Final Report for ECE 445, Senior Design, Spring 2024

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Project No. 2

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By

Seeing-Eye hat

**Abstract**

The abstract is short (150 words or less) and provides enough of a summary of the report for the reader to decide whether to read the entire document. State very concisely what your device or system does, and the main findings and results of your project. Save background information (e.g., motivation, competitors) for the introduction and design details for the body of the report. Do not give an advertising pitch. Note that the abstract does not appear in the table of contents. (This achieved by stripping out the heading style.)

Note that **you can ignore the TOC on next page because it is generated automatically.** Work on the body of the report, then hit the Update tab on the TOC and *voilà*.

When you double-clicked “ECE 445 Template.dotx,” you opened a new, untitled document in Microsoft Word, which has the main components of your final report set up for you. Save the new document, replace the red text and bracketed section heads with your own, insert carefully prepared graphics, follow the guidelines document (“Preparing Your Final Report for ECE 445”), proofread and revise, and you’ll likely end up with a successful report.

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# 1. Introduction

Briefly describe the science or engineering problem to be addressed in the report, as well as the purpose and usefulness of the device or system you have built. Summarize the contents of the upcoming chapters as well as the main conclusions of your project, to be elaborated in the last chapter.

## 1.1 Block Diagram

To create a section head, go to the Styles gallery under the Home tab and pick Heading 2. It automatically formats as above and creates a table of contents entry (after you click the Update tab). Word will not make the capitalization consistent; you have to do that yourself.

Figure 1 is an example of figure and caption style. Table 1 is an example of table and table title style. A starter table for parts costs is in Chapter 4 of this template.

Use the References🡺Insert Caption tool to generate consistently formatted captions (always *below* the figure), and use the grouping function in Word’s drawing tools to hold figure and caption together. Use picture formatting tools to hold figures in place (preferably at top or bottom of page) and to define text wraps (“top and bottom” is best).

Use Word’s table design and layout tools to format titles, column heads, and borders.

Insert page break at end of every chapter to ensure next chapter starts on new page.

Figure 1 Example of placement and caption for a block diagram. With picture selected, go to References🡺Insert Caption. This creates a neat, consistent caption style that stays connected to the figure. Size the figure so that one-inch margins are preserved. Group the figure and caption to hold them together.

|  |  |  |
| --- | --- | --- |
| **Table 1 Example of a Table and Its Title** | | |
| **Part** | **Electricity** | **Magnetism** |
| Field intensity | **E** | **H** |
| Flux density | **D** | **B** |
| Constitutive factor | **ɛ**b | **µ**c |

# 2 Design Procedure

Discuss general design alternatives. Give equations, simulations, general circuits. Describe design in detail, addressing each major component. Include schematics with components, drawings, flowcharts, etc. Some teams may wish to split this chapter in two: 2. Design Procedure, and 3. Design Details. This template will not automatically update numbering systems for chapters, sections, figures, tables, etc., so keep track of them as you develop and revise the text.

Following is a “template” for displayed math. Use the MathType extension of Word to generate your own content, and note the use of the invisible table (no borders) to keep the optional number flush right.

|  |  |
| --- | --- |
| Insert math here using MathType | (number) |

## 2.1 Control Unit Design

To create a section head, go to the Styles gallery under the Home tab and pick Heading 2. It automatically formats as above and creates a table of contents entry (after you click the Update tab).

### 2.1.1 [Subcomponent or subblock]

To create a subsection head, go to the Styles gallery under the Home tab and pick Heading 3. It automatically formats as above and creates a table of contents entry (after you click the Update tab). Even lower level section heads can be created the same way, but they are likely unnecessary.

## 2.2 Sensing System Design

### 2.3.1 LiDAR

### 2.3.2 Doppler

### 2.3.3 Hall Effect Module

## 2.3 Haptic Feedback System Design

The Haptic Feedback system’s purpose is to translate the locational data into sensory feedback for the user. The core design has remained consistent. Haptic Motors, otherwise known as Linear Resonant Actuator (LRA) Motors, are used to convey sensor feedback to the user. The system consists of 12 haptic motors, and 12 switching transistors.

Haptic motors are evenly distributed across the inside rim of the hat. This divides the surrounding area into evenly spaced “zones” extending out from the angles between the motors. For example, the final product uses 12 motors. This places a motor every 30 degrees around the hat. Each haptic motor now represents a 30 degree “slice” of the world surrounding the user.

The strength of the vibration is determined by the Control Unit. The control unit uses a PWM Signal and switching transistors to regulate the power delivered to the motor. These are used to not over-tax the maximum current drawn from the microcontroller. With a sufficiently powerful microcontroller, and a limit on the maximum number of motors activated, the switching transistors may be able to be removed.

We used a 150 CM threshold distance to turn on the motor. We considered having the strength of the signal proportional to the distance to the nearest measured object within the motors zone. Testing showed that this was difficult to perceive by users.

The proposed design intends to have all motors on at one time. When testing, we learned that most test subjects struggled to distinguish the locations of the haptics once more than one was active simultaneously. Therefore, we limited the scope to only pulse one motor at a time. We also considered using 8 motors instead of 12 if the product became overstimulating.

## 2.4 Scanning System Design

The scanning system’s primary purpose is to rotate the LiDAR. It also rotates the magnet that is used to trigger the Hall Effect Sensor used by the control unit during the calibration process. The most important requirement of the scanning system is to ensure the LiDAR can spin fast enough to meet the “one measurement every two seconds” requirement. This essentially translates to a 30RPM Requirement.

The scanning mechanism and the sensing system work in tandem to track the position of the Motor, and thus the LiDAR. This information is critical for mapping distance measurements to directions and haptic motors.

The LiDAR requires 5 wires to operate. Therefore, a slip ring is required for this design. The use of a slip ring necessitates that the LiDAR must be driven by a gear instead of the motor directly.

Initially, the scanning mechanism consisted of a brushless motor and a 1:1 gear ratio. This design prioritized speed over control. The hypothetical benefit of this system is that more LiDAR readings could be collected faster, which would provide a better experience for the users. Practically, the control unit was not fast or powerful enough to perform LiDAR Readings at the pace required for this. It additionally placed a heavy burden on the control unit and sensing systems to track the motor.

The final version of the scanning mechanism uses a stepper motor and a 2:1 gear ratio to turn the LiDAR. The stepper motor is preferable because, after calibration, the control unit will have a perfect understanding of the motor’s position at any given time. This heavily reduces computational and developmental burdens. Detrimentally, the motor operates at 15RPM. We used a 2:1 gear ratio to meet the 30RPM requirement.

## 2.5 Power System Design

The power system had a dynamic development process. Failures during the verification process, alongside untimely component ordering problems, caused the team to abandon the original power system described in the proposal.

Our team proved resourceful. With two days until the demonstration, we found a commercially available and accessible power system that still passed every verification test that we designed for its predecessor. This section will first describe the final version of the power system as it appeared in the demo. Afterwords, we will detail the process of designing the failed power system.

### 2.5.1 Final Power System

The final product utilizes a multi-stage power system. The primary power supply is a standard USB Portable Cell Phone Charger. The rated output voltage from the portable charger is 5 V. The rated output current is 2.1 A.

The primary battery directly powers the Control Unit. Alongside acting as the control unit, the Arduino Mega functions as the voltage regulators for the power system. The development board contains linear regulators to create stable 5 V and 3.3 V power buses. These two buses are used to power all components of the Scanning, Sensing and Haptic systems. The maximum current draw from the Arduino is 800 mA. This effectively limits the maximum current draw from the power system to 800 mA. The Arduino development board has built-in Undervoltage Lockout and Short Circuit protection. Under either of these conditions, the Arduino will shut down, which cuts power to all other subsystems by extension.

This model was chosen because our PCB design failed the final verification test. However, this design has a lot of merit. Custom designs introduce points of failure. Utilizing stable commercial components grants consistency to a design, which is valuable for key systems. The new power system was able to pass the required verification tests. Prioritizing time and consistency allowed the product to be completed and for the demo to be successful.

### 2.5.2 PCB Power System

The power system’s design process can be described as a lesson in overengineering. The power system was designed as a part of the standard project PCB. The initial concept was to use a 7.4 V LiPo battery as the primary power supply. The on-board power system would include branches for a 5 V and a 3.3 V power bus. This would be accomplished with two buck converters. Buck converters were used because, at the time, we did not think linear regulators could perform the necessary conversion without overheating. Undervoltage and short circuit protections were initially provided by e-Fuse components. Figure X shows the schematic included in the design document.

A diagram of a circuit

Description automatically generated

Figure 2: Power System V1

The e-Fuse components were removed to reduce cost and complexity. The LM22678 Buck Converters can use an output inductor to limit the maximum output current. A voltage divider between the Vin and EN pins could act as undervoltage protection. Because the safety features covered by the e-Fuse were redundant, they were removed. A professional product would still prefer to include these components for redundancy. Figure X shows the second model of the power system. This model adds capacitance to stabilize the ripple voltage.

A computer screen shot of a diagram

Description automatically generated

Figure 3 Power System V2

The power system was designed to use LM22678-ADJ converters. ADJ denotes that the output voltage is adjustable using the compensation loop shown in the previous figures. Mistakenly, LM22678-5.0V components were ordered instead. These components have a fixed 5 V output voltage. Upon realizing this, the correct components were ordered, but they never arrived. At this stage, we realized that the design is needlessly overcomplicated. The flaw with using linear regulators was that 7.4 V to 3.3 V at 1 A would hypothetically heat the regulator to 302 degrees Celsius. However, a linear regulator could be used to branch the 5 V buck converter output to the 3.3 V line. This would lower the cost of the system, increase component safety, and reduce design complexity.

A computer screen shot of a circuit board

Description automatically generated

Figure 4: Power System V3

Power System V3, shown in Figure X, was never completed due to time constraints. We proceed with power system V2. Power System V2 smoked upon connecting the 7.4 V LiPo Battery for the first time. We believe this is due to in-rush currents. However, we have no way of testing this hypothesis. If further development decided to return to a custom power supply, this would require investigation.

# 3 Design Details

## 3.1 Control Unit Details

## 3.2 Sensing System Details

## 3.3 Haptic System Details

## 3.4 Scanning System Details

## 3.5 Power System Details

The power system is broken down into two stages. The primary source powers the Arduino Mega though USB. The battery is rated 5 V and 2.1 A. The USB Input for the Arduino is limited to 500 mA.

|  |  |
| --- | --- |
| Component | Maximum Rated Current |
| Arduino Mega | 500 mA |

The Arduino Mega acts as the second stage of the power system. The internal linear regulators are used to form a 5 V and 3.3 V power bus. The scanning mechanism, the haptic system, and the sensing systems are all powered by Arduino’s +5 V Pin. The LiDAR takes an additional reference voltage from the Arduino’s +3.3 V pin.

|  |  |
| --- | --- |
| Component | Maximum Rated Current |
| LiDAR Lite | 100 mA |
| Hall Effect Sensor | 25 mA |
| Doppler Radar | 60 mA |
| Haptic Motor | 60 mA |
| Stepper Motor | 250 mA |

Each pin from the Arduino is individually rated for a maximum draw of 200 mA. To avoid overdrawing, the stepper motors were powered through a motor controller and four digital pins. For the effectiveness of the product, the maximum number of haptic motors active at a time is limited to two. This change ensured the Arduino would be capable of powering the haptic system without an external power supply.

# 4. Design Verification

The final product met all the high-level requirements submitted with the design document. The final product was generally easy to debug. This is due to the design changes we made throughout the project heavily prioritizing consistency. Alongside design changes, the verification table had to be updated. The verification table that the final product was judged against is in Appendix X. This table includes the results of each test. The verification table included in the design document is in Appendix Y.

## 4.1 Control Unit

The PCB Version of the control unit never progressed to the verification step. Once the control unit was changed to a development board, the control unit passed each of the final verification tests included in appendix X.

Most requirements for the control unit overlapped with the sensing and haptic feedback system, so these requirements will be discussed in detail in their appropriate sections. A requirement was added to the control unit that it would be able to control the stepper motor. It was able to do so. The requirement to read from an accelerometer and gyroscope was removed as previously discussed.

## 4.2 Sensing System

The LiDAR and Doppler Radar components were straightforward to verify. The LiDAR Measurements were verified by placing the LiDAR at a known location away from a wall using a tape measure. Measurements were printed to the serial terminal from the Arduino. The results are included in Appendix X. The Doppler Radar was tested similarly. Once the control unit was able to perform I2C and analog reads, these components fell into place. The requirement initially required that the LiDAR could detect a wall from 5 meters away. This test was verified; however, it is not useful to the user. The more relevant threshold was 1.5 meters, which was also successfully tested.

The final version of the hall effect module was equally simple to debug. We supplied the single hall effect sensor with 5 V, manually placed and removed a magnet, and observed that the output voltage fell from 5 V to 0.25 mV.

The version of the hall effect module with 12 sensors never passed verification. The same procedure as above was used, however it was determined that one of the hall effect sensors was broken, as it could not register the presence of the magnet regardless of orientation or distance. This led to us simplifying the design.

## 4.3 Haptic Feedback System

Early testing for the haptic motors using a bench power supply revealed that the motors could run at 5V, however they would begin to overheat and cause discomfort to the users after 10 seconds of continuous power.

The completed haptic feedback system was tested with a specific program that ran on the Arduino. The Arduino would loop between turning a specific haptic motor on for two seconds, turning the motor off, waiting one second, and then repeating the process for the next motor. This process verified the complete functionality of the haptic feedback system. All verification tests were passed.

Prior to connecting the haptic motors directly, the program was run, and the output voltage of each switching transistor was measured with a voltmeter. This ensured that the transistors were working correctly, and the output voltage drop was enough to not overheat the motors.

The major obstacle to debug was poor soldering connections between the switching transistors and the protoboard, and the inconsistency of the crimps we used before finally opting to solder the motors to the switching transistor module directly.

## 4.4 Scanning System

Verifying the scanning system was very straightforward. The LiDAR did spin, and the control unit could read the LiDAR through the slip ring while the LiDAR was spinning. That observation completed the verification table.

Notably, the requirement to spin the LiDAR at 30 RPM was absent from the design documents verification table. This was tested regardless. 30 RPM is slow enough to be counted manually. The motor, running at a fixed 15 RPM could spin the LiDAR at an average of exactly 30 RPM over a 10-minute period. An RPM meter could accomplish this task better.

## 4.5 Power System

The verification table for the power system underwent as many revisions as the power system itself. The current draw thresholds for the “HVPS” and “LVPS” line changed dramatically. Notably, the haptic motors were moved to the HVPS Line caused an increase to the maximum current from the HVPS bus. The maximum acceptable ripple voltages increased likewise. Starting from Power System V3, the HVPS and LVPS current limits were combined into one 3 A maximum current draw, and the shutdown tests were merged. The final power system, using the commercially available USB charger, was tested against the verification table designed for Power System V3. The exact results can be seen in Appendix X. The only “failed” test was the 3 A maximum current draw. This shortcoming was inconsequential to the demonstration of the product but could cause a problem if somehow more haptic motors turned on than should be allowed.

# 5. Costs

The total cost to produce this project fell within the $150 USD Budget given by the department. Over the course of changing components, and parts breaking, we had to spend our own money to finish the project.

## 5.1 Parts

Many components for this project were sourced from the personal supply of the team members. This was to cut costs and reduce production delays from delivery times. The LiDAR Sensor was provided by the university. These components are not included in the total cost, but the unit costs are provided.

|  |  |
| --- | --- |
|  |  |
| **Part** | | | **Number** | **Count** | **Manufacturer** | **Unit Cost ($)** | **Total Cost ($)** |
| Pirate Hat | | | 482444 | 2 | Party City | $25.00 | $50.00 |
| Arduino Mega 2560 V2 | | |  | 1 | Arduino | $22.88 | $0.00 |
| LidarliteV1 | | | 010-01722-00 | 1 | Garmin | $129.99 | $0.00 |
| Doppler Radar | | | CQRSENWB01 | 1 | CQRobot | $11.99 | $11.99 |
| Haptic Motors 20 PCS | | | B09XMXDN7M | 1 | Zard zoop | $11.99 | $11.99 |
| Transistors | | |  | 12 |  |  |  |
| Hall Effect | | | A3144 | 1 | Eplzon | $0.35 | $0.35 |
| 330 Ohm Resistor | | |  | 1 |  |  |  |
| Slip Ring | | | CP164 | 1 | Comidox | $9.59 | $9.59 |
| Stepper Motor | | | 28BYJ-48 | 1 | DIYables | $4.99 | $0.00 |
| Skateboard Bearing | | | 608 2RS | 1 | SHKI | $0.60 | $0.00 |
| Solderable Breadboard | | | EP-52PCB | 1 | EPZLON | $9.99 | $0.00 |
| Portable Battery | | |  |  |  |  |  |
| **Total** | | |  |  |  |  |  |

## 5.2 Labor

# 6. Conclusion

The conclusion may contain the following sections or others of your choosing.

## 6.1 Accomplishments

## 6.2 Uncertainties

## 6.3 Ethical considerations

## 6.4 Future work

# References

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# Appendix A Requirement and Verification Table

An appendix is a good place for the Requirement and Verification Table from your design review. Below is a starter table. Including these details here will help to avoid lengthy and tedious narrative descriptions in the main text, which may not be of immediate interest to your imagined audience of company managers and professionals. Any requirement that is not verified should be explained either in the main text or the appendix. Note that both the pagination and the numbering of figures, tables, and equations continues from main text to appendices.

|  |  |  |
| --- | --- | --- |
| **Table X System Requirements and Verifications** | |  |
| Requirement | Verification | Verification status  (Y or N) |
| 1. Requirement    1. Subrequirement    2. Subrequirement    3. Subrequirement | 1. Verification    1. Subverification    2. Subverification    3. Subverification |  |
| 1. Requirement    1. Subrequirement    2. Subrequirement    3. Subrequirement | 1. Verification    1. Subverification    2. Subverification    3. Subverification |  |
|  |  |  |
|  |  |  |