Component Analysis

**Year: 2021**  **Semester: Fall** **Team: 8** **Project: Sink or be Sunk**

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Assignment Evaluation:

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| **Item** | **Score (0-5)** | **Weight** | **Points** | **Notes** |
| **Assignment-Specific Items** | | | | |
| **Analysis of Component 1** |  | x2 |  |  |
| **Analysis of Component 2** |  | x2 |  |  |
| **Analysis of Component 3** |  | x2 |  |  |
| **Bill of Materials** |  | x6 |  |  |
| **Writing-Specific Items** | | | | |
| **Spelling and Grammar** |  | x2 |  |  |
| **Formatting and Citations** |  | x1 |  |  |
| **Figures and Graphs** |  | x2 |  |  |
| **Technical Writing Style** |  | x3 |  |  |
| **Total Score** |  | | |  |

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

General Comments:

*Relevant overall comments about the paper will be included here*

IMPORTANT NOTE: The Bill of Materials is a separate document and should be downloaded and filled out for another assignment. The Bill of Materials is to be submitted separately, per the course calendar (possibly on a different week), and will graded collectively with this assignment.

1.0 Component Analysis:

The critical components for Sink or be Sunk are LEDs, the microcontroller, resistive sensing, and a battery charge management system. The LEDs will be used to indicate hits/misses as well as necessary signaling, such as identifying a player’s turn. The microcontroller will be responsible for the connectivity between the board and the WebSocket server, as well as utilizing GPIO for controlling the rumble motor driver, DAC for game audio, and ADC for communicating boat locations from the board to the server. Resistive sensing is essential to identifying the boats placed by the user during game setup. Finally, the battery management will indicate to the user the status of the battery, regarding its charge.

1.1 Analysis of Component 1: LEDs

The LEDs are an integral part of the project because they indicate whether or not the player has hit or miss a battleship. Without this notification system, the user would not know about the progress of their game or their opponents. The two main types considered were discrete LEDs. This would necessitate 256 individual LEDs and soldering all of them individually. Due to needing different colors at each LED, this would require an RBG LED and there would be considerable amount of work needed to use these. Each LED would need to be sent data to be told what color to be.

The second option is to use LED strips. [19] There are multiple different ICs, but the three main options are WS2811, WS2812B, and WS2813. Each has its own pros and cons. The WS2811 is an older version that is much more cost effective, however, the LEDs are not individually addressable. They are controlled in groups of three. The WS2812B and WS2813 are both individually addressable but in different ways. The WS2812B has four total pins: one for power, one for ground, and two for the data (DIN and DOUT). [17] The WS2813 has six pins: one each for power, ground, and hanging, and three for the data. [18] These have a data in and a backup data in pins which allow the entire strip not to go out if one LED burns up. This backup means that just one would go out. Another advantage of the WS2813 chip is the refresh rate is five times higher at a rate of 2000Hz when compared to the WS2812B. Both LED types draw about 60mA of current which means each strip would draw approximately 0.5A. These strips also both require a 5V source. [20]

LED strips would be significantly easier to use because they could be cut every eight LEDs and connected at one end instead of having to solder 256 individual LEDs. Connecting 32 strips would be significantly faster. However, the amount of power required to run 16 strips of LEDs on each board would be around 50W which is significantly high. Due to this, a surface mount device LED was chosen because it has a much lower current draw of about 15mA [28]. This would cut power consumption by a factor of four. When using individual LEDs, there would need to a shift register for each set of 8 LEDs. These would then be programmed like normal LEDs because they don’t have an IC on each LED like the strips.

1.2 Analysis of Component 2: Microcontroller - ESP32, ESP32-S2, ESP8266

The microcontroller component requires several key parts for our usage case. For functionality, one of the main considerations is WiFi connectivity. The microcontroller is expected to spearhead all communications of the game server, so RF transmission and WiFi support is a must. The microcontroller will also need at least two channels of DAC and ADC for ship detection. SPI communication will be utilized for LCD so the microcontroller must also support the SPI protocol. A significant amount of GPIO ports is also crucial considering the number of lines and communications the project will utilize. Ballpark estimate, 1 line for the 128 LEDs on a strip, 1 SPI communication line for the LCD screen, 11 lines for multiplexed port monitoring of the 64 ship slots, a line for motor driver control, a GPIO for the speaker, and roughly 8 lines for keypad/attack buttons for a total of 22 GPIO lines. To reiterate, this is a rough estimate as more peripherals and design choices will almost certainly change this number. LED PWM is a desirable feature, although the LED strips are likely to have PWM already built into the strip, but still would be useful for other LEDs on the board. DMA access is also a desirable feature, mainly for playing audio files to make the data processing and acquisition high speed.

For computational concerns, computational power is not an enormous concern, as the microcontroller tasks for the project are relatively lightweight for today's microcontrollers. However, managing the whole system and communicating to the server does require the microcontroller to be active quite often, meaning some decent computational power is necessary. This would ensure that the game flow works smoothly behind the scenes, as the user should not expect the game to play slowly. Power consumption needs to be as low as possible in the interest of battery life. The LED matrix, RF Transmission, and microcontroller among other things will consume a concerning amount of power. In general, the usage case requires support and functionality for many features, but does not require anything much beyond that.

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| --- | --- | --- | --- |
| Microcontroller | ESP32 | ESP32-S2 | ESP8266 |
| Launch Year | 2016 | 2020 | 2014 |
| Price | $4.62 | $10.73 | $6.95 |
| Core | Xtensa Dual Core | Xtensa Single Core | Tensilica L106 32-bit |
| WiFi Protocols | 802.11 b/g/n, 2.4 GHz | 802.11 b/g/n, 2.4 GHz | 802.11n 2.4 GHz |
| SRAM | 520 Kb | 320 Kb | 160 Kb |
| ROM | 448 Kb | 128 Kb | 0 Kb |
| Flash | 2 or 4 Mb | 2 or 4 Mb | None |
| ADC | Two 12-bit, 18 channels | Two 13-bit, 20 channels | One 10-bit |
| DAC | Two 8-bit channels | Two 8-bit channels | None |
| GPIO | 34 | 43 | 17 |
| SPI | 4 | 4 | 2 |
| UART | 3 | 2 | 2 (1 Tx only) |
| DMA | Dedicated DMA to UART, SPI, I2S, SDIO slave, SD/MMC host, EMAC, BT, and Wi-Fi | Dedicated DMA to UART, SPI, AES, SHA, I2S, and ADC Controller | Dedicated DMA to SDIO, I2S, and SLC |
| LED PWM | 16 Channels | 8 Channels | 5 Channels |
| Power Consumption | 80 mA average | ~< 20 mA while not transmitting RF | ~100 mA average |

**Table 1.1 - Microcontroller Comparison**

The project will utilize the ESP32, specifically the WROOM-32. For launch date, the ESP32 is not obsolete nor bleeding edge, so many issues with unresolved bugs should be dealt with. The price is another factor, as not just are the boards cheaper, but there are dev boards available at no cost in the ECE Lab to further maintain economic constraints. Mainly, the ESP32 offers flexibility. The dual-core processor, additional SRAM, ROM, and large number of peripherals that can utilize the DMA allow the ESP32 to satisfy the projects needs and allows adaptability as development begins to expand and change. The 34 GPIO ports will be more than enough to manage the user I/O and it satisfies all criteria necessary for the project. Additionally, the team has worked with ESP32 before and has already begun development utilizing the ESP32, so switching for no benefit would be unnecessary.

1.3 Analysis of Component 3: Ship Detection – Hall Effect, NeoTrellis Button Matrix, Resistive Sensing

One fundamental aspect of the project is to include a tactile, tangible method of interacting with ship positioning and gameplay more broadly. It was therefore a priority for the team to keep this in mind while considering ideas. This ruled out concepts such as resistive and capacitive touch screens due to the fear of having a user experience too similar to a tablet. Additionally, the team identified a constraint with the sensing that is different from a generalized keyboard matrix. The system must be able to identify not only the position of a ship but also the unique identity of the ship. For both three-position boats, the board must distinguish between the submarine and destroyer boats. With these constraints in mind, three main methodologies were considered: Hall Effect/magnetic sensing, push-buttons, and analog voltage monitoring through resistor dividers.

Hall Effect sensing uses magnetic fields to trigger a solid-state switch within the device. This can then be used as a digital trigger for detection. In theory, these devices could provide great wireless detection of ships by adding a small magnet to each ship peg. The main issue with these devices is sensitivity and tuning. It is important to get the magnetic field correct to ensure reliable detection. For this specific use case, where there will be a grid of sensing devices, there is a high chance of cross-talk between fields. This means that false sensing would be a real problem for this design. Additionally, this system does not have a great answer to the issue of identifying different ships. Theoretically, the team could attempt to tune different intensities of magnetic fields to correspond to different ships; however, this would be difficult and worsen the issue of field interference (cross talk) with increased magnet intensities.

The next option considered was the Adafruit NeoTrellis Button Matrix. This system uses an i2c interface to address and control individual push buttons. This is desirable because it allows for pin pointing exactly where in the matrix a button was pushed without the need for a complicated scanning. Additionally, it allows for a “multi-touch” approach so that multiple ships can be positioned on the board at the same time. The downside with this approach is that it is expensive and has a limit to 32 buttons per IC. This would mean that we would need to double the communication protocol to achieve the 64 inputs on the ship positioning grid.

The final method considered for detection was to use a simple resistor divider circuit to generate unique voltages for each boat. This option simplifies the circuitry and software protocols from the other systems. The signal only needs to be read from the ADC of the microcontroller; a basic task of any modern microcontroller. This option has the added benefit of having the lowest cost due to the large availability of through-hole resistors. The downside of this design is having electrodes exposed to the user. This will require careful consideration by the team to ensure safety should the user abuse the system so as not to cause electrical/thermal failure from a short.

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| --- | --- | --- | --- |
| Detection Component | Hall Effect | NeoTrellis Button Matrix | Resistor Divider |
| Unit Price | $0.95 | $12.50/(MOQ 16) =  $0.78 | $0.05\*2 = $0.10 |
| Power (per unit) | 230mW | 92mA\*3.3V=349.6mW | 3.3V^2/100k = 0.1mW |
| Protocol | Digital GPIO | i2c | ADC |
| Detection Method | Near Field | Force (push button) | Plug In |
| Form Factor | 3.2x2.8x2.03mm | 3.75x3.75x0.71mm (avg over 4x4 board) | 6.3x2.4x2.4mm |

**Table 1.2 - Ship Sensing Comparison**

In addition to what has been previously stated, above is a table with some comparison information about the devices in question. Power consumption for the devices is based on max device ratings for the ICs and the typical resistance for the divider circuit. Note that if the team desires to decrease the power consumption, the resistance values can be increased by orders of magnitude with marginal differences in the cost and other factors.

1.4 Analysis of Component 4: Battery/Battery Capacity

To maximize environmental flexibility while playing Sink or be Sunk, the boards will be battery-powered. Before looking into the specific charging or recharging aspect of the batteries, it is important to first identify the type of battery required and layout the overall battery management. Our team has already selected to use a Lithium Polymer (Lipo) battery; however, we must determine the appropriate capacity. Our team did so by estimating the overall power consumption based on the most power-hungry devices. The LEDs and the Microcontroller will have the largest strain on the batteries.

To calculate the load placed on the batteries by the LEDs we used the specifications for the surface mount LEDs selected in Section 1.1. If the LEDs require 7.8V and 15mA each, and there are at most 128 LEDs on at once, then this requires 14.976W, approximately 15W [28]. Next, to calculate the load from the ESP32, we approximated from the datasheet used in Section 1.2 that under full peripheral load it will use 80mA at 3.3V. Therefore, the ESP32 will use approximately 264mW. Together, these two main power consumers will require 15.264W, rounded to 16W. (To account for the 7.8V and the 3.3V requirements, the LEDs will require a boost regulation circuit and the microcontroller will require a “buck and boost” circuit to maintain 3.3V). The 16W to ultimately power the ESP32 and LEDs will come from a voltage regulator. In order to account for and efficiency discrepancies, we account for a 20% decrease in voltage transfer. Thus, the voltage coming into the regulator should be 1.2 \* 16 = 19.2, which is approximately 20W. Finally, if the nominal voltage for a Lipo battery is 3.7V, the battery capacity must be 5.405A, which we rounded to 6A to account for any transfer deficiencies.

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|  | **6Ah Lipo** | **12Ah Lipo** |
| Cost per unit | $29.95 | (Only available in bulk) |
| Play Time | 1 hour | 2 hours |
| Max Continuous Charge Current | 1C | 3C |
| Standard Charge | 0.2C | 0.3C |

**Table 1.3 - Lipo Battery Capacity Comparison**

Above are two available battery options. Unfortunately, the 12Ah Lipo is primarily sold in bulk, and otherwise very far outside of our price range [31]. The 6Ah Lipo is sufficient because it will be able to uphold the strain from the LEDs for an hour [29]. Additionally, it is important to note that a game of Sink or be Sunk should average around 45 minutes if both players are actively engaged. On top of this, only in extremely rare cases will more than 100 LEDs be on at one time. Thus, if we continue to take the battery approach, it makes the most sense to continue with the 6Ah Lipo battery.

1.5 Analysis of Component 5: Battery Charge Management Controller

Once we have determined the type of battery best suited to our project, we are able to identify the best methods of charging or recharging the battery. By analyzing different ICs from popular battery charge management systems, we can focus on which aspects are more relevant to our needs. To preserve the lifespan of our batteries, proper charging procedures, such as preconditioning and constant charge, must be considered. Additionally, having a battery charge management controller capable of programmable current values and voltage regulations will be extremely beneficial for testing and debugging later.

The first option for a battery charge management controller is the MCP73833 IC. This chip is equipped with many desirable specifications, in particular the programmable options for the current during constant-current charge mode and voltage during the constant-voltage mode. Preconditioning of the battery begins when the battery is at a low state of charge, then switches into the constant-current charging once the threshold has been reached. The constant-current charging takes place until the voltage regulated value is met – this methodology of charging is utilized by all chips. By allowing our team to manipulate the regulated voltage and current during these times, we will be able to best preserve the battery life, and determine the proper balance of preconditioning, fast charging, and constant-voltage charging. Another feature of this chip is the Reverse-Blocking protection, which prevents the accidental discharging of the battery due to a shorted or potentially damaged input to the IC. The Undervoltage Lockout (UVLO) also protects the battery lifespan by maintaining “shutdown” mode until the input voltage is above the UVLO threshold and returns the battery to “shutdown” mode if the battery voltage is within 50mV of the input supply.

The next option is the MAX1811ESA. This chip is the most expensive of the options provided but has a wide range of capabilities. Similar to the MCP73831, it has the UVLO and thermal regulation features, but also over current protection. Something else unique to this chip is the precision of the battery regulation voltage; while it has fewer programmable options, it has the most accurate response. The constant-current charging is more limited than the MCP73833, however it still offers a large range of programmable values. One significant constraint of this chip is that it is specifically for lithium-ion batteries.

The final option is the MCP73831. This is extremely similar to the MCP73833, with a few changes that make it the most affordable option. The selection for voltage values during constant-voltage charging is the same, with the same tolerance, however the programmable values for the fast charging are only between 15mA and 100mA; granted, this is still more than the MAX1811ESA. Moreover, the MCP73833 features preconditioning configurations based on the selected current and voltage ratings whereas the MCP73831 has selectable preconditioning values and end-of-life values. Ultimately, these features can further support the lifespan of the battery, if properly adjusted.

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| --- | --- | --- | --- |
|  | **MCP73833** | **MAX1811ESA** | **MCP73831** |
| Cost per unit | $1.12 | $3.35 | $0.69 |
| Input Supply Voltage | 3.75V – 6V | 4.35V – 6.50V | 3.75V – 6V |
| Supply Current | Charging (max): 3000 μA | Charging (max): 2mA | Charging (max): 1500μA |
| Thermal Regulation | Yes | Yes | Yes |
| Protection Types | UVLO Start: 3.4V to 3.7V  UVLO Stop: 3.3V to 3.6V  UVLO Hysteresis: 100 mV  Thermal Regulation  Reverse-Blocking | UVLO: 3.75V to 4.35V  UVLO Hysteresis: 50 mV  Over Current  Thermal Regulation | Over Voltage  Reverse-Blocking |
| Battery Type | Lithium Ion / Polymer | Lithium Ion | Lithium Ion / Polymer |
| Max Current Charge | 1A | 500mA | 500mA |
| Programmable Charging Features | Constant- Current, Constant-Voltage | Charge-Current  (100mA or 500mA),  Constant-Voltage | Constant- Current (15mA to 500mA), Constant-Voltage |
| Battery Regulation (Constant) Voltage | 4.2V, 4.35V, 4.4V, or 4.5V with tolerance of ± 0.75% | 4.1V or 4.2V with 0.5% battery regulation voltage accuracy | 4.2V, 4.35V, 4.4V, or 4.5V with tolerance of ± 0.75% |

**Table 1.4 - Battery Charge Management Controller Comparison**

Overall, the chip best suited for our project is the MCP73833. Pricewise, this chip falls between the most expensive and most affordable options, while providing the battery protection features and programmable constant-current and constant-charge values. On top of this, because it has a max current charge of 1A and programmable constant-current values, charging the 6Ah battery will be quicker. This battery charging management controller will effectively support our game by maintaining battery lifespan and charge efficiency.

However, it is important to note that after further investigation of Section 1.4 and 1.5, it appears that it may be more beneficial to make Sink or be Sunk a wall-powered game. In doing so, this may decrease the cost of components and increase play time (by avoiding the time to play). This exercise has been critical in our decision-making process and helped us identify potential areas of instability or shortcomings within our decision. Moving forward, we will continue to explore these options and the pros and cons of restricting gameplay to being wall powered.

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