1 Purpose

This document presents the functional requirements for Virtual Reality Vision Therapy as a product for BME 495/496: Capstone Design.

2 Reason for Re-Issue

ISSUE		REASON FOR RE-ISSUE
1	MR #VRVT0001	This is the first time the plan has been issued

3 Overview

Virtual Reality Vision Therapy is the hardware complement to a series of vision therapy games produced by the Vision and Neural Engineering Laboratory at NJIT. It uses infrared cameras and microcomputers, running proprietary eye tracking software, integrated with a Oculus Rift HMD, to affect the virtual gameplay environment in the display. The HMD assembly contains the infrared LEDs and cameras in their respective mounts. Each Raspberry Pi assembly contains a Raspberry Pi and a Raspberry Pi 7” touchscreen. The game, BugEyes, will be run on the desktop PC.

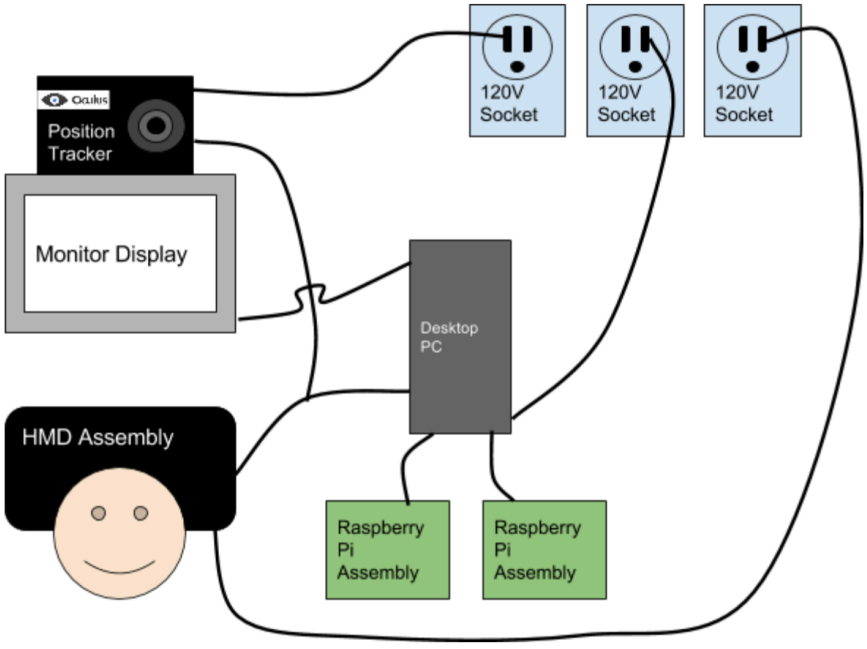


Figure 1: Overview of the VRVT system and subsystem connections

The nomenclature used in this document is as follows:

***REQxxxx** denotes a **specific requirement** that must be met.*

***BACKxxxx** denotes an **information** statement that may be useful in interpreting requirements and the numbering should match the requirement number.*

Relevant abbreviations contained in this document include:

OSHA: Occupational Safety and Health Administration
HMD: Head Mounted Display
VRVT: Virtual Reality Vision Therapy
IR: Infrared
CPU: Central Processing Unit
IRED: Infrared-emitting diode
DSI: Display Serial Interface
CSI: Camera Serial Interface
PoC: Point of Convergence
UDP: User Datagram Protocol

4 Document References

The following document references are either cited directly or may be useful in interpreting requirements, objectives and information statements contained herein:

- OSHA Z136
- Everlight Technical Data Sheet 5mm Infrared LED, T-1 ¾
- IETF RFC768 - User Datagram Protocol

5 Hardware Subsystem Requirements

This section contains the physical requirements for all of the hardware in VRVT.

5.1 *HMD Requirements*

This section provides the physical specifications for acquiring the HMD.

REQ0001: The head mounted display (HMD) shall be the Oculus Rift Developer Kit 2.

BACK0001: This is not the final retail model of the Oculus Rift.

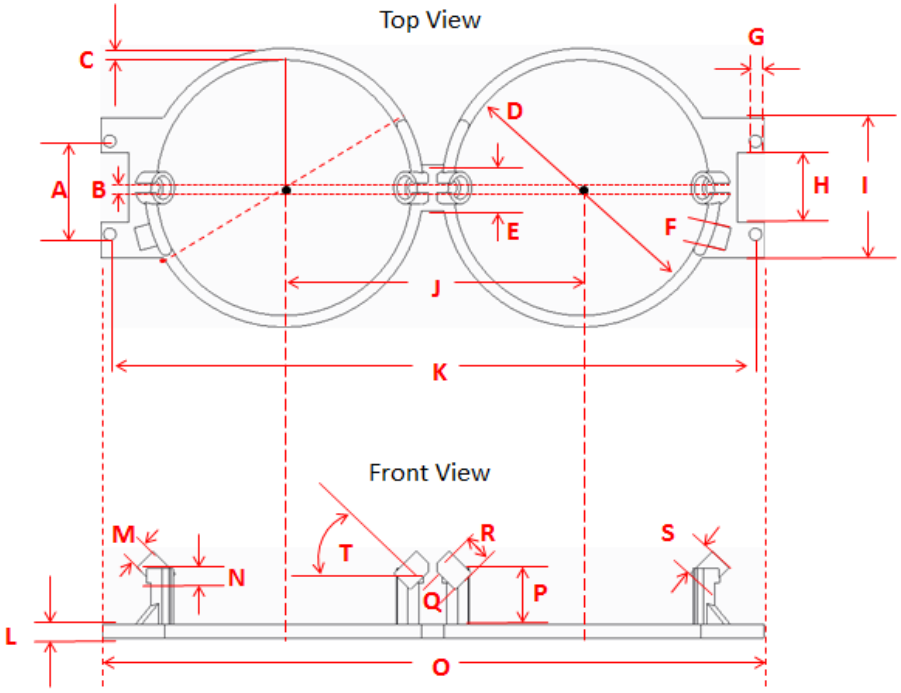
REQ0005: The Oculus Positional Tracker shall be used to monitor the HMD motion during use.

BACK0005: This camera and its required cables are included in the Developer Kit 2, from the manufacturer.

5.2 *IRED Mount Requirements*

This section provides the physical specifications for constructing the mount for the Infrared LEDs.

REQ0010: The IRED mount shall be constructed according to the size and shape specifications in Figure 2.



A	20 ± 1 mm
B	2 ± 1 mm
C	2.5 ± 1 mm
D	55 ± 2 mm
E	10 ± 2 mm
F	5 ± 1 mm
G	2 ± 1 mm

H	15 ± 2 mm
I	30 ± 2 mm
J	66 ± 2 mm
K	141 ± 2 mm
L	3 ± 1 mm
M	5 ± 2 mm
N	3 ± 0.5 mm

O	143 ± 2 mm
P	12 ± 2 mm
Q	3 ± 0.5 mm
R	5 ± 1 mm
S	7 ± 2 mm
T	45° ± 2°

Figure 2 (both images): The engineering sketch of the IRED mount, with relevant dimensions referenced as letters A-N.

REQ0015: The IRED mount shall be 3D printed out of ABS plastic

BACK0015: When printing, minimize the chord length and control angle for a truer print.

5.3 *IRED Circuit Requirements*

This section provides the physical specifications of the Infrared LEDs and their installation within the IRED Mount.

REQ0025: The infrared LEDs used shall be Everlight LED's.
BACK0025A: The item number of these IREDs is IR323.
BACK0025B: Specification Sheet is available in Document References.
REQ0026: The power LED shall be a Microtivity IL111.
REQ0030: The device shall utilize four IREDs as shown in Figure TBD (This figure shows the IREDs in the IRED holder, installed in the HMD)
REQ0035: Each lens shall be illuminated by two of the four IREDs as shown in Figure TBD (This figure is the same figure as in REQ0030)
REQ0040: The combined power of two illuminated IREDs shall not exceed 10 mW/cm^2.
BACK0040A: This requirement is imposed by the OSHA Z136 document.
BACK0040B: The power output can be measured using an optical power meter
REQ0045: The IREDs shall emit light at a wavelength outside of the range 370-710 nm.
BACK0045: The visible spectrum is 380-700 nm.
REQ0050: The IREDs shall be attached to the IRED mount by the holes in the IRED mount.
REQ0051: The IRED circuit shall use four 100Ω +/-5%, ½ watt resistors and one 120Ω +/-5%, ½ watt resistor.
REQ0052: The IRED circuit shall use a series-parallel construction as shown in Figure 3

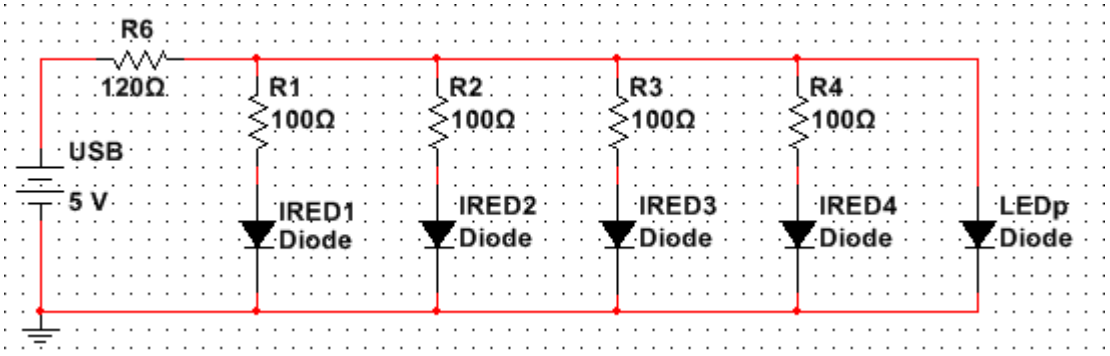


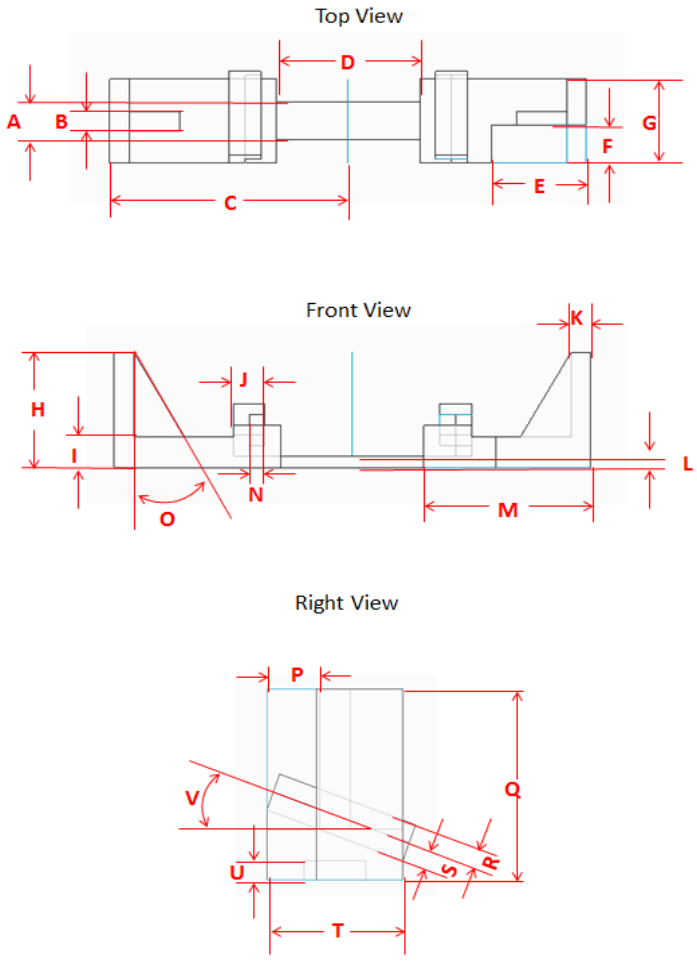
Figure 3 Circuit in series-parallel

REQ0053: The IRED circuit shall use a USB cable as the power source as shown in Figure 3.
BACK0053: The USB cable uses only the red for positive and black for negative, all other wires can be cut off if desired.

5.4 *IR Camera Mount Requirements*

This section provides the specifications constructing the mount for the IR cameras.

REQ0055: Two identical camera mounts shall be constructed according to the size and shape specifications in Figure 4.



A	5 ± 2 mm
B	2.5 ± 2 mm
C	30 ± 2 mm
D	20 ± 1 mm
E	12 ± 2 mm
F	5 ± 1 mm
G	11 ± 1 mm

H	15 ± 2 mm
I	4 ± 1 mm
J	4 ± 1 mm
K	2.5 ± 1 mm
L	1.5 ± 1 mm
M	20 ± 2 mm
N	2 ± 1 mm

O	30◦ ± 10◦
P	5 ± 2 mm
Q	15 ± 2 mm
R	1.5 ± 1 mm
S	1.5 ± 1 mm
T	11 ± 2 mm
U	1.5 ± 1 mm
V	20◦ ± 4◦

Figure 4 (three images): The engineering sketch of the camera mount, with relevant dimensions referenced as letters A-T.

REQ0065: The camera mounts shall be 3D printed out of ABS plastic

BACK0065: When printing, minimize the chord length and control angle for a truer print.

5.5 *IR Camera Requirements*

This section provides the physical specifications of the IR cameras and their installation within the IR Camera Mount.

REQ0075: The cameras used shall be the Raspberry Pi: Pi NoIR cameras

BACK0075A: The item number of this camera, from MCM Electronics, is 28-18030.

BACK0075B: The Pi NoIR cameras include a camera and camera board

REQ0080: Using the 24-pin cable extending from the camera, the camera shall be connected to the 24-pin port native to the camera board. These ports are labelled in Figure 5.

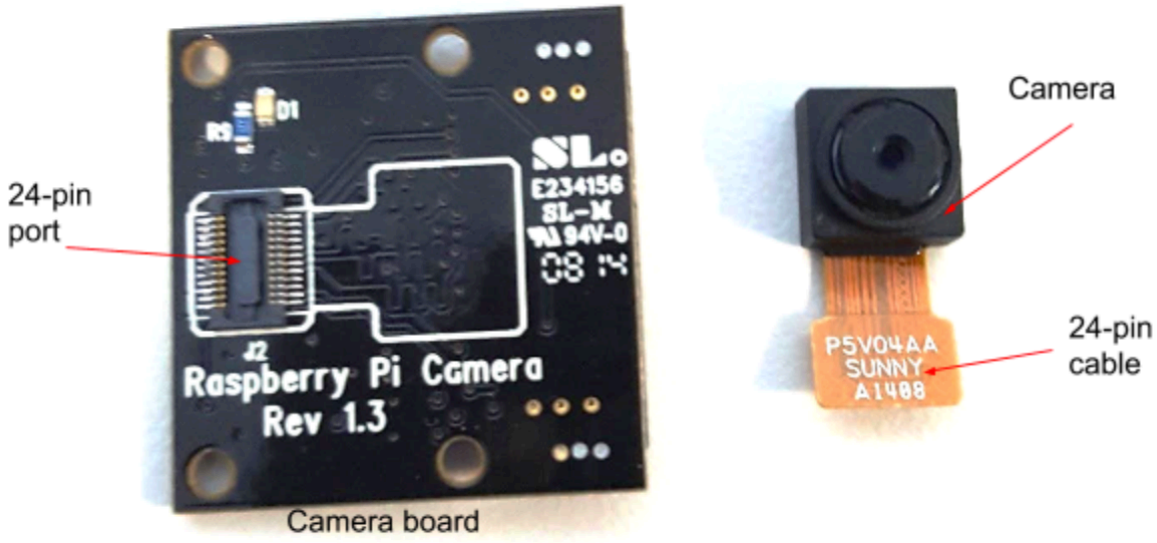


Figure 5: The Raspberry Pi NoIR camera and camera board

REQ0085: The camera and camera board, together, shall be no larger than 25x25x25mm³ ± 0.5 mm in any dimension.

REQ0086: The camera shall be connected to the camera board according to the orientation shown in Figure 6.

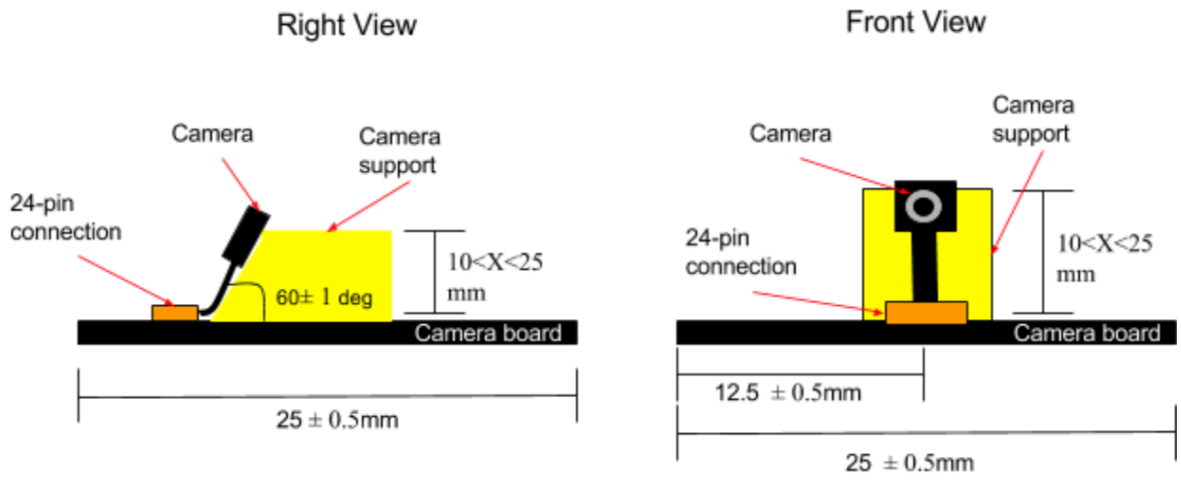
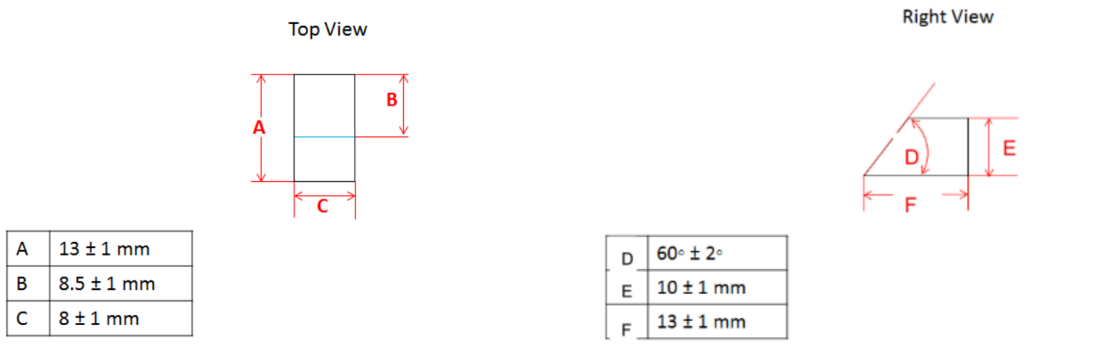


Figure 6: The camera and camera board, connected via the 24-pin cable and in the correct orientation, via the camera support, for assembly to the IR camera mount

REQ0087: Two identical camera supports shall be constructed according to the size and shape specifications in Figure 7.



A	13 ± 1 mm
B	8.5 ± 1 mm
C	8 ± 1 mm

D	60◦ ± 2◦
E	10 ± 1 mm
F	13 ± 1 mm

Figure 7 (both images): The engineering sketch of the camera support, with relevant dimensions referenced as letters A-T.

REQ0089: The camera supports shall be 3D printed out of ABS plastic

BACK0089: When printing, minimize the chord length and control angle for a truer print.

REQ0095: The camera support shall be attached to the camera and camera board, using super glue, in the orientation shown in Figure 6.

REQ0100: The camera board shall rest in the center cavity of the camera mount, as shown in Figure 8.

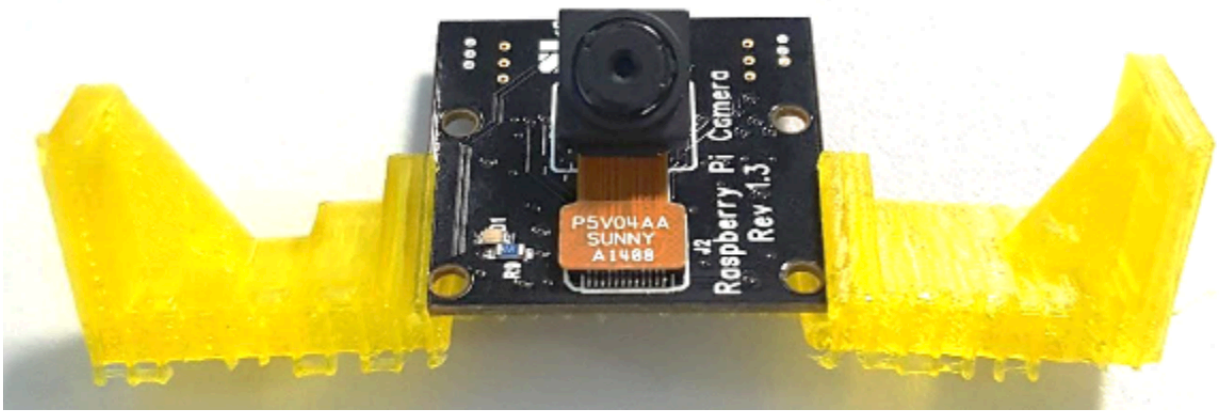


Figure 8: The camera and camera board installed in the camera mount

5.6 *Interactive Tablet Requirements*

This section provides the physical specifications of the interactive tablets.

REQ0105: Two Raspberry Pi 7" Touchscreen displays shall be used as interactive tablets.

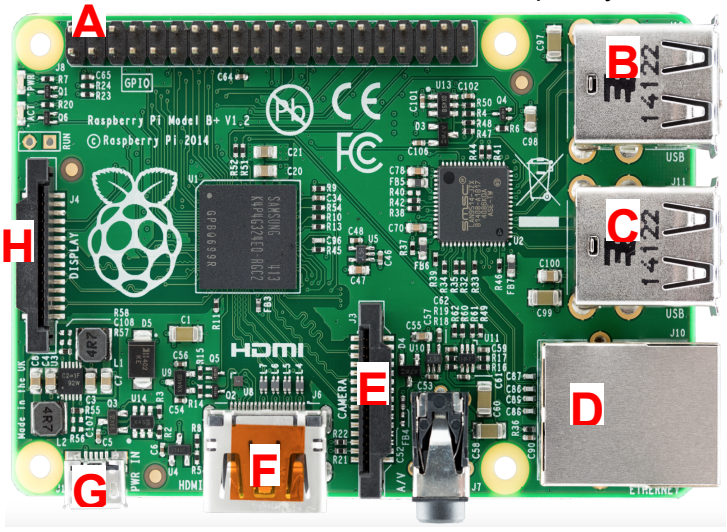
BACK0105: The item number of these touchscreens, from MCM Electronics, is 83-16872.

5.7 *Computing Requirements*

This section provides the physical specifications of the desktop PC and Raspberry Pi microcomputers.

REQ0115: Two Raspberry Pi 2 Model B microcomputers, as shown in Figure 9, shall be used.

BACK0115: The item number of this Raspberry Pi, from MCM Electronics, is 83-16530.



A	40-pin GPIO
B	USB
C	USB
D	Ethernet
E	15-pin Camera
F	HDMI
G	microUSB
H	15-pin Display Serial Interface

Figure 9: The Raspberry Pi 2B with connectivity ports labelled A-H

REQ0122: One desktop PC, with Windows 10 installed, shall be used for the operation of the VRVT system.
REQ0125: The desktop PC shall have a minimum 8GB RAM
REQ0127: The desktop PC shall have a GTX970 graphics card
BACK0127: This is necessary for running the Unity game environment.
REQ0130: The desktop PC shall be connected to a 1080p monitor display via an HDMI cable, as shown in Figure 10.

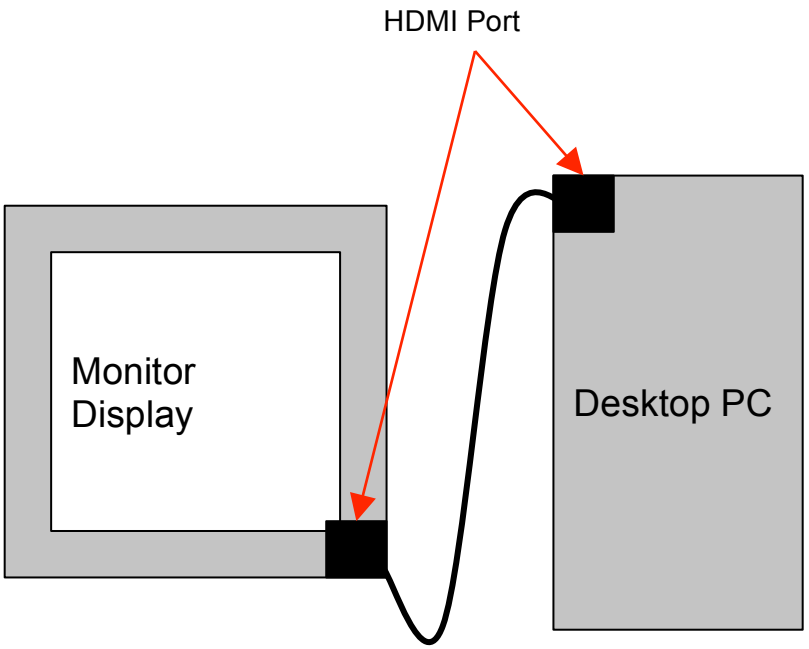


Figure 10: Schematic of the connection between the desktop PC and the monitor display via a double-ended HDMI cable

6 Software Subsystem Requirements

This section contains requirements about the platform and logic of each of the pieces of software that will be running to operate VRVT.

6.1 *Point of Convergence Software Requirements*

This section provides the description of the steps of the algorithm used to calculate the point of convergence of the user's eyes.

Performance Requirements:

REQ0135: The PoC software shall operate at the same rate as the Unity game environment.

REQ0140: The PoC software shall receive the location of the centroid of the pupil of each eye from the Eye Tracking software at rate greater than or equal to 14fps.

BACK0140: 14Hz is the Nyquist rate required for convergence eye movements.

Functional Requirements:

REQ0145: The PoC software shall be written in C#.

REQ0150: The Unity game environment, on the PC, shall run the PoC software.

BACK0150: The PoC software is written as a subscript within the Unity game. The subscript is called once per frame buffer output, or every time the screen refreshes with a new image from the game.

REQ0155: The PoC software shall receive the pixel value of the centroid of each eye to the Eye Tracking software via a UDP socket connection.

BACK0155: The specification sheet for UDP connections is available in Document References.

REQ0160: The PoC software shall calculate the point of convergence according to the algorithm outlined in Figure 11.

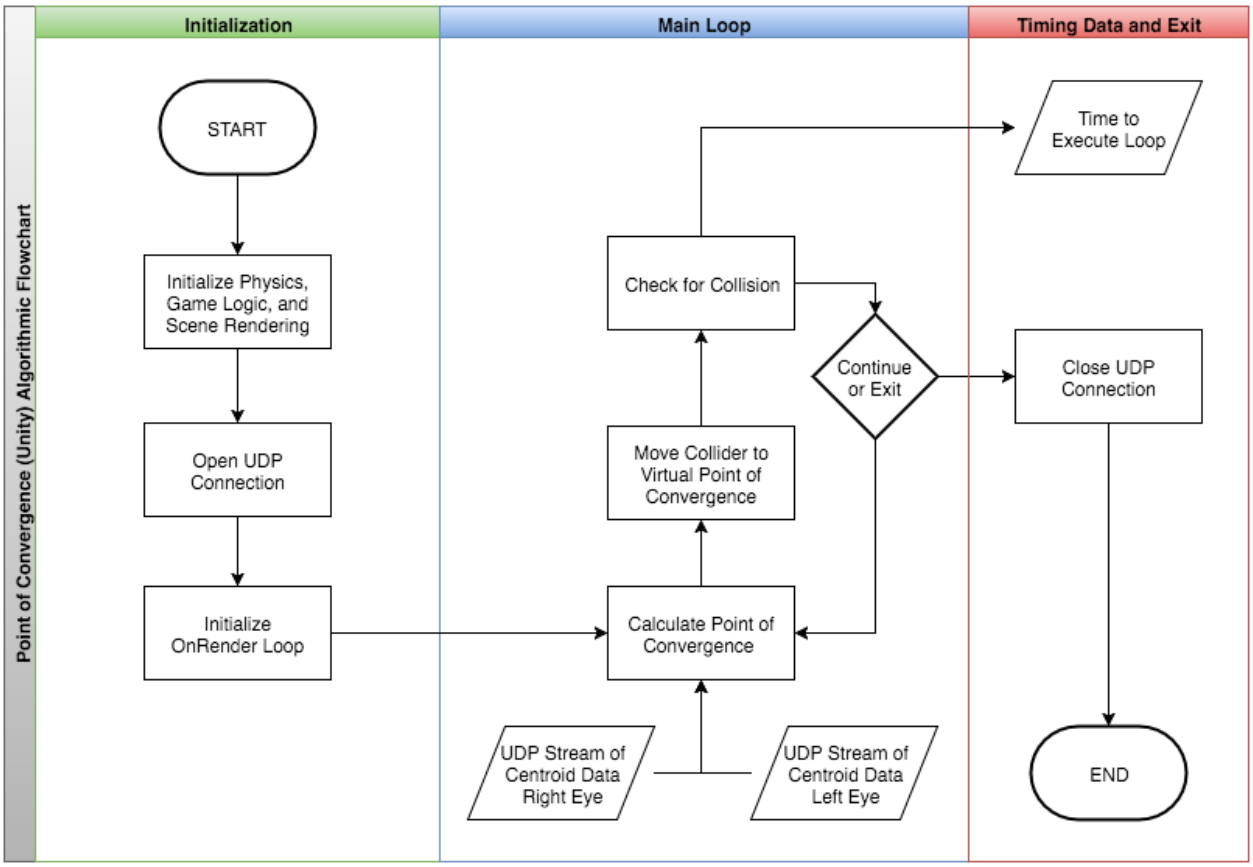


Figure 11: The algorithmic flow chart of the PoC software

6.2 *Eye Tracking Software Requirements*

This section provides the description of the steps of the algorithm used to calculate and follow the centroid of each of the user's eyes.

Performance Requirements:

REQ0170: The Eye Tracking software shall operate at rate greater than or equal to 14fps.

REQ0180: The Eye Tracking software shall receive the image of the illuminated eye from each Pi NoIR camera at 90 frames per second.

BACK0180: Each camera is capturing images at 90 frames per second.

Functional Requirements:

REQ0185: The Eye Tracking software shall be written in C#.

REQ0190: The Eye Tracking software shall operate within the CPU of each Raspberry Pi

BACK0190: Both Raspberry Pi's will be running the same Eye Tracking software

REQ0195: The Eye Tracking software shall send the pixel value of the centroid of each eye to the PoC software via a UDP socket connection.

REQ0200: The Eye Tracking software shall calculate the position of the eye according to the algorithm outlined in Figure 12.

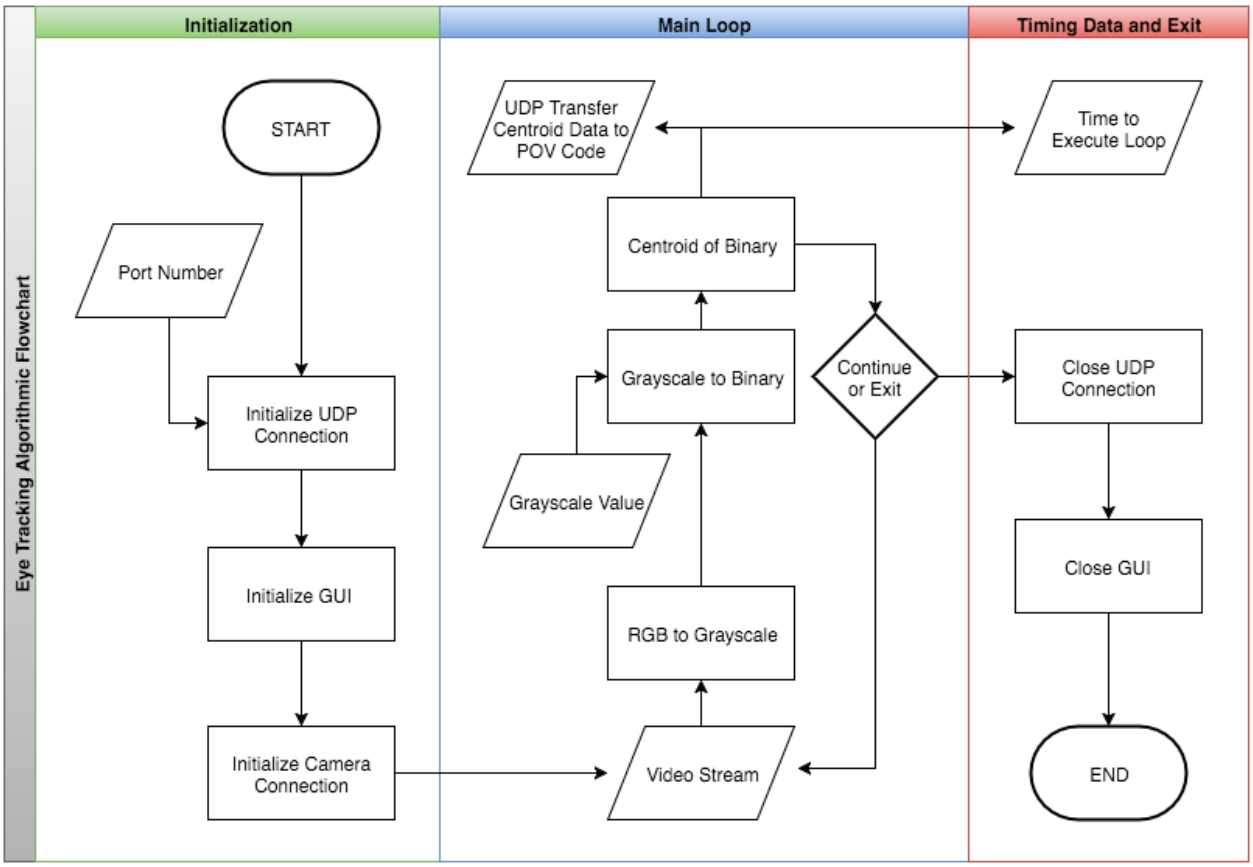


Figure 12: The algorithmic flow chart of the Eye Tracking software

7 Power Requirements

This is how each of the subsystems and the entire assembly will be powered.

REQ0205: The HMD shall be powered by plugging it in directly to a standard United States, 120 volt wall socket as shown in Figure 17.

BACK0205: The cable for plugging in the HMD is included in the kit from the manufacturer.

REQ0210: The Oculus Position tracker shall be powered by a plugging it in directly to a standard United States, 120 volt wall socket as shown in Figure 18.

REQ0215: The circuit, shown in Figure 3, shall receive power from the USB port native to the HMD, shown in Figure 13.

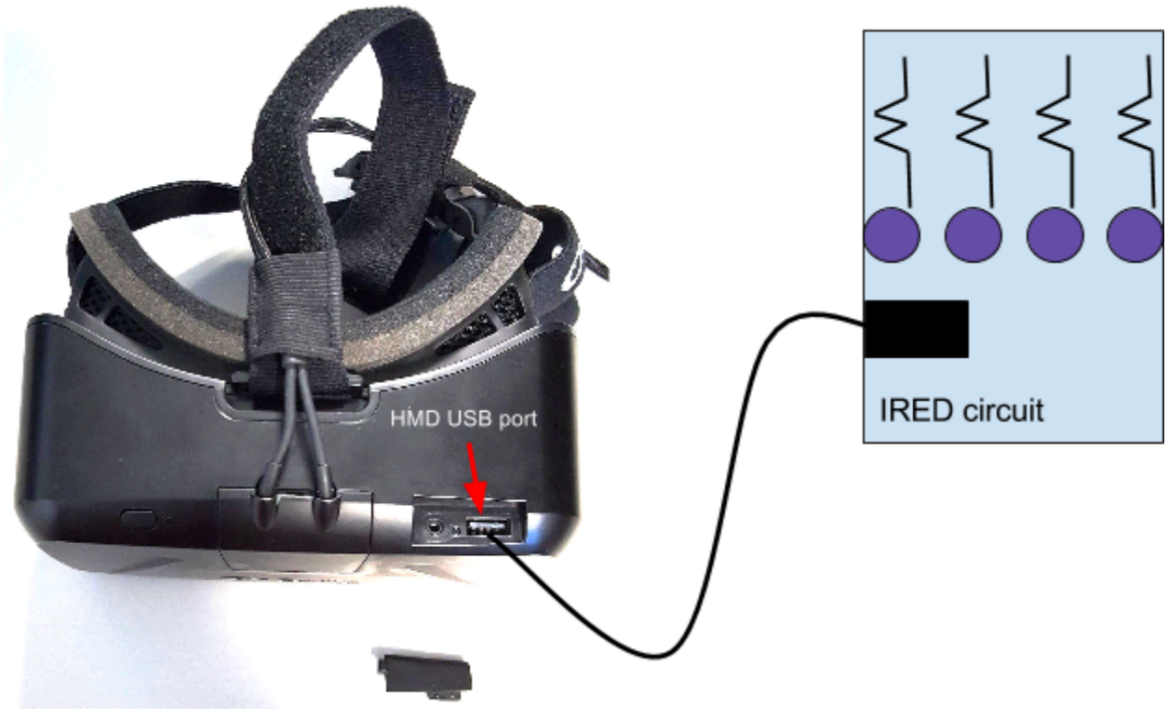


Figure 13: A top-view of the HMD with the port cover removed, connected to the IRED circuit. The USB port is labeled in red.

REQ0216: The USB cable shall provide 5V +/- 2%, and 100mA +/-5%.
REQ0217: Each resistor shall have current values of 25mA +/-4% and voltage values of 3.75V +/-3% across each resistor.
REQ0220: Each Pi NoIR camera shall receive power from its respective Raspberry Pi 15-pin ribbon cable port, as shown in Figure 26.
REQ0225: The desktop PC shall be powered by plugging it in directly to a standard United States, 120 volt wall socket, as shown in Figure 17.
REQ0230: The Raspberry Pi's shall be powered by one of the desktop PC's native USB ports, as shown in Figure 14.

BACK0230A: Each Raspberry Pi is powered independently

BACK0230B: Each Raspberry Pi requires a minimum of 5 Volts and 1.2 Amps to operate.

BACK0230C: The desktop PC's USB port is capable of supplying 5 Volts and 1.2 Amps.

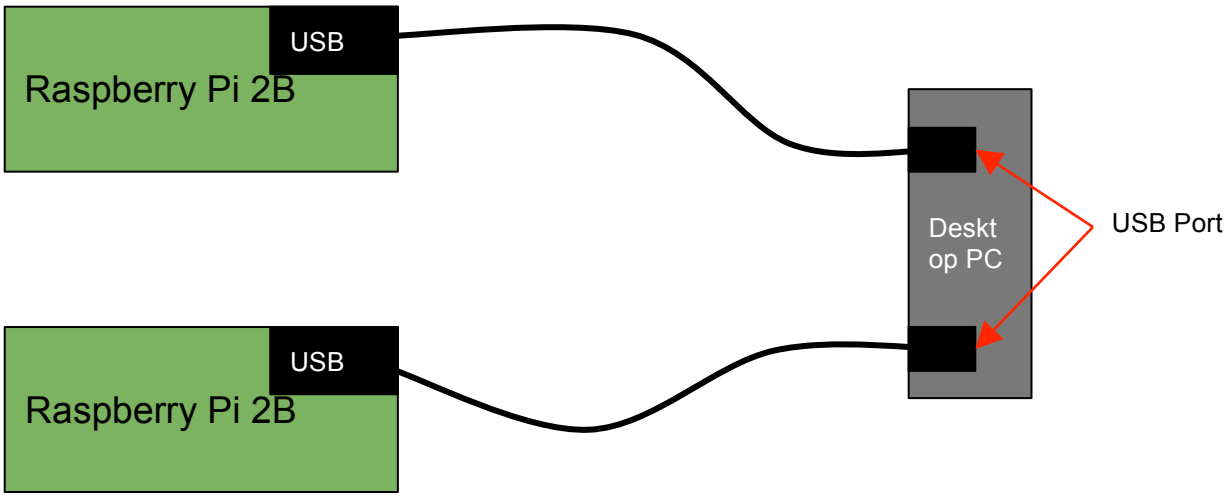


Figure 14: Schematic showing the powered connection between the Raspberry Pi 2Bs and the desktop PC

REQ0235: Each Raspberry Pi touch screen shall receive power from its respective Raspberry Pi display serial interface (DSI), as shown in Figure 21.

BACK0235: The Raspberry Pi Touch Screens require a minimum of 200 milliVolts and 500 milliAmps to operate.

8 Subsystem Assembly and Connectivity Requirements

This section describes how each of the subsystems are connected to each other and installed within one another.

8.1 *Hardware Assembly and Connection Requirements*

This section contains the requirements for connecting each of the physical subsystems and manufactured parts to each other in the correct orientation.

REQ0240: A USB to exposed wire cable shall connect the USB port native to the HMD to the circuit that controls the IREDs, as shown in Figure 17.

BACK0240: This connection will supply the power to the circuit to power the IREDs, as described in section 7, REQ0215.

REQ0245: The HMD shall be connected to the desktop PC by the cord native to the HMD, as seen in Figure 15, that has HDMI and USB ends, as shown in Figure 16.

Figure 15: HMD with its irremovable cable

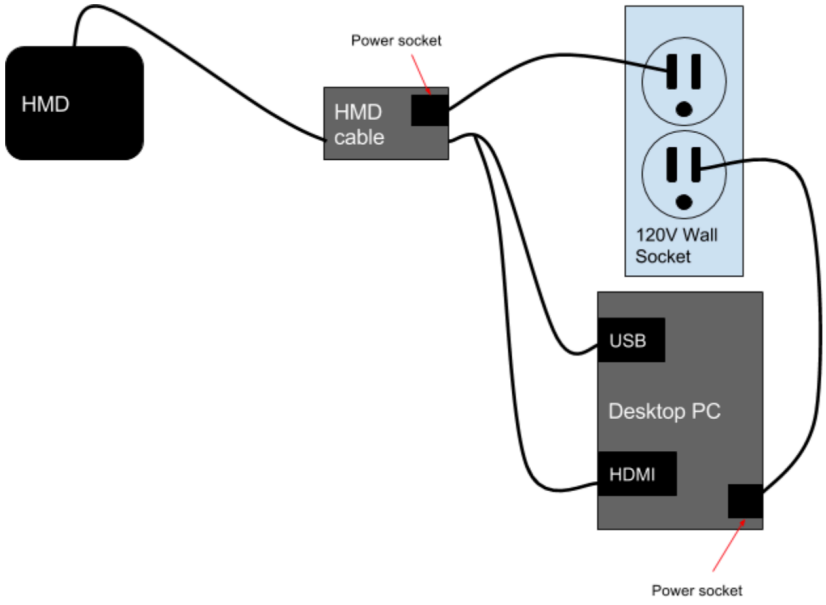


Figure 16: Schematic of the HMD connection to the PC and power source

REQ0255: The Oculus Positional Tracker shall be connected to the powered wall socket using an outlet to microUSB cable, as shown in Figure 17.
REQ0260: The Oculus Positional Tracker shall be attached to the Sync Out port on the HMD's cord using a double ended 2.5mm auxiliary cable, as shown in Figure 17.

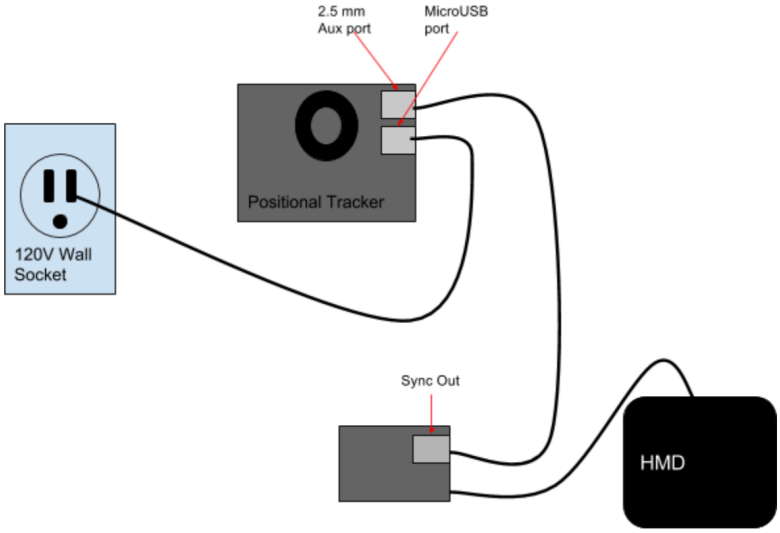


Figure 17: Schematic of the Oculus Positional Tracker connected to the Oculus HMD and the wall socket

REQ0265: The user-side of the HMD shall be unscrewed, according to the diagram in Figure 18, and removed to facilitate the installation of the IRED mount and the IR camera mounts.

Figure 18: A fully disassembled Oculus Rift

REQ0270: The IREDs and IRED mount assembly shall be attached, using the screws depicted in Figure 18, to the interior of the HMD according to the diagram in Figure TBD.

BACK0270: The requirement, REQ0050 in section 5.3, contains the method for attaching the IREDs to the IRED mount.

REQ0275: The IR camera and camera mount assemblies shall be pressed into the interior of the HMD according to the diagram in Figure 19.

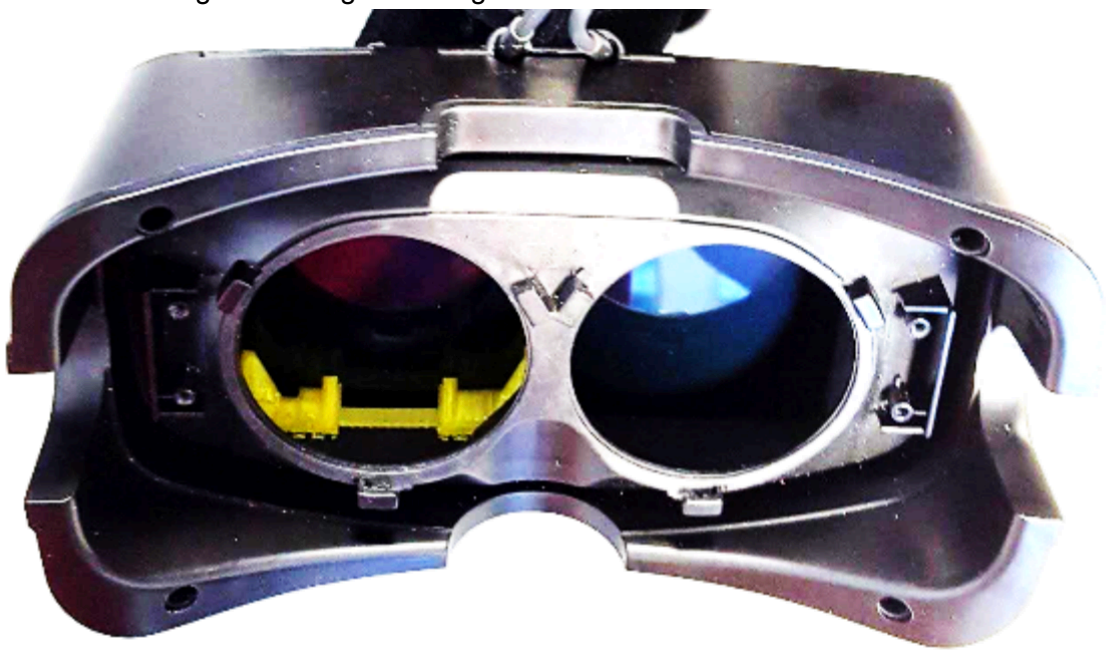


Figure 19: The camera mount, without the camera and camera board, installed in the HMD.

BACK0275: The requirement, REQ0100 in section 5.5, contains the method for attaching the cameras to the camera mount.

REQ0280: Following the installation of the IRED mount and the IR camera mounts, the front of the HMD shall be reattached to the body of the HMD using the screws shown in Figure 18.

REQ0285: Cables originating from the cameras and IREDs shall exit the HMD at the origin of the cables on the HMD as shown in Figure 20.

Figure 20: Top view of the HMD showing the attachment point of the fixed cable

REQ0295: The DSI on each Raspberry Pi 7” Touchscreen display shall be connected directly to the DSI on its respective Raspberry Pi microcomputer using a double-ended DSI cable, as shown in Figure 21.

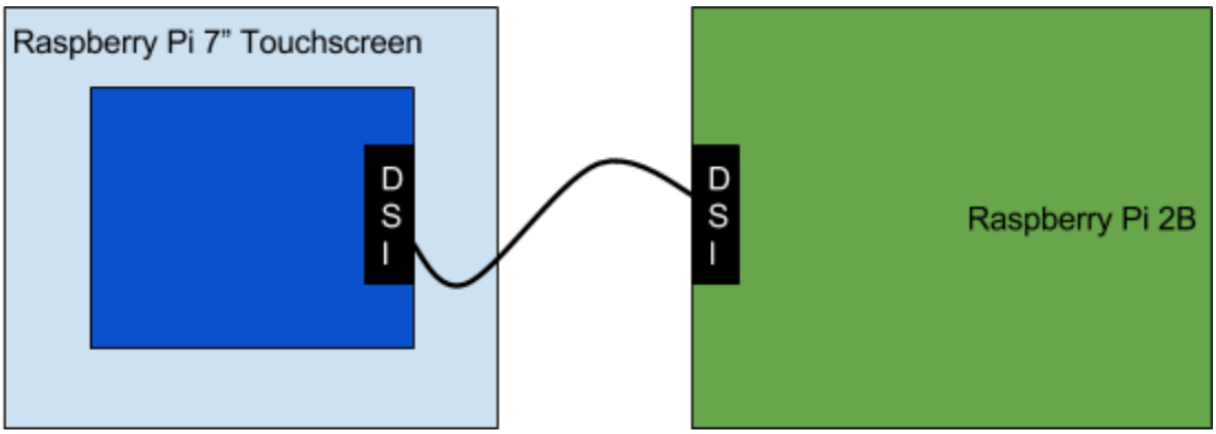


Figure 21: Schematic showing the powered connection between the DSI on the Raspberry Pi 2B and the Raspberry Pi 7" touch screen

REQ0300: The red GPIO wire shall be connected to the 5V output on the Raspberry Pi Touchscreen and the first GPIO pin on the Raspberry Pi as shown in Figure 22.

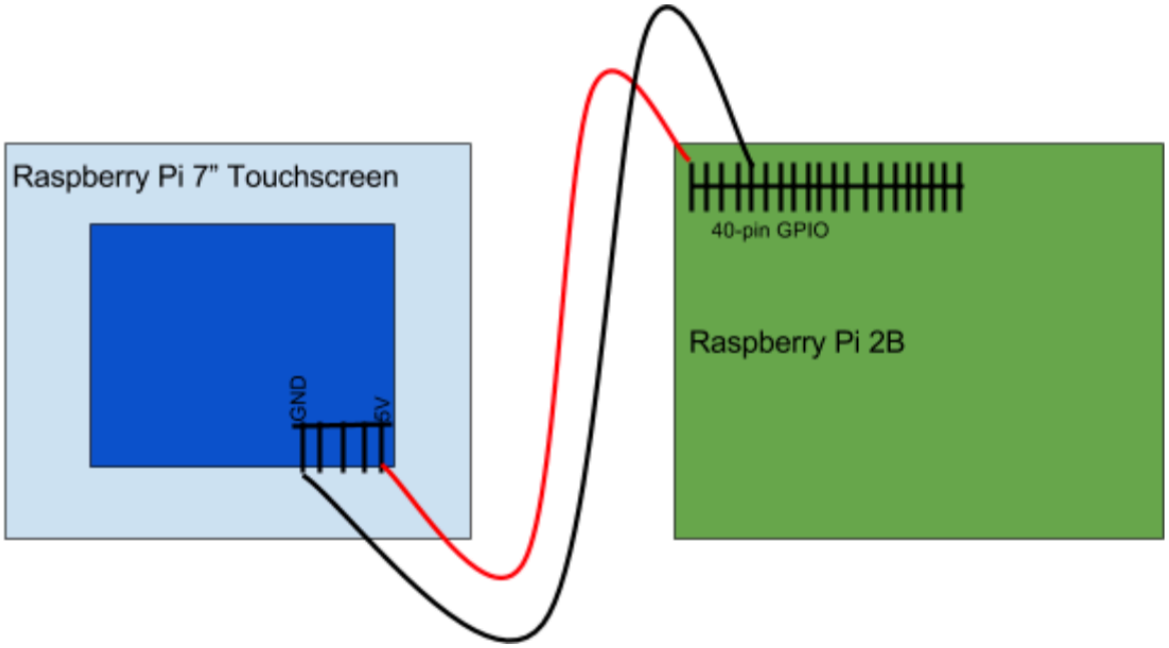


Figure 22: Schematic of the connection between the Raspberry Pi 2B's 40-pin GPIO and the voltage pins on the Raspberry Pi 7" Touchscreen

REQ0305: The black GPIO wire shall be connected to the GND output on the Raspberry Pi Touchscreen and the 5th GPIO pin on the Raspberry Pi as shown in Figure 22.
REQ0310: The Raspberry Pi microcomputer shall be screwed into the Raspberry Pi Touchscreen as shown in Figure 23.
BACK0310: The required screws come with the Raspberry Pi 7" Touchscreen.

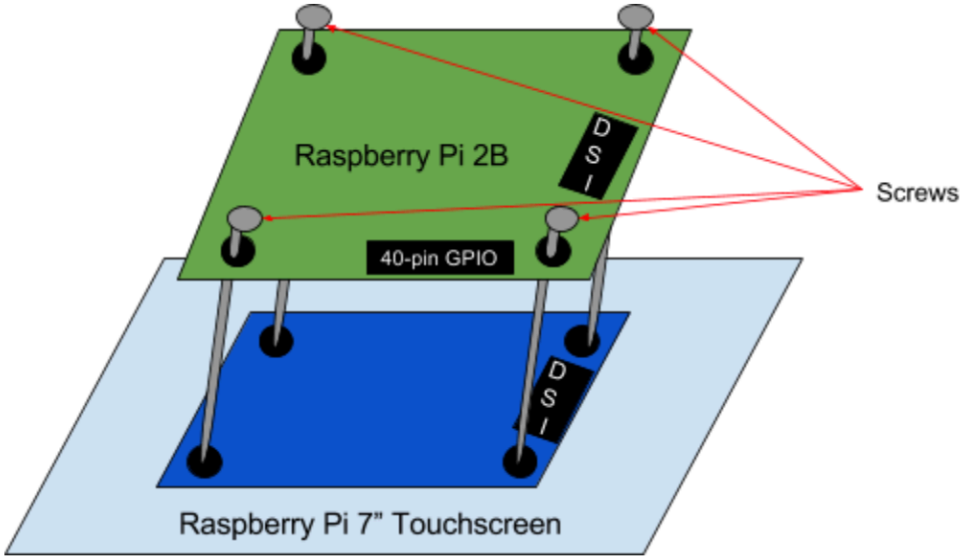


Figure 23: Schematic of the final assembly of the Raspberry Pi 2B to the Raspberry Pi 7" Touchscreen, showing the matching DSI ports for orientation

REQ0312: Requirements from REQ0295 to REQ0310 shall be completed for two Raspberry Pi's and two Raspberry Pi Touchscreens, resulting in two identical versions of the assembly shown in Figure 23.
REQ0315: A male-to-male ethernet cable shall connect the ethernet port of each Raspberry Pi microcomputer to an ethernet port on the desktop PC as shown in Figure 24.

BACK0315: This requires two available ethernet ports on the desktop PC.

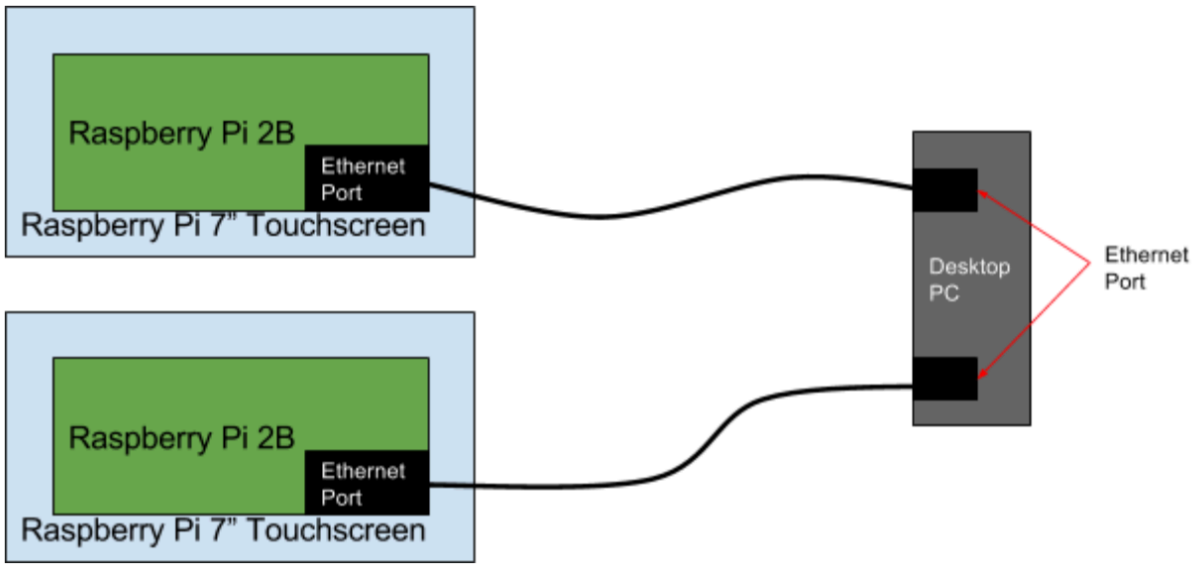


Figure 24: Schematic of the connection between the Raspberry Pi 2B ethernet port and the ethernet port on the desktop PC

8.2 *Software Connection and Data Transfer Requirements*

This section contains the requirements for connecting each of the computing subsystems to each other in the appropriate orientation so that the necessary data can be transferred between the subsystems.

REQ0320: A double ended 15-pin ribbon cable shall connect the Raspberry Pi's 15-pin ribbon cable port to the Pi NoIR's 15-pin ribbon cable port as shown in Figure 25.

BACK0320A: This connection supplies power to the Pi NoIR cameras.

BACK0320B: This connection allows for the transfer of the images of the eye from the cameras to the Eye Tracking software on the Raspberry Pi

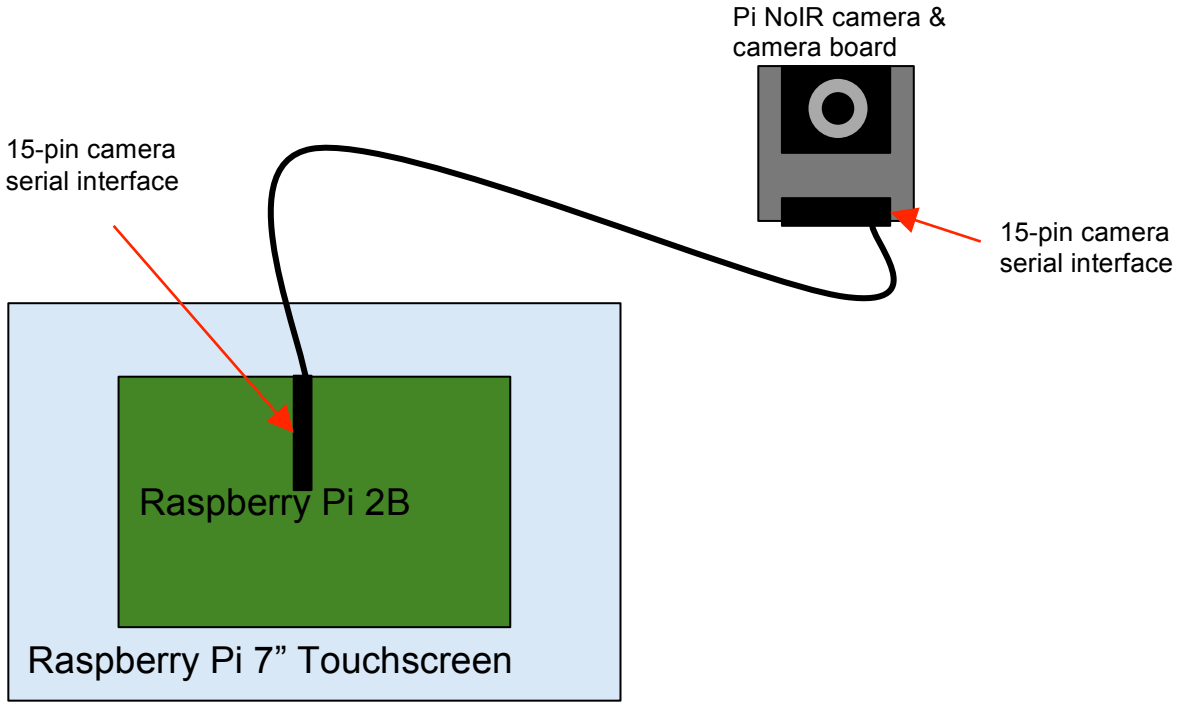


Figure 25: Schematic of the powered connection between the Raspberry Pi and Touchscreen assembly 15-pin camera serial interface and the 15-pin camera serial interface on the camera board

REQ0325: A USB to microUSB cable shall connect a USB port on the desktop PC to the Raspberry Pi's microUSB port as shown in Figure 26.

BACK0325A: This connection supplies the power to the Raspberry Pi.

BACK0325B: This connection allows for the transfer of the location of the centroid of the eye, from the Eye Tracking software, to the PoC software running in the Unity environment on the computer

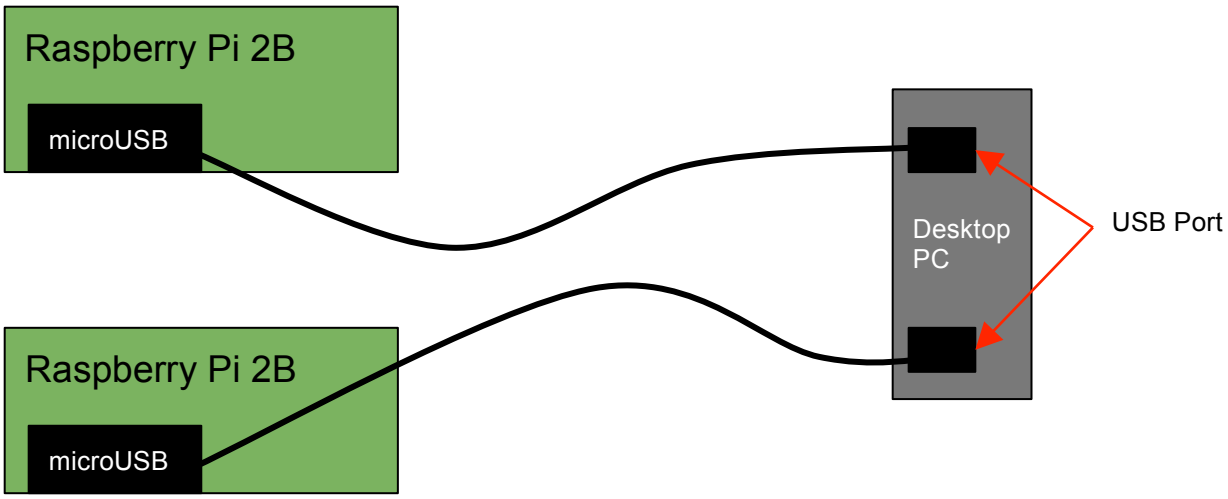


Figure 26: Schematic showing the connection between the Raspberry Pi 2B microUSB port and the USB port on the desktop PC

9 System Operation Requirements

This sections describes the methodology for powering up the system and any connections that need to be done upon powering up the system each time.

REQ0330: The assembly steps in Sections 8 and 9 shall be completed.

REQ0335: The desktop PC shall be powered on.

REQ0340: The Raspberry Pis shall be powered on, and the GUI started, with the command `startx`.

REQ0345: The Oculus Rift shall be powered on.

REQ0350: The Unity game environment shall be initialized on the desktop PC by clicking on the shortcut on the desktop titled “CapstoneDemo.”

REQ0355: The game shall be initialized by the start button at the top center of the Unity environment.

REQ0360: The operator shall instruct the user to focus his/her eyes on the target in the game environment, and record the presented values (`Xl, Yl, Xr, Yr`) for calibration.

REQ0365: The operator shall input the values of `Xl, Yl, Xr, Yr` into the variables `Dlx, Dyl, Drx, Dry` respectively.

10 Reliability Requirements

This section provides reliability requirements for each of the VRVT components.

REQ0330: The reliability of the IRED’s shall be the manufacturer’s specification, or a DoA (dead on arrival) of 0.001%.

BACK0330: Each IRED is considered separately.

REQ0335: The reliability of the cameras shall be the manufacturer’s specification, or a DoA (dead on arrival) of 0.001%.

BACK0335: Each camera is considered separately.

REQ0340: The reliability of the RaspberryPi shall be the manufacturer's specification, or a DoA (dead on arrival) of 0.001%.

BACK0340: Each RaspberryPi is considered separately.

REQ0345: The reliability of the RaspberryPi touchscreen shall be the manufacturer's specification, or a DoA (dead on arrival) of 0.001%.

BACK0345: Each RaspberryPi screen is considered separately.