Functional Specification

Year: 2025 Semester: Spring 2025 Team: 01 Project: Electronic Skee Ball
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Assignment Evaluation: See Rubric on Brightspace Assignment

1.0 Functional Description

Team 1 is designing an electronic, miniature version of a traditional skee-ball machine, reworked to provide an accessible gaming experience for individuals with disabilities. In this version, a motor-driven mechanism launches the ball up the ramp, with the force controlled by the duration of a button press and the angular direction guided by a joystick. Scoring occurs when the ball lands in one of six designated holes, each associated with a specific point value. The game incorporates audio and visual feedback: a speaker plays a short success tone upon scoring, and the user's cumulative score is displayed on an OLED display. The ball is automatically returned to its starting position for subsequent attempts, with manual retrieval required only if it leaves the game entirely. Each game consists of three attempts, with the objective of achieving the highest score possible.

2.0 Theory of Operation

The Electronic Skee Ball machine utilizes a variety of systems and interfaces to accomplish its intended operation. The most scientifically notable of such systems is the usage of ultrasonic sensors as efficient and accurate distance-measuring tools. The Electronic Skee Ball machine makes use of ultrasonic sensors to detect when the user has scored a point by landing the ball in one of the game's designated scoring holes. At a high level, this is accomplished by having one ultrasonic sensor positioned inside of each hole, and each one continually reads the distance between itself and the nearest object. When no ball is present, the sensor yields the distance between itself and the opposing wall of the scoring hall, and when the ball enters, this distance suddenly decreases. This sudden decrease in distance measurement is thus interpreted as an indication that the ball has entered the hole.

To achieve this measurement, an ultrasonic sensor emits a burst of high-frequency (outside of the audible spectrum), short-duration pulses and measures the time it takes to detect a returning pulse [1]. The implementation of the time measurement is specific to the sensor, but it is usually accomplished via a timer governed by an internal clock signal. Once a returning pulse (i.e., a reflection of the originally emitted pulse off of a nearby surface) is detected, the distance to the object is calculated as

$$D = k \cdot T_f \cdot V_s$$

where D is the distance between the ultrasonic sensor and the reflecting surface in meters, T_f is the measured time in seconds between the emission of the initial pulse burst and the reception of the returning pulse, V_s is the velocity of the pulse through the ambient medium (in this case, the atmosphere of Earth immediately above the surface), and k is a dimensionless constant describing the ratio of the distances between (i) the emitter and the reflecting object and (ii) the receiver and the reflecting object. This ratio is thus dependent on the geometry of the object, but it is usually approximated as 0.5, indicating equal distances between the emitter and the object and the receiver and the object. Most mass-produced sensors generate pulse signals of frequency 40kHz to ensure that the pulse is not audible to humans and also does not interfere with surrounding wireless communications [2]. Thus, an approximate timing diagram of the ultrasonic sensor operation can be depicted as shown in Figure 1:

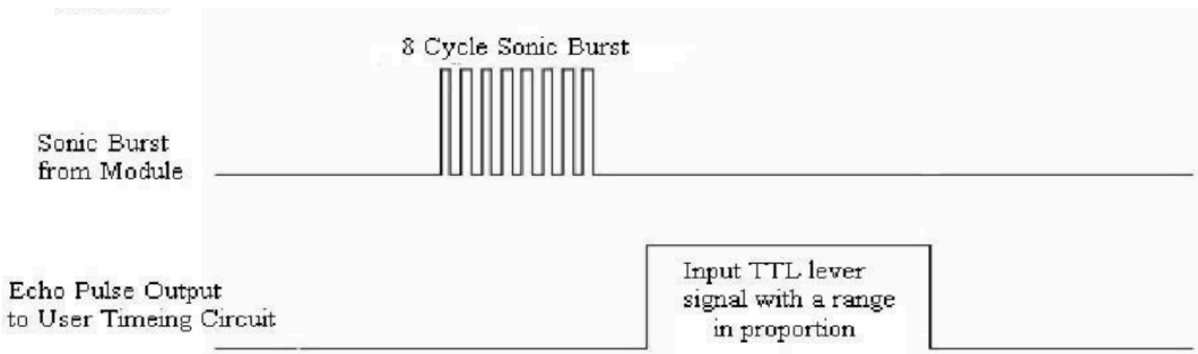

Figure 1: Approximate timing diagram displaying transmission of ultrasonic signal burst followed by reception of returning signal, separated by time T_s

Team 1 therefore utilizes ultrasonic sensors to detect ball presence by repeatedly triggering each ultrasonic sensor and recording the duration between the burst transmission and return signal reception. This duration is used in combination with the speed of sound in the game's target environment (an approximately 68℉ air conditioned building) to calculate the distance to the nearest opposing object. This information is used to make a final determination regarding the presence or absence of a ball in the corresponding hole.

3.0 Expected Usage Case

The Electronic Skee Ball Machine is designed for use in arcades, game rooms, and home settings, providing a more accessible and portable version of the classic game. This version of Skee Ball's targeted users are individuals with physical disabilities who may not be able to participate in the traditional game. However, it can also be played by anyone of all ages and sizes. The potential clients for this product include arcade owners, parents of children with disabilities, individuals with disabilities, and anyone who likes to play arcade games. Since this is a scaled-down version, it is lightweight and easily transportable, making it ideal for portable usage offering an alternative to the larger versions typically found in arcades. The game is intended for single-player use, however, the user can play multiple times to beat their previous score or play other people to beat their score..

4.0 Design Constraints

4.1 Computational Constraints

1) Audio Playback: Playing sound from a WAV file stored in memory introduces constraints on both memory and processing power. The ESP32 must decode audio data in real time and transmit it to the external speaker via the I2S interface. This requires continuous data streaming, which could consume a significant portion of the processor's resources. Additionally, the ESP32 has limited RAM and flash memory, which constrains the size of WAV files.
2) Joystick Input Processing: The ESP32 must read and process the analog output of the joystick to determine the angular displacement for controlling the ball's launch direction. This requires ADC sampling at a sufficient resolution and frequency to provide accurate and responsive inputs.
3) Motor Control and Force Calculations: The ESP32 must calculate the motor force based on the duration of a button press. This involves real-time measurement of input duration and mapping it to a PWM duty cycle to control the motor. To ensure a smooth and responsive user experience, the timing resolution for these calculations must remain within a few milliseconds. Any delay in these computations could cause noticeable latency or inconsistencies in the ball launch mechanism.
4) Sensor Data Processing: The ultrasonic sensors connected via an I2C GPIO extender will require periodic polling to monitor the ball's position and detect scoring events. Managing multiple I2C devices introduces bus latency or congestion, possibly requiring scheduling of sensor polling intervals.
5) Display Updates: The OLED display will be updated via SPI to show the current score and other game information. While the display update frequency is relatively low, it must remain consistent and avoid interfering with higher-priority tasks like motor control or audio playback.

4.2 Electronics Constraints

For this project, Team 1 will be using an ESP32 microcontroller to interface an OLED display, a DC motor, several ultrasonic sensors, a joystick, and an external speaker. Some of these peripherals require a higher voltage than the ESP32 can provide, making our design dependent on an external power supply. As a result, careful power management is crucial. The external power supply must provide sufficient current and ensure voltage stability to avoid any brownouts or fluctuations that could destabilize the ESP32 or cause other components to malfunction. Additionally, the external power supply will need to be integrated into the design, requiring space for proper housing, routing of power lines, and possibly the addition of filtering or protection components to prevent electrical noise and voltage spikes. This constraint may also impact the overall portability of the system, as the need for an external power source could limit the system's ability to operate independently of a fixed power outlet or require a larger battery pack. Based on this constraint, the power supply's integration will influence the physical layout, component placement, and overall design of the system.

The use of I2C and SPI communication protocols in this design introduces several constraints related to signal integrity, bus management, and peripheral compatibility. The ultrasonic sensors will be interfaced through a GPIO extender, communicating with the ESP32 over I2C. This introduces the need for proper pull-up resistors on the I2C lines to maintain signal integrity. Additionally, latency and bus congestion could become concerns, as the extender adds another layer of communication overhead. On the other hand, the OLED display and external speaker will communicate via SPI and I2S, respectively, which require dedicated GPIO pins and precise timing for data transmission. The use of SPI introduces constraints related to the availability of unused GPIO pins, as each peripheral requires distinct clock, chip select, and data lines. Furthermore, proper management of SPI bus speed and synchronization must be ensured to prevent data corruption or display glitches. The use of multiple communication protocols simultaneously also requires careful consideration of the microcontroller's processing power and available memory to manage the data flow without overloading the system.

Generating and amplifying sound from a WAV file stored in static memory introduces several constraints related to memory usage and real-time data processing. The size of the WAV file, particularly if it has a high sampling rate or bit depth, can place a significant strain on the ESP32's available flash memory. Larger audio files may need to be split into smaller segments to fit within memory, or an alternative solution like streaming the audio data in smaller chunks could be implemented to minimize memory consumption. The ESP32's processor must also handle the real-time task of reading, decoding, and transmitting audio data to the external speaker via I2S. This could impose a constraint on the available processing power, especially if the microcontroller is also managing other peripherals like sensors or motors. Additionally, there is a trade-off between audio quality and memory usage. Higher sample rates and bit depths result in better audio quality but require more memory, potentially limiting the length of the audio file or the complexity of the sound. Finally, to ensure smooth audio playback, stable and continuous data transmission to the speaker is essential, which may require effective buffering and memory management to avoid glitches or distortion.

Reading the angular displacement of the joystick introduces constraints related to the ADC resolution, signal noise, and range matching. The ESP32's ADC has a limited resolution, which may impact the accuracy of the joystick's displacement readings, especially if finer precision is needed. To mitigate signal noise, the joystick's analog output may require filtering to ensure clean data. Additionally, the joystick's voltage range must align with the ESP32's ADC input range (typically 0 to 3.3V) to avoid loss of resolution or signal clipping. Proper scaling or adjustment circuitry may be required to ensure reliable and accurate readings.

4.3 Thermal/Power Constraints

The Electronic Skee Ball Machine both consumes and dissipates power, leading to a variety of thermal and power constraints. Regarding power consumption, the machine is constrained to being powered by a standard U.S. wall outlet with an adapter capable of supplying at least 7.05A at 8.4V to satisfy the power requirements of the full integrated product. A U.S. wall outlet is capable of supplying at least 15A at 120V, making it a viable and easily accessible option for the machine's end power source [3]. The current constraint is determined by calculating the total maximum current drawn from all components in the machine:

1. HC-SR04 ultrasonic sensor, 25mA maximum at six units: 0.15A maximum [2]
2. HPS-2018 servo motor, 3A maximum at two units: 6A maximum [4]
3. SOC1602A OLED display, 40mA maximum at one unit: 0.045A maximum [5]
4. MAX98357 amplifier, 360mA maximum at one unit: 0.36A maximum [6]
5. ESP32 microcontroller, 500mA maximum at one unit: 0.5A maximum [7]

Thus, the machine must be capable of drawing 7.05A in the worst case. However, the current draw will nearly always remain well below this number due to the fact that many components will not be in constant use, and when they are in use, they will not be utilized to the most power-consuming extent. Likewise, the machine must be supplied with 8.4V in the worst case due to the maximum power requirements of the HPS-2018 motor [4].

The target temperature of the machine is mainly constrained by the temperature range in which users will continue to feel comfortable handling the machine. Research has shown that the maximum temperature at which a user can comfortably use a plastic appliance (e.g., the joystick or button of the machine) is 45℃ [9]. Given that the Electronic Skee Ball Machine is intended for usage in indoor, air conditioned environments, usually having an ambient temperature near 20℃, meeting this constraint is trivial.

4.4 Mechanical Constraints

The Electronic Skee Ball Machine is a scaled-down, more accessible version of the traditional skee ball game. Instead of using the traditional method where the user throws/rolls the ball, this version uses a button/launch technique, which requires the machine to be compact enough to sit on a standard table for easy access. This design decision ensures that users of all abilities can comfortably access the game. Portability is a key consideration as well, so the machine's weight must remain manageable to transport by people. A traditional skee ball machine weighs over 400 pounds [8], but this scaled-down version will be significantly lighter. The physical machine should not exceed the load capacity of typical tables, which can support up to 100-200 pounds. This weight ensures that the game remains portable and safe for use on common tables.
The skee balls themselves must both be light enough to avoid causing injuries or damage if a player misses the target, but also heavy enough to successfully roll up the ramp. Since the machine is designed for indoor use in game rooms, arcades, or home settings, weatherproofing is unnecessary. However, durability is still really important. For the actual durability of the machine, the ramp and structure should be constructed from materials like wood, which can withstand repeated impacts and force from the game. Less sturdy materials, like cardboard, would not withstand the repeated stress of regular usage. Components that the player uses like the buttons and joysticks, will also need to be made of study materials and good quality components that can withstand constant wear and tear without losing its functionality.

4.5 Economic Constraints

Our team's design aims to provide an affordable and compact alternative to traditional skee-ball machines. The cost of commercial skee-ball machines typically ranges from $4,500 [10] to $9,000 [8] depending on the features and size of the model. These machines often require significant space and lack features tailored to individuals with disabilities. In contrast, this project's estimated material cost is $115, making it a cost-effective alternative for individual consumers, schools, and rehabilitation centers. This design also minimizes logistical constraints by reducing the size of the machine and incorporating features that simplify use and enhance accessibility. The design aims to achieve this lower price point by using a miniature skee-ball body (includes game board and 5 wooden balls) [11] ($30), product packaging (includes the materials for the body, connections, any aesthetic inclusions, etc.) ($25), and low-cost electrical components, such as printed circuit boards ($20), a power supply ($20), and an ESP32 microcontroller ($20). By keeping the total cost significantly lower than commercial machines, this rendition of skee-ball offers an affordable option for those seeking an inclusive and miniature version of the game. Constraints include maintaining affordability while ensuring the durability of components for accessibility features.

4.6 Other Constraints

NA; the above contents of this document fully describe the constraints associated with the Electronic Skee Ball Machine.

5.0 Sources Cited:

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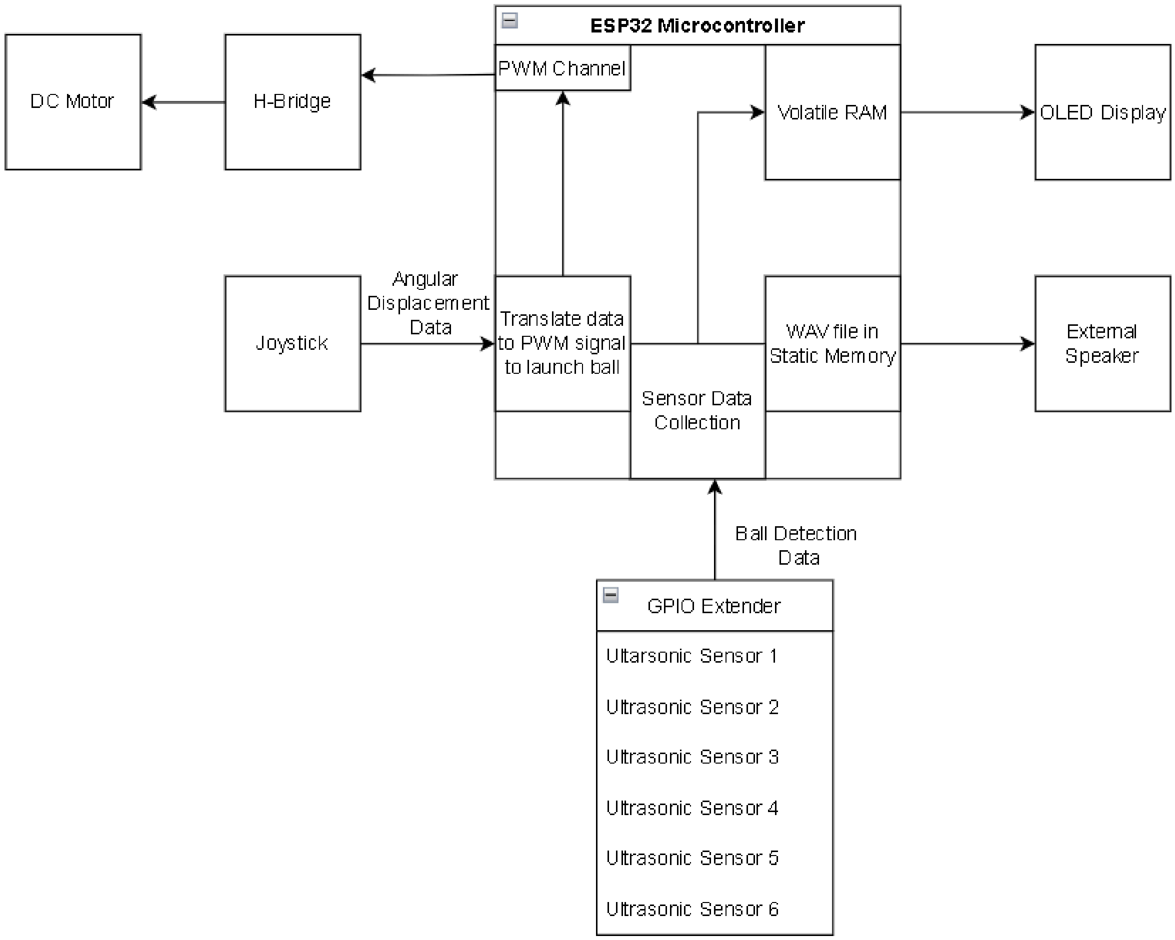
5.1 Appendix 1: Functional Block Diagram


ESP32 Microcontroller
PWM Channel
Volatile RAM
OLED Display
DC Motor
H-Bridge
Joystick
Angular Displacement Data
Translate data to PWM signal to launch ball
Sensor Data Collection
WAV file in Static Memory
External Speaker
Ball Detection Data
GPIO Extender
Ultarsonic Sensor 1
Ultrasonic Sensor 2
Ultrasonic Sensor 3
Ultrasonic Sensor 4
Ultrasonic Sensor 5
Ultrasonic Sensor 6