Puzzle Module for a Mobile Escape Room

ECE 445 Design Document

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Group 33

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1. Introduction

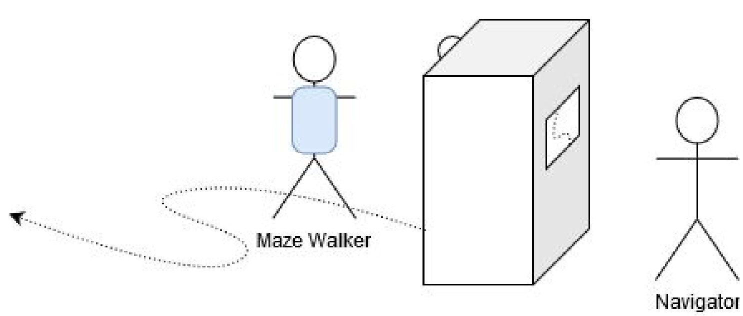
1.1. Objective

Champaign-Urbana Adventures in Time and Space, a local escape room company, is producing the "Adventure Crate," a portable escape-room-in-a-box device. For this device, they need a series of "puzzle modules," which are smaller puzzles or games that the players must solve in order to progress through the experience. These puzzles should be novel and entertaining, with an emphasis on teamwork and communication within the group.

1.2. Background

Few escape rooms currently utilize any motion-tracking technology, even in fixed-location rooms. Typical escape room puzzles might involve the finding and placing of objects in correct locations, solving passcodes, or other similar games, but few to none of them involve the motion of the player themselves.

Our group plans to build one of the larger modules for the Crate. This module is an "invisible maze," which requires a player to follow a path that they cannot see, directed by another player who views the path to follow on an LCD screen on another side of the Crate. We will track the location of the maze-walker using the AprilTag computer vision system. The maze-walker will wear a backpack that has the AprilTag tag (similar to a QR code) on it that will be tracked using a USB webcam mounted on the main Crate. The path walked will be compared to the correct path as shown on the screen, and the screen will update in real-time with the location of the maze-walker. The path will have 1ft of tolerance on either side of the correct path as "correct." 1ft outside of that will be a "warning" zone, and any farther outside of that will count as exiting the border of the maze. When the maze-walker is on the correct path, we will have RGB LEDs on the backpack stay green. In the warning zone, they will turn yellow and there will be vibration motors that go off. When you exit the border, the LEDs will flash red, and the motors will vibrate more intensely. At this point, you need to reset to the start and try again. The processing of the maze and location will be done on a series of Raspberry Pi's. There will be an additional Raspberry Pi located within the backpack that will communicate with the main control Pi's and control the LEDs and vibration.



1.3. High-Level Requirements

- The location of the player in the maze must be tracked accurately, ideally within the resolution of 1 foot.
- A maze must be automatically generated and displayed via LCD screen to the player outside of the maze
- Players must be notified when maze walls are crossed. The player in the maze should be notified via haptic feedback on a wearable device, and the player outside of the maze should be notified on the LCD screen.

2. Design

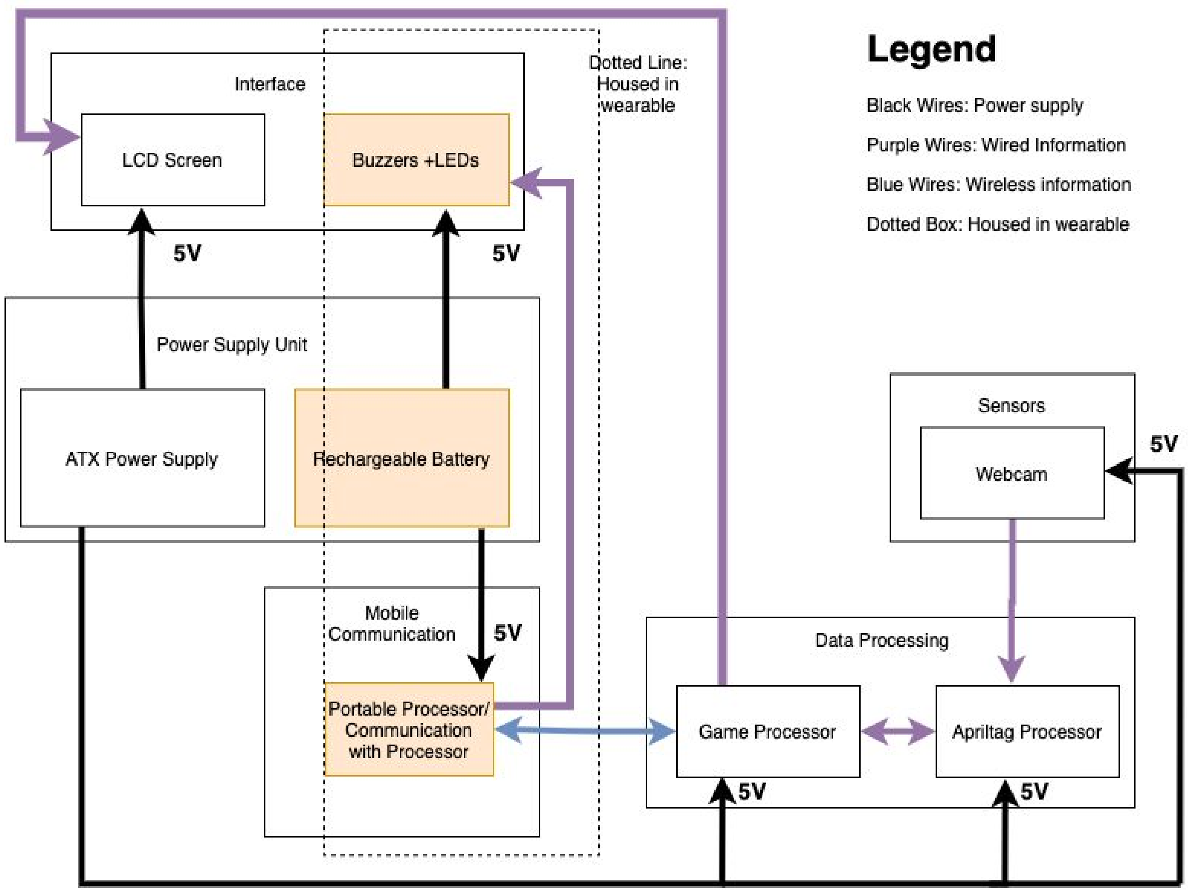


Figure 1: Block Diagram

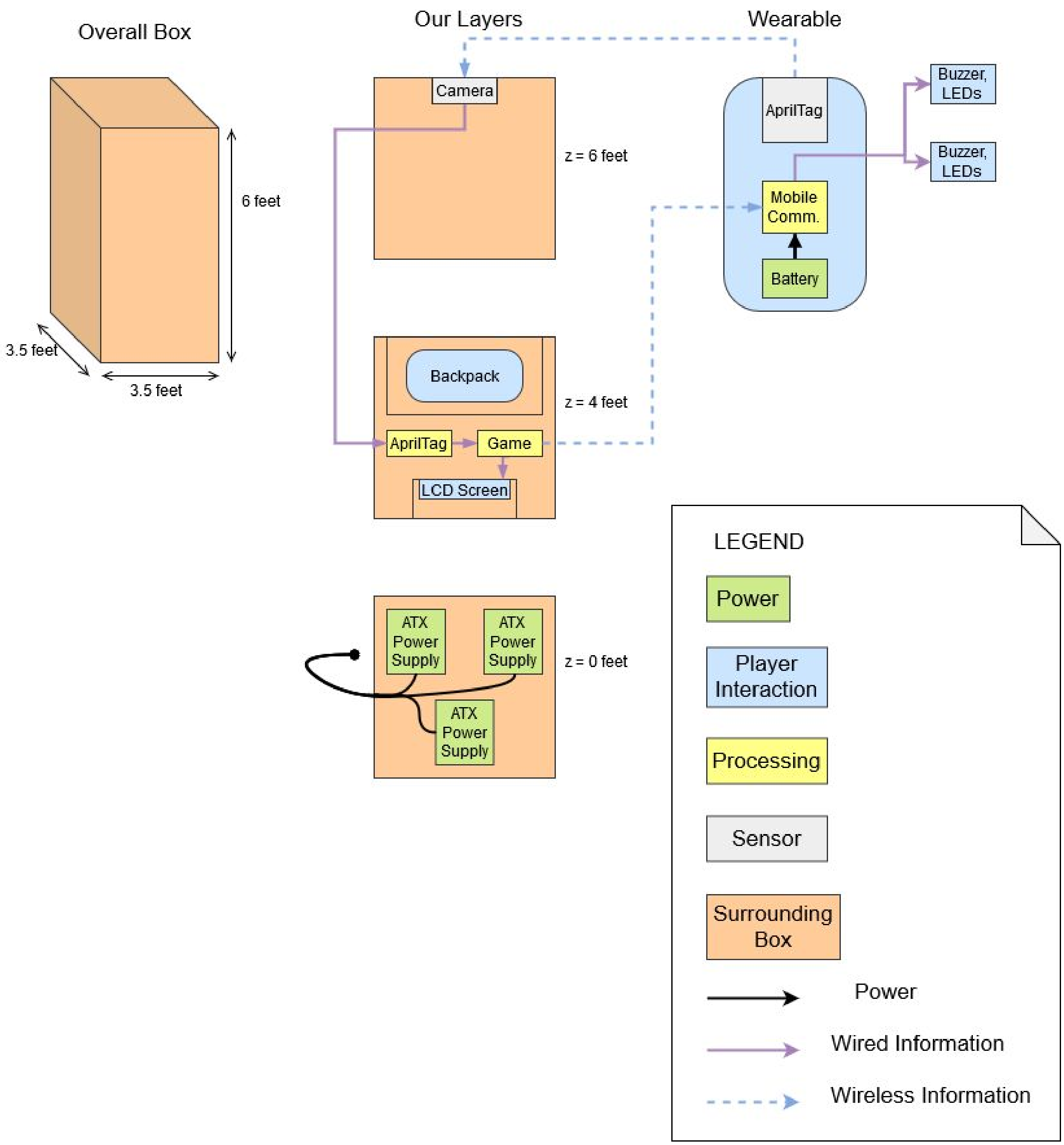


Figure 2: Physical Diagram

There are five main aspects to this project. First, everything must be powered by two separate power supplies. Sensors are also required, in the form of a webcam to search for the player in the maze. The data both to create the game and to process the camera feed to calculate the player's location must be processed in two separate processing units. Then, this data must be communicated to the player's wearable device in the case that they cross a boundary. Finally, the game must have an interface to display the maze to other players.

2.1. Power Supplies

Power supplies are required for both the units in the main housing for the processors and in the wearable device.

2.1.1. ATX Power Supply

The ATX Power supply converts the outlet AC voltage to DC rails at 5, 9, and 12V. The escape room we're working with has asked for several DC rails so this serves both our module's needs as well as the rest of the box's modules.

Requirement	Verification
Must consistently supply DC rails at 5±0.5V, 9±0.5V, and 12±0.5V.	A. Check each voltage with a voltmeter to ensure it remains within tolerance

2.1.2. Rechargeable Battery

The wearable device also must have a power supply to power the processor communicating with the game processor, as well to power the haptic feedback device. This needs to last for at least an hour, but ideally it could last for a whole day.

Requirement	Verification
Battery must supply 5±0.5V at 3A	A. Measure the open-circuit voltage and ensure it doesn't surpass 5.5V with a voltmeter B. Ensure the current through the load can reach 3A with a dummy resistor load and an ammeter in series
Battery must continue to function after being dropped at least 5 feet	A. After checking it works within the voltage and current specifications, drop the battery from 5 feet B. Recheck the voltage and current from the first requirement to ensure it still works

2.2. Data Processing

Both information about the player's location, and information about the maze needs to be constantly updated. There are two main processors used to do each of the different tasks.

2.2.1. Game Processor

The maze is rendered, and as information is fed in concerning the player's location, the processor calculates if any boundaries are crossed, and communicates that to the interfaces.

Requirement	Verification
Must be able to communicate via iEEE standard 802.11 wireless LAN connection	A. Establish connection between the two Raspberry Pis B. Program dummy data block to one Raspberry Pi C. Send data block to the other Raspberry Pi D. Compare to make sure they are same
Software must be able to render a maze	A. Write maze software B. Display a generated maze to an LCD screen

2.2.2. Apriltag Processor

Information is fed in from the camera to a Raspberry Pi processor. Using an AprilTag library, the location from the camera is calculated, then fed into the game processor.

Requirement	Verification
The processor must be able to calculate a user's location from the camera accurate to ±1 foot	A. Setup and calibrate the computer vision software B. Print an Apriltag C. Measure various distances away from the camera and place the Apriltag in the camera view D. Check that the distance the system calculates is within the tolerance of 1 foot.

2.3. Interface

The maze and the player's current location will be displayed on an LCD screen. When the player crosses a boundary, a buzzer for haptic feedback on the player in the maze should go off, and a notification on the LCD screen should be displayed.

2.3.1. LCD Screen

The LCD Screen displays the map and the player's location within the maze. If the player in the maze crosses a maze wall, a notification will be displayed. It gets this data from the game processor.

Requirement	Verification
Refresh rate must be at least 60Hz	A.

2.3.2. Haptic Feedback Device (buzzer + LEDs)

When a player crosses a maze wall, they should get haptic feedback and be flashed lights to notify them. It gets activated by a processor on the wearable that is communicating with the game processor in the main housing.

Requirement	Verification
LEDs must be visible from at least 5 feet away with a drive current of 25mA	A. Adjust resistors to ensure 25mA current per LED, test with an ammeter B. Measure 5 feet away from an LED C. Ensure the LED is clearly visible from that distance
Vibration from the ERM motors must be easily felt through the backpack with a drive current of 100mA	A. Adjust resistors to ensure 100mA of current per motor, test with an ammeter B. Place motors in the four corners of the backpack C. Activate motors while wearing the backpack to see how easily they are felt
Device must continue to function after being dropped at least 5 feet	A. Drop haptic feedback device from 5 feet and ensure it is stable and functions properly as before

2.4. Communication

When the player in the maze crosses any boundaries, it is necessary to notify them. However, without wireless communication between the haptic feedback

2.4.1. Wifi Processor on Wearable

The wearable must have a WiFi communication with the game processor so that it can be notified when the haptic feedback must be activated.

Requirement	Verification
Processor needs to activate haptic feedback when signalled to	A. Send a signal from the game Raspberry Pi B. Ensure the wearable Raspberry Pi receives the signal C. Check the voltage out to the LED and Buzzer are correct
Processor must continue to function after being dropped at least 5 feet	A. Drop the wearable from 5 feet B. Repeat the steps from the first requirement

2.5. Sensors

A camera is required to and track the location of the player via AprilTags.

2.5.1. Camera

The camera should be at a resolution high enough to accurately see the Apriltag on the player, and steadily communicate via USB connection to its associated processor.

Requirement	Verification
The camera resolution needs to detect an Apriltag from 20 feet away	A. Set up the camera and computer vision system B. Place an Apriltag 20 feet away from the camera C. Ensure the camera can detect the Apriltag

2.6. Schematics

2.6.1. LED Schematic

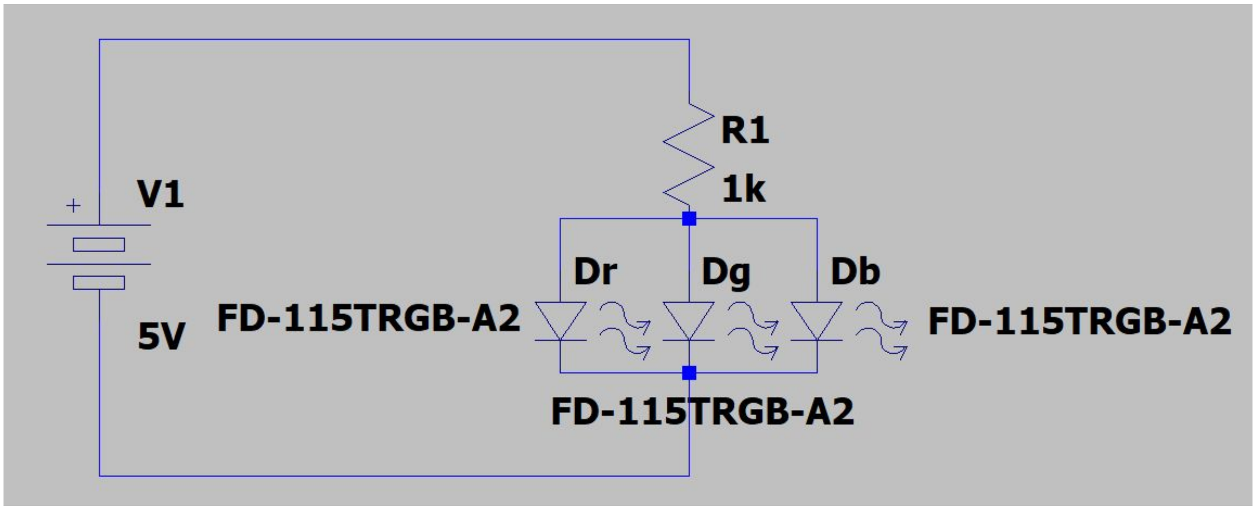


Figure 3: LED Schematic for 1 Diode

2.7. Board Layout

2.8. Software

Software is an extremely important aspect of this project. We need to take in constant data from the camera, process it to find the location of the player in the maze, and then compare it to the maze to make sure no walls were crossed. Then, in the case someone crosses a maze boundary, a notification must be sent to all the players in the game.

2.8.1. Computer Vision

The brunt of the processing power goes into the computer vision portion of the project. Since we are using the Apriltag system, the libraries are all online and open source. For this project, we chose to use OpenCV to access the Apriltag libraries.

2.8.2. Game Mechanics

A maze must also be rendered for the gameplay. During setup, the distance to the back and side walls will be set. From that information, we know the boundaries of the room and render the maze accordingly. The main game will then take the location data of the player from the computer vision, and then compare it to the map data. If between data points, the player crosses a boundary, the player must go back to the starting position and restart the maze.

2.9. Risk Analysis

Wireless communication has the most potential problems with our project. The haptic feedback should go off as soon as a boundary is hit, so a fast and reliable connection is needed. In addition, the correct LEDs need to go off in the correct maze regions, so it needs to constantly be communicating with the gaming processor for what needs to be displayed. On top of all this, everything in the wearable will be abused by players, so they need to be made sturdily.

The Raspberry Pi microprocessors we plan to use have a built-in wifi router, which have specs of up to 94 Mbps [1], so they theoretically should be fine. However, with all the other data being processed, speed can become a potential issue. We need to be efficient with our software so that processing power does not become an issue.

3. Costs

Our development costs are estimated at around $40/hour, 10hours/week, for 3 people. We consider there are 10 weeks left in the course to complete the project. This neglects weekly TA meetings, and meetings with the escape room, this comes to $12,000 in labor costs

Part	Cost
(Raspberry Pi 3) x 2	$35 (provided by CATS) x 3 = $105
Buzzer x 4	$5.46 x 4 = $21.84
LED	$10
ATX Power Supplies x 2	$23 x 2 = $46
Camera	$48.99
Total	$231.83

We are only building one prototype, so the total materials cost should be $231.83. Overall, this implies a total cost of $12,231.83.

4. Schedule

Date	Nick Russo	Colin Flavin	Helen Swearingen
2/27			
3/2			
3/9			
3/16			
3/23			
3/30			
4/6			
4/13			
4/20	Prepare final presentation	Prepare final presentation	Prepare final presentation
4/27	Finish final report	Finish final report	Finish final report

5. Safety and Ethics

There are a few safety issues with our project. Safety of the players must be our biggest concern at all times. According to the IEEE code of ethics, we must “avoid injuring others...by false or malicious action” [2]. Rechargeable batteries have the potential for combustion if overcharged or overheated. Since this is indoors and use is somewhat limited, overheating should not be a large concern. In addition, it must be sturdy enough to deal with the potential misuse of the device by players. Our housing should be built to take this into consideration.

Although we do deal with wall power, it goes straight into ATX Power supplies, which are built to deal with all potential issues we would have.

The height and weight of the escape room box also could be potential concerns. At 6 feet tall, the box has the potential to tip over. In addition, things may fall off of the box and injure players during play. We will work with CATS to weight down the box and securely mount everything to the escape room box.

References

[1] R. Zwetsloot, "Raspberry Pi 4 specs and benchmarks — The MagPi magazine", *The MagPi magazine*, 2019. [Online]. Available: https://magpi.raspberrypi.org/articles/raspberry-pi-4-specs-benchmarks. [Accessed: 13- Feb- 2020].

[2] "IEEE Code of Ethics", *Ieee.org*, 2016. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 13- Feb- 2020].