VISION

Visually Impaired Spatial Interactive Orientation Network

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1. Project Narrative

1.1 Project Background and Goals

Billiards is a collection of many different games played with a billiards table, cue stick, and several colored billiard balls. The objective of a billiards game varies depending upon what specific game is played, but the typical goal is to use a cue stick to pocket a targeted game ball. Every specific billiard game introduces rules and requirements that make sinking a shot more difficult than it may seem. One of the more common billiard games, and the focus of this project, is 8-ball pool. The goal of VISION is to design and implement a system that allows individuals suffering from visual impairments to play a game of 8-ball billiards.

Billiards was selected as the game of choice because of its significant complexity compared to other games such as chess. Chess is a game commonly associated with masterful planning that requires crafting moves multiple turns in advance to be successful. Although chess certainly is a complex logic game, it is a discrete problem in terms of computation. Chess has a fixed number of locations on the board, pieces with strict rules about where they can move, and a finite number of possible ways for the game to progress. All of these characteristics have led chess to become a commonly studied problem in computer science. There are many computer programs and algorithms for chess that are quite good at the game. There has been much less research conducted on creating a robust billiards program. Furthermore, there does not appear to be any billiards-style game developed specifically for the visually impaired.

Like chess, billiards also requires players to plan their moves many turns in advance in an offensive or defensive manner. An offensive move is when a player tries to sink as many balls as possible. A defensive move is when a player tries to put their opponent in a position such that their opponent cannot complete a shot. The careful shot selection necessary for billiards is significantly more involved than the equivalent chess decision because there is an infinite number of positions that the state of the billiards table can be in. The billiard balls can arrange themselves in any position on the table at any point during the game, the same cannot be said for chess. There are many ways for a game of billiards to progress, and it can oftentimes be difficult to know what the best shot to take is given the current state of the game.

For the vast number of chess programs and significantly fewer billiards programs that have been developed, nearly all of these projects have been software implementations of the game. The programs that were created were designed to be used for virtual games, not physical chess boards or actual billiards tables. The successful simulations of billiards games prove that a software system can be used to augment a game of pool. The goal of VISION is to expand upon previous work by using an actual game of billiards, rather than a simulation of the game.

The success of VISION will be determined if an individual dealing with visual impairments is able to successfully compete in a modified game of billiards. With the help of VISION, a user should have the billiards table represented algorithmically and have the best shot determined for them. The user's location should be tracked and used to navigate the user around the billiard table. The result of the user's shot should then be displayed in a program to spectators around the room. If all of these individual goals are met, VISION will be a success. VISION should be compact and portable so that the system can be disassembled, moved, and assembled in a timely manner.

1.2 Project Motivation

The motivation of VISION is to develop a systematic way to represent a real-life game of 8-ball pool computationally and then develop an elegant way to guide a visually impaired user through the best shot for them to take to win the game. VISION is a tool that can leverage the power of modern technology to help improve the inclusiveness of one of society's most popular pastimes.

For VISION to truly have an impact, the team decided to develop it in a way that allows individuals dealing with visual impairments to develop a sense of autonomy. There are not many games that have support for people dealing with disabilities. It can be difficult for some individuals to feel included when they are not able to participate in the same pastimes as their friends and family. Globally, about 295 million people have a case of near or far distant visual impairment. In addition to this, about 43 million people worldwide suffer from complete blindness. One of the biggest troubles they face in their everyday life is having their freedom limited by moving in an obstructed or limited environment where spatial awareness is preventing them from being able to engage in their daily activities.

A lot of systems are in place in different media to help counteract or ease these issues to breach issues of orientation, localization, and way-finding through different technologies. Navigation technologies or electronic travel aids have been the backbone when it comes to developing technologies to help visually impaired people bridging the way for more specific applications such as the one we are working on for this project. Similar to the goal of our project, a lot of sports rules have been adapted and modified to develop games that are more inclusive to visually impaired individuals. For instance, beep baseball where the bases beep to let the players know which direction they need to go in, or soccer where the regular ball is replaced by an audible ball. We will use these and similar concepts as a motivation and a basis to determine which objectives and checkpoints are needed to make VISION an impactful visually impaired technology. Our team is motivated to broaden the inclusiveness of billiards by creating a system that leverages technology to plan, strategize, and see for a player.

1.3 Project Function

A visually impaired individual that is using the VISION system will be able to have the system locate all of the billiard balls and determine the optimal shot for them to win the game. VISION will actively track the user and be able to guide the user to the required location through audio instructions. The system will provide instructions to the user to ensure that they are positioned in the general direction of the cue ball. At this point, VISION's job is complete and the SCRATCH program (group #17) will take over. VISION will provide SCRATCH with the optimal shot angle, required force, and location of the cue ball.

There is certainly a concern when two projects are interrelated with each other in Senior Design. It would not be fair if one project's failure leads to the failure of the other project. With the help of our mentor, the teams designed their projects in a way that minimizes interaction between the two projects. VISION will transmit three quantities to SCRATCH and the three values can easily be artificially constructed if needed. The SCRATCH team does not need to transmit any information back to the VISION team. If the VISION team fails to complete their project, the SCRATCH team can craft inputs that the VISION team should have provided. If the SCRATCH team fails to complete their project, the VISION team will lay the groundwork for future work. VISION will detect billiard balls, find the optimal shot, track the user, guide the user to the appropriate position, and position the user in the appropriate direction.

The VISION team must design a system that is lightweight and able to be moved between different locations. The system must be designed so that it can quickly be disassembled and reassembled so the team can work on the project in a variety of locations and environments. The mobility of the system will also be helpful when demonstrating VISION to others and must be set up in different locations.

2. Project Objectives, Requirements, and Standards

2.1 Project Objectives

VISION should encompass a system that allows a visually impaired individual using our system to be detected around the pool table. Before a game begins, this will allow us to determine where the user is and bring them to the position where they would make their initial shot from the cue ball to the stack of balls. After every turn and during their subsequent turns, the same system should be once again able to detect the user to know where they are with respect to either the cue ball or within a set coordinate system determined by the project and with respect to the table. VISION might also encompass other localization schemes as either outlined during the research section or in the future considerations section. The first one would require a system that expands the range of localization from anywhere in the room containing the pool table. The second one would require a system that detects any obstacles around the user in the room containing the pool table or around the pool table itself. Both of these localization schemes are secondary to the main one requiring the user to be located around the pool table itself which we deem to be the most relevant objective when it comes to allowing the visually impaired user to pursue a game of pool.

VISION should encompass a system that captures the current state of the pool table at every point during the game, that is, at the start of a game, and every round during the game. This system would then process the image to isolate the pool table from any sort of background present in the image. The system should be able to detect, isolate and localize the billiard balls present on the pool table. The system should be able to differentiate the cue ball, the eight ball, the player balls, and the opponent balls. This system should also be able to render a mapped image of the billiard table layout with the balls at the right position on the rendered image to continuously reflect the current state of the game and will be used in other systems described below.

VISION should encompass a system that computes the optimal shot that the user, visually impaired or not, can make based on a shot selection algorithm. This will involve making some considerations and assumptions described in later sections of the document due to the multitude of factors coming into play such as the skill level of the user, outside interference during the shot, and other relevant factors. We will outline the optimal output that this algorithm will need to provide after considering different options such as how much force would need to be put to make the shot, the positioning of the user's hand on the cue stick, the angle from the base of the table to the cue stick, user posture, and other related metrics.

VISION should encompass a system that navigates the visually impaired user to the necessary position that the aforementioned algorithm would determine, the position in which he/she has the best odds to make a ball. This system will rely on the previous systems to determine what the optimal location of the user will be to take the desired shot. This calculation will be needed after every shot the user takes. Our system should also be able to navigate the visually impaired user through a non-visual mechanism such as audio, tactile inputs, or similar methods. This system should be able to outline clear commands or properly explain commands to provide concise instructions to the user.

VISION should encompass a system akin to a dashboard available for all users around the pool table, player, or spectators. The system should have the rendered image of the pool table mentioned above, as well as different statistics about the current game updated in real time. The system should hence have a way of tracking, storing, interpreting, and displaying information about the ongoing game. Considerations would need to be taken to determine the optimal way to display different information about the game in an eye-catching and intuitive manner for all users. For a visually impaired user, this system might include audio outputs to vocalize shot results and important information about the game progression. Considerations would need to be taken to avoid audio overload if audio is also being used as a way to navigate the user. This system would need to be presented on a medium or display readily available for everyone around the table without obstructing the game in session.

All of the components of VISION should be modular and able to be individually tested before being integrated with the entire system. The components of VISION should also be able to be assembled and disassembled quickly. The entire system should be able to be transported in a sedan so that there is no problem moving the system from one location to another.

VISION is currently a self-funded project and also would like to be made affordable enough for someone to reproduce themselves. For these reasons, the team would like to keep the project under $800, so each member will not have to contribute more than $200. If significant changes are needed, the budget may need to be reevaluated.

2.2 Requirement Specifications and Constraints

The previous sections describe the goals and objectives of the project and what the motivation behind VISION is. To transform VISION from an idea into an actual project, a set of requirement specifications must be clearly defined. These requirements are what the VISION team believes are necessary to bring the project to life. These requirements serve as a contract between the team members and the senior design advisors clearly stating what the project will be able to do. The success of VISION will be based on meeting the requirements specified below in table 2.1.

Requirement/ Constraints	**Description**
1.1	Locate up to 10 billiard balls on the billiards table
1.2	Differentiate between red, blue, black, and white billiard balls
1.3	Locate all billiard balls in an (x,y) coordinate system within 15 pixels
1.4	Locate all six of the pockets in an (x,y) coordinate system within 15 pixels
1.5	The latency of the computer vision algorithm does not exceed 5 seconds
2.1	The latency of the shot selection algorithm does not exceed 5 seconds
2.2	Shot selection algorithm will produce a shot suggestion with a minimum specificity of 5 degree increments
2.3	Shot selection algorithm will produce a shot suggestion with a minimum specificity of three possible force levels
3.1	Locate the user around the pool table within 10 seconds at longest run time
3.2	Locate the user around the pool table within a foot of accuracy
3.3	Localization aid should be deployable either on the table or in a region around the table independently of the surroundings
4.1	Position user within 1 foot of desired standing position for shot
4.2	Orient user within 15 degrees of desired shooting direction toward cue ball
5.1	VISION is able to be assembled or disassembled in less than 30 minutes
5.2	The total cost of VISION should not exceed $800
5.3	The product’s audio aids will be limited to English only
5.4	Any battery-powered devices used within the system should be viable for about a year

Table 2.1 VISION Requirement Specifications and Constraints

2.3 Related Standards

VISION needs to implement many technologies that have accompanying IEEE standards. Some of the most prominent technologies that will be used are Wi-Fi, Bluetooth, USB, micro USB, HDMI, UART, I2C, SPI, computer vision, machine learning, power supplies, Python, C, and cameras. These technologies have accompanying IEEE standards that will have to be further researched and documented in the official design document. This is not a fixed list and will likely change as further research into the project is completed.

2.4 House of Quality

							+					
									+			
					+		+	+	+	+		
				+	+	+		-	-	+		
			+	+	+	+		+				
			Functional Requirements									
		Direction of Improvement	▲	▲	▲	□	□	▲	▼	▲	▲	▼
Relative Weight	Customer Importance	Requirements	Cost	Response Time	User Accuracy	Power Consumption	Product Size	Functionality	Admin Controls	BLE Accuracy	Shot Selection Quality	Audio Quality
18%	10	Ease of Use	●	●	●	▽	●	●	●	●	○	○
13%	7	Wait Time	●	●	●	○	▽	○	▽	●	▽	▽
15%	8	Navigation Accuracy	●	●	●	▽	▽	●	▽	●	▽	○
9%	5	Ideal Shot Selection	▽	▽	○	▽	○	●	▽	○	●	▽
5%	3	Differentiation of Balls	○	▽	●	▽	▽	○	▽	▽	●	▽
16%	9	Reliablity for Visually Impaired	○	●	●	▽	▽	●	●	●	●	●
7%	4	Affordable price	●	●	○	●	●	○	▽	●	○	○
11%	6	User Safety	▽	○	○	○	▽	○	●	○	▽	○
4%	2	System Display	●	▽	▽	●	●	○	○	○	○	▽
2%	1	Portability	○	▽	▽	○	●	▽	▽	▽	▽	○
		Importance Rating Sum (Importance x Relationship)	598.1	674.5	692.7	238.1	365.4	645.4	470.9	700	405.4	336.36
		Relative Weight	12%	13%	14%	5%	7%	13%	9%	14%	8%	7%
		Technical Competitive Assessment										

Correlations	
Positive	+
Negative	-
No Correlation	

Relationships		Weight
Strong	●	9
Medium	○	3
Weak	▽	1

Direction of Improvement	
Maximize	▲
Target	□
Minimize	▼

Figure 2.2 House of Quality Analysis

To best quantify the correlation of various portions of VISION's defined deliverables and scope, the house of quality shown in Figure 2.2 was devised. The table connects the required deliverables shown on the left side of the table to important functional factors of scope shown on the upper row. Those required deliverables are additionally ranked by level of importance. The interior bulk of the table relays the correlation direction between these factors, a solid dot representing strong, hollow dot representing a medium, and a down arrow representing weak correlation. A similar metric is utilized on the roof of the house with positive and negative signs measuring the correlation between the functional requirements of the scope to one another. These features are connected diagonally with one another. The direction of improvement is added at the conclusion of the additional importance ratings as this allows for the team to best approach areas that require attention due to their high relation to the success of the project. The table shows the areas with the highest relative weight to be the most crucial to project success. This includes areas of accuracy, response time, functionality, and overall cost.

3. Project Block Diagram

VISION is a large project that incorporates a large variety of technology into a single, user-friendly system. The central processor for the system will be a powerful, computer-like processor capable of running computer vision and artificial intelligence algorithms. There are many systems that must be integrated for VISION to work properly. Figure 3.1 below shows a block diagram of all of the systems needed.

All systems will be controlled by the powerful central processor shown in the middle of the diagram. The processor will ask the computer vision system to capture the current state of the board with a camera and transform the physical billiards game into data expressed in a computational way. The shot selection algorithm is then used to determine the best shot to take is given the current state of the table. The information regarding the best shot to take will then be sent to the SCRATCH team and used internally. The shot information is used by the user localization and user guidance systems to determine where the user is and how to guide them to the proper location. Once the user is in position, the control will be transferred to the SCRATCH team to take the actual shot. Once the shot has been executed, VISION will take back control and determine the results of the player's shot. The results are displayed on a monitor and announced through an audio system.

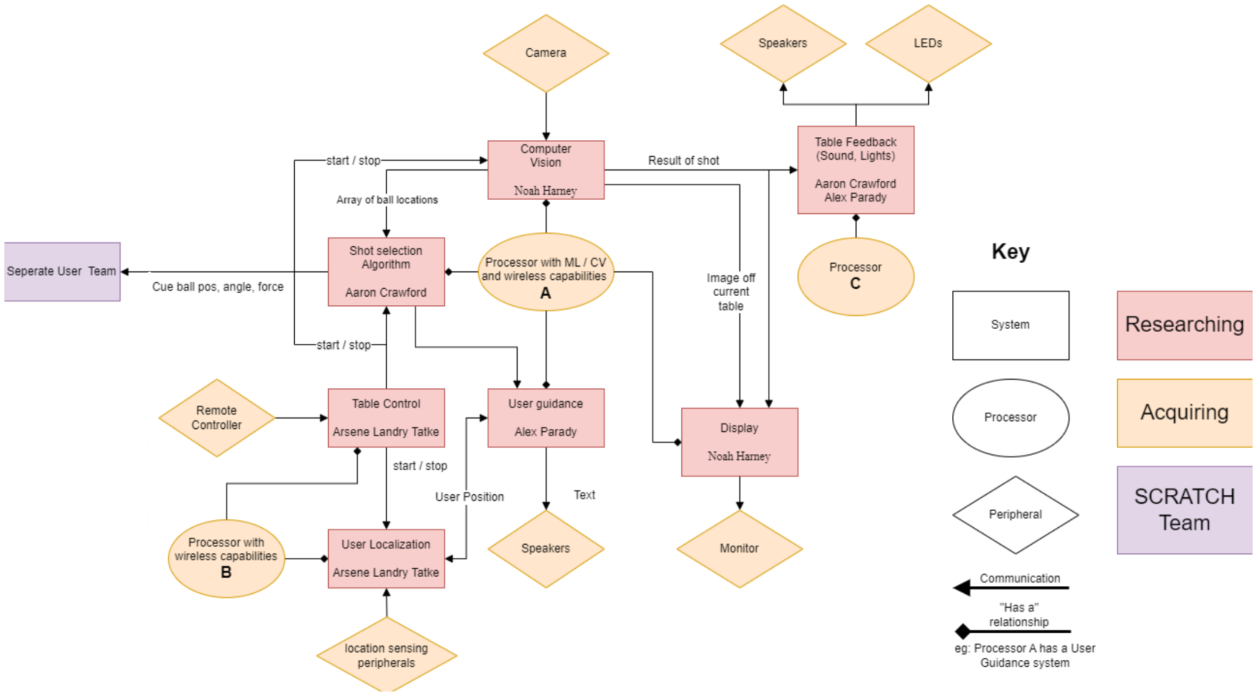

Figure 3.1 Project Block Diagram

4. Project Budget and Financing

Component	Quantity	Unit Cost	Total
Pool Table	1/2	$480	$240
Camera / Webcam	1	$50	$50
Low Power Microcontroller	2	$15	$30
Bluetooth Tracking Devices	3	$20	$60
PCB Testing Parts	1	$20	$20
High Power (AI Capable) Processing Board	1	$200	$200
Speakers	12	$2	$24
Monitor	1	$40	$40
Total			$664

Table 4.1 Tentative Bill of Materials

The table above is a comprehensive list of the most critical components for VISION. The pool table will be shared with the SCRATCH (group #17) project, meaning the team is only responsible for half of the cost of the pool table. Although the price of the project is within the $800 project budget, there are opportunities to reduce the overall cost. Due to supply chain shortages, most high-power processors (Jetson Nano, Google Coral Dev Board, Raspberry Pi) are not in stock and are subject to third-party resale prices. The team is currently reaching out to suppliers to try and obtain a board at retail price. VISION and SCRATCH are actively seeking sponsorship and outside funding for the project. In the worst case, the members of VISION will split the costs of the project between themselves.

5. Initial Project Milestones

The VISION team started collaborating and brainstorming throughout the summer to prepare for the Senior Design 1 course. The team finalized the project selection with the help of their supervisor Dr. Chan before the Fall semester. The team has planned aggressive milestones for the Fall semester with the plan of starting to build the project during Senior Design 1. The tentative schedules are senior design 1 and senior design 2 are shown in tables 5.1, 5.2, and 5.3 below.

Task	Start Date	Anticipated End Date	Duration
Project Brainstorming	Summer	Summer	0 weeks
Project Scope Finalized (Finalize big picture design and what the end goal is)	08/22/2022	08/26/2022	1 week
Individual Research Begins (Begin breaking the project into smaller subsections such as CV or AI)	08/22/2022	09/02/2022	2 weeks
Initial Design Document (Based upon the D&C documents)	08/22/2022	09/05/2022	1.5 weeks
30-Page Milestone (General system design, project motivation, project goals, project concepts)	08/22/2022	09/09/2022	3 weeks
60-Page Milestone (Independent technology research, system requirements, part ideas/availability)	09/10/2022	09/30/2022	3 weeks
90-Page Milestone (Independent technology research, system communication)	10/01/2022	10/21/2022	3 weeks
120-Page Milestone (System testing, PCB design, PCB testing, citations)	10/22/2022	11/11/2022	3 weeks
Group Review: Final Draft	11/14/2022	11/18/2022	1 week

Table 5.1 Senior Design 1 Project Documentation Milestones

Task	Start Date	Anticipated End Date	Duration
Individual System Design (Create some proof of concept design in hardware or software)	09/05/2022	10/02/2022	4 weeks
Individual System Testing (Develop and demonstrate the proof of concept design to the team)	10/03/2022	10/30/2022	4 weeks
Breadboard Prototyping (Finalize what the PCB will do and breadboard the design)	10/31/2022	11/21/2022	3 weeks (Assuming we can get parts in time)
PCB Design / Ordering (Design the PCB in Eagle and order from a reputable PCB company)	11/22/2022	12/12/2022	3 weeks (Assuming we can get parts in time)

Table 5.2 Senior Design 1 Project Design Milestones

Task	Start Date	Anticipated End Date	Duration
PCB Testing (Test all of the PCBs to ensure they work properly)	01/09/2023	01/23/2023	2 weeks
System Integration / Testing (Begin integrating the individual systems together in the main code)	01/24/2023	02/13/2023	4 weeks
Practice Project Demo (Go through a mock project demonstration to ensure everything is functioning)	02/14/2023	02/27/2023	2 weeks
Finalize Documentation (Final edits and construction of the documentation)	02/28/2023	03/13/2023	2 weeks
Practice Final Presentation	03/14/2023	03/20/2023	1 week
Final Presentation	TBD	TBD	TBD

Table 5.3 Senior Design 2 Project Design Milestones