SCRATCH

Shot Consultation and Refinement Applied Through Computer Hardware

Final Presentation

Group 17:

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Introduction

- SCRATCH is a billiards training tool
- Provide training drills with accurate data measurement and feedback
- Data will be measured by a camera and sensors placed on the user and cue stick
- Goal of enabling visually impaired individuals to play pool.
    - To accomplish this final point, the SCRATCH team will work in conjunction with VISION (Group 14)

VISION's Logo

Luke, CpE

Motivation

- Create a system that improves performance of billiards players at all skill levels
- Allows everyone to enjoy the sport more
- Creates an environment where visually impaired individuals can enjoy the game in social environments

Mena, EE

Goals and Objectives

- HUD
  - Goals:
    - Provide basic visual pre-shot information to inform the user where to aim and shot strength
    - Provide auditory instructions to impaired individual for aiming of cue stick
  - Objective:
    - Use of camera to provide impact point feedback
    - Display will be used to provide post-shot feedback for strength and impact point
    - Use speaker to provide audio feedback based off communication with other subsystems

- Cue Stick
  - Goals:
    - System can collect and transmit data regarding the orientation and force applied to the cue stick
  - Objective:
    - Implement IMU determine cue ball speed and stick position, with buttons to control gamemode

Goran, EE

Goals and Objectives (Continued)

- Glove
  - Goals:
    - Transmit current angle and distance of user to the cue ball to the CCU
  - Objectives:
    - Send distance obtained from ultrasonic sensor and angle from IMU via BLE
- Central Control Unit (CCU)
  - Goals:
    - System receives and analyzes cue stick motion data and camera shot impact placement and send this data to HUD
    - Control full system integration
  - Objective:
    - Use received data from subsystems to control information sent to user by sending either audio or visual feedback depending on gamemode

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Standards and Design Constraints

Standards

- IEEE 802.15 (Bluetooth)
- IEEE 802.11 (WiFi)
- SPI
- I2C
- I2S
- C/C++
- Arduino
- Python

Design Constraints

- Ergonomics of Glove, HUD, Stick
- HUD feedback performance
- Temperature
- Design time
- Economic constraints

Goran, EE

Specifications

HUD should be lightweight	< 1500 grams
HUD should be able to provide post-shot feedback after a shot attempt is completed	< 8 seconds
Sampling user aim and providing audio feedback should be done on predetermined intervals.	< 2 seconds
Cue stick sensors should be able to determine the orientation of the cue stick within an acceptable margin of error	< 3 degrees
Cue stick should be able to determine the speed of the cue stick within an acceptable margin of error	< 1 meter per second
Electronics should not reach uncomfortable temperatures	< 100 degrees Fahrenheit
Central control unit should be able to respond to button inputs from the cue stick with minimal latency	< 500 milliseconds

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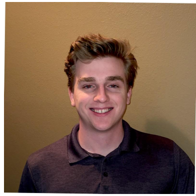

System Descriptions

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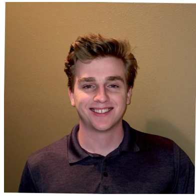
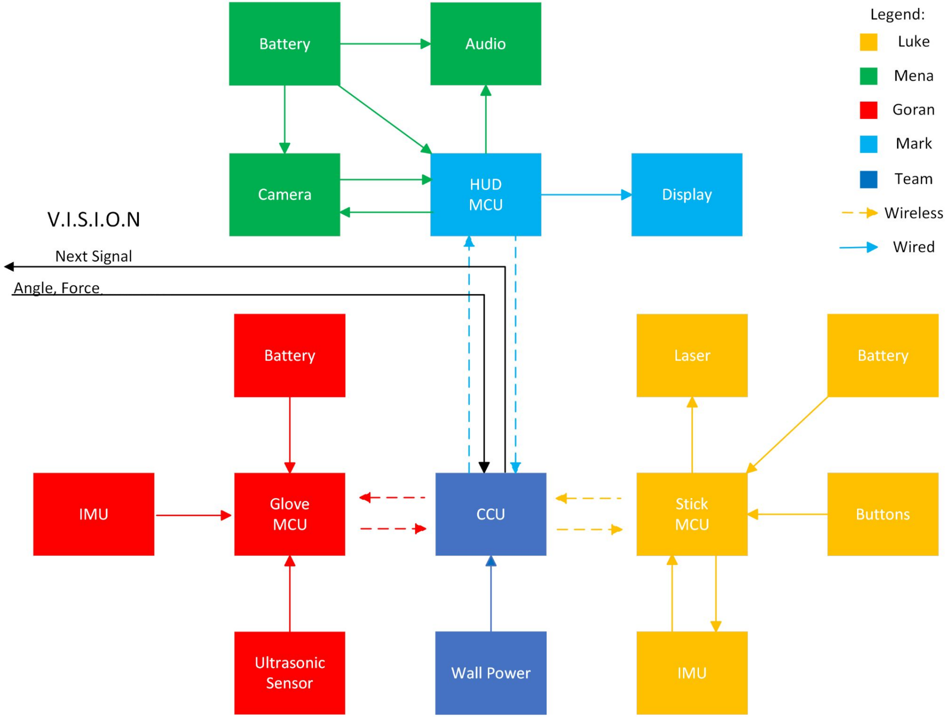


Hardware Block Diagram



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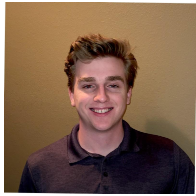
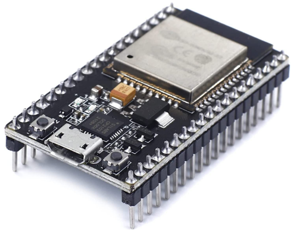


Microcontroller Options

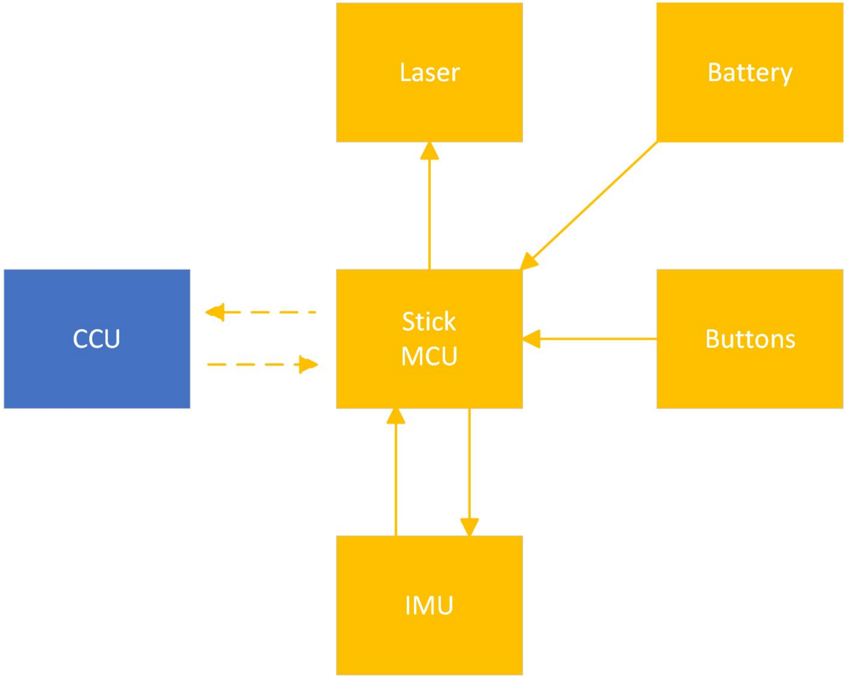
- Three microcontrollers needed:
  - Independent module used in cue stick PCB
  - Development boards used in HUD and glove
- Selection criteria:
  - Integrated Bluetooth
  - Low power consumption
  - Easy to program



Microcontroller	Wireless Connectivity	Maximum Power Consumption	Dev Board Price
ATMega4809	N/A	0.95 W	$10.20
SAMD21 Cortex®-M0+	802.11 b/g/n, Bluetooth 5.0, BLE	0.99 W	$42.20
ESP-WROOM-32	802.11 b/g/n, Bluetooth 4.2, BLE	1.65 W	$5.96

Luke, CpE

Cue Stick Block Diagram



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Cue Stick Description

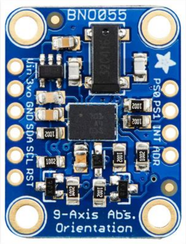
- Primary means of user interaction
- IMU is used to determine the orientation and speed of the cue stick during a shot attempt
- Buttons for user input
- Mounted laser which aids the computer vision system



Luke, CpE

Inertial Measurement Unit

- Purpose: determine the orientation and speed of the cue stick during a shot attempt
- Also used in glove to determine shot angle
- Selection criteria:
  - Small form factor
  - Compatible with ESP32
  - Low power consumption



IMU	Dimensions	Connectivity	Maximum Power Consumption	Dev Board Price
MPU-6050	26.0 mm x 17.8 mm x 4.6 mm	I2C/SPI	11.3 mW	$6.95
BNO055	20.0 mm x 27.0 mm x 4.0 mm	I2C/SPI	36.9 mW	$34.95
LSM6DSOX	25.6 mm x 17.8 mm x 4.6 mm	I2C/SPI	0.99 mW	$11.95

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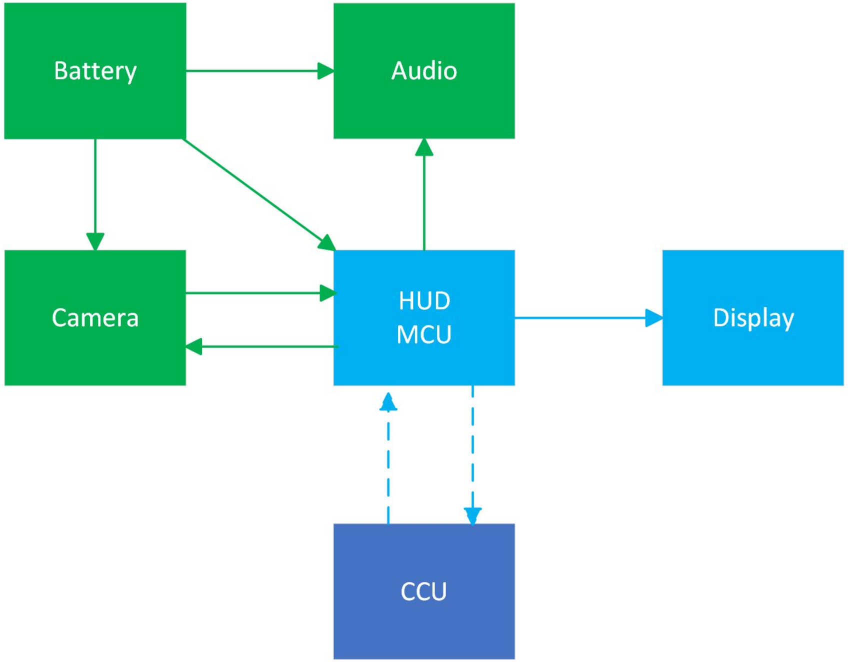
HUD/Camera/Speaker Block Diagram



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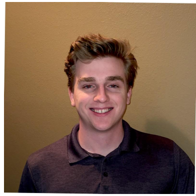
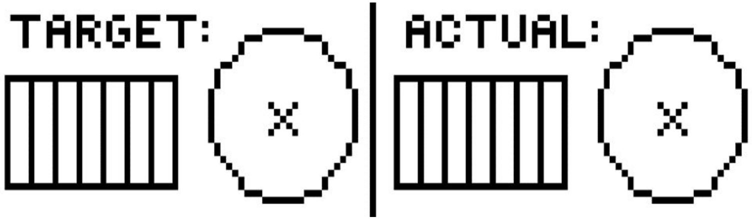


HUD Description

- The wearable HUD consists of three subsystems all of which are worn on the user in a similar fashion to glasses
- The first system is the actual HUD, which is accomplished using two mirrors and a display to place the image clearly in front of the user's eye
- The information consists of pre-shot directions and post-shot feedback



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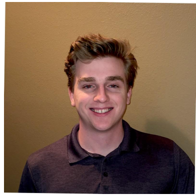
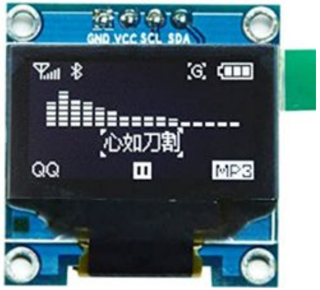


Display

- Purpose: Display pre and post-shot information
- Selection Criteria:
  - Small size and low weight
  - 3.3V Input
  - I2C Communication Protocol
  - Ease of programming
- Selection:
  - HiLetGo 128x64 OLED LCD I2C Display



Display	HiLetGo LCD Display	Maker Focus	Wave Share
Resolution	128 x 64	128x32	128x128
Voltage	3.0 - 5.0	3.3 - 5	5
Cost	$7.29	$4.99	$18.99
Communication Protocol	I2C	I2C	SPI

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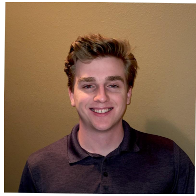


Speaker Description

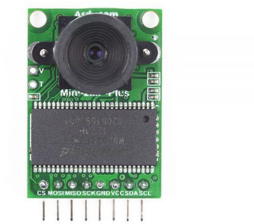
- The purpose of the speaker system is to provide pre-shot guidance for the visually impaired user
- Guidance based on auditory commands
- I2S communication between SD card and DAC
- Physically the system is composed of:
  - The I2S port on the ESP32
  - The MAX98357a DAC
  - A simple 3W speaker
  - An SD card
- Command selection is done depending on input from the CCU

DAC	Cost	Power
MAX98357A	$5.95	1.8W-3.2W
PCM5102	$9.00	3.3V, undisclosed current draw or power

Mena, EE

Camera Description

- The purpose of the camera subsystem is to provide post-shot feedback to the non-impaired user regarding point of impact between the cue stick and the cue ball
- Computer vision to determine position of laser
- Computer vision performed on CCU
- The Camera subsystem consists of:
  - 2MP ArduCAM Mini camera
  - EP32 MCU
  - Raspberry Pi (CCU)



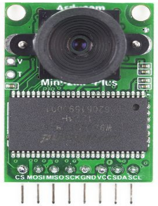
Camera	ArduCAM 2MP
Size	34x24mm
Power	0.35W
Cost	$26
Interface	SPI and I2C

Mena, EE

Camera Selection

- Purpose: take a picture used for point of impact determination
- Selection Criteria:
  - Small size to fit in HUD
  - Low power
  - Low cost
  - Ease of programming
  - Customizable resolution for accuracy/latency trade off
- Selection:
  - ArduCAM Mini 2MP Camera

Camera	Cost	Power	Size	Ease of Programming
MT9D111	$17	0.348 W	30x30mm	Hard
OV5640	$32	0.42 W	8.5x8.5x6mm	Hard
OpenMV	$65	0.56 W	36x45	Medium
ArduCAM (2MP)	$26	0.35 W (5V * 70mA)	34x24mm	Easy
ESP32 CAM	$18 + ESP cost	0.14 W	36x24mm	Medium



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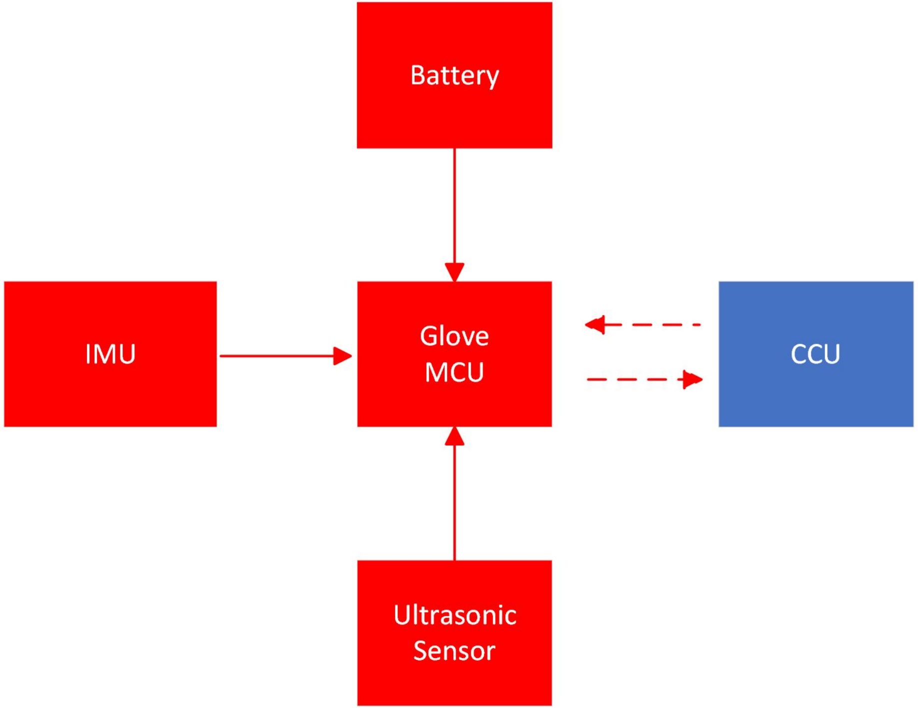
Glove Block Diagram



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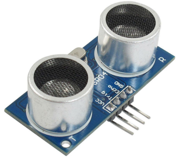
Glove Description

- The glove is a key component for guiding visually impaired users to the correct location to take a shot
- The IMU is used to determine the angle of the user with respect to the side of the pool table
- The ultrasonic sensor is used to determine the distance from the glove to the cue ball
- The users current angle and distance from the ball are sent to the CCU to be compared with the desired values
- Speaker system tells user how to adjust in order to match desired values of angle and distance



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Ultrasonic Sensor

- Purpose: determine the distance of visually impaired users hand from the ball
- Selection Criteria:
  - Powered by 3.3V
  - Small Size
  - Low Power Consumption
  - Able to measure distance up to 90cm
- Selection:
  - RCWL-1601

Chip	RCWL-1601	HC-SR04	Ping Ultrasonic
Size	40x18mm	45x20 cm	46x22cm
Range	2cm-450cm	2cm-400cm	3cm-300cm
Working Voltage	3V-5.5V	5V	5V
Price	$4.00	$3.50	$35.00

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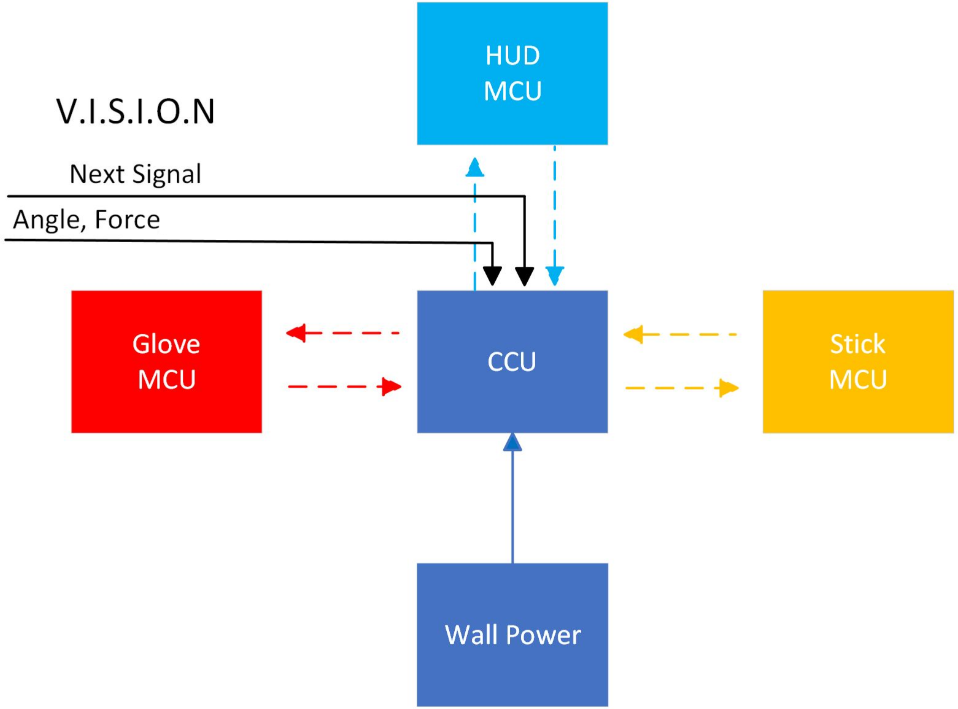
Central Control Unit (CCU) Block Diagram



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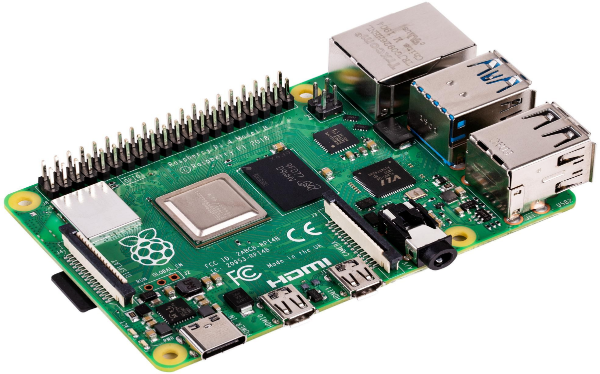
Central Control Unit (CCU) Description

- The central control unit (CCU) connects to all the other subsystems, as well as the VISION team's hardware
- Responsibilities:
  - Interpreting shot data from cue stick
  - Display selection
  - Computer Vision
- For this system, we will be using a Raspberry Pi 4
- Major FSM



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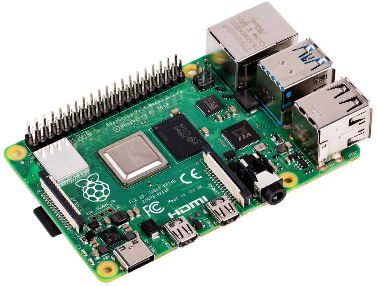
Microprocessor

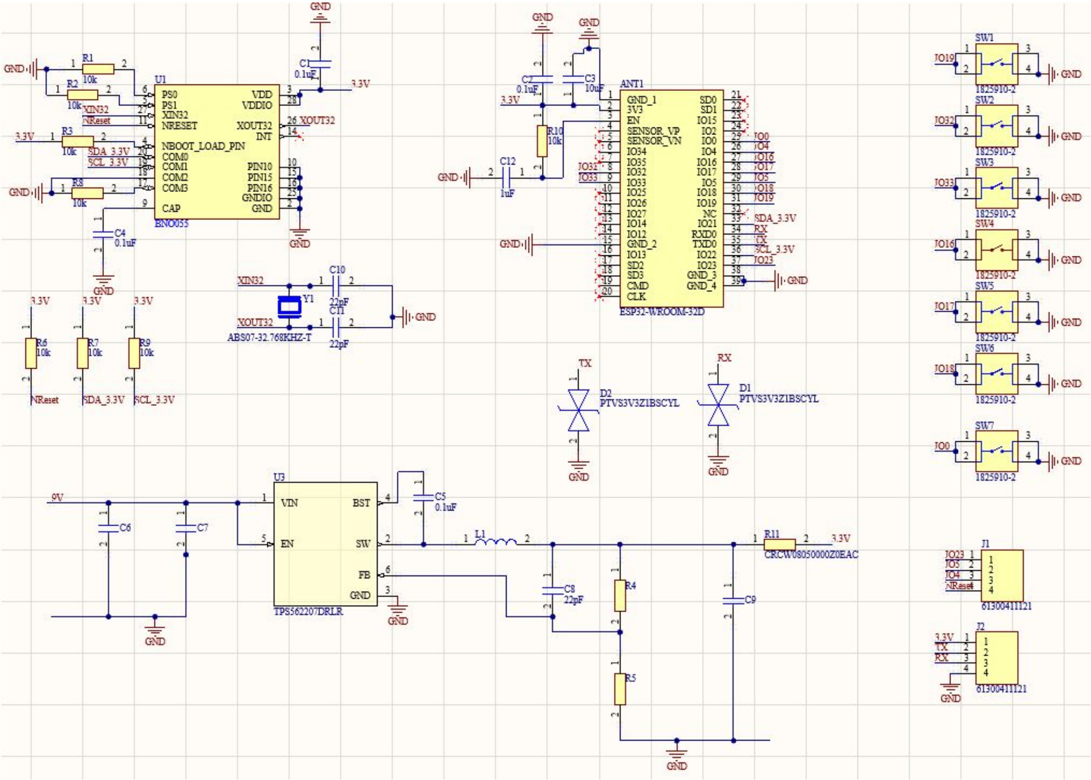
- Selection Criteria
  - Integrated wireless communication
  - Processing power to communicate with systems concurrently
  - Ability to perform computer vision
- Selection: Raspberry Pi 4 Model B 8GB



Microprocessor Board	Processor	Wireless Connectivity	Price
Raspberry Pi Zero 2 W	Quad-core Arm Cortex-A53 (1 GHz)	802.11 b/g/n, Bluetooth 4.2, BLE	MSRP: $15 Market: $90
Raspberry Pi 4 Model B	Quad-core Broadcom BCM2711 (1.5 GHz)	802.11ac. Bluetooth 5.0, BLE	MSRP: $35 - $75 Market: $114.99 - $156.99
Rock Pi 4 Model C	Hexa-core Rockchip RK3399 (1.8 GHz)	802.11ac, Bluetooth 5.0	MSRP: $59 Market: $107.11-$135

Luke, CpE

PCB Schematic



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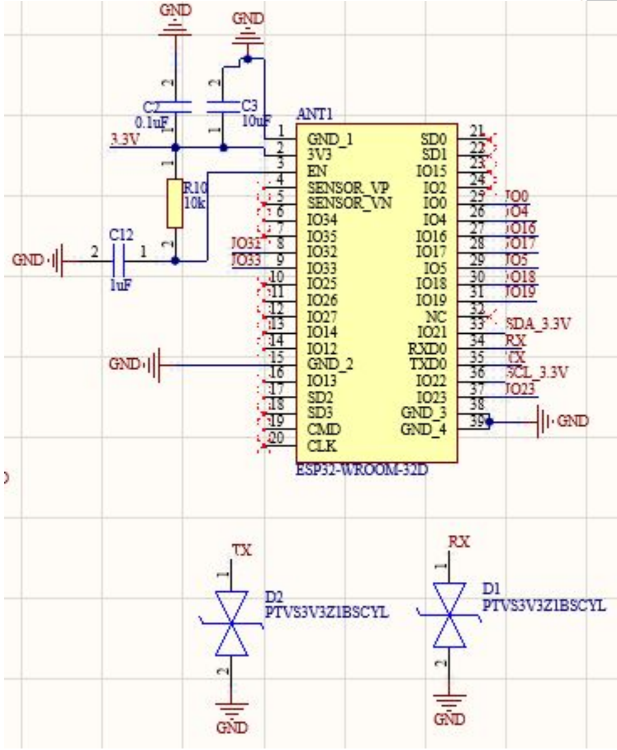
Microcontroller Schematic

- On the PCB we are using an ESP32 as the main control system
- The microcontroller controls the connection to both the IMU and the push buttons
- TVS diodes are used for ESD protection on the Transmit and Receive lines that used to program the device
- This device takes the 3.3V from the power regulator circuit



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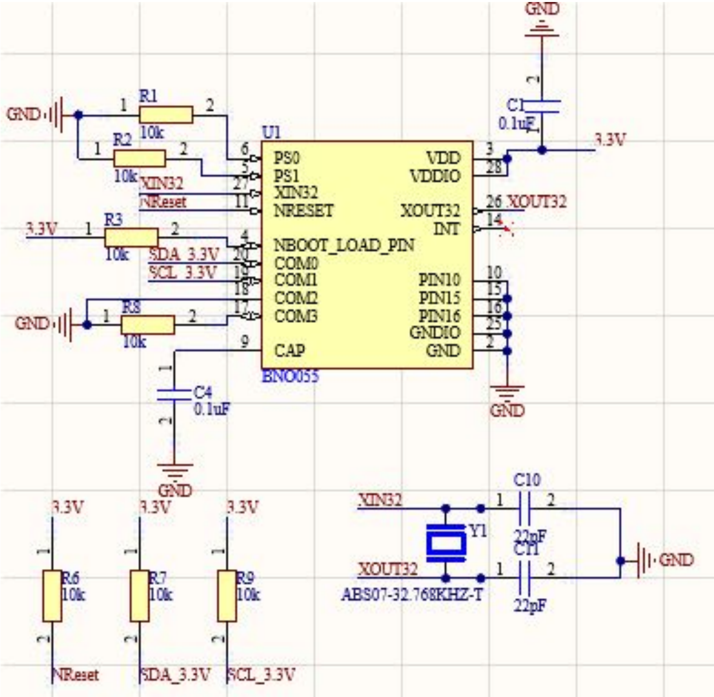
IMU Schematic

- We are using the BNO055 Inertial Measurement Unit on our PCB
- This device communicates with the ESP32 via I2C, These lines are pulled up to 3.3V to communicate with the MCU
- The IMU has an internal clock that it can run off of but an external crystal provides much better timing for this system



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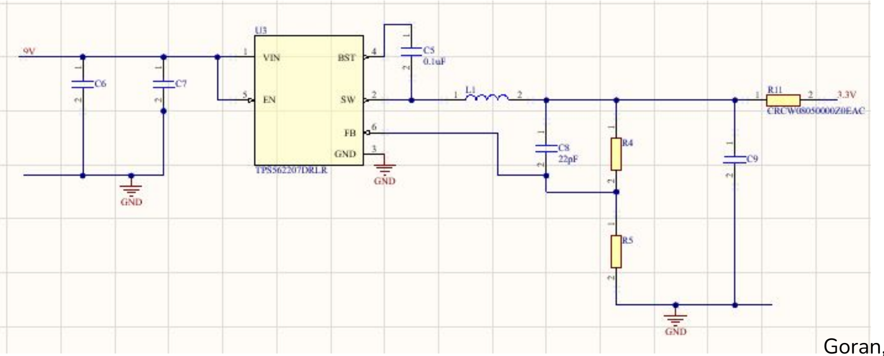
Power System Schematic

- This power system converts our input of a 9V battery to 3.3V which is used as the input to both our MCU and IMU
- We are using the TPS562207DRLR which is a Buck converter that combined with the external circuitry makes a switching regulator (Webench)
- We chose a switching regulator to provide higher efficiency



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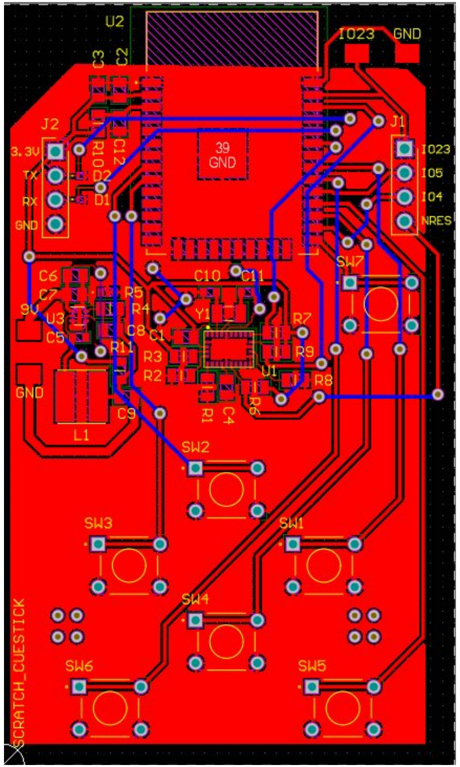
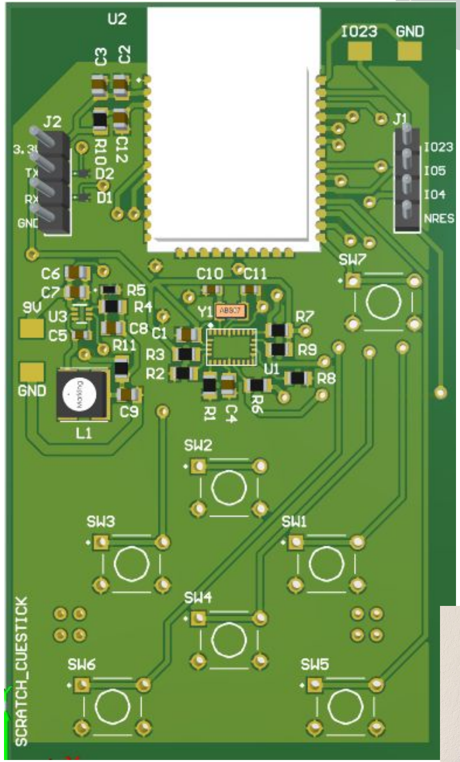
PCB Layout

- This is a two layer board designed in Altium that follows basic PCB guidelines
- Layout recommendations followed for devices
- Dimensions of the board are limited since this is mounted on the rear of a cue stick
- Push buttons are set up in a configuration to navigate the practice tool





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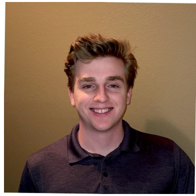
Battery

- Purpose: Supply power to main PCB and all peripherals
- Selection Criteria:
  - >= 5V output
  - Small Size and Weight
  - Easily replaceable
- Selection:
  - Standard 9V Li-Ion Battery

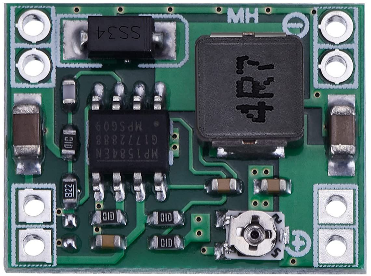
Part Number	9V Li-ion Battery	US-702528-500 0PCBJST	Adafruit 328
Dimensions (in)	1.9 x 1 x 0.65	1.18 x 1 x 0.28	2 x 2.55 x 0.3
Weight	45 g	12	50
Output Voltage	9V	3.7	3.7
Capacity (maH)	750	500	2500

Mark, EE



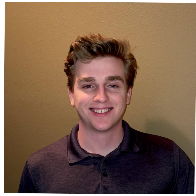
Buck Converter

- Purpose: For peripherals not powered by PCB, convert power from 9V input to required output
- Selection Criteria:
  - 9V in input range
  - Adjustable to both 3.3V and 5V output
  - Small size and weight
  - Low Cost
- Selection:
  - eBoot Mini MP1584EN DC-DC Buck Converter



Dimensions	22mm x 17mm
Weight	45 g
Input Voltage	4.5V - 28V
Output Voltage	0.8V - 204V
Maximum Current Output	3A

Mark, EE



Software/Operation

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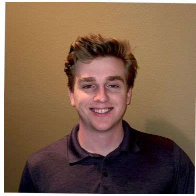
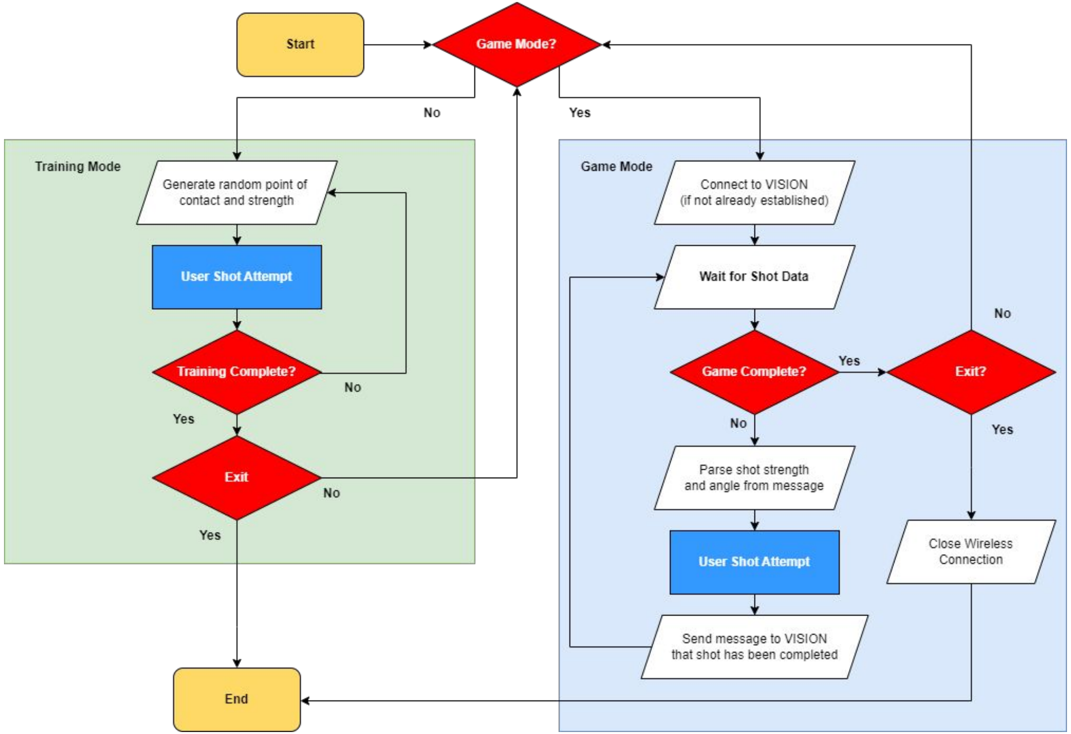


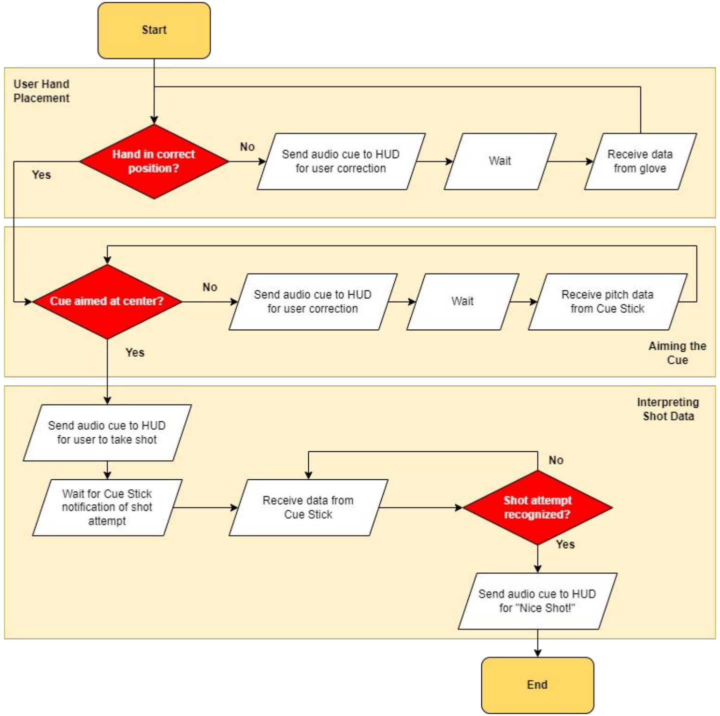
Normal Operation



Luke, CpE

User Shot Attempt (Impaired)

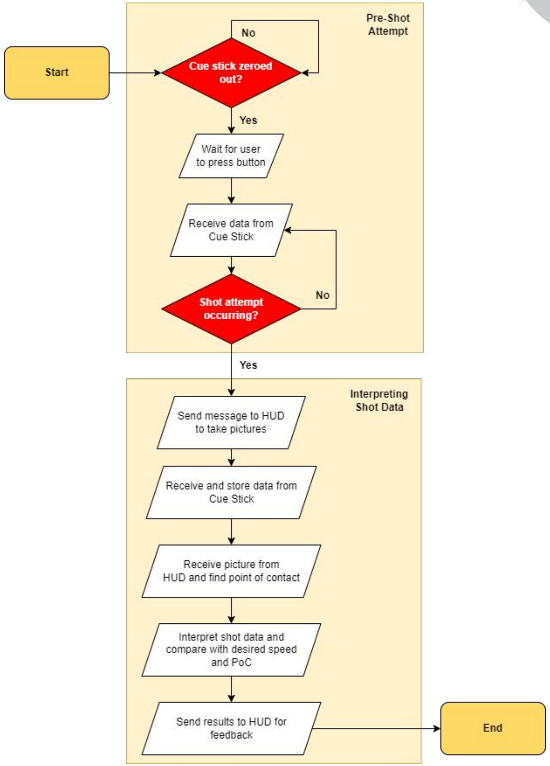
- Peripherals used:
  - Glove
  - Cue Stick
  - HUD speaker
- Glove Procedure:
  - Perform sweep of the glove to match desired angle
  - Measure distance until it meets the desired distance from the cue ball
- Stick Procedure:
  - Wait for cue stick to be level with table
- HUD Procedure
  - On CCU notifications, play appropriate audio files to guide the impaired user's body motion



Luke, CpE

User Shot Attempt (Non-Impaired)

- Peripherals used:
  - Cue stick
  - HUD display
  - HUD camera
- Cue stick orientation and acceleration is reset
- Pre-shot information is displayed on the HUD
- HUD's camera takes a picture at the trigger provided by CCU / Cue Stick
- Picture is sent to the CCU via BLE after the shot attempt is completed



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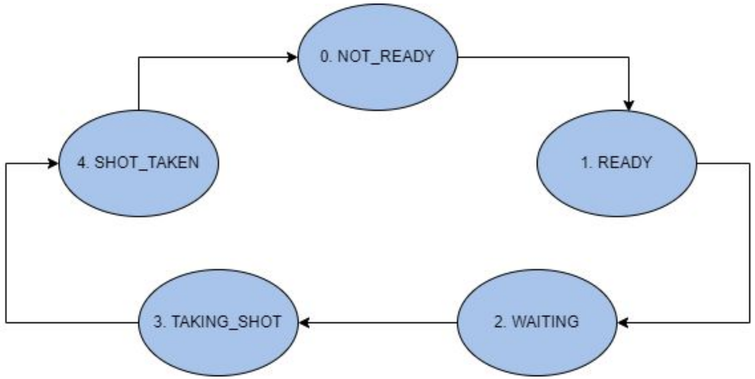
Cue Stick Finite State Machine

0. NOT_READY
    - Stick is not stationary, user is not ready
1. READY
    - Stick is stationary, user is not ready to take shot
2. WAITING
    - Stick is stationary, user is ready to take shot
3. TAKING_SHOT
    - Stick is not stationary, user is taking a shot
4. SHOT_TAKEN
    - Stick is stationary, user in done taking a shot



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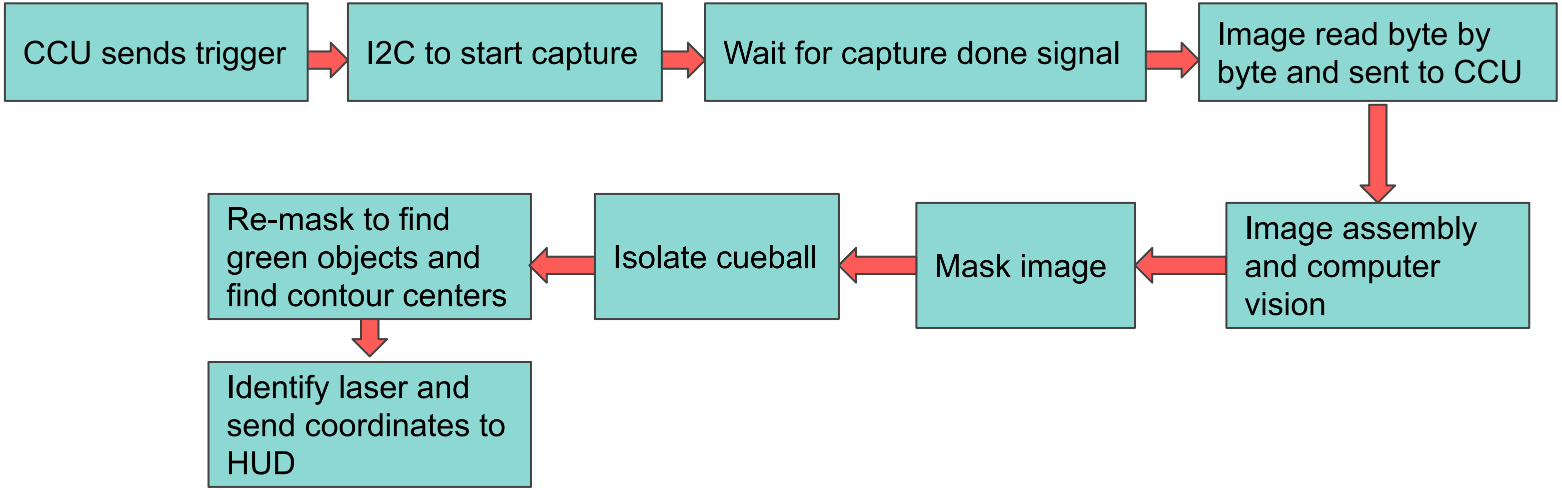
Point of Contact Recognition

- Hardware:
  - ArduCAM mini camera
  - ESP32
  - CCU (Raspberry Pi)
- Procedure:



Mena, EE

Design and Testing

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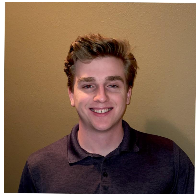
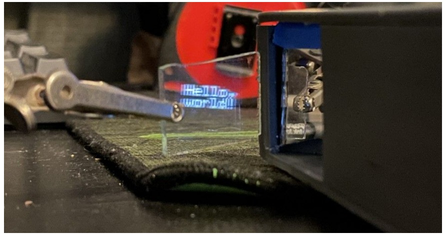
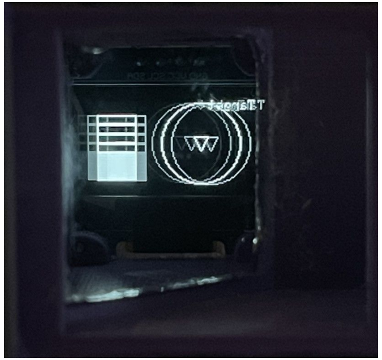
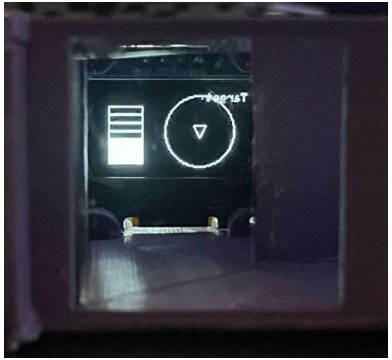


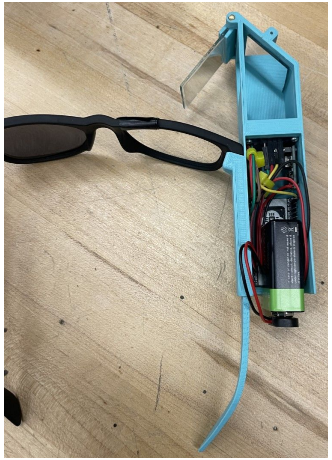
HUD Display Early Prototyping

- Started with a very simple box to verify the design and iron out image quality
- The image quality has been improved by using a first surface mirror and clear reflective film to remove double imaging effects and maximize light reflection

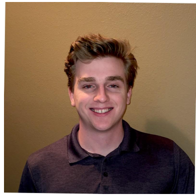




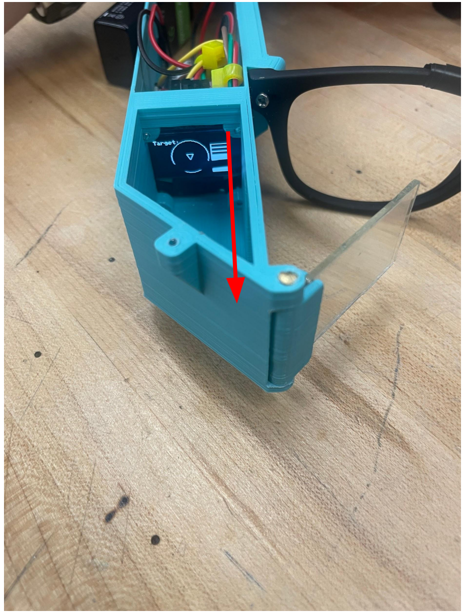




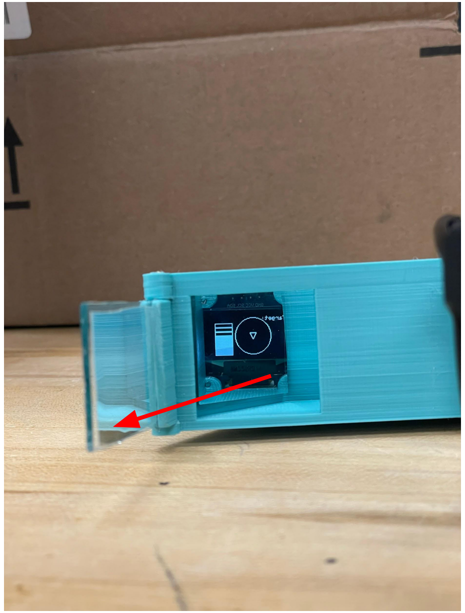
Mark, EE



HUD Display Optical Path



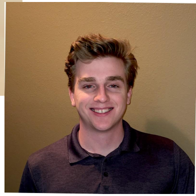
1st Step



2nd Step

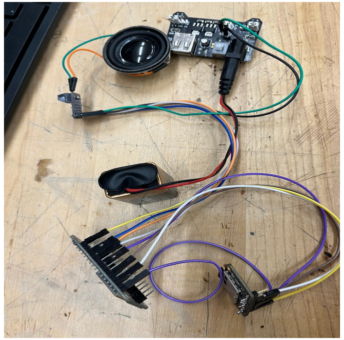
3rd Step

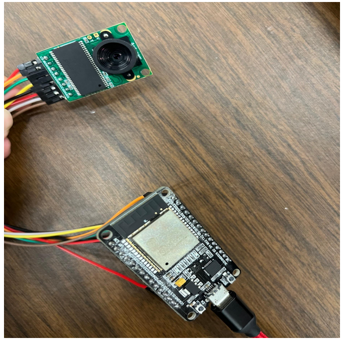
Mark, EE



HUD Speaker and Camera Prototyping

- Individual testing of the speaker subsystem
- Individual testing of the camera subsystem
- Mechanical assembly of HUD





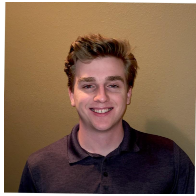
Mena, EE

Power System Design

- All components require either 3.3V or 5V
- System design is to supply each ESP or PCB board with 5V and power peripherals through ESP Dev Board
- To exceed battery requirements of at least 30 minutes of operation, a battery with capacity of at least 439 mAH is necessary
- The chosen battery to use was a 9V, 600 maH D cell battery

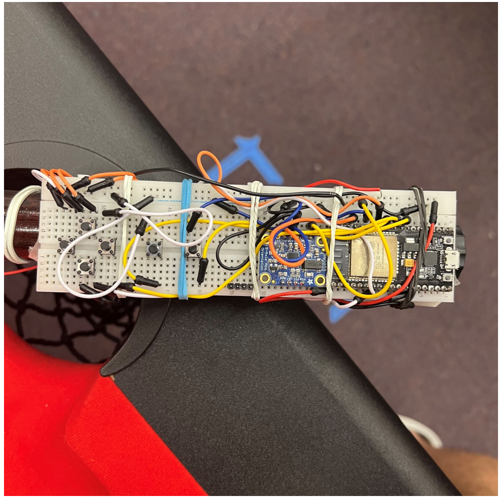
Battery Requirements			
Component	**Voltage Req**	**Power Draw (Peak)**	**Power Draw (Typical)**
ESP32	3.3 or 5	240	80
Display	3.3	0.78	0.43
Camera	3.3-5	70	20
DAC/Speaker	3 to 6	40	16
Total		351	117
Total (With 1.25 Tolerance)		439	146

Mark, EE



Cue Stick Prototyping

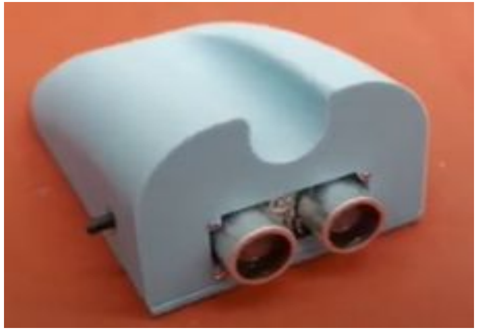
- Testing began by connecting the IMU to the development board and reading out raw IMU values
- Button functionality was then tested separately
- Code for IMU and buttons combined and finite state machine was added
  - Mounted to cue stick for further testing
- After FSM was finalized, BLE connectivity was added
- Final step was replacing the breadboard with the PCB

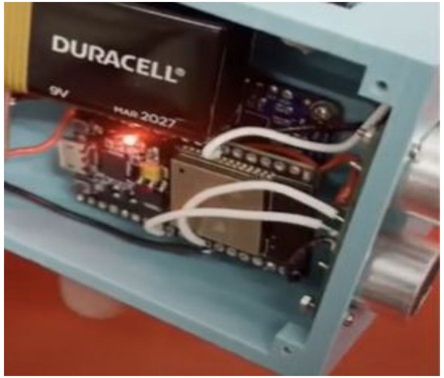


Luke, CpE

Glove Prototyping

- Started out with testing different devices to determine angle of user, this includes 3-axis magnetometer and IMU, the IMU was chosen due to accurate angle measurements
- Testing ultrasonic sensor with MCU to determine distance to cue ball, then eventually combining both ultrasonic sensor and IMU into one system that communicates with the ESP32
- Finally getting these values to send via BLE and developing mechanical housing for system

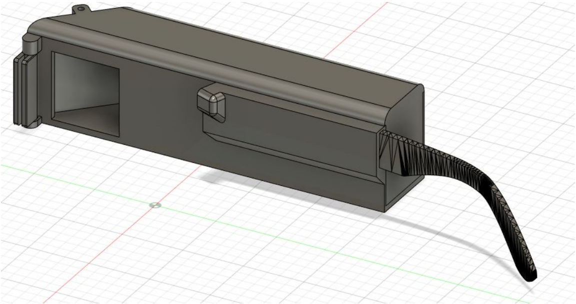


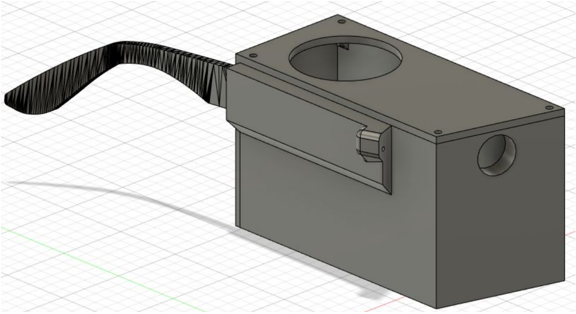


Goran, EE

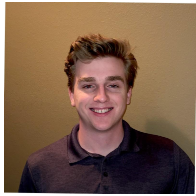
Mechanical Design - HUD

- The wearable HUD consists of two sides
  - The right side is for projecting the information in front of the user’s eye and housing the ESP32
  - The left side houses the camera, speaker, and the speaker’s digital to analog converter
  - The challenges associated with this design are weight, ergonomics, and wiring the two sides together



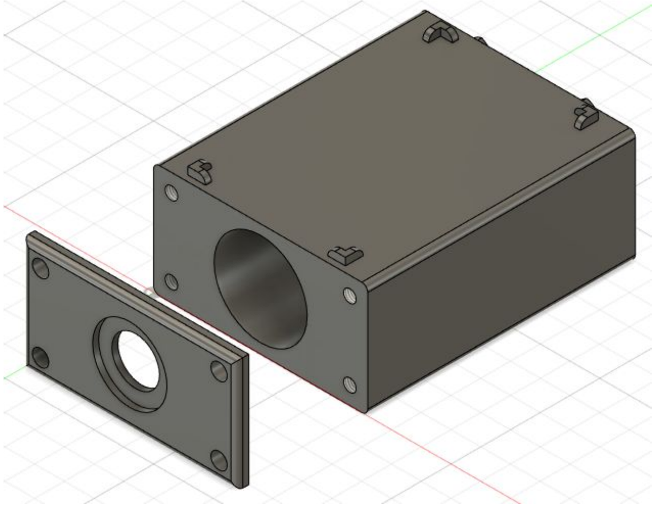


Mark, EE

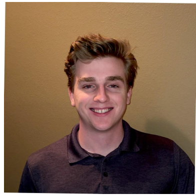


Mechanical Design - Cue Stick

- The cue stick's housing is mounted and secured at the end of the stick
- This holds the PCB which controls or powers a laser, an IMU, and user input buttons
- The major challenges of this design was related to minimizing weight and securing the housing onto the cue stick

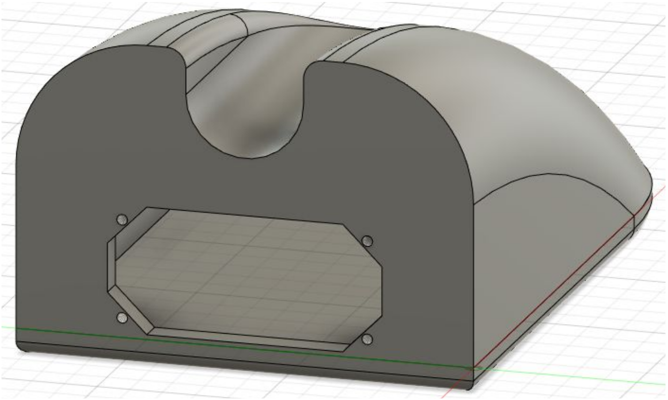


Mark, EE

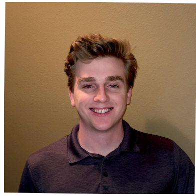


Mechanical Design - Glove

- The glove houses an ESP32, IMU, Ultrasonic Sensor, 9V battery and a regulator circuit
- It fits in the palm of the users hand and have a guide channel in place

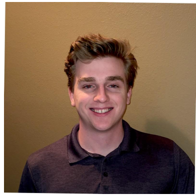


Mark, EE



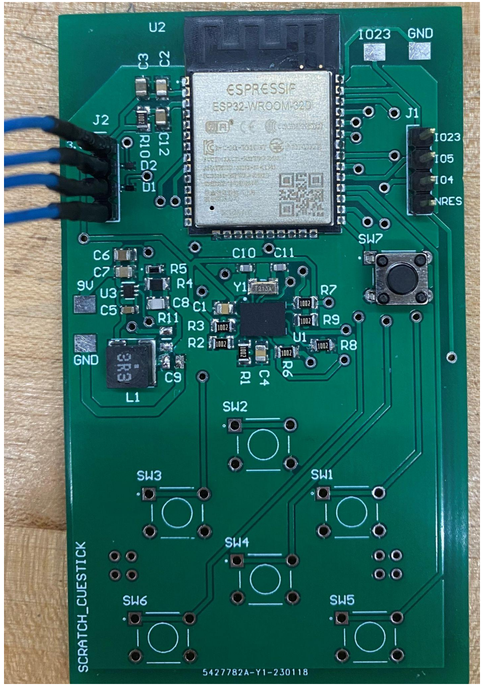
Troubleshooting

Mark, EE



PCB

- The PCB design was first tested on breadboard and worked properly with the use of development boards
- Received PCB and tested functionality of individual components to ensure functionality of full system
- Determined issue with BNO055 placement on board through X-Ray:
    - Chip-select lines shorted as well as GNDIO not connected to GND
- After correct placement PCB achieved full functionality



Goran, EE

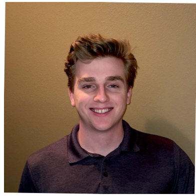
Integration / BLE

- Proper interpretation of BLE data from the various subsystems
- Re-connection issues
  - Device disconnection killed all other connections
  - Duplicate data reception
- Speed of image transmission
- Managing multiple connections simultaneously
- Timing problems with audio

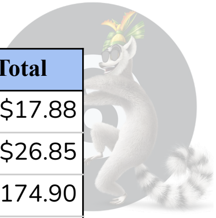
Mena, EE

Administrative Content

Mark, EE



Financing / Budget



- Our initial budget was $800
- This is the theoretical cost of producing quantity one of the SCRATCH system
- The budget anticipated having to buy multiples of certain components

Component	Quantity	Unit Cost	Total
ESP-32 Development Boards	3	$5.96	$17.88
ESP-32 Module	3	$8.95	$26.85
Raspberry Pi 4 8GB	1	$174.90	$174.90
Raspberry Pi PSU	1	$7.99	$7.99
Raspberry Pi Case	1	$11.59	$11.59
Display	1	$7.30	$7.30
3D Printing Materials	1	$25.00	$25.00
Mirror	1	$10.00	$10.00
ArduCAM camera	1	$25.99	$25.99
microSD card (512MB)	1	$4.95	$4.95
microSD card breakout board	1	$2.95	$2.95
MAX98357A DAC	1	$5.95	$5.95
Speaker	1	$1.95	$1.95
PCB and Components	1	$30.00	$30.00
Laser	1	$35.00	$35.00
Ultrasonic Sensor	1	$4.00	$4.00
Adafruit BNO055	2	$29.95	$59.90
Pool Cue	1	$13.97	$13.97
		Total Cost	$466.17
		Planned Budget	$800

Goran, EE

Distribution of Work

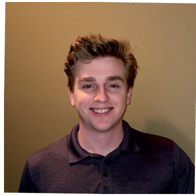
Name	HUD	CCU	Stick	Glove	Mechanical Design	Wireless Communications	PCB Design
Luke		P	P			S	
Mark	P				P		S
Goran			S	P			P
Mena	S	S				P	

Mena, EE

Future Developments

- Full integration with the VISION team
- Further refinement of cue stick button and laser placement
- User database to save and record progress

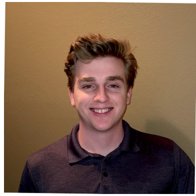
Mark, EE



Final Remarks and Acknowledgements

- SCRATCH is a billiards training system that assists both visually impaired and non-visually impaired users to improve the experience of playing billiards
  - The subsystems that make this tool are the HUD, the glove, the cue stick, and the central control unit
- Through this project we have learned a lot about product design, development, and management which will greatly assist us as we begin our career
- Acknowledgements:
  - JRT Manufacturing and Lockheed Martin's Failure Analysis Department
  - Dr. Mingjie Lin
  - Dr. Suboh Suboh
  - Dr. Sonali Das
  - Dr. Chung Yong Chan

Mark, EE



Thank You for Watching