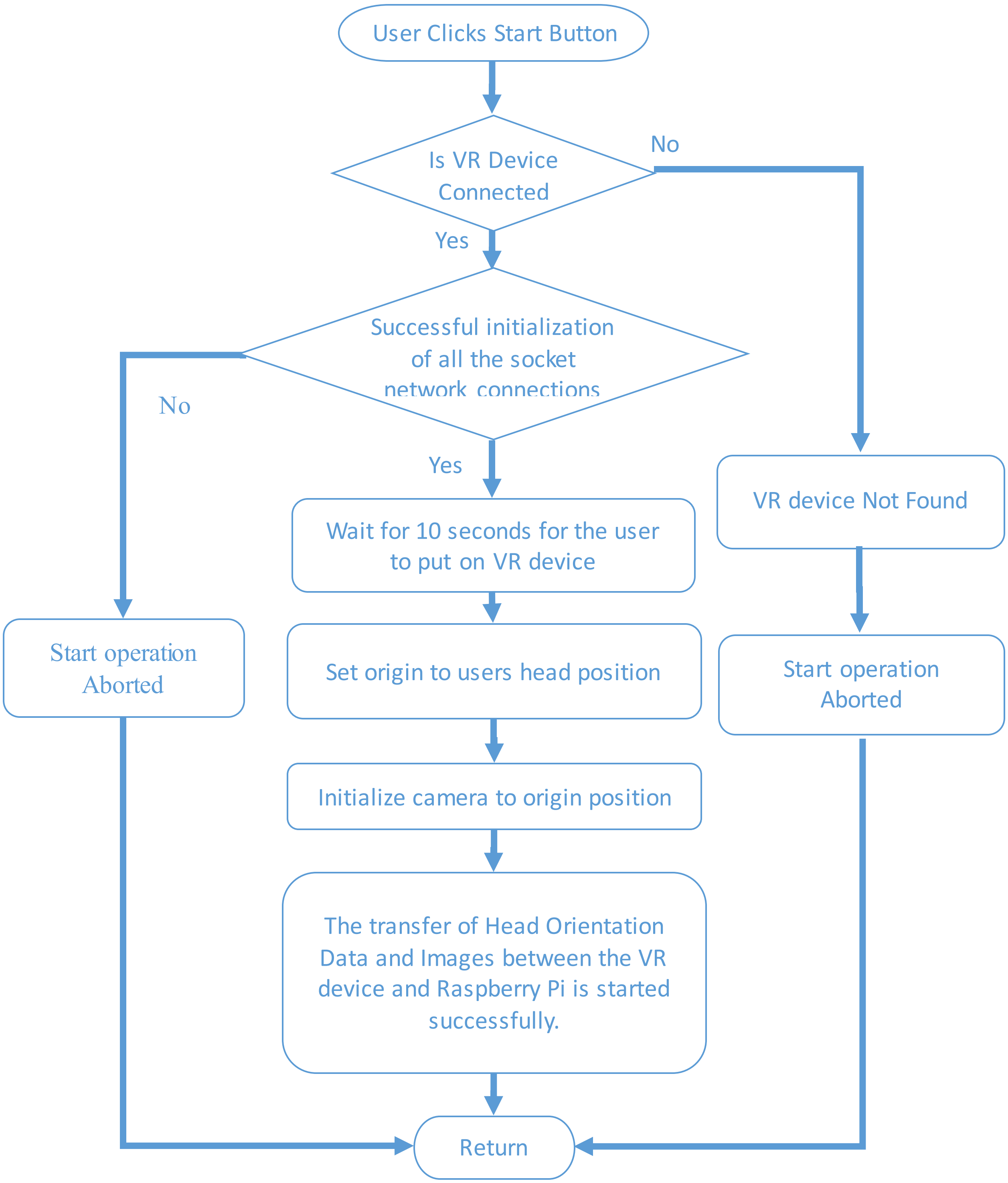

Figure 13: Response of the ART system to the start button

Once the user clicks the start button, the VR device is first verified to be connected and working with the PC. If the there is an issue with the VR device and error message is displayed to the user and the start operation is aborted.

After the GUI initializes all network connections required for communication. If network communication has been established successfully then a 10 second duration is defined before capturing the users initial head position else the procedure is aborted. The initial head position allows for relative head positioning with respect to the HCSC, as any change in orientation is just the difference with the initial head position.

After the HCSC system is initialized, the ART system begins to transfer the images and head orientation data between the VR device and the HCSC.

4.2.2 Stop Button

The ART system software follows a sequence of steps when the user presses the button. The procedure is outlined in Figure 14: Response of the ART system to stop button

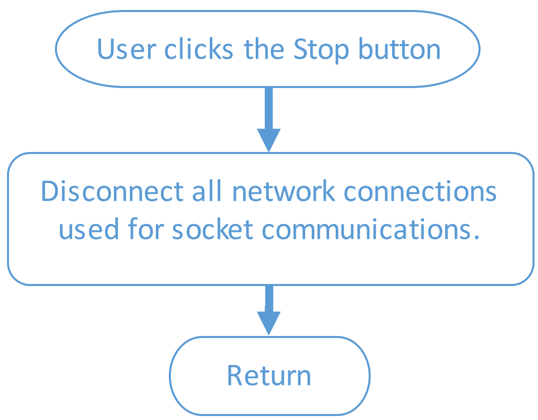

Figure 14: Response of the ART system to stop button

Once the user clicks the stop button, all established network connections are disconnected to stop data transfer between the HCSC system and the VR device.

4.2.3 Reset Button

The procedure is outlined in Figure 15 occurs when the user presses the Reset button.

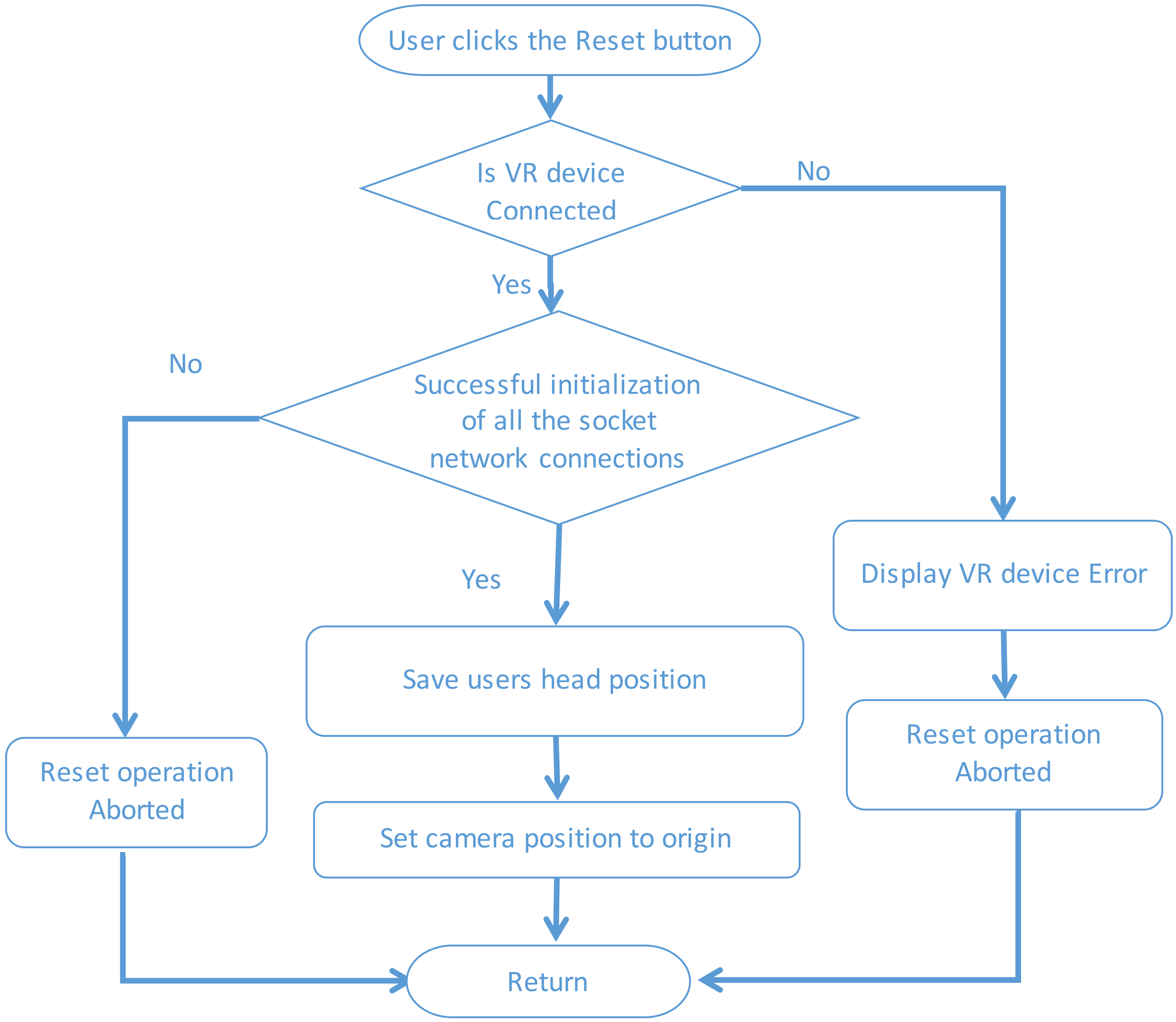

Figure 15: Response of the ART system to Reset Button

After the Reset button is pressed the VR device is first verified to be connected and working with the PC. If there is an issue with the VR device, an error message is displayed to the user and the reset operation is aborted.

The network connections are then re-initialized and if the connection fails the procedure aborts. Once communication has been successfully established then the user's initial head orientation is captured and reset to make the HCSC system relative to the users new head orientation.

4.3 Backend Implementation Details

To implement the network communication sockets 8000-8003 are defined on the control system. The network communication is based on client-server architecture in which the server sits and waits for the client to establish a connection [20]. In the client server model, the GUI software residing on the PC will serve as the server while the VR device and the HCSC will act as the clients. The socket ports assigned for pitch and yaw head orientation data transfer and the image transfer between the VR device and GUI software are shown below in Table 7.

Table 7: Socket ports for Data transfer

Data to be transferred	Socket	Protocol	Data
Pitch	8000	TCP	unsigned integers [0, 180]
Yaw	8001	TCP	unsigned integers [0, 180]
Left Image	8002	UDP	H.264 compressed data stream
Right Image	8003	UDP	H.264 compressed data stream

4.3.1 Backend Head Orientation Data Transfer

The head orientation data received from a VR device cannot match or could potentially be out of range of the HCSC. Hence the data received from the VR device is error checked [R-100-A] and converted to Euler angles described in Figure 16: Block diagram for head orientation data transfer. The head orientation data is converted to the Euler angle format on the PC [R-101-A].

Figure 16: Block diagram for head orientation data transfer

4.3.2 Backend Video Transfer

Video captured by the HCSC are transferred to the VR device after some image processing. Figure 17: Block diagram for Image data transfer illustrates the processing steps that the left and right images go through before reaching the VR device as one single stitched image. The images are in H.264 format when they are fed into the PC [R-32-A]. The individual left and right images are first decoded, then concatenated and then encoded again before transferring to the VR device. The image concatenation is necessary because of the stereoscopic rendering concepts defined in section 5.1.

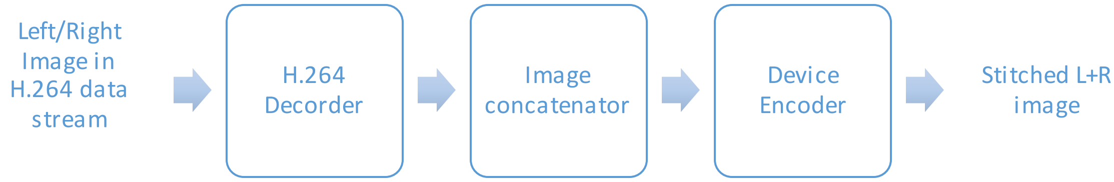

Figure 17: Block diagram for Image data transfer

5 VR Device

A VR device purpose is to isolate the user from the surroundings, display a stereoscopic image, and determine the head orientation of the user. The device consists of a head mounted display, a gyroscope, an accelerometer, and any software required on the device to create stereoscopic 3D image.

Throughout the document Pandora Vision has limited the VR device to a Google Cardboard plus an android phone for the prototype. For the production model VR device will extend our definition further to include more VR devices such as the oculus rift and Samsung gear VR.

5.1 Stereoscopic Rendering

For stereoscopic rendering the VR device requires the left image and right image to be rendered in split screen with half the screen used for each eye. When using a VR Device the left eye sees the left half of the screen and the right eye sees the right half. Figure 18 and Figure 19 show the distortion created by using lenses to increase field of view.

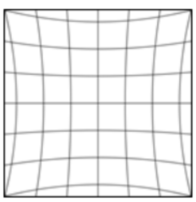

Figure 18: Pincushion Distortion [21]

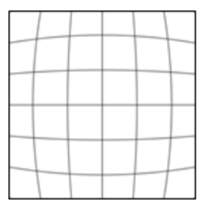

Figure 19: Barrel Distortion [21]

Lenses increase the FOV enhancing the immersion of the experience but by using lenses the image perceived by the user becomes distorted. To counteract the distortion the software must apply a post processing effect with an equal and opposite barrel distortion effect to the left and right image before being passed to the VR Device. The exact distortion depends on the lens characteristics and eye position relative to the lens. Hence only VR Devices such as the Google Cardboard will be used with the prototype and oculus rift that provide distortion APIs will be usable with the production level ART system.

5.2 Head Orientation

Head orientation is maintained by a gyroscope on the VR Device which measures the rate or rad/s around a device's x, y, and z axis. Rotation is positive in the counter clockwise direction which matches the mathematical definition of positive rotation. [22]

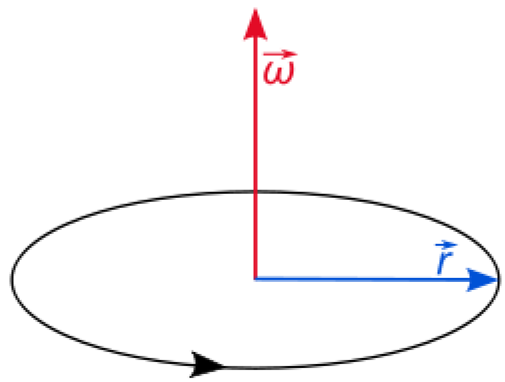

Figure 20: Definition of positive rotation reported by a gyroscope [23]

The change in position is obtained by integrating over time to calculate the rotation over a time step. Gyroscopes provide raw rotational data without any filtering, correction for noise, and drift (bias) and will begin to introduce errors that need to be compensated for over time. Monitoring the error can be done by using another piece of hardware such as the gravity sensor or an accelerometer. For the prototype using Google Cardboard google has implemented a SensorManager class to handle any bias that might accumulate. For the oculus rift and other VR Devices other robust methodologies will need to be developed. [24]

5.3 VR Device Application

An android application for VR device has been designed to provide visual feedback to the user as well as send head orientation data to the control system. The android application is wirelessly connected to control system through WiF [R-103-C]. Figure 21 below depicts the GUI and related functionality.

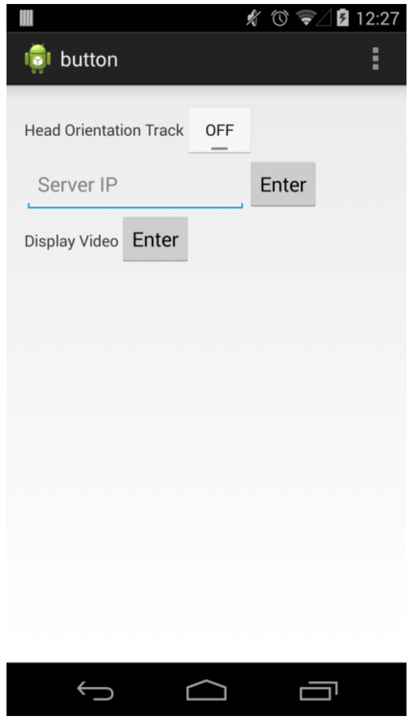

Figure 21: Android Application GUI design for VR device

The application buttons and functionality is outlined in Table 8: Field and Button Response

Table 8: Field and Button Response

Field/Button	Functionality
Head Orientation Track	Toggles head position tracking. If the button is off, head orientation information will not be captured anymore
Enter Server IP	Establishes a network connection to a specified IP address. For our first prototype, server would be a PC and client would be an Android smart phone
Display Video	Plays stereoscopic video which is obtained from HCSC system

5.4 Android Socket Implementation

Sockets are typically used in conjunction with the Internet protocols, TCP and UDP. There are three different types of socket outlined in

Table 9.

Table 9: Socket types and associated protocols [25]

Socket Type	Protocol
Datagram sockets	User Datagram Protocol (UDP)
Stream sockets	Transmission Control Protocol (TCP)
Raw sockets	Non protocol specific

To communicate over the Internet, IP socket libraries use the IP address to identify specific computers. Stream and data sockets use IP port numbers to distinguish different applications from each other.

Figure 22 illustrates our android app socket implementation. Server-Client socket communication implemented to stream the data from PC to android. The android app needs IP address and port details of the computer where video data stream is to be transmitted. Once the connection is established, android application will be capable of sending information to server [R-103-C] and the PC will transmit video data stream to android application using User Datagram Protocol [R-105-C].

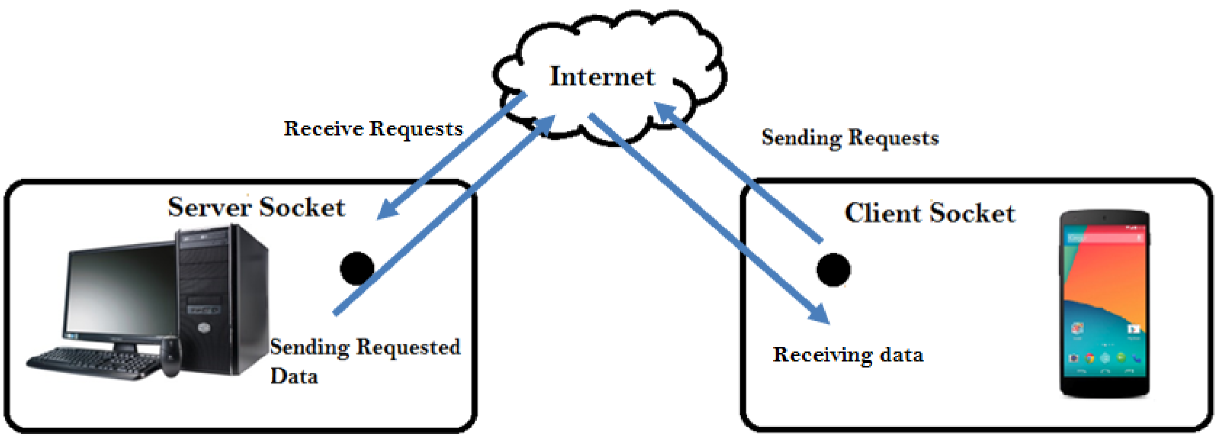

Figure 22 Android Socket Implementation [26]

5.5 Video Streaming and Android Media App Architecture

The following diagram shows the high level video streaming of our android media application. Encoded data stream is fed from control system. The video data stream is decoded in order to display on VR device illustrated in Figure 23.

Figure 23 High Level Diagram of Video Streaming

Figure 24 depicts the detailed architecture of our android media application.

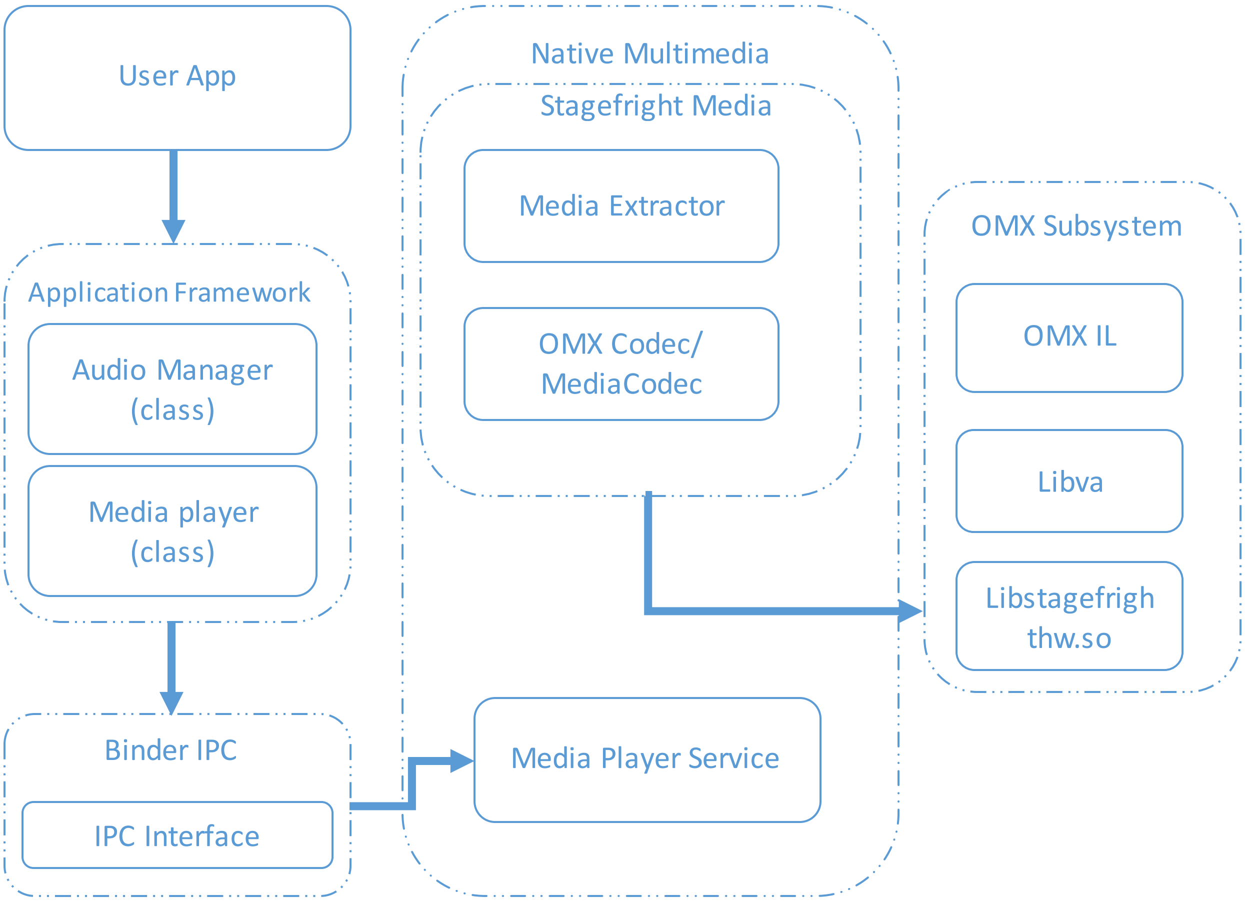

Figure 24: Architecture of Android Media Application

User application uses the application framework's java class AudioManager and mediaPlayer to provide interfaces for manipulating different types of media. For example, Java MediaPlayer.start() invokes the native start() method written in C++. The user application is written in Java at an application framework level. The user application utilizes the android.media API to interact with the multimedia hardware.

Binder is an Android-specific interprocess communication mechanism, e.g., one Android process can call a routine in another Android process, using binder to invoke and pass the arguments between processes. Inter-Process Communication (IPC) is a mechanism which allows different types of android component to communicate. The IPC requests from the media player are handled by the media player service which instantiate a new MediaPlayerService::client upon request.

At native level, Stagefright media player is used for audio and video recording and playback. Stagefright comes with a list of supported codec (OpenMAX codec, mediacodec). We could use both codec, but with Mediacodec, you can access hardware-level encode/decode functionality from within the Java application space. Mediacodec also allows us to encoder/decoder a raw H.264 video streaming.

OpenMAX is a cross-platform API that provides abstractions for routines especially useful for audio, video, and images processing. The OpenMAX Integration Layer (OMX IL) API enables integration and communication with multimedia codecs implemented in hardware or software. The plug-in, libstagefrighthw.so links your custom codec components to stagefright.

Finally, decoded video data stream will be displayed and audio data streaming will be synchronized based on time stamp.

6 ART 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 individual components meet the functional requirements before integration into the overall system. As the prototype approaches completion, we will begin to conduct user-based trials of the ART system. Testing methodologies are outlined in appendix A below, which focus on verifying design specifications of the prototype model.

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

1. User connects a VR device to their control system
2. User starts ART software
3. User wears a VR device
4. While user is wearing the VR device, the user controls the ART system's cameras by rotating their head

6.1 HCSC Sub-system Test Plan

The responsiveness of the HCSC system will be broken down into two different categories: responsiveness of the video and responsiveness of the rotation. The responsiveness of rotation will be measured by creating an automated test program that rapidly changes the orientation of the HCSC system. The responsiveness of the video will be tested by measuring latency between moving an object in front of the HCSC system to viewing the object on the VR device. In the prototype model, the goal is to minimize the latency as much as possible given that an acceptable duration of latency exists. In developing the production model, we aim to achieve a latency of less than 150 ms on wire, and a latency of less than 300 ms wireless.

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.

6.2 Control Sub-System Test Plan

The control system will be tested with a VR device, verifying that the output of the PC software matches the head orientation of the user. Once communication is initialized between the VR device and the PC software, tests will be completed to verify orientation data from the VR device is accurately measured.

7 Conclusion

This document lists technical details and specifications related to the HCSC system, the control system and the interconnection between them. The purpose of this document is to assist Pandora Vision in designing the ART system successfully with respect to the specifications laid out in this document. Appendix A contains test plans for the overall system, sub-systems, GUI, head-mounted display, individual parts, and integration of the sub-systems to ensure all aspects of the design are built according specifications. More importantly, the test plans include tests for individual components and their integration to guarantee reliability and performance of the ART system. In addition, this document aims to provide a design path for the company to complete the prototype model of the ART system. Meanwhile, it outlines further design specifications and considerations for the production model of this system as future work.

Pandora Vision has currently divided each sub-system within the ART system into several components. Each member is working on individual components that we aim to have completed by the second week of November. Integration and overall system testing will commence following the completion of individual components and the goal is to prepare a demonstration of the ART system by the first week of December.

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Appendix A: **Test Plan**

Test Sheet		
		Date:

HCSC		
Performance Tests		
	Pass/Fail	Comments
Records 720p at 60 fps		
Yaw rotation causes rotation along yaw axis		
Pitch rotation causes rotation along Pitch axis		
Transmits Video to a PC		
Mechanical Tests		
Rotates from 0 to approximately 180 degrees		
Weight is less than 5.0 kg		
Height is less than 50 cm		
Cables do not restrict movement		
Electrical Tests		
Electrical components connected through breadboard		
Input Voltage: 5V		
Safety Tests		
Wires remain soldered upon stress		
Electronic devices must be enclosed		

Test Sheet		
		Date:

VR Application		
General Tests		
	Pass/Fail	Comments
Collects accelerometer and gyroscope data		
Converts motion data to yaw and pitch		
Sends data to control system through WiFi		
Performance Tests		
Plays 720P video		
Plays video at 60 FPS		
Software Tests		
Compatible with Android 4.4		
UI Tests		
Have a user-friendly interface		
Fits within 1/3 of the users viewing area		

Test Sheet	
	Date:

Control System Software		
General Tests		
	Pass/Fail	Comments
Receives video from HCSC system		
Receives head orientation from VR device		
Sends information to HCSC system		
Sends video to VR device		
Performance Tests		
Creates side-by-side placed video		
Prioritizes frame rate over camera resolution		
Software Tests		
Stop button works		
Start button works		
Reset button works		