Functional Specification

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Assignment Evaluation:

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| **Item** | **Score (0-5)** | **Weight** | **Points** | **Notes** |
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| **Total Score** |  | | |  |

5: Excellent 4: Good 3: Acceptable 2: Poor 1: Very Poor 0: Not attempted

General Comments:

1.0 Functional Description

The final deliverable we plan to create is an interactive table tennis table. This involves integrating multiple peripherals into and around the table. This may be accomplished through mounting the overhead devices to an extendable arm or installing them in the room. The specific peripherals we plan to use are a microphone array, display, and panel for user interface.

There are five functionalities we plan to accomplish: Firstly, the microphone array and associated microcontroller must be able to accurately detect ball collisions with the table. Secondly, the camera should be able to accurately report the position of the ball while it is in play. Thirdly, the game state and points should be tracked using these two data streams. Additionally, the user should be able to interact with the device using the button controls on either side of the table. And, finally, information about the game must be displayed to the table or screen. These five functionalities will be accomplished throughout the course of a regulation table tennis game [2].

A few features we would like to implement to elevate our product include: building new and more interactive game modes, using triangulation of microphone signals to find ball bounce position, including novel user interaction through hand gestures, and realtime ball graphics like trails and heatmaps.

2.0 Theory of Operation

As we only have communication needed between 2 devices at a time, we can use the UART protocol, with 1 bus between the microcontroller and the laptop. We will have the laptop also connected to the camera through USB, and to the projector through VGA. Neither of these links will be created by us – these will use built-in drivers in the laptop.

The controller will handle sensor inputs, minus the camera. This includes, but is not limited to, the contact microphones and keypad matrices. In order to detect ball bounces we will have to implement layers of signal processing including signal cleaning and amplifying through our hardware circuits (pre-amp, filter) and interpretation of the data using the ADC of the controller. To accomplish this we will employ knowledge of fundamental electrical engineering concepts found in signal processing, probability, and hardware courses. This controller also will handle user input from the keypad matrices, through repeated powering the rows and reading the columns. The collected sensor data will be sent through UART to the laptop to be deciphered.

The laptop will be responsible for controlling the game logic, such as

determining score (using the information sent from the secondary controller) and commanding the projector to display particular graphics. To do so, the laptop will directly interface with the projector through VGA. The laptop will also directly handle the object detection logic, read from the camera through a USB connection.

The most computationally heavy task of our product is object detection. As our microcontroller will not be powerful enough to handle this task, we will be using the laptop for these computations. For this we plan to use off-the-shelf, publicly available libraries. Specifically we are considering using blob detection offered by open CV. This algorithm groups together groups of similar pixels based on a variety of tweakable parameters. The ball will be selected from the blobs and the center will be communicated to the controller, if necessary.

3.0 Expected Usage Case

R.A.C.H.E.L. is expected to be used by a typical table tennis player, not a professional. Due to budgeting constraints (as will be explained below), it is likely that a professional table tennis player will hit the ball too quickly to be accurately detected by our camera. Our product is intended to be used where someone may already have a table set up - particularly an indoor table, as we expect the projector and camera to perform poorly in high lighting. R.A.C.H.E.L. should be used in a stationary setting, as we will mount the projector system to the ceiling. If mounted to the table, there will be a vertical support system that may hinder gameplay. With a stationary table and projector system, the user will not need to worry about calibrating the game system.

This product likely will be set up by parents, for their children. As such, the typical end-user will not have deep technical literacy. To handle this, we plan to develop a simple process to calibrate the projector system to the table, with instructions displayed by the projector. For any expected user input, the projector will show instructions; our intention is that the user manual will exist, but will never be necessary.

An example interaction between the user and our product would be as follows:

1. The users turns on the device through a power switch
2. One of the users selects a game using the information displayed and the button interface.
3. The user configures parameters to their liking, such as final score, minimum point difference, time limit before a ball is counted as out, etc. These configurable parameters are subject to change.
4. The user starts the game and both users begin playing.
5. The microphone array and camera detects ball motion and bounces to assign points and display feedback to the table in real-time.
6. The user overrides any discrepancies between the automatically tracked game and the real one using the button interface.
7. The game is completed when an end condition is met and the user is brought back to the starting menu.

4.0 Design Constraints

4.1 Computational Constraints

The most computationally heavy process R.A.C.H.E.L. is faced with is on the computer vision side. A powerful device, such as a laptop, will have to handle the video feed coming from a depth/color sensor and also process what is a ball in the feed and where the ball is in respect to the table. The standard microcontroller will be able to take in ball coordinates but would not be able to process coordinates itself. Graphics that are displayed by the projector will also have to be handled by the laptop as the task may be too daunting for an microcontroller. Nevertheless, every other task could be handled by a mid-range microcontroller: handling sensor data, processing user input from a keypad, and determining game logic. But to keep things easy, we will also have the laptop control the game logic; this reduces the complexity of the UART structure.

4.2 Electronics Constraints

I will begin by listing the highest level devices and moving onto the lowest level. So first up, there will be a color/depth sensor attached to the laptop through USB. This will require us to install drivers for it and we may require a library to aid in processing the video feed. Next up, there is a projector that will have the highest power draw and will most likely be connected directly to an outlet. The projector will be connected to the laptop through VGA to display graphics. The keypad that will handle user input will be connected to a microcontroller with GPIO pins. On the microcontroller connected to the keypad, there will have to be code that takes into account button ghosting and masking. There will be a preamp circuit attached to the contact sensors that will be detecting ball bounces. The circuits will be connected to ADC channels on a microcontroller. There may or may not be a need for a software filter.

4.3 Thermal/Power Constraints

The environment our product will exist in is indoors and it will draw power from a standard home outlet at 120V AC. Because of this, we are not meaningfully constrained on how much power we can draw. The maximum wattage that a home outlet can handle varies; a safe range is less than 1,320W. The maximum power requirements for each component is listed below in figure 1:

|  |  |
| --- | --- |
| EPSON PowerLite x12 [4] | 283W |
| STM32F091RCT6 (x2) [8] | 1W |
| Xtion Pro Live [9] | 2.5W |

**Figure 1. Maximum Power Requirements**

From this info we can determine that under load our product will require a maximum of 286.5W, which is well within the safe range for a standard home outlet.

Additionally, the microcontroller we have picked for this project operate at a maximum temperature of around 85 degrees celsius [8] and the projector operates at up to 35 degrees celsius [4]. According to ADT [11] the average home temperature is around a max of 25 degrees celsius, which is 10 degrees less than our maximum operating temperature of 35 degrees celsius.

4.4 Mechanical Constraints

As we will have a large system suspended in the air (incorporating a projector and camera), there must be a safely designed package to hold it all. While a floor or table mount is most convenient, and safest, this may interfere with the game; a tall wood structure near the center-line of the table to hold the system in the air could easily be a target for ping pong balls, causing an obstruction and making the game less exciting. Thus, a ceiling-mount will be necessary. The laptop and PCB will reside under or near the table, with minimal wiring going above the table to the camera and projector.

Since this is a prototype, and we are not structural engineers, our focus will not be on how to properly rig the package. We will build a package that holds the entire sky system together, leaving no PCB, wire, or circuit component exposed. This will be representative of what we will create for a final product.

Besides having a safe suspension system, we must keep in mind standard room height. Many table tennis enthusiasts will keep a table in a game room, den, or basement. As such, our mount must fit in the typically sized room, being no higher than 8 feet [3].

4.5 Economic Constraints

As briefly explained in Section 3.0, we think a professional player will hit the ball too fast for it to be properly tracked by the camera. Our camera is an already-owned device, 11 years dated, that may not handle the frame-rate necessary to pick up a 50 mph ping pong ball [5]. With the standard table size being 2.74 m [5], and the camera running at 30 fps [7], we have approximately 3 frames of data to capture the ball, which will not be accurate.

A casual player will not be hitting this quickly. As this is our target audience, and this is a prototype, we could not be convinced to purchase a new-generation camera system, such as the Zed 2i, with an MSRP of $499, a price larger than our budget.

While there are similar products to our own, nothing fits into the same market. The Stiga Sensorscore (MSRP of $49) was a contact microphone array system used to track the score. It was met with poor reviews, and has since been removed from their website. Thus, we expect to need the camera system for accurate score tracking. Of course, our product will do more than only score-tracking; we will have an interactive game integration system. There exist systems with similar features, utilizing a large-screen interface; companies sell air-hockey tables that use a screen as a table for various uses, but those run around $5,000.

Our prototype will cost approximately $130, using borrowed parts. The full cost of our parts would equate to nearly $800. At a production level design, this could likely be between $100-200, if we were to integrate our own camera and projector lens into a custom package.

4.6 Other Constraints

Our product requires for there to be a standard table for table tennis and an environment suitable for playing table tennis. Meaning, players have enough room to move around to hit the ball and enough vertical room above the table for the ball to be in play. We are not designing the table to be played outdoors so water/dust/wind damage will not be accounted for in the design.

The depth sensor only picks up objects farther than 1 foot (according to our testing last week), which will limit us on certain things we can do, such as a constant effect following the ball's path or constant data displayed on the table of the ball's trajectory and speed.

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