SCRATCH: Shot Consultation and Refinement Applied Through Computer Hardware

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1. PROJECT NARRATIVE

1.1 PROJECT BACKGROUND AND MOTIVATION

The game of billiards, commonly known as pool, is enjoyed by millions of players daily. In many situations, the game of pool can serve as an icebreaker and a facilitator of social interactions between different people. In other situations, the game is played competitively by professional athletes. Nevertheless, there are many people who cannot reap the social benefits of the game due to a lack of proficiency. Additionally, there has not been any significant effort to include visually impaired individuals in the game by making it accessible to them. While there have been a couple of papers written, information is scarce and the projects were never commercialized. This creates two problems: (1) there exists a proficiency wall that beginners face and find difficult to overcome when trying to play the game of pool and (2) visually impaired personnel are excluded from the game, regardless of talent or ability. As engineers, it is our job to solve such problems through technology.

1.2 PROJECT FUNCTION

Overall Functionality: The overall functionality of the project is to solve the two problems mentioned above. In short, it is to provide a lightweight, low-power, and convenient training system that aids users in improving their proficiency in the game of pool by providing pre-shot guidance and post-shot feedback to the user in a simple-to-understand manner. The other goal is to make the game of pool accessible to the visually impaired user. SCRATCH focuses on data collection, processing, and presentation via wearable technologies and modified equipment that is custom-made for this project. Most of the data that scratch focuses on comes from interaction with the user. SCRATCH consists of four main subsystems; their functionalities are highlighted below.

HUD Functionality: The HUD consists of three different subsystems, these are an audio system, a camera system, and a display system. The audio and display serve to provide impaired and unimpaired users the pre and post-shot information. This information will aid in improving user performance. The camera is on the HUD to place it on the user's head and ensure it has a clear view of the cue stick's impact point on the ball for post-shot feedback. The camera will aid the system in determining the point of impact between the cue stick and the cue ball. Overall, the HUD is to provide a low power, low heat, and lightweight solution which will aid in making both visually impaired and non-visually impaired users better at the game of pool. This is through providing pre (including aim assistance for the visually impaired user) and post-shot information.

The display and related peripherals will be used to clearly project the following required information directly in front of the user's point of view. Before the shot is taken, cue impact point, shot strength, and the target ball color will be communicated to the user. After the shot is taken, there will be two feedback screens. The first will show the target cue impact placement VS. the actual cue impact point, and the second will show the target shot strength VS. the actual shot strength.

For impaired users, the display will be turned off to conserve power and reduce heat output, and the audio system will be enabled. A speaker will be used to convey all instructions to the impaired individual. This includes the information received via the VISION team for localizing and directing the user to the table in the correct orientation. Then, the hand placement and cue aim will be fine-tuned via the other SCRATCH subsystems.

The camera system is being used to help gather the unimpaired user's post-shot feedback. The camera will know to take the picture based on IMU data received from the cue stick and then, working in conjunction with a laser on the cue stick, the point of impact between the cue stick and cue ball will be computed.

Cue Stick Functionality: The primary function of the cue stick subsystem is to accurately determine the orientation and speed of the user's cue stick. This gives the rest of the system the data necessary to provide meaningful and constructive feedback to both impaired and non-impaired users. The secondary function of the cue stick is to give the user control of the GUI displayed on the HUD.

As this system will be mounted to a cue stick, it is critical that this system be as lightweight as possible to minimize changes to the user's shot. As this system will not have a physical connection to any other subsystem, it must be able to wirelessly communicate with the other subsystems. For that same reason, the stick's system must be a low-power solution as it will be battery-powered.

Glove Functionality: The primary function of the glove is to assist the vision-impaired user with pre-shot feedback in order to be facing the cue ball at the correct angle as well as the at the correct distance from the ball, this angle will be provided by the VISION team. This system will have to be very compact in order to not impact the user's shot.

Central Control Unit (CCU) Functionality: As the name implies, the central control unit will be the subsystem responsible for sending and receiving data to and from the other subsystems. This will also be the portion of our project that will communicate with the VISION team's system.

When communicating with the HUD, the CCU has two major responsibilities. The first is rendering and sending the images that will be displayed on the HUD's display when in normal use. When the system is being used by the visually impaired, the CCU will be responsible for telling the HUD's audio system which audio clip to play. The second responsibility is to interface with the HUD's camera system. The CCU will be responsible for controlling when the camera begins recording. The CCU will then receive the images from the HUD; with this data, the CCU will render a low-resolution image of the location of cue impact on the ball that will be sent back to the HUD to provide feedback to the user.

When communicating with the cue stick, the CCU's primary responsibility is to receive the motion from the cue stick and use it to provide meaningful feedback to the user. The secondary responsibility is to receive the button input data from the stick and change the state of the CCU's program accordingly. Related to both of these responsibilities is the fact that the CCU will occasionally have to send switching information to the cue stick depending on the button inputs.
When communicating with the glove, the CCU will receive sensor data from the glove. With this data, the CCU will determine whether the user should position their hand closer or farther from the cue ball.

When communicating with the VISION team, the CCU will be responsible for receiving the angle and speed data for the desired shot. The CCU will also be responsible for notifying the other system when SCRATCH is ready for the next shot.

Separate from all other subsystems, the CCU is responsible for keeping track of user data. This includes the user's mapped cue speed, the number of games played, as well as other useful metrics for gauging user performance. The CCU will save each user's data in separate files and store them on the CCU's SD card.

2. PROJECT OBJECTIVES AND GOALS, REQUIREMENTS, AND STANDARDS

2.1 PROJECT OBJECTIVES AND GOALS

The objective of SCRATCH is to provide a training system that can improve the performance of visually-impaired and non-visually impaired users in the game of billiards. This project occurs in conjunction with VISION, which has the same final objective. While VISION focuses on table analysis and getting the visually-impaired user to the table (among other things), SCRATCH specifically focuses on interaction with the user. This will be in the form of pre- and post-shot guidance and feedback suitable to the visually-impaired and the unimpaired user. The data will be provided in a simple-to-understand manner in both display and audio formats in order to assist different users. While a small portion of this data will be procured from the VISION team (the data can be easily simulated in case of VISION failure), most of the data procurement is done via a variety of sensors placed on different parts of the user in the form of low-power, lightweight, and convenient wearable technologies that are custom made for the project.

In order to have the ability to complete the project without relying on the success of the VISION team, we will have the option to simulate the data that they would be sending. This would include setting up basic shots and simulating the angle of the user in order to take a shot, the force of the shot, and the ball color.

- HUD Goals
    - Basic
        - HUD can provide basic audio commands to guide the visually impaired user (commands include turn right/left, move hand forward/backward)
        - HUD display system provides clear visual information to guide the unimpaired user on pre-shot information such as cue ball impact point, shot selection, and shot strength
    - Advanced
        - HUD can use camera to show point of impact between cue stick and ball
        - HUD Display system will provide post-shot information to give user feedback on actual impact point and strength compared to desired impact point and strength
    - Stretch
        - Use an FPGA to do image processing instead of the Pi
- Stick Goals
    - Basic
        - The system can collect and transmit data regarding the orientation and force applied to the cue stick
        - The system can collect and transmit button input data
- Glove
    - Basic
        - Read angle of users body to align shot
        - Locate ball position along angle
- Central Control Unit Goals
    - Basic
        - The system can interpret cue stick motion data and send visual and auditory feedback to the HUD
        - The system can respond to button inputs and change display output accordingly
    - Stretch
        - The system can maintain user profiles that contain shot speed data and play history
        - The system can communicate with and use data from the VISION team

2.2 REQUIREMENT SPECIFICATIONS

Specifications for each individual subsystem are listed below:

HUD Requirement Specifications:

- Should weigh less than 1500 grams
- Does not protrude more than 2” out from the head of the user
- Should stay at least 30 minutes without the need to charge
    - Normal usage is just a simple pool game, blind or not

- Temperature of all the skin touching portions of HUD must not exceed 120 degrees Fahrenheit
- Should be able to snap pictures when the cue stick is less than 5 centimeters from the cue ball to provide accurate feedback
- Should be able to provide post-shot feedback within 4 seconds of impact with the ball
    - This includes data roundtrip and Bluetooth latency
- Display should be crisp and easy to view in standard, well-lit room
- Sampling user aim and providing audio feedback pre-shot should be done on 2-second intervals. This is the time between the end of the first audio feedback and the start of the second

Cue Stick Requirement Specifications:
- Determine the orientation of the cue stick within 5 degrees
- Determine the speed of the cue stick within 1 meter per second
- The latency between data being collected and sent to other subsystems must be less than 1 second
- The latency between a button being pressed and the rest of the system recognizing it must be less than 500 milliseconds
- System must be able to be used by both impaired and non-impaired players
- System must be able to sustain operation for 30 minutes
- Entire subsystem must weigh less than 1 kilograms

Glove Requirement Specifications:
- Glove weight less than 500 grams
- Glove design should not obstruct players shot
- Electronics should not exceed 100 degrees Fahrenheit
- For detection of user direction latency should be under 1 second
- Total circuitry area should not exceed size of back of palm less than 80cm^2

Central Control Unit Specifications:
- Be able to render and send images to HUD within 3 seconds of receiving images taken by camera
- Be able to respond to button inputs from the cue stick within 500 milliseconds
- Be able to trigger audio feedback within 1 second of correction being recognized
- Be able to load user save data within 5 seconds of startup

3D Printed Housings:
- Housings will entirely enclose sensitive components to prevent damage
- Balance and ergonomics will be a top priority as they will all be held or worn

The specifications that will be our team’s primary focus are summarized in Table 2.1 below. The items in italics will be prioritized.

Table 2.1 Prioritized Specifications

Specification	**Value**
HUD should be lightweight	< 1500 grams
HUD should be able to provide post-shot feedback after impact with the ball	*< 4 seconds*
Sampling user aim and providing audio feedback pre-shot should be done on pre-determined intervals.	*< 2 seconds*
Cue stick should be able to determine the orientation of the cue stick within an acceptable margin of error	*< 5 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

2.3 RELATED STANDARDS

The SCRATCH team acknowledges that we will have to conform to various existing standards, including some set by IEEE. These possible standards are as follows:

- IEEE 802.15 (Bluetooth)
- IEEE 802.11 (WiFi)
- IEEE 802.3 (Ethernet)
- TCP/IP
- DMA (potentially)
- SPI
- I2C
- I2S
- USB
- C/C++
- Arduino
- Python
- 120V/60Hz

3. PROJECT BLOCK DIAGRAM

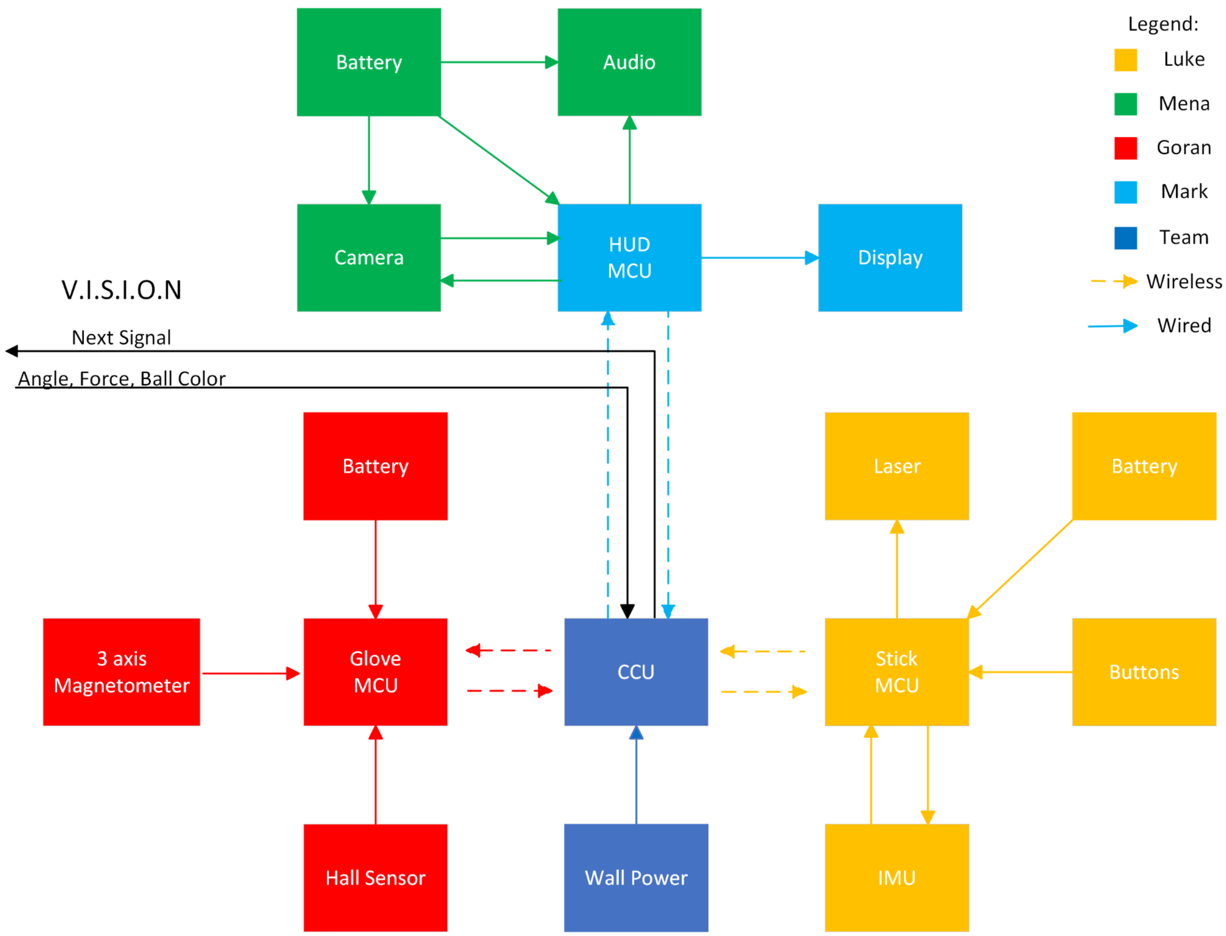

Figure 3.1 Hardware Block Diagram

4. HOUSE OF QUALITY

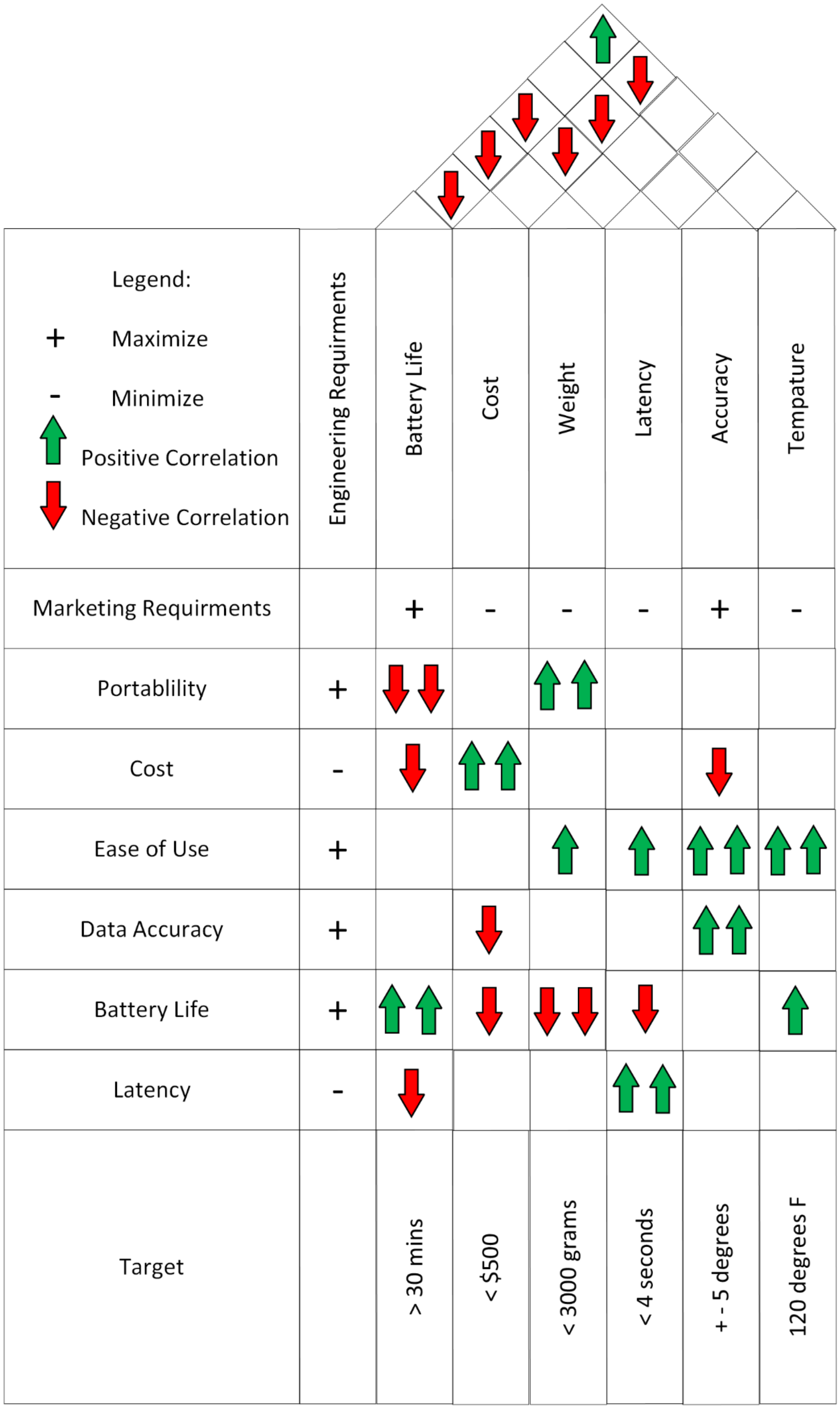

Figure 4.1 House of Quality

5. PROJECT BUDGET AND FINANCING

SCRATCH, like VISION, will be funded jointly by the 8 members of the SCRATCH and VISION teams. No external sponsors were found to fund this project. The following is the SCRATCH:

Table 4.1 Build of Materials

Component	Subsystem	Quantity	Unit Cost	Total
MCU Development Boards	All	3	$15.00	$45.00
MCU Module	All	1	$10.00	$10.00
PCB	All	1	$40.00	$40.00
Microprocessor	CCU	1	$200.00	$200.00
Flex sensor	Glove	1	$8.00	$8.00
Digital Compass	Glove	1	$10.00	$10.00
Glove	Glove	1	$7.00	$7.00
Display	HUD	1	$7.30	$7.30
3D Printing Materials	HUD	1	$25.00	$25.00
Mirror	HUD	1	$5.00	$5.00
Lens	HUD	1	$5.00	$5.00
Camera	HUD	1	$30.00	$30.00
Laser	Stick	1	$7.01	$7.01
IMU	Stick	1	$12.95	$12.95
Pool Cue	Stick	1	$15.00	$15.00
microSD card	HUD	1	$10.00	$10.00
microSD card breakout board	HUD	1	$2.95	$2.95
DAC	HUD	1	$5.95	$5.95
Speaker	HUD	1	$2.00	$2.00
Pool Table	All	0.5	$400.00	$200.00
Miscellaneous Costs	All	1	$50.00	$50.00
Total				**$698.16**

6. INITIAL PROJECT MILESTONES

The SCRATCH team formed at the beginning of the summer and started collaborating and brainstorming ideas throughout the summer to prepare for Senior Design I. Therefore, the milestones for our team have been placed according to the progress made thus far.

Table 5.1 Senior Design I Project Documentation Milestones

Item	Start Date	Anticipated End Date	Duration
Project Brainstorming	Summer	Summer	0 weeks
Project Scope Finalized	08/22/2022	08/26/2022	1 week
Individual Research	08/22/2022	09/02/2022	2 weeks
Initial Design Document	08/22/2022	09/05/2022	1.5 weeks
30-Page Milestone	08/22/2022	09/09/2022	3 weeks
60-Page Milestone	09/10/2022	09/30/2022	3 weeks
90-Page Milestone	10/01/2022	10/21/2022	3 weeks
120-Page Milestone	10/22/2022	11/11/2022	3 weeks
Final Draft	11/14/2022	11/18/2022	1 week

Table 5.2 Senior Design I Project Design Milestones

Item	Start Date	Anticipated End Date	Duration
Individual System Design	09/05/2022	10/02/2022	4 weeks
Individual System Testing	10/03/2022	10/30/2022	4 weeks
Breadboard Prototyping	10/31/2022	11/21/2022	3 weeks
PCB Design/Ordering	11/22/2022	12/12/2022	3 weeks

Table 5.3 Senior Design II Project Design Milestones

Item	Start Date	Anticipated End Date	Duration
PCB Testing	01/09/2023	01/23/2023	2 weeks
System Integration/Testing	01/24/2023	02/16/2023	4 weeks
Practice Project Demo	02/14/2023	02/27/2023	2 weeks
Finalize Documentation	02/28/2023	03/13/2023	2 weeks
Practice Final Presentation	03/14/2023	03/20/2023	1 weeks
Final Presentation	TBD	TBD	TBD