California State University Chico

# Engineering Requirements Document (ERD)

# ULAMA

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Version 3: 03 - 30 - 2023 Version 4: 04 - 07 - 2023

Version 5: 04 - 20 - 2023 Version 6: 04 - 30 - 2023 Version 7: 10 - 15 - 2023

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# 1. Product Definition

## *1.1. Summary*

Based on a traditional American Indian sport called ōllamalīztli, the product replicates gameplay of this 4,000-year-old sport in a tabletop format. The product's objective is to use displacement sensors to detect when a player strikes a goal on the tabletop court. When a sensor is activated the LEDs, a screen and a speaker will become operational.

## *1.2. Identification*

Ulama: A Table Top Game.

## *1.3. Users*

Customers for Ulama, a tabletop game, have been identified as those who are usually interested in playing tabletop games such as Battleship, or arcade-style games such as pinball. While this product will be a tabletop game it has appeal for console and hand-held digital gamers as well. This was based on feedback from market research. Due to small parts and electronics the lower age limit was determined to be around 9 years of age.

## *1.4. Interfaces*

Users will turn Ulama on/off with a pushbutton, and is recommended for indoor use. An NFC reader will be embedded, into the wall that will read an NFC tag each player will use for the duration of the game. Two, 3D-printed obstacles, will be placed by the defending team in the defensive zone. Two, 3D- printed, goals will be located along the sides such as in a traditional ōllamalīztli court. A wildcat ball tee will be placed in the offensive zone by the player currently attempting to score points. While on the offensive players will place a ball on the top of the wildcat's head and flick it towards the game's goals. To use Ulama the battery will need to be charged.

## *1.5. User Requirements*

Due to small parts and electronic components the age limit is 9+ years of age. Hand-eye coordination is required to place obstacles, wildcat tee, game ball, and to launch the ball toward a goal. The game is accessible to those with slight to moderate vision impairment due to the design of buttons, and game pieces. Potential users who have seizures triggered by flashing lights are advised to play with caution since there will be flashing LEDs when goals are scored. Users must be able to lift 5 pounds, the maximum weight of the game.

## *1.6. Customer Needs*

*1.) Cost*

a. Under $70 to remain competitive with console games.
b. Between $45 - $50 to remain competitive with traditional board games.
c. Less than $1000 to remain competitive with classical pinball machines.
d. Up to $200 if the novelty of the game is intriguing enough, is designed like a table top pin ball style game.

*2.) Portability*

a. Game Board Footprint

i. Big enough for players to move ball tee, obstacles and goals around board.

ii. Not to small that the game board feels crowded.

iii. Must fit on a small desk or table.

iv. Weigh less than 10 pounds.

b. Long Term Storage

i. Container for storing is sturdy, not awkward when stacked, and small.

ii. Easy to put away, separate locations for pieces to be housed.

iii. Piece design to accommodate how it will be stored.

c. Game Board Pieces

i. Heavy enough to withstand impacts without falling over.

ii. Nothing too small that poses a choking hazard.

iii. Circuitry interfaces are robust and don't break.

d. Setup & Teardown

i. Circuitry must withstand multiple setups and tear downs.

ii. Internal wires aren't exposed.

*3.) Engagement*

a. Audio

i. Speakers play several sounds during game play, turn on, shut down, etc.

b. Visual

i. LEDs display colors at different time intervals.

ii. Display score on screen.

iii. LEDs light up when someone scores.

c. Tactile

i. Obstacles, NRC tags, the ball and ball tee.

d. Digital

i. NFC reader, optional ideal functionality implemented to set up teams and players.

4*.) Power*

a. USB 3.0 and/or USB-C Rechargeable battery to power microcontroller LEDs, Display, Speaker and goals.

b. Small enough to be housed in the ball-court's compartment that will also house the microcontroller.

c. Affordable and easy to replace.

d. Average Components require 3 - 5 volts.

e. Fast charging less than 2 hours for 80% charge.

f. Minimum 5,000 mAh (~5 hours of game play), Ideally 10,000 mAh (10 hours of game play).

g. Maximum, marginal, operating temperature at 60° F. Ideal maximum operating temperature 120° F.

*5.) Data storage*

a. Enough local memory to hold current gameplay statistics.
b. Affordable and easy to replace if need be.

*6.) Replacement parts*

a. Ability to affordably and easily replace components, game play pieces if need be.

*7.) Speakers*

a. Loud enough to be heard over typical conversation at 60 dBs.
b. Adjustable based on environment, indoors to outdoors 50 - 65 dBs.
c. Powered by 3.3 volts.
d. Maximum, marginal, operating temperature at 80° F. Ideal maximum operating temperature 120° F.

*8.) Display*

a. Bright enough to be seen indoors up to 2400 lumens.
c. Powered by 3 or 5 volts.
d. Maximum, marginal, operating temperature at 80° F. Ideal maximum operating temperature 120° F.

*9.) Microcontroller*

a. Several $I^2C$, UART and SPI pins to control all components.
b. Must have Several PWM and General Purpose pins to control speakers, sensors and LEDs.
c. Must provide 3 and 5 volt power supply for component needs.
d. Maximum, marginal, operating temperature at 80° F. Ideal maximum operating temperature 120° F.

*10.) Near Field Communication (optional ideal functionality)*

a. $I^2C$, or SPI pins to communicate with microcontroller
b. Reader is powered by 3 or 5 volts.
c. Tags that can be read a maximum distance of 10 centimeters.
d. Type 1 - Type 4 RFID and NFC tag compatibility.
e. Maximum, marginal, operating temperature at 80° F. Ideal maximum operating temperature 120° F.

*11.) Displacement Sensors*

a. Vibrational displacement sensor

b. Powered by 1 - 3 Volts.

c. Provide 1 - 2 Amps of current.

d. Maximum, marginal, operating temperature at $80^{o}$ F. Ideal maximum operating temperature $120^{o}$ F.

*12.) Ball Launcher*

a. Easy to load a ball.

i. 3 - 15 grams.

b. Launch around 0.001 meters per second.

c. Safety latch to prevent misfires when being handled.

*13.) LEDs*

a. Addressable/Programmable.

b. Red, Green and Blue diode LED for multicolor options.

c. Fade in and Fade out functionality.

d. Maximum, marginal, operating temperature at $80^{o}$ F. Ideal maximum operating temperature $120^{o}$ F.

# 2. Project Definition

## *2.1. Summary*

Ulama features a backlit display that will present a welcome message, a running count of goals scored, and a goodbye message. When a goal is scored the display will update the total points, a speaker will play a sound, and LEDs will flash. When the game turns on a speaker will play a welcome tone, and LEDs will turn on. When the game turns off the speaker will play a second tone, the display will say goodbye, and the LEDs will turn off. Ulama will have a minimum of two goals and two obstacles. Pushbuttons will turn the game off and on.

## *2.2. Constraints and Limitations*

Ulama is constrained by expected weight limit, footprint, and time-to-market deadlines. For portability, the intended customers require the game to weigh no more than 5 pounds. The portable design of Ulama will depend upon the proper implementation of a battery pack.  This game must be small enough to be set up in a variety of settings, so a footprint of 18 inches wide, 24 inches long, and 14 inches high is the goal. Ulama will need to be self-standing, like a traditional pinball machine, if theses parameters are not met. Due to the 13-week deadline, Ulama must utilize 3D-printing technology to create the game board and gameplay pieces. Using additive manufacturing will ensure the project timeline proposed in section 2.7 will be met.

Ulama has a couple of limitations including the microcontroller and optional functionalities listed in sections 1.4 and 1.6. The Ulama proof of concept prototype will use the TIVA TM4C123 microcontroller because this component has more than the required 20 pins for this project. In the future, Ulama may be implemented using the ATmega328P, an 8-bit microcontroller that has 23 GPIO pins, $I^2C$, and SPI interfaces.

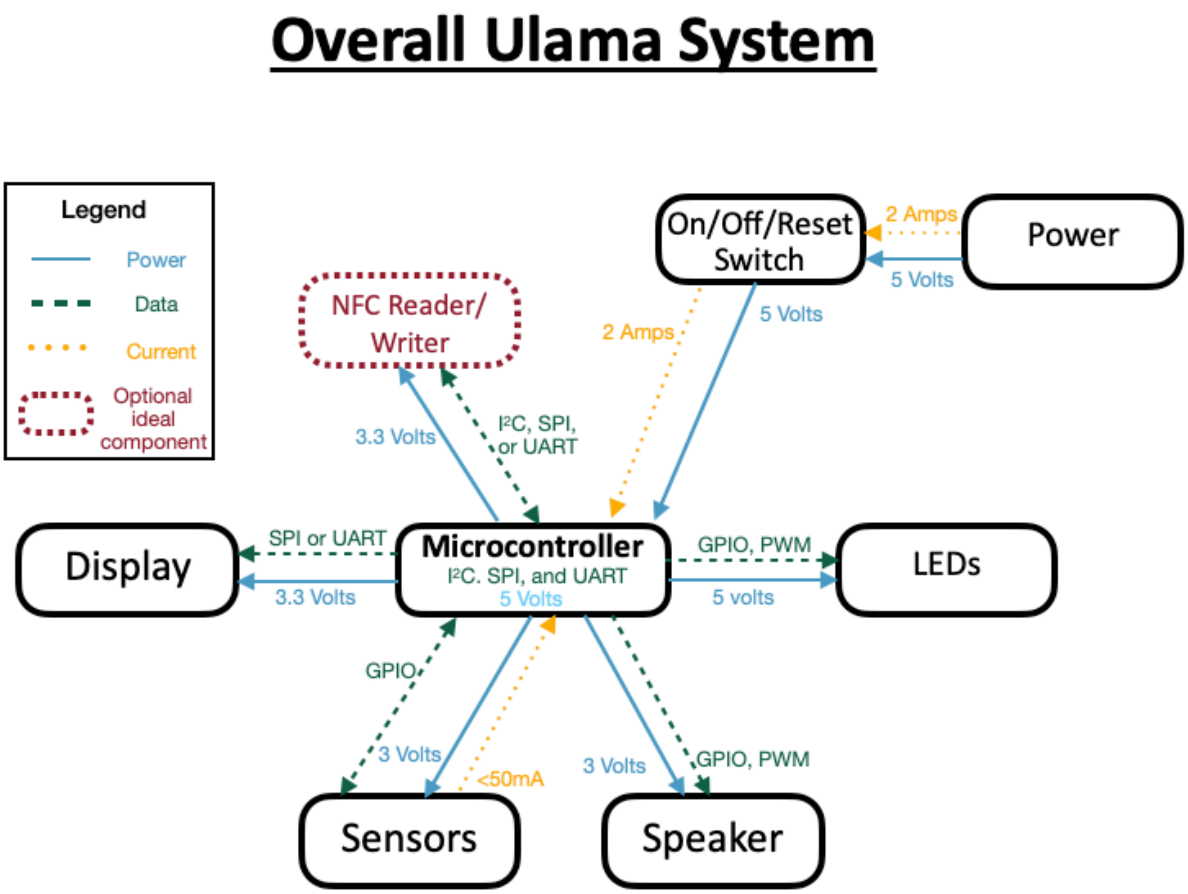
Optional functionality limitations may exist when concerning the implementation of color displays, and an NFC tag reader to set up the game. Ideally, a color display capable of presenting animations and color logos would be implemented. $I^2C$, UART, and SPI will be a major factor in determining what component will be used. The display will be based on the most power efficient component with a long life cycle, to meet customer needs presented in section 1.6. The minimum requirements for the display will be a 16 character, 2 line LCD screen.

Ideally, an NFC tag reader/writer would be implemented to keep track of gameplay statistics such as win/loss records, switch team logos, and team color during gameplay. To overcome this possibility the minimal design of Ulama will not require players to sign in or set up the game in any way.

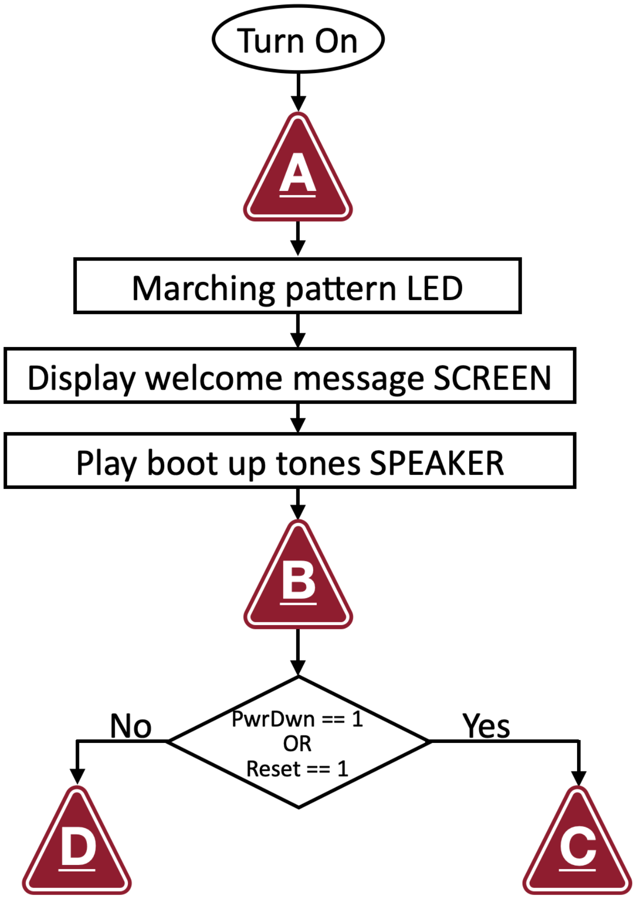
### *2.3. Assumptions and Dependencies*

Successful Ulama performance will depend on a commercially available USB rechargeable battery pack, LCD, and LEDs. It is assumed that Ulama will operate both indoors and outdoors but not in temperatures above $100^{o}$ F or the rain, and that it will be placed on a sturdy table large enough to hold five pounds or more. Interacting with Ulama will require users to recognize symbols for “on/off” to turn the game on/off. If the 16 X 2 LCD screen is implemented Yoeme phrases will be used for greetings (Tevote), see you later (Ito te vitne), and you may rejoice, (Empo allea) when a goal is made. Other game prompts such as next player, or reset and quit options will be presented in English.

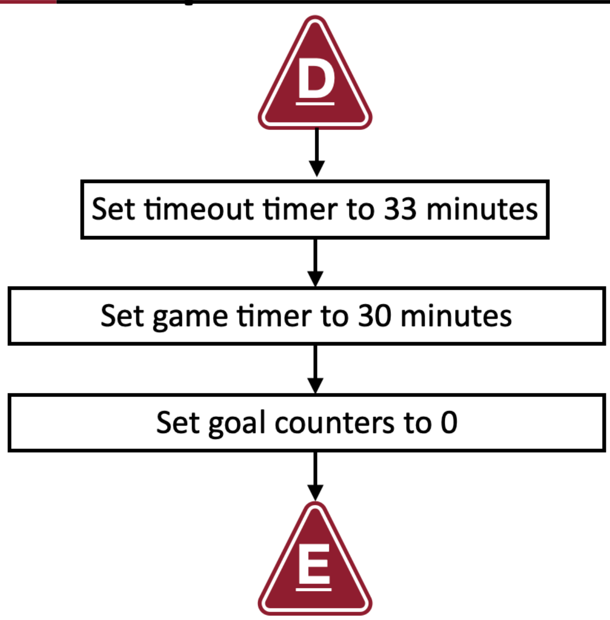
## *2.4. Architecture*



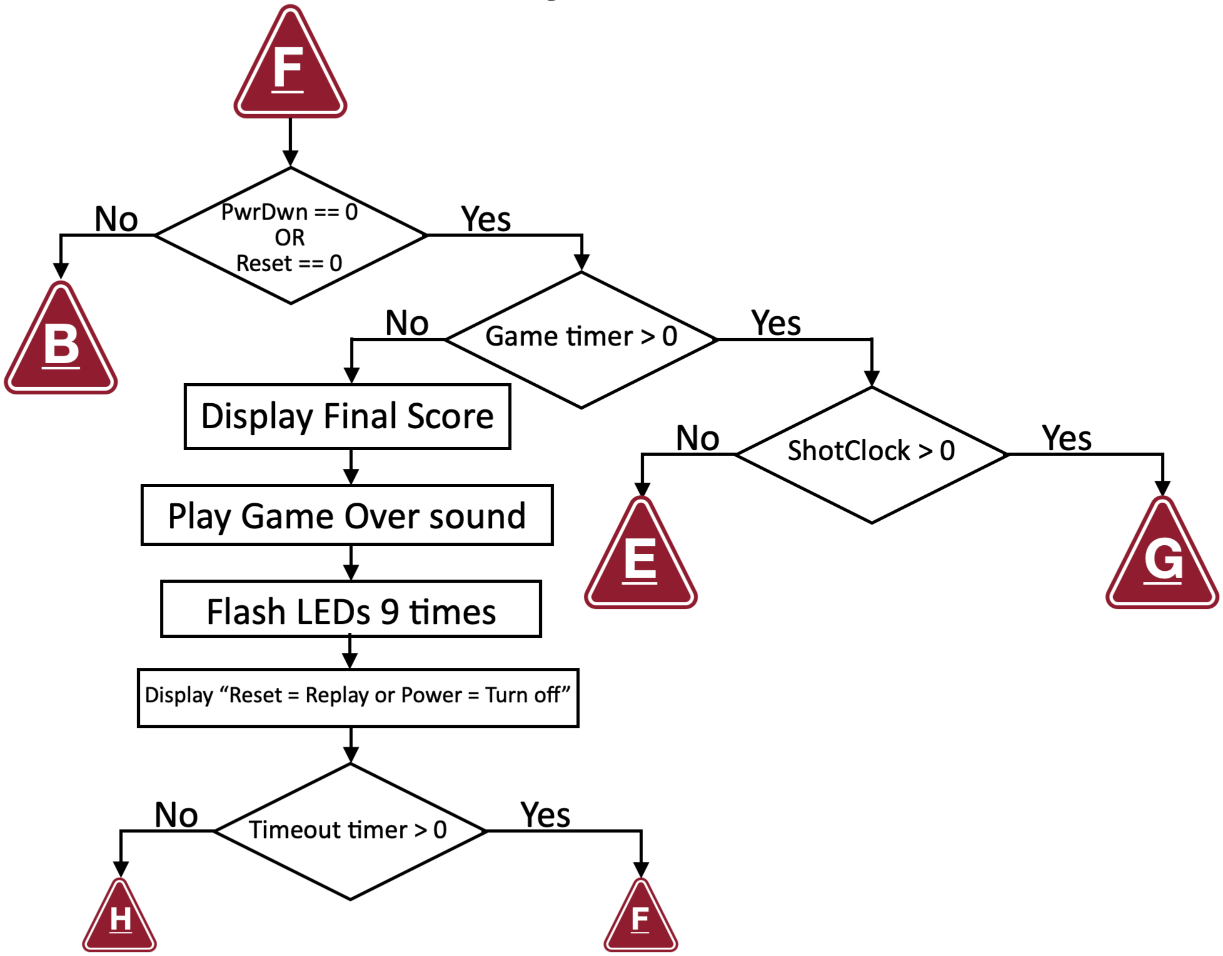
# Ideal Booting up Software Flowchart



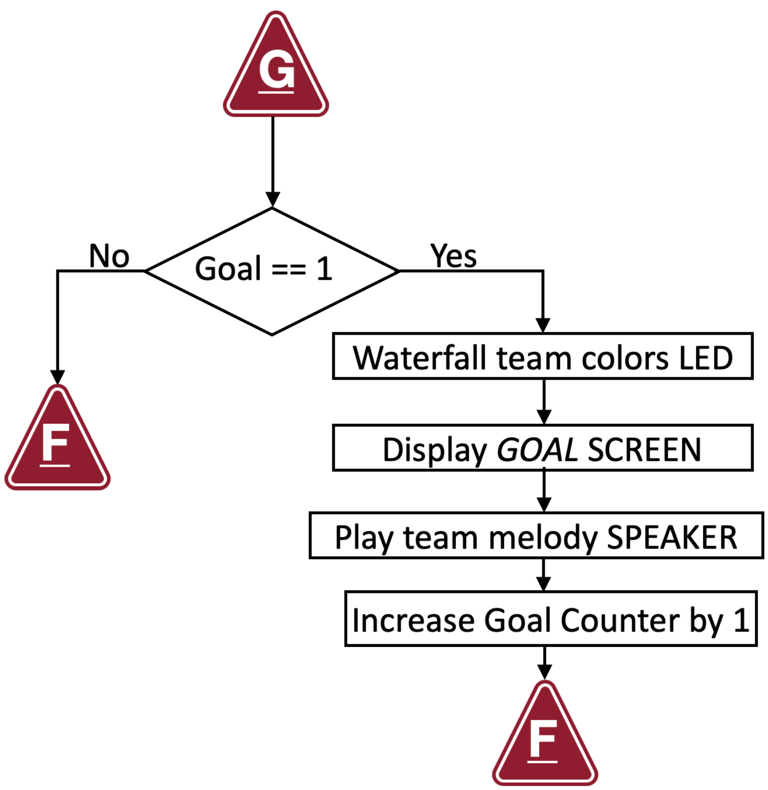

# Ideal Setup Software Flowchart



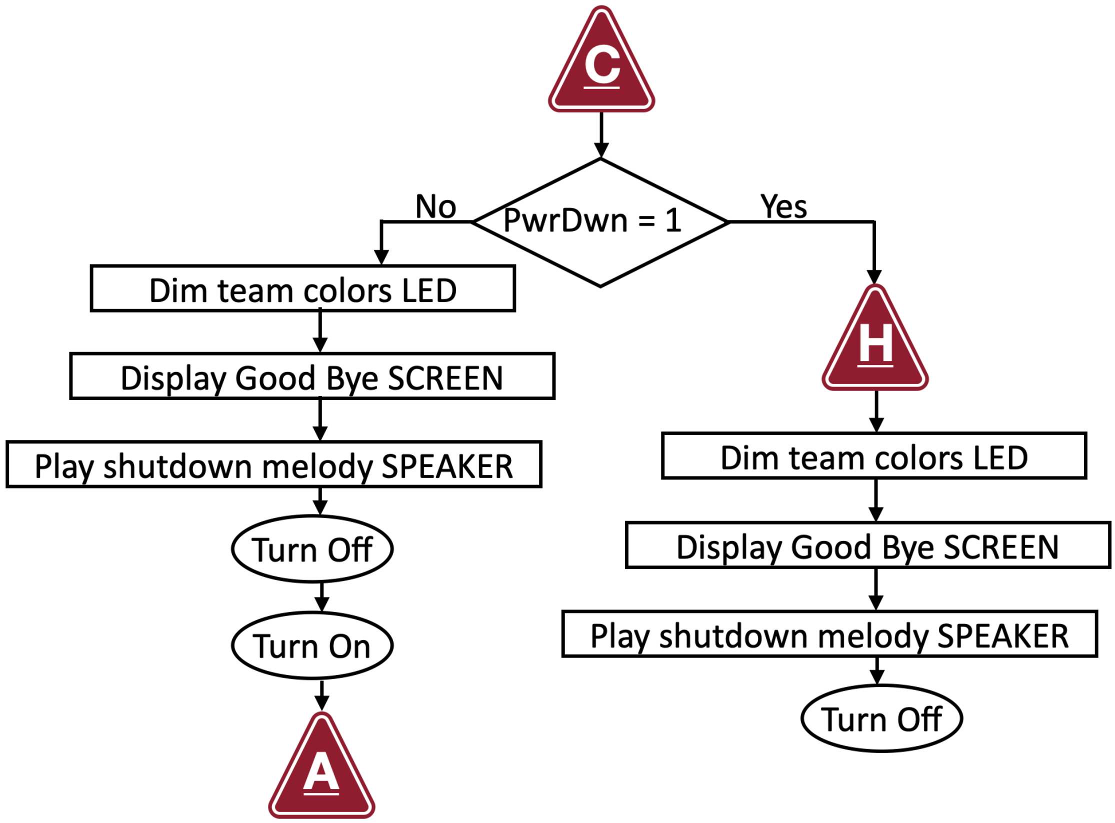
# Ideal Game Play Software Flowchart



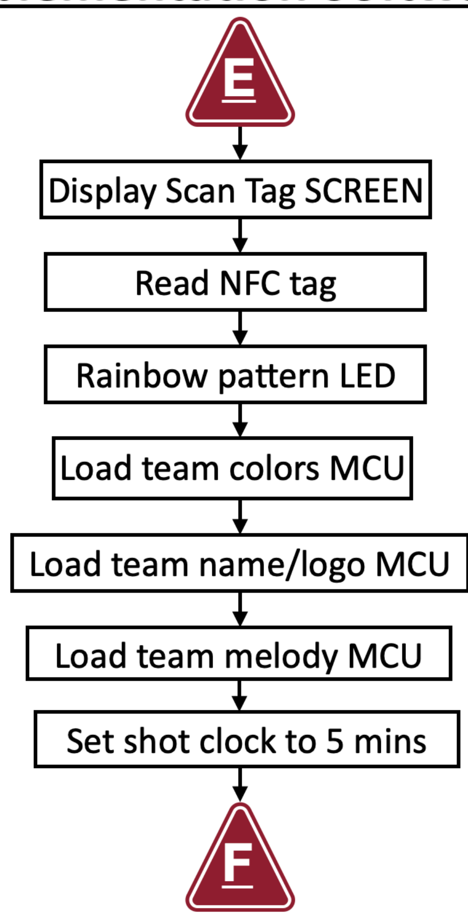

# Ideal Goal Software Flowchart



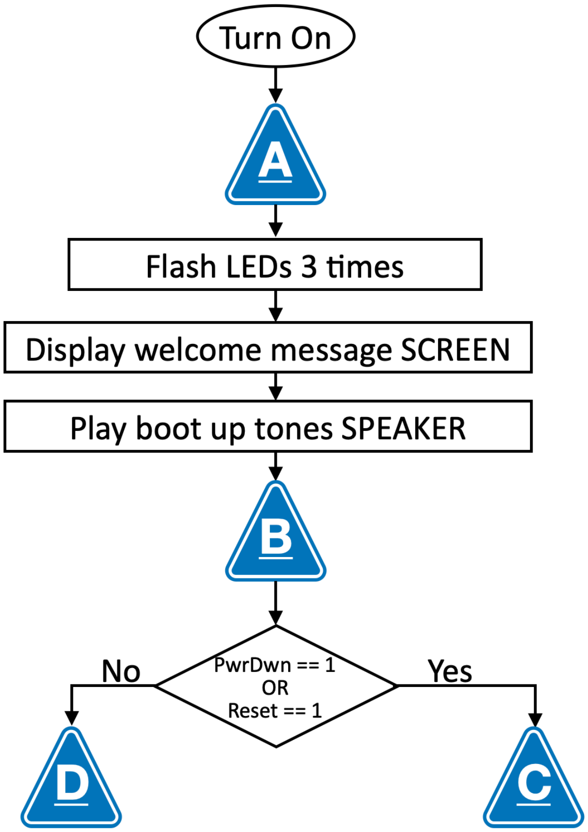
# Ideal Shutdown Software Flowchart



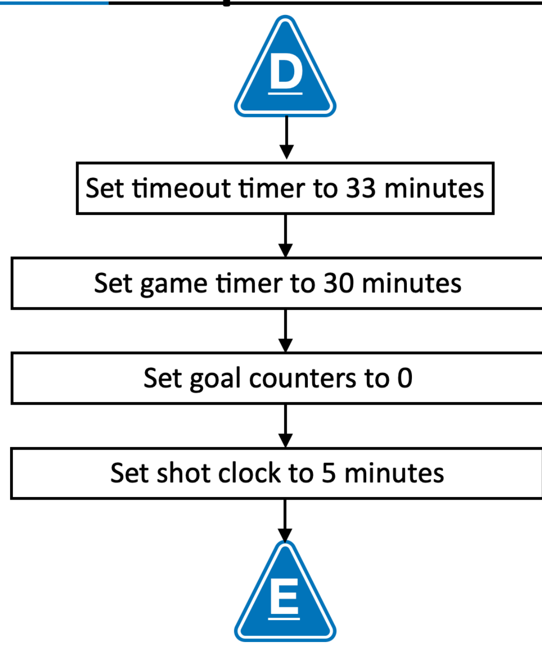

# Ideal NFC implementation Software Flowchart



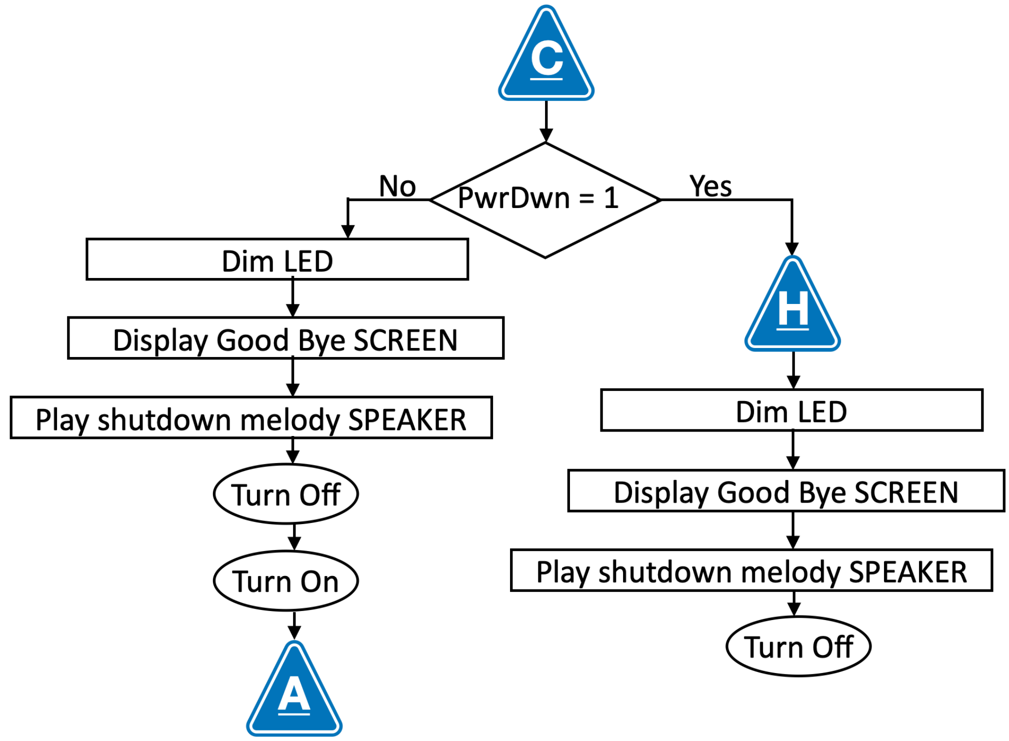
# Minimum Booting up Software Flowchart



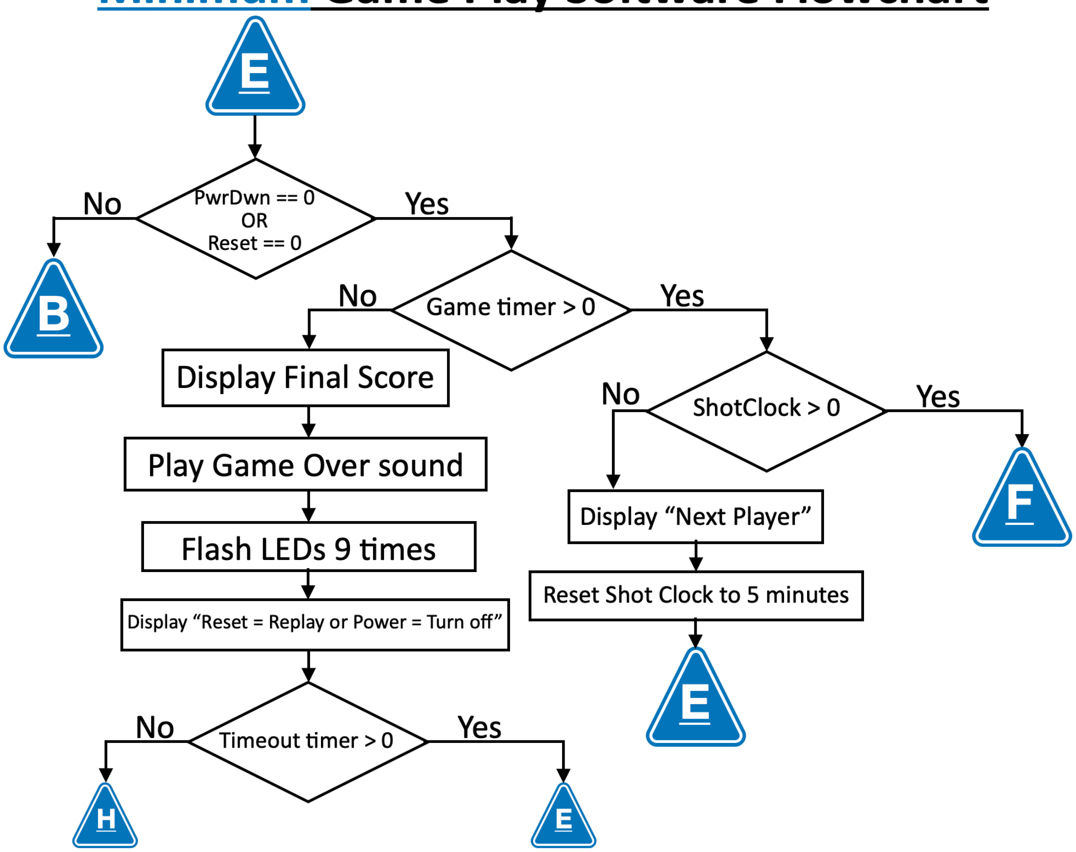

# Minimum Setup Software Flowchart



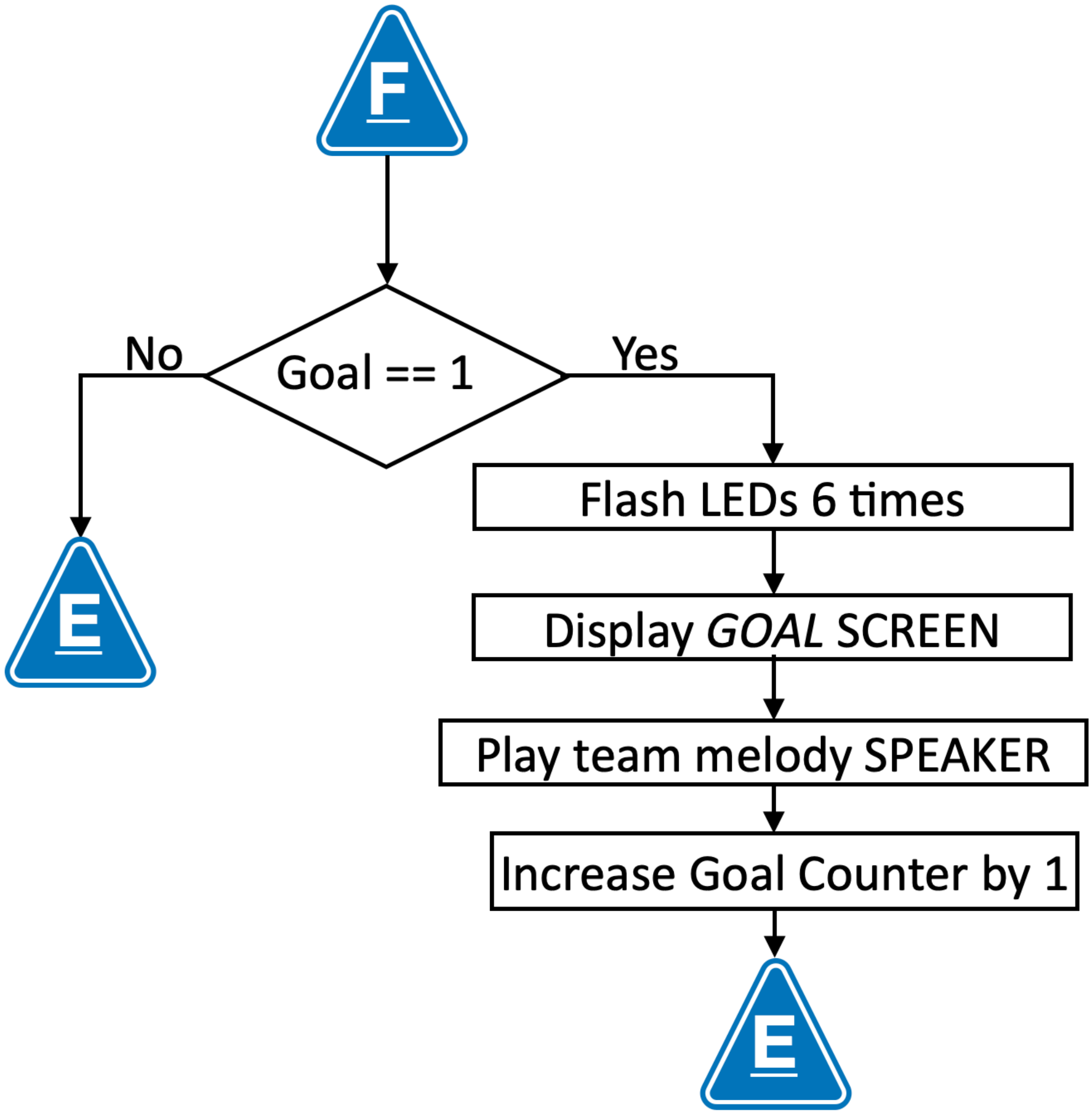
# Minimum Shutdown Software Flowchart




# Minimum Game Play Software Flowchart



# Minimum Goal Software Flowchart




### *2.5. Design Alternatives*

There are two major design alternatives for Ulama which concern communication protocols and displacement sensors. The minimal requirement for communication between peripherals would be using the GPIO pins on the TIVA TM4C123 microcontroller allowing the design to implement a 16 X 2 LCD, single color 5 mm LEDs, and a speaker. Displays with a full range of colors, and multi-color 5 mm LEDs would be ideal for Ulama. The second alternative design factor for Ulama concerns the displacement sensors which trigger most of the peripherals such as the screen, LEDs, and speaker. A slide potentiometer would meet the minimum requirements to determine when a player scores but would increase the goal component's footprint and ball weight. Slide potentiometers would also require the design of additional mechanical systems to reset the slider's location, and the tee would need to be redesigned to launch a heavier ball. The ideal displacement sensor is a vibration sensor because of the sensitivity and small footprint. Contactless or vibration sensors both will reduce goal component footprint and internal PCB.

### *2.6. Specifications*

General specifications for the project derived from customer needs section 1.6 of this report. Market research conducted in person, as well as online, formed the basis when developing metrics to address customer needs.

Target Specifications

| Metric Number | Need Number | Metric | Units | Marginal Value | Ideal Value |
|---|---|---|---|---|---|
| **1** | 4a, 4b, 4c | Power System | Charges | 100 | 250 |
| **2** | 4f | Battery Operation | mAH | 5,000 | 10,000 |
| **3** | 11d | Battery Output | A | 1 | 2 |
| **4** | 4d, 7c, 8c, 9c, 10b, 11c, 13c | Battery Output | V | 3 | 5 |
| **5** | 7a, 7b, 7c | Speaker Voltage | V | 1 | 3 |
| **6** | 7a, 7b, 7c | Speaker Current | mA | 125 | 707 |
| **7** | 8a, 8b, 8c | Display Voltage | V | 3.3 | 3.3 |
| **8** | 8a, 8b, 8c | Display Current | mA | 1.5 | 2.5 |
| **9** | 4d, 7c, 8c, 9c, 10b, 11c, 13c | Microcontroller Voltage | V | 3 | 5 |
| **10** | 4, 7, 8, 9, 10, 11, 13 | Microcontroller Current | mA | 12 | 15 |
| **11** | 13c | LED Voltage | V | 3.3 | 5 |
| **12** | 13 | LED Current | mA | 45 | 50 |
| **13** | 11c | Displacement Sensors Voltage | V | 3.3 | <12 |
| **14** | 11d | Displacement Sensors Current | mA | 25 | <50 |
| **15** | 10b | NFC Voltage | V | 3.3 | 3.3 |

| Metric Number | Need Number | Metric | Units | Marginal Value | Ideal Value |
|---|---|---|---|---|---|
| **16** | 9a, 9b | Microcontroller Protocols | N/A | 2 $I^2C$<br>UART<br>2 SPI pins | 3 $I^2C$<br>3 SPI pins |
| **17** | 10, 11 | Microcontroller response time | ms | 2 | 2 |
| **18** | 7, 9b | Protocol to Speakers | N/A | 2 GPIO | 4 GPIO pins |
| **19** | 8, 9a | Display Protocol | N/A | 16 GPIO pins | 6 SPI pins |
| **20** | 9a, 9b, 13 | LED Protocol | N/A | 3 GPIO pins | 2 $I^2C$ pins |
| **21** | 9b, 11 | Displacement Sensor Protocol | N/A | 4 GPIO pins | 8 GPIO pins |
| **22** | 9a, 10a | NFC Tag Type 1- 4 Protocols | N/A | 2 $I^2C$ pins | 5 SPI pins |
| **23** | 7a, 7b | Speakers Volume | dB | 50 | 65 |
| **24** | 8a, 8b | Display Brightness | Lumens | 2398 outdoors<br><br>1000 indoors | Dimmable from 1000 - 3000 |
| **25** | 5 | Microcontroller memory | GB | 0.128 | 3 |
| **26** | 3ai, 3bi, 3bii, 3biii, 3c | Displacement Measurements | mm | 1 | 0.5 |
| **27** | 3d, 10a, 10c, 10d | NFC tag distance | cm | 10 | 3 |
| **28** | 2a, 2b, 2c | Game dimensions | in | 18 x 24 x 12 (court) | 26 x 26 x 12 (court) |
| **29** | 2aiv,2ci, | Game weight | lbs | 10 | 5 |
| **30** | 1a, 1b, 1c, 1d | Cost | US $ | 90 | 200 |
| **31** | 1a, 1b, 1c, 1d, 6 | Replacement Parts | US $ | 5 - 10 | 10 - 15 |
| **32** | 2, 4g, 8d, 9d, 10e, 11e, 13d | System Operating Temperature | $^oF$ | 60 - 80 | 60 - 120 |

## *2.7. Project Schedule*

1.
    a. Program turn on, turn off, and goal pattern and colors.
    b. Program NFC functionality patterns.
    c. Program NFC functionality team colors.
2.
    a. Program three different tones for speaker.
    b. Program several melodies using PWM for multiple NFC uploaded teams.
3.
    a. Program turn on, turn off, and goal messages.
    b. LEDs and speaker are triggered by displacement sensor.
    c. Program NFC to read tags and call functions to load team assets.

4. Program displacement sensor interrupts and timeout.

5. Program timers, shutdown, reset, and counters.

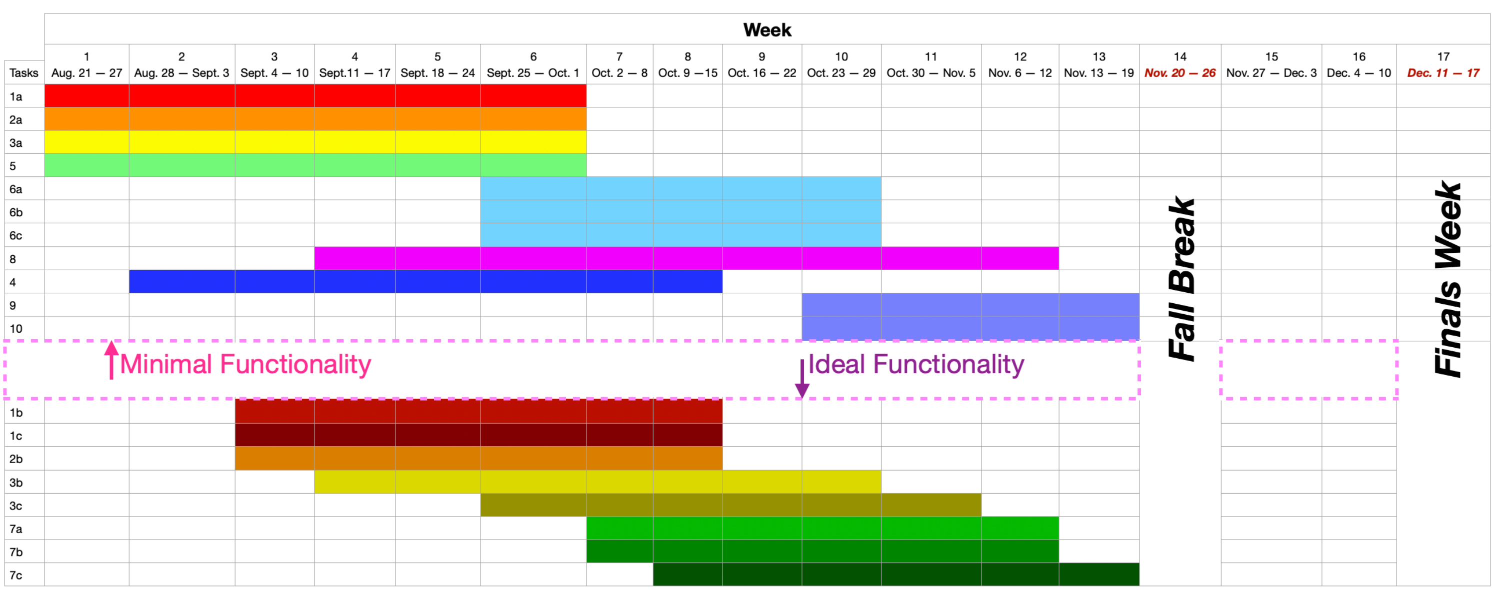
6.
    a. Design and 3D print game board.
    b. Design and 3D print goal components.
    c. Design and 3D print moveable obstacles.
7.
    a. Program display to switch between full color logos when NFC is read.
    b. Program display to show updated goal counter when displacement sensor is triggered.
    c. Program NFC to write Tags updating tag statistics like high-score, and games played.

8. Design and fabricate goal displacement PCBs.

9. Create Poster.

10. Create Presentation slide deck.

Revised Ulama Production Schedule Fall 2023



### 2.8. Prototype Costs

In this bill of materials for the prototype of Ulama items for minimum functionality is highlighted in yellow, and ideal functionality are highlighted in blue. The red highlighted row indicates components already owned that will not need to be purchased for the prototype. Included in the maximum discount are discrete, diffused 5 mm LED because these are also already owned. It was more important to highlight this item as a minimum functionality component even though it is also already purchased.

| Quantity | Description | Vendor | Part Number | Unit Cost | Line Cost |
|---|---|---|---|---|---|
| 1 | 16X2 LCD | DFRRobot | DFR0063 | 9.90 | 9.9 |
| 1 | Adafruit 1.47" TFT Display | Adafruit | 5393 | 17.50 | 17.5 |
| 1 | 5 color Diffused 5 mm LED QTY 25 | Adafruit | 4203 | 4.95 | 4.95 |
| 50 | LED Super Bright RGB Diffused 5 mm Common Cathode 4 pin | Jameco | 2219559 | 0.89 | 44.5 |
| 2 | 10 mm Mini 8 Ohm Speaker | Mouser | SPKM.10.8.A | 1.67 | 3.34 |
| 1 | USB Battery Pack for Raspberry Pi 10,000mAH 2 x 5v outputs | Adafruit | 1566 | 39.95 | 39.95 |
| 2 | 16 mm illuminated Pushbutton Blue | Adafruit | 1476 | 1.95 | 3.9 |
| 1 | 3D-printed game board components (estimation) | CSU Chico's 3D Printing Club | N/A | $60 | $60 |
| 10 | Vibrational Displacement Sensor | Adafruit | 1766 | 0.95 | 9.5 |
| 1 | 100 FT 30 AWG tinned copper wire | Jameco | 22542 | 12.95 | 12.95 |
| 1 | TRF790A Booster Pack | Mouser | 595-DLP-7970ABP | 38.57 | 38.57 |
| 15 | MCP6004 Op-Amp | Mouser | 579-MCP6004-I/SL | 0.54 | 8.1 |
| 20 | 2N3904 NPN Transistor | Mouser | 512-2N3904TFR | 0.23 | 4.6 |
| 2 | 220 Ω Resistor set of 50 | Vilros | VILP080 | 3.99 | 7.98 |
| 60 | 180 Ω Resistor | Digi-Key | CF14JT180RCT-ND | 0.031 | 1.86 |
| 3 | Copper Clad Boards double Sided 4x6 1/32 in. | Mouser | 590-587 | 13.39 | 40.17 |

| | | | | | |
|---|---|---|---|---|---|
| 1 | 0.003 PCB Engraving Bit | Bantum Tools | | 28 | 28 |
| 1 | MiFare Classic NFC 13.56 MHz 1k 10 pack | Amazon | | 7.90 | 7.9 |
| **Total Cost minimum functionality with 3D-printed components** | | | | | 154.08 |
| **Total Cost ideal functionality, with 3D-printed components** | | | | | 328.82 |

# 3. References and Standards

## *3.1. References*


[1] M. Crescentini, S. Syeda, and G. Gibiino, "Hall-Effect Current Sensors: Principles of Operation and Implementation Techniques," *IEEE Sensors Journal,* vol. 22, no. 11, June 2022.

[2] A. Karsenty, "A Comprehensive Review of Integrated Hall effects in Macro-, Micro-, Nanoscales, and Quantum Devices," *MDPI Sensors,* vol. 20, no. 4163, July 2020.

[3] W. Sriratana, and R. Murayama, "Application of Hall effect Sensor: A study on the Influences of Sensor Placement," In Proc. IEEE International Symposium on Industrial Electronics (ISIE), Taipei, Taiwan, 2013.

[4] Honeywell Technical Staff, *Hall effect Sensing and Application,* Honeywell International Inc.

[5] C.Zheng, K. Zhu, J. Davies et. Al, "Advances in Magnetics: Magnetoresistive Sensor Development Roadmap (Non-Recording Applications)," *IEEE Transaction on Magnetics,* vol. 55, no. 4, April 2019.

[6] J. Lenz, " A review of Magnetic Sensors," In Proceedings of the IEEE, vol. 78, no. 6, June 1990.

[7] D. Partin, J. Heremans, C. Thrush, and L. Green, "Magnetoresistive Sensors," 6th Technical Digest IEEE Solid-State and Actuator Workshop, Hilton Head, SC, USA June 1992.

[8] J. Lenz, G. Rouse, L. Strandjord, B. Pant, A. Metze, H. French, E. Benser and D. Krahn, "A High-Sensitivity Magnetoresistive Sensor," 4th Technical Digest IEEE Solid-State and Actuator Workshop, Hilton Head, SC, USA June 1990.

[9] "Decibel Scale," soundear.com, [Online]. Available: https://soundear.com/decibel-scale/ [Accessed Mar. 5, 2023].

[10] I. Kilin, “The best charts for color blind viewers,” datylon.com, [Online]. Available: https://www.datylon.com/blog/data-visualization-for-colorblind-readers [Accessed Mar 6, 2023].

[11] C. Winske, “Understanding Brightness in Outdoor Displays,” mytechdecisions.com, April 7,2014. [Online]. Available: https://mytechdecisions.com/video/understanding-brightness-in-outdoor-displays/ [Accessed Mar. 5, 2023]

[12] H.Colorado, E Gutierrez Velasquez, S Monteiro, “Sustainability of additive manufacturing: The circular economy of materials and environmental perspectives,” Journal of Materials Research and Technology, vol. 9, no. 4, p. 8221-8234 June, 2020. [Online]. Available: Science Direct, https://www.sciencedirect.com/science/article/pii/S2238785420312278. [Accessed March 19, 2023].

[13] Z. Liu, Q. Jiang, Y. Zhang, T. Li, H.Zhang, “Sustainability of 3D Printing: A critical Review and Recommendations,” In Proceedings of the ASME International Manufacturing Science and Engineering Conference, Blacksburg, Virginia, USA, June 2016.

[14] D. Lupton, “3D Printing Technologies: Social Perspectives,” Blackwell Encyclopedia of Sociology, [Online]. Available: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2865290. [Accessed March 18, 2023].

[15] R. Jiang, R. Kleer, F. Piller, “Predicting the future of additive manufacturing: A Delphi study on economic and societal implications of 3D printing for 2030,” Technological Forecasting and Social Change, vol. 117, p. 84-97. January, 2017. [Online]. Available: Science Direct, https://www.sciencedirect.com/science/article/pii/S0040162517300276. [Accessed March 19, 2023].

[16] B. Rylands, T. Bohme, R. Gorkin, J. Fan, T. Birtchnell, “3D Printing - To print or not to print? Aspects to consider before adoption - A supply chain perspective,” Australian Institute for Innovative Materials, [Online]. Available: University of Wollongong Australia https://ro.uow.edu.au/aiimpapers/1761/. [Accessed Mar 18, 2023].

[17] M. Gebler, A. Uiterkamp, C. Visser, “ A global sustainability perspective on 3D printing technologies,” Center for Energy and Environmental Sciences Energy Policy, vol. 74, p. 158-167. August 2014. [Online]. Available: Science Direct, https://www.sciencedirect.com/science/article/pii/S0301421514004868. [Accessed March 18, 2023].

[18] K. Pierrakakis, M. Kandias, C. Gritzali, D. Gritzalis, “ 3d Printing and its Regulation Dynamics: The World in Front of a Paradigm Shift,” Proceedings of the 6th International Conference on Information Law and Ethics, p. 1-20, May 2014.

[19] Oxford English Dictionary, Oxford University Press, [Online]. Available: oed.com [Accessed March 18, 2023].

[20] United Nations, “ Pollution Action Note — Data you need to know,” UN Environment Programme, [Online]. Available: https://www.unep.org/interactive/air-pollution-note/. [Accessed March 19, 2023].

[21] National Toxicol Program, “Toxicology and carcinogenesis studies of acrylonitrile in B6C3F1 mice (gavage studies),” October 2001, [Online]. Available: National Library of Medicine, https://pubmed.ncbi.nlm.nih.gov/11803701/. [Accessed March 18, 2023].

[22] G. Ritzer, N. Jurgenson, “Production, Consumption, Prosumption,” Journal of Consumer Culture, January 2015, [Online]. Available: California State University, Bakersfield, https://www.csub.edu/~ecarter2/CSUB%20F18/Production_Consumption_Prosumption.pdf. [Accessed March 19, 2023].

[23] R. Lindsey, E. Dlugokencky, “ Climate Change: Atmospheric Carbon Dioxide,” National Oceanic and Atmospheric Association, June 23, 2022, [Online]. Available: climate.gov, https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide. [Accessed March 19, 2023].

[24] Z. Hu, “I2c Protocol Design for Reusability,” 2010 Third International Symposium on Information Processing, Qingdao, China 2012, pp. 83-86.

[25] D. Trivedi, A. Khade, K. Jain and R. Jadhav, "SPI to I2C Protocol Conversion Using Verilog," 2018 Fourth International Conference on Computing Communication Control and Automation (ICCUBEA), Pune, India, 2018, pp. 1-4.

[26] E. Larsson, P. Murali and G. Kumisbek, "IEEE Std. P1687.1: Translator and Protocol," 2019 IEEE International Test Conference (ITC), Washington, DC, USA, 2019, pp. 1-10.

[27] D. S. Dawoud; P. Dawoud, "Serial Communication Protocols and Standards RS232/485, UART/USART, SPI, USB, INSTEON, Wi-Fi and WiMAX," in *Serial Communication Protocols and Standards RS232/485, UART/USART, SPI, USB, INSTEON, Wi-Fi and WiMAX* , River Publishers, 2020, pp.i-xl.

[28] L. M. Kappaganthu, M. D. Prakash and A. Yadlapati, "I2C protocol and its clock stretching verification using system verilog and UVM," *2017 International Conference on Inventive*

*Communication and Computational Technologies (ICICCT)*, Coimbatore, India, 2017, pp. 478-480.

[29] R. R. Pahlevi, A. G. Putrada and M. Abdurohman, "Fast UART and SPI Protocol for Scalable IoT Platform," *2018 6th International Conference on Information and Communication Technology (ICoICT)*, Bandung, Indonesia, 2018, pp. 239-244.

[30] A. Yadav and U. Mehta, “DESIGN AND SIMULATION OF I2C PROTOCOL”, *IEJRD - International Multidisciplinary Journal*, vol. 6, no. ICMRD21, p. 10, Apr. 2021.

[31] F. Leens, "An introduction to I2C and SPI protocols," in *IEEE Instrumentation & Measurement Magazine*, vol. 12, no. 1, pp. 8-13, February 2009.

[32] Texas Instruments, “TRF7970A Multi-Protocol Fully Integrated 13.56 MHz RFID and NFC Transceiver IC,” TRF7970A Guide, May 2014 [Revised April 2015].

[33] Texas Instruments, “TRF7970A Reader Module Users Guide,” TRF7970A User’s Guide, June 2013 [Revised June 2014].

[34] Texas Instruments, “TRF7970A Multi-Protocol Fully Integrated 13.56 MHz RFID/NFC Transceiver IC Data Manual,” TRF7970A Data Manual, June 2011 [Revised March 2020].

[35] Texas Instruments, “NRC active and passive peer-to-peer communication using the TRF7970A,” NFC Communication Manual, April 2014 [Revised March 2019].

[36] Texas Instruments, “Tiva TM4C123GH6PM Microcontroller,” Tiva TM4C123GH6PM Micro-controller Datasheet, April 2007 [Revised June 2014].

[37] Microchip, “1 MHz Bandwidth Low Power Op Amp,” MCP6001/2/4 Datasheet, 2003.

[38] Cudevices, “Model CMS-402057-18SP,” Speaker Datasheet, July 2023.

[39] Texas Instruments, “xx555Precision Timers,” NA555, NE555, SA555, SE555 Datasheet, September 1973 [Revised September 2014].

[40] Continental Device India Limited, “NPN Silicon Planar Epitaxial Switching Transistors,” 2N3903/ 2N3904 Datasheet, March 2006.

[41] Dongguan Pengyuan Optoelectronices Technology Co. LTD, “5WRGB4-Y-T-CC,” LED Datasheet, August 2023.

[42] ST, “1.2V to 37V Voltage Regulator,” LM117/217/LM317 Datasheet, November 1999.

### 3.2. Standards

Electronic Industries Alliance (EIA) EIA RS-426

National Electrical Code (NEC) Article 411.4

National Electrical Code (NEC) Article 411.6

Underwriters Laboratories Standard (UL) UL 60950

International Commission on Illumination (CIE) CIE 1976

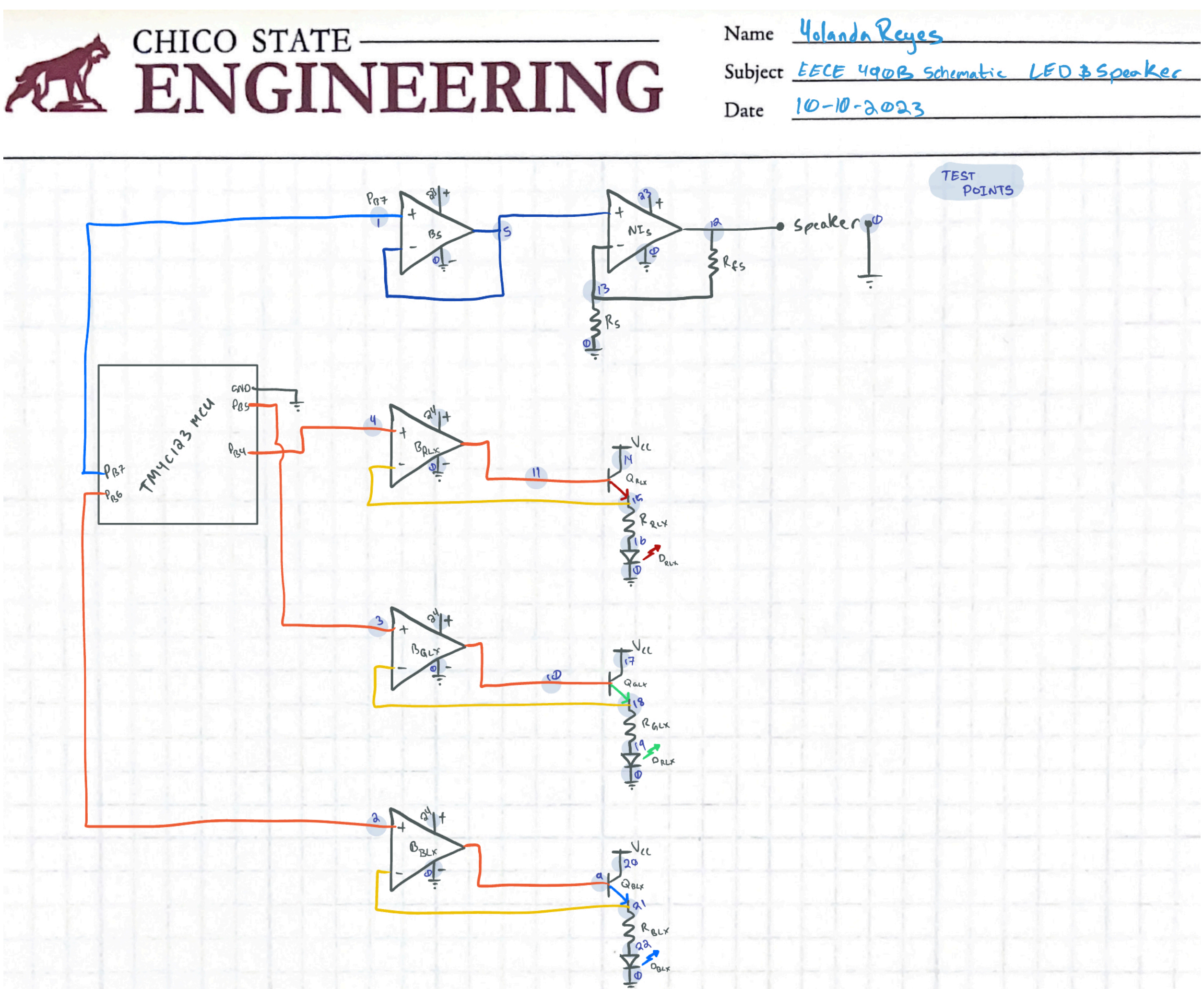
Institute of Electrical and Electronics Engineers (IEEE) 1789

International Standard Organization (ISO) ISO 3744

International Standard Organization (ISO) ISO 18092

International Standard Organization (ISO) ISO 14443

### 3.3. Schematics



# 4. Glossary

| Term or Acronym | Meaning in This Context |
|---|---|
| 3D | Three Dimensional Printing, additive manufacturing |
| ASCII | American Standard Code for Information Interchange |
| cm | Centimeters |
| dBs | DeciBels |
| F | Fahrenheit |
| GB | Giga Bytes |
| gifs | Graphics Interchange Format |
| GPIO | General Purpose Input Output |
| $I^2C$ | Inter-Integrated Circuit |
| IEEE | Institute for Electrical and Electronics Engineers |
| in | Inches |
| LCD | Liquid Crystal Display |
| Lbs | Pounds |
| LED | Light Emitting Diode |
| mAh | Milli Amp Hours |
| mA / mAmps | Milli Amps |
| MCU | Microcontroller Unit |
| mm | Milli Meters |
| mins | Minutes |
| N/A | Not Applicable |
| NFC | Near Field Communication |
| PCBs | Printed Circuit Boards |
| PWM | Pulse Width Modulation |
| RFID | Radio Frequency Identification |
| SPI | Serial Peripheral Interface |
| TFT | Thin Film Transistor |
| UART | Universal Asynchronous Receiver-Transmitter |
| US $ | United States Dollar |
| USB | Universal Serial Bus |
| Yoeme | "The People", Indigenous American Indians found in Sonora, Chihuahua, and Durango Mexico, as well as the Southwestern United States. |

# 5. Appendices

## Appendix A: Displacement Sensor Standards

Ulama will require multiple displacement sensors to detect goals and foul balls. There are two types of displacement sensors contactless and contact under consideration for this project. Potential options for sensors are required to address target specifications 1,6,8,20 and 22 which are directly related to customer needs 1, 2c, 2d,3a, 3b, 3c, 3e, 4b, 4c, 4d 5, 6, 7, 8, 13c, 13d. Literature review was conducted to establish standards for the two types of displacement sensors. In this paper publications from the Institute of Electrical and Electronics Engineers (IEEE) were reviewed since this organization is well known for their global standards of many electrical components. Presented here are standards for two sensors the Hall effect, and Magnetoresistive.

The Hall effect sensor is contactless and found in many applications such as automotive, power electronics and energy conversion [1]. Hall-effect current sensors (HECS) are under consideration because they have good linearity, a large dynamic range and are compatible with silicon based technologies which will be utilized in this project. For HECS output voltage as a function of measurand current is described by the following equation:

$$V_{out} = S^* I + V_{os} + F_{nl}(I) + V_n \qquad (1)$$

$V_{out}$ is the main metric of consideration when implementing these sensors and has units of [V]. References [1] — [4] define six figures of merit when considering HECS which are sensitivity, additive DC offset, nonlinearity, noise, bandwidth and dynamic range.

Sensitivity, S in equation 1, for HECS is described as the ratio between the increment in the output voltage divided by the increment in the measurand current.

Additive DC offset, $V_{os}$ in equation (1), is described as non-zero output voltage at DC during the presence of a null measurand current and has units of [V]. This quantity includes the electrical offset produced by the front-end and the magnetic field of the Earth as well as the result of other effects.

Nonlinearity, $F_{nl}(I)$ in equation (1), is described as a deviation from linearity concerning thee relationship between the measurand current and the output voltage.

Noise, $V_n$ in equation (1), relates the output-referred noise density integrated over the acquisition bandwidth measured in [$V_{rms}$]. This variable can also be described as input-referred noise mathematically described as the ratio $V_n$/ S.

Bandwidth is described as the frequency interval from the DC source to a 3 [dB] attenuation point from the transfer function of a HECS.

Dynamic range is described as the ratio between the maximum measurable current and the minimum detectable signal.

Using HECS components allow a design to detect Hall effect voltage to determine if displacement, and how much, has occurred in a system [1]. This voltage can be expressed by the equation:

$$V_H = \int_{S_1}^{S_2} E_H \, dy = \frac{\mu_n}{\sigma t} I_{bias} B_z \qquad (2)$$

Where $E_H$ is the electric field created, $\mu_n$ is the mobility of charge carriers, σ refers to the electrical conductivity of the plate, $I_{bias}$ is the input current, and $B_z$ is a magnetic field applied to the plate in the z direction.

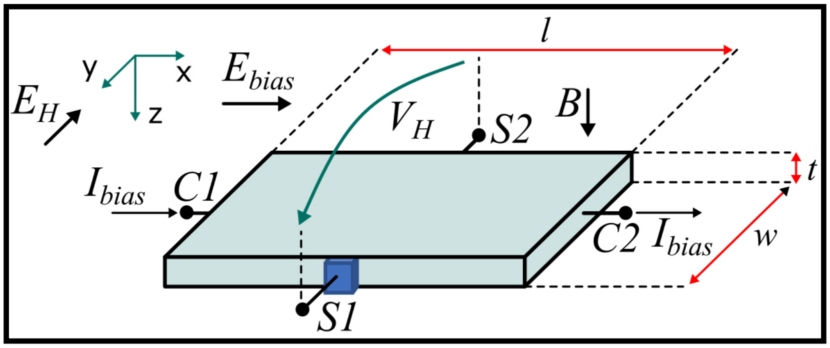



Figure 1. Hall plate semiconductor indicating the generation of a transverse electric field when an out of plane magnetic field is applied [1].

In Figure 1. We see the Hall plate which is the fundamental element of a HECS component. The Hall voltage is measured in [V], is orthogonal in the same plane as the input current $I_{bias}$, and is measured through S1 and S2. For this project to properly implement this type of displacement sensor studies will need to be conducted into the expected force from impacts of the game ball. Future Simulations will take into account a range of ball weights to determine the best ball to trigger a detectable Hall voltage.

The second type of contactless displacement sensor is a magnetoresistive sensor which can be found in biological sensors, spatial applications and Magnetic resonance imaging [5] — [8]. The magnetoresistive sensor is a potential candidate for this project because of their high sensitivity, low cost, and low power consumption. Reference [5]] define five figures of merit when considering magnetoresistive sensors which are sensitivity, detectivity, power consumption, mechanical flexibility and robustness.

Sensitivity is described by the linear operation range of the magnetic transfer curve which can be represented by the equation:

$$S = \frac{MR}{2\mu_0 H_{\text{sat}}} \tag{3}$$

MR / $H_{sat}$ describe the magnetoresistive ratio and saturation field. A high MR ratio and low saturation field improves sensitivity of a magnetoresistive sensor. A high MR value is obtained by selecting thin-film materials as the thickness plays a critical role in the active component of a magnetoresistive sensor. If a magnetic flux concentrator is incorporated into the design suppression of the saturation field will be attained.

Detectivity determines what the smallest magnetic signal the sensor is able to detect. This standard is associated with the component sensitivity and noise level which can be described by the equation:

$$D = \frac{1}{S}\sqrt{\frac{S_V}{V^2}} \tag{4}$$

Where D is the detectivity, S is the sensitivity, V is the applied bias voltage and $S_V/ V^2$ is the normalized noise level. Sensor detectivity can be enhanced by reducing the normalized noise which is diminished with an enlarged sensor area. Some sensors are capable of producing a detectivity of ~ 60 [$pT/Hz^{0.5}$] at 10 [Hz] [5], [7]. Incorporating a magnetic flux concentrator will also reduce the low-frequency noise in magnetoresistive sensors. It is important to consider that the expected detectivity may not be possible without incorporating magnetic shielding into the design because of external background magnetic field noise. This background noise may in fact render the low-field detectivity useless [5], [7], [8]. Current sensors are able to reduce the magnetic field noise by about 25 [dB].

Power consumption by the displacement sensors for Ulama must be as low as possible because power supply is limited to battery operation. Commercially available components range from 500 -100 [nW]. Literature reviewed for this paper indicate there may soon be commercially available components with about 1 [nW] power consumption rating.

Mechanical flexibility of magnetoresistive sensors is a vital metric for sensors installed in flexible devices or sensors that will sustain mechanical strains. In Ulama repeated impacts from game ball is anticipated and so this standard is of considerable importance for meeting customer needs. Current research [5] reports that components available are capable of exhibiting tolerable tensile strains from 2.7 — 29%. For this project to properly implement this type of displacement sensor studies will need to be conducted into the expected force from impacts of the game ball and correlate them to a specific range of expected tensile strains. Future simulations will take into account a range of tensile strains to determine the component best suited for Ulama.

Robustness of magnetoresistive sensors is also of importance because Ulama is projected to operate in a wide range of environments including outdoors in direct sunlight. According to [5] — [8] components will need to be moderately robust which is related to thermal endurance. Literature reviewed for this paper indicated that there are commercially available components that can operate in temperatures >200 [$^oC$], but components with the highest stability operated at 170 [$^oC$] for about 4000 hours.

## References

[1] M. Crescentini, S. Syeda, and G. Gibiino, “Hall-Effect Current Sensors: Principles of Operation and Implementation Techniques,” *IEEE Sensors Journal,* vol. 22, no. 11, June 2022.

[2] A. Karsenty, “A Comprehensive Review of Integrated Hall effects in Macro-, Micro-, Nanoscales, and Quantum Devices,” *MDPI Sensors,* vol. 20, no. 4163, July 2020.

[3] W. Sriratana, and R. Murayama, “Application of Hall effect Sensor: A study on the Influences of Sensor Placement,” In Proc. IEEE International Symposium on Industrial Electronics (ISIE), Taipei, Taiwan, 2013.

[4] Honeywell Technical Staff, *Hall effect Sensing and Application,* Honeywell International Inc.

[5] C.Zheng, K. Zhu, J. Davies et. Al, “Advances in Magnetics: Magnetoresistive Sensor Development Roadmap (Non-Recording Applications),” *IEEE Transaction on Magnetics,* vol. 55, no. 4, April 2019.

[6] J. Lenz, “ A review of Magnetic Sensors,” In Proceedings of the IEEE, vol. 78, no. 6, June 1990.

[7] D. Partin, J. Heremans, C. Thrush, and L. Green, “Magnetoresistive Sensors,” 6th Technical Digest IEEE Solid-State and Actuator Workshop, Hilton Head, SC, USA June 1992.

[8] J. Lenz, G. Rouse, L. Strandjord, B. Pant, A. Metze, H. French, E. Benser and D. Krahn, “A High-Sensitivity Magnetoresistive Sensor,” 4th Technical Digest IEEE Solid-State and Actuator Workshop, Hilton Head, SC, USA June 1990.

# Appendix B: Communication Protocol options for Ulama peripherals

The Ulama table top game will implement several displays. Communicating between the microcontroller and these peripherals will require the implementation of communication protocols depending on the type of component that is selected. These peripherals will be a main design component and are partially responsible for the Human-Computer Interface (HCI) of Ulama overall. These essential components will engage players, and will be a main software design component for my senior capstone project. In review of current research, industry literature and commercially available components [1] — [10] several communication protocols are being considered for this project based on target specifications 3, 6, 7, 8, 11, 13, and 16. For Ulama there are several types of displays that have been considered, such as Liquid Crystal Displays (LCD), Thin Film Transistor (TFT), and Organic Light Emitting Diode (OLED).

Based on customer needs 3bii, 3ei, 6a, 6b, and 8cii it was determined that standard LCD displays would be minimally acceptable due to their lack of color variation and low resolution. While LCD components will satisfy target specifications 6, 8 only some appease 10. The communication protocol for LCDs is very simple to implement since it would just require several General Purpose Input and Output (GPIO) pins. The LCD type of display is affordable and easy to replace, however the restrictive brightness and low resolution put this type of display lowest on the list of consideration for Ulama.

TFT displays cost more than the LCD options but will meet all of the target specifications and satisfy all Ulama customer needs. Commercially available TFT displays utilize the Serial Peripheral Interface (SPI) or the Inter-Integrated Circuit ($I^2C$) communication protocol. SPI has several software advantages such as full duplex communication, as well as a lack of acknowledgement, start and stop bits during data transmission [2, 3, 4, 6, 8]. Because of this SPI program overhead is reduced significantly when compared to $I^2C$. Full duplex communication enables two way traffic at the same time which is a bonus when compared to $I^2C$ which implements only half-duplex communication. If acknowledgement of data being successfully received is required then $I^2C$ would be the protocol of choice. The hardware consideration for SPI includes the requirement of four wires but no pull-up resistors. The $I^2C$ protocol requires only two wires but multiple pull-up resistors for proper implementation [1, 2, 3, 5, 7, 8]. SPI displays require less power than $I^2C$ so Ulama would have longer playtime before needing to be recharged if a SPI display is selected. Displays that use $I^2C$ are cheaper than those that implement the SPI protocol.

OLED displays are the most expensive of all the displays under consideration. The OLEDs commercially available utilize the SPI protocol. The hardware of OLEDS are designed such that they consume less power than LCDs, have a high contrast and vivid color. However the organic material that produces blue light has a shorter life time so there is the potential for color shifting and an overall shorter lifespan than LCD, or TFT displays.

# References


[1] Z. Hu, “I2c Protocol Design for Reusability,” 2010 Third International Symposium on Information Processing, Qingdao, China 2012, pp. 83-86.

[2] D. Trivedi, A. Khade, K. Jain and R. Jadhav, "SPI to I2C Protocol Conversion Using Verilog," 2018 Fourth International Conference on Computing Communication Control and Automation (ICCUBEA), Pune, India, 2018, pp. 1-4.

[3] E. Larsson, P. Murali and G. Kumisbek, "IEEE Std. P1687.1: Translator and Protocol," 2019 IEEE International Test Conference (ITC), Washington, DC, USA, 2019, pp. 1-10.

[4] D. S. Dawoud; P. Dawoud, "Serial Communication Protocols and Standards RS232/485, UART/USART, SPI, USB, INSTEON, Wi-Fi and WiMAX," in *Serial Communication Protocols and Standards RS232/485, UART/USART, SPI, USB, INSTEON, Wi-Fi and WiMAX* , River Publishers, 2020, pp.i-xl.

[5] L. M. Kappaganthu, M. D. Prakash and A. Yadlapati, "I2C protocol and its clock stretching verification using system verilog and UVM," *2017 International Conference on Inventive Communication and Computational Technologies (ICICCT)*, Coimbatore, India, 2017, pp. 478-480.

[6] R. R. Pahlevi, A. G. Putrada and M. Abdurohman, "Fast UART and SPI Protocol for Scalable IoT Platform," *2018 6th International Conference on Information and Communication Technology (ICoICT)*, Bandung, Indonesia, 2018, pp. 239-244.

[7] A. Yadav and U. Mehta, “DESIGN AND SIMULATION OF I2C PROTOCOL”, *IEJRD - International Multidisciplinary Journal*, vol. 6, no. ICMRD21, p. 10, Apr. 2021.

[8] F. Leens, "An introduction to I2C and SPI protocols," in *IEEE Instrumentation & Measurement Magazine*, vol. 12, no. 1, pp. 8-13, February 2009.

# Appendix C: High Risk Areas For Ulama Board Game

There are two design elements that are considered high risk areas when concerning the development and construction of the proposed Ulama board game. The capacitive displacement sensors and the use of Near Field Communication (NFC) to set up the game. The game requires several displacement sensors to notify the microcontroller of a goal, a gutter-ball and potential hotspots in the board game which trigger game faults and bonuses. Options for high risk area alternatives include QR code, manual entry via a smart phone app, hall effect switches, magnetoresistive and potentiometer sensors.

Initial product design considerations for game play setup described NFC technology to activate team and player profiles. Each team profile will consist of a logo, team colors, as well as goal, gutter-ball and taunting melodies. Statistics for a team and players include but are not limited to wins, losses, high score, faults and bonuses. This information will have to be recorded during game play and entered into the system when a team and player is loaded during game play setup.

Utilizing dynamic QR code technology the game would come with a set of pre designed teams and players embedded in QR codes printed on card-stock. If this implementation is chosen the NFC reader would be swapped out for a camera that could image the QR code and load the pre designed team and player data into the game at setup. Set backs from this approach compared to the NFC would be power consumption and additional LEDs to light the area where the QR code will be placed. If players do not scan the setup data into the system then there is the option of manual entry.

Manual entry of setup data would take place via a website or smart phone application that I would program. The user would be asked a series of questions such as team logo, colors, player name and melody choice. When a player finished setup the system would need to gain access to this information so Wi-Fi ability would replace the NFC reader or QR camera. With this implementation users may be able to design their own teams and players using the website or application which would expand on the creative engagement customer need. Sensors are the other high risk area for this project in the event capacitive sensors are not feasible other sensors must be considered.

Hall effect switches utilize a change in magnetic field resulting in a measurable voltage potential [1, 2, 3, 5]. This type of sensor doesn't require contact and so it would last longer than other types of sensors. Some considerations for this type of sensor include device design that can measure change within a half of an inch, the ideal depth of goal game pieces. Tests will have to be conducted for a range of displacement values that are possible during game play. This also includes determining the weight of the ball to be used. Another contact-less sensor for deliberation is the magnetoresistive type.

Magnetoresistive sensors utilize a change in magnetic field resulting in a measurable change in resistance [1, 2, 5, 6]. This type of sensor may but a viable option for the several areas in the board game that require the acknowledgment of displacement, depending on the expected displacement range determined in testing. Aside from hall effect switches and magnetoresistive switches there is a contact sensor that could possibly be used in the final product design, the linear potentiometer sensor.

Potentiometer sensors utilize a change in resistance resulting in a change in voltage potential [2,4]. This would have to be implemented within the ideal half inch range since the goal game pieces are not expected to exceed this value. This type of sensor is known as a contact sensor so another design aspect to consider is the wear and tear on this component as the game is played. From a business standpoint if they are cheap enough to produce this could be an additional source of revenue as it is more likely these parts would need to be replaced. From a user's perspective this type of sensor would need to last long enough and be easily replaceable to not become a nuisance.

# References


[1] D. Collins, "How do Hall effect sensors work and where are they used in motion applications?," September 21, 2021. [Online]. Available: https://www.motioncontroltips.com/how-do-hall-effect-sensors-work-where-are-they-used-in-motion-applications/. [Accessed Feb. 26, 2023].

[2] Althen Sensors & Controls, "Linear Position Sensors," althensensors.com, 2021. [Online]. Available: https://www.althensensors.com/sensors/linear-position-sensors/. [Accessed Feb. 26, 2023].

[3] How To Mechatronics, " What is Hall effect and how Hall effect Sensors Work?," December 30t, 2015. [Online]. Available: https://youtu.be/wpAA3qeOYiI. [Accessed Feb. 26, 2023].

[4] Skill Lync, "What is a Potentiometer Sensor?," April 7th, 2020. [Online]. Available: https://youtu.be/rZOuIbqNVsU. [Accessed Feb. 26, 2023].

[5] TE Connectivity, " Connect without Contact," 2023. [Online]. Available: https://www.te.com/usa-en/products/sensors/position-sensors/intersection/intro-into-mr-sensor-applications.html. [Accessed Feb. 26, 2023].

[6] Murata Manufacturing Co. Ltd., "Fundamentals of magnetic sensors: Principles of operation for AMR sensors (magnetic switches),"murata.com, 2023. [Online]. Available: https://www.murata.com/en-us/products/sensor/amr/overview/basic/principle. [Accessed Feb. 26, 2023].

# Appendix D: Final Design choices for Ulama Board Game

The Ulama board game required an extensive literature review to establish the best design approach. This project has both electrical and programming design factors to consider for achieving an acceptable grade in the Senior Capstone course. To meet degree program requirements, customer needs as well as target specifications there are two design factors to consider, communication protocols, and displacement sensors. This document covers the minimal, ideal, and optional features of the Ulama board game.

The screen peripherals will be a main programming design component and are partially responsible for the Human-Computer Interface (HCI) of Ulama. These essential components will engage players and will require proper software design for successful integration in the senior capstone project.

Ulama will implement a screen to display game information. The minimum requirement for the screen to display is the game score, the HCI phrases “GOAL!”, “Next up…”, and “Player # (1-4)”. To meet the minimum screen requirement for Ulama a, 16-character, 2-line Liquid Crystal Display (LCD) can be used. This type of screen will utilize up to 16 of the General Purpose Input Output (GPIO) pins. This type of screen will also use the digital output communication standard available on the TIVA TM4C123 microcontroller.

In the review of current research, industry literature, and commercially available components the Serial Peripheral Interface (SPI) communication protocol is considered the ideal design choice for Ulama [1] — [8]. SPI has a lower overhead since it does not require extra start, stop, or acknowledgment bits when processing peripheral communication [6]. Using SPI communication enables Ulama to use 1.5 inch, full-color, Thin Film Transistor (TFT) screens. TFT screens are capable of animating the HCI phrases, presenting logos, and have a longer lifespan than OLED screens. Because Ulama will be battery-operated it is essential to minimize power consumption when possible. With SPI the design will be able to minimize power use and maximize transmission efficiency using full duplex communication when required [4, 6, 8]. SPI-enabled screens would perform better than screens that use I2C for communication, therefore SPI is considered the ideal choice for Ulama [3, 5, 7, 8].

Optional screen functionality includes expanding the number of screens from one to four and rotating information displayed on each one. If TFT screens are employed then more HCI phrases could be added and animated because several options include a micro SD slot for preloading images and animations. For example, the score, team logo, player number, and shot clock could be displayed simultaneously. Screens could also rotate the information from one screen to the next, animating the game board during a player’s turn. The second design factor for Ulama is the impact-detecting displacement sensors.

The displacement sensors will be the main electrical design component and are fully responsible for determining game goals. The displacement sensors trigger many of the HCI design elements such as screen phrases, LEDs, and speaker activation. These components will require proper electrical and programming design for successful integration in my senior capstone project.

The literature review of industry research and commercially available components have determined that a slide potentiometer would meet the minimum requirement for detecting game ball contact with goals found on Ulama's game board [17, 18]. To meet target specifications 1, 3, 8, 13, 14, and 20 - 22 there are two factors to consider when implementing the slide potentiometer as a displacement sensor. Ulama's ball would increase in weight, so impacts can displace the slide far enough for a difference to be measured. The second factor to consider would be the added requirement of a mechanical system to return the slide to a baseline position after an impact [17, 18]. Using the slide potentiometer would also require a mechanical ball launcher since a heavy ball would not be easily flicked off the ideal stationary Wildcat ball tee. If a mechanical ball launcher and heavier ball are implemented then additional safety precautions would have to be considered to minimize hazards and injuries.

The ideal design choice for Ulama would be a contactless displacement sensor such as a Hall effect current sensor (HECS). HECS components have a large dynamic range, great linearity, and are compatible with silicon-based technologies that will be utilized in this project [1, 2, 3, 4, 6]. Using HECS to measure displacement will not require a mechanical system to return the sensor to a baseline location after an impact, and will not increase the game ball weight. HECS components are estimated to have a longer lifespan since there will be no physical contact and no mechanical components required.

Optional functionality for displacement sensors includes placing game fault locations around the screen component and in certain game board elements like walls or obstacles. Using contactless HECS would enable the implementation of game fault locations adding to the game dynamic and variability of play each time. This component can be implemented in a smaller footprint, enabling two additional moveable goalposts to be placed on the game board by the offensive team during gameplay.

There are two major design factors for Ulama, communication protocols and displacement sensors. The minimal requirement for communication between peripherals would be using the GPIO pins on the TIVA TM4C123 microcontroller allowing the design to implement an LCD screen. Screens with a full range of colors, which can play animations would be ideal for Ulama and would require the execution of SPI communication protocols. The second design factor for Ulama is the displacement sensors which trigger many of the HCI peripherals such as the screen, LEDs, and a speaker. The slide potentiometer would meet the minimum requirements to determine when a player scores but would increase the goal footprint and ball weight. Slide potentiometers would require the design of additional mechanical systems to reset the slider's location, and to launch a heavier ball. The ideal displacement sensor would be a contactless HECS. HECS would reduce goal footprint, enable the incorporation of game fault locations, and allow the addition of two moveable goals.

# References


[1] Z. Hu, "I2c Protocol Design for Reusability," 2010 Third International Symposium on Information Processing, Qingdao, China 2012, pp. 83-86.

[2] D. Trivedi, A. Khade, K. Jain and R. Jadhav, "SPI to I2C Protocol Conversion Using Verilog," 2018 Fourth International Conference on Computing Communication Control and Automation (ICCUBEA), Pune, India, 2018, pp. 1-4.

[3] E. Larsson, P. Murali and G. Kumisbek, "IEEE Std. P1687.1: Translator and Protocol," 2019 IEEE International Test Conference (ITC), Washington, DC, USA, 2019, pp. 1-10.

[4] D. S. Dawoud; P. Dawoud, "Serial Communication Protocols and Standards RS232/485, UART/USART, SPI, USB, INSTEON, Wi-Fi and WiMAX," in *Serial Communication Protocols and Standards RS232/485, UART/USART, SPI, USB, INSTEON, Wi-Fi and WiMAX* , River Publishers, 2020, pp.i-xl.

[5] L. M. Kappaganthu, M. D. Prakash and A. Yadlapati, "I2C protocol and its clock stretching verification using system verilog and UVM," *2017 International Conference on Inventive Communication and Computational Technologies (ICICCT)*, Coimbatore, India, 2017, pp. 478-480.

[6] R. R. Pahlevi, A. G. Putrada and M. Abdurohman, "Fast UART and SPI Protocol for Scalable IoT Platform," *2018 6th International Conference on Information and Communication Technology (ICoICT)*, Bandung, Indonesia, 2018, pp. 239-244.

[7] A. Yadav and U. Mehta, "DESIGN AND SIMULATION OF I2C PROTOCOL", *IEJRD - International Multidisciplinary Journal*, vol. 6, no. ICMRD21, p. 10, Apr. 2021.

[8] F. Leens, "An introduction to I2C and SPI protocols," in *IEEE Instrumentation & Measurement Magazine*, vol. 12, no. 1, pp. 8-13, February 2009.

[9] M. Crescentini, S. Syeda, and G. Gibiino, "Hall-Effect Current Sensors: Principles of Operation and Implementation Techniques," *IEEE Sensors Journal,* vol. 22, no. 11, June 2022.

[10] A. Karsenty, "A Comprehensive Review of Integrated Hall effects in Macro-, Micro-, Nanoscales, and Quantum Devices," *MDPI Sensors,* vol. 20, no. 4163, July 2020.

[11] W. Sriratana, and R. Murayama, "Application of Hall effect Sensor: A study on the Influences of Sensor Placement," In Proc. IEEE International Symposium on Industrial Electronics (ISIE), Taipei, Taiwan, 2013.

[12] Honeywell Technical Staff, *Hall effect Sensing and Application,* Honeywell International Inc.

[13] C.Zheng, K. Zhu, J. Davies et. Al, “Advances in Magnetics: Magnetoresistive Sensor Development Roadmap (Non-Recording Applications),” *IEEE Transaction on Magnetics,* vol. 55, no. 4, April 2019.

[14] J. Lenz, “ A review of Magnetic Sensors,” In Proceedings of the IEEE, vol. 78, no. 6, June 1990.

[15] D. Partin, J. Heremans, C. Thrush, and L. Green, “Magnetoresistive Sensors,” 6th Technical Digest IEEE Solid-State and Actuator Workshop, Hilton Head, SC, USA June 1992.

[16] J. Lenz, G. Rouse, L. Strandjord, B. Pant, A. Metze, H. French, E. Benser and D. Krahn, “A High-Sensitivity Magnetoresistive Sensor,” 4th Technical Digest IEEE Solid-State and Actuator Workshop, Hilton Head, SC, USA June 1990.

[17] Conrad Electronic SE, “Slide Potentiometer, F2031N single type,” F2031-NN0SC2B10k data-sheet, Feb. 2023.

[18] WayCon Positionsmesstechnik, “Linear potentiometer Series LZW2,” LZW2 - S, LZW2 - F, LZW2 - A datasheet Feb. 2023.