Automated Sound Panel Modification for Audio Lab

ECE 445 Design Proposal

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1. Introduction

1.1 Objective

The Illinois Augmented Listening Laboratory is one of a handful of acoustic labs in the country. In order to enable others to contribute more easily to this field, the lab intends to build a fully automated, remotely accessible, audio lab. Researchers could also submit a configuration to run an experiment, and the experiment will be autonomously set up (speakers, mic arrays, sound panels, etc.) and run to capture data. By constructing a space as described, research on hearing aid technology, the "cocktail party problem" [1], and other acoustics research becomes much easier for any research group to study by using this automated, fully remote, lab facility.

Our goal to contribute to this automated lab space is to construct a system to autonomously set up sound panels around the room based on the incoming configuration. We will construct a motorized shutter system that will sit over each individual sound panel. When the shutter is open,sound is allowed to contact the panel and ends up trapped in the panel's geometry . In the closed position it will lie flat over the shutter and will mimic a wall for the sound to bounce off, not allowing any sound to reach the panel. In any given set of sound panels (some N x N configuration of panels), each panel's shutter will be controlled by a controller, which determines each panel's state (open/closed) based on the experiment's configuration file. This design modifications to the room acoustics from experiment to experiment, allowing the space to simulate different acoustic environments on the fly.

1.2 Background

Most hearing aid devices struggle to clearly articulate incoming noise (voice, tv, music, etc.), from surrounding noise, and result in unclear audio assistance. A report published by the *International Journal of Audiology* even lists background noise as the second most contributing reason to the underutilization of hearing aids [2]. A report by the National Institute on Deafness and Other Communication Disorders (NIDCD) states that only 30% of people aged 70 and older with hearing loss have ever worn hearing aids [3]. That number is even lower (roughly 16%) for those aged 20 to 69 [3]. Consequently the NIDCD highlights one of its priorities as improving performance of hearing aids, especially in separating background/ambient noise from relevant input [3].

Solving these problems requires equipment to simulate a variety of environments as well as technology to simulate in-ear acoustics is required. However, equipment of this nature is inherently expensive, making funding and purchasing power a restricting factor in this research. This problem exists in other fields as well, with some having created ways to share their equipment across research spaces. The Robotarium at Georgia Tech is a swarm robotics research space that allows remote access by researchers who want to test new algorithms or experiments, without needing to buy robots or travel to the lab themselves [4n]. This idea can now be applied to the acoustics lab space. Providing other researchers remote-access to an autonomous lab, it greatly increases the opportunity to contribute towards research. This innovation facilitates improvements to hearing aid technology and quicker solving of other acoustics problems.

1.3 Physical Design

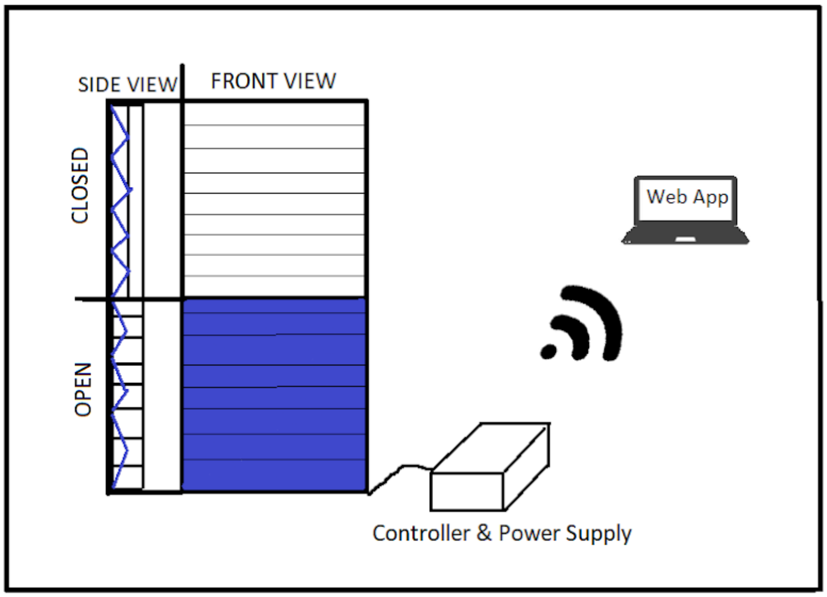

Figure 1. High-Level Component Diagram

1.4 High-Level Requirements

1. The system should significantly change the acoustics of the room, measurable by the T60 Reverberation Time.
2. The time from sending configuration (assuming normal network conditions) to complete execution of instructions on each shutter should be < 10 seconds.
3. The system should be easily scalable up to a 5x5 set of acoustics panels (25 total panels).

2. Design

2.1 Block Diagram

Our system requires various components for full functionality. These components are the Power Supply, WiFi Module, Control Unit, and Shutter Subsystem. The power supply consists of batteries and a voltage generator that supplies 3.3 V to various components. The Control Unit consists of a microcontroller to handle the data from the user and send the corresponding information to the shutter subsystem and the WiFi module. The WiFi module allows for a remote connection to a web application to provide our system with a wireless functionality. The shutter subsystem will consist of a servo motor and potentiometer per panel and allows the shutters to open and close depending on the desired configuration.

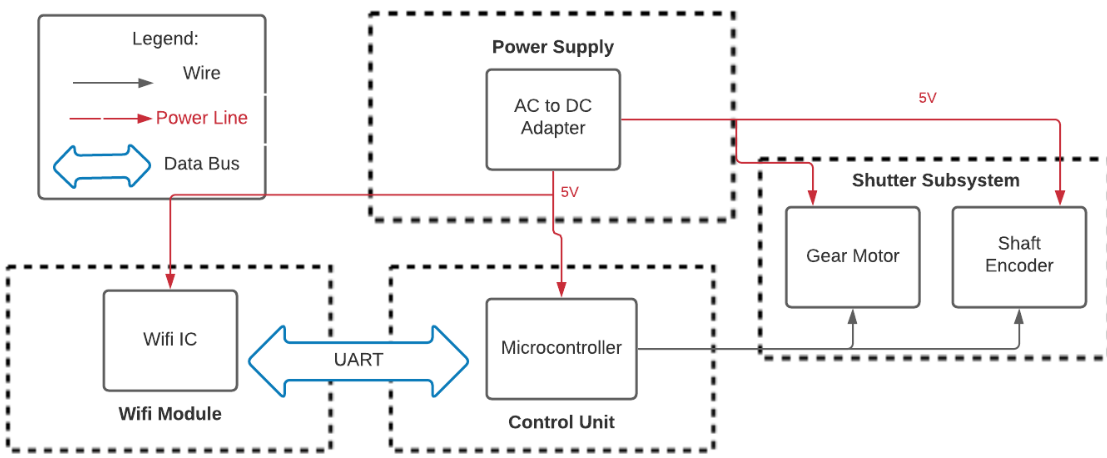

Figure 2. Subsystem Diagram

2.2 Control Unit

The control unit should be able to collect the data from the user via a config file and control the servo motors. It will also control the data being sent and received from the WiFi module. We will use UART to communicate between the Wifi module and the microcontroller.

2.2.1 Microcontroller

The microcontroller will be an ATMEGA32 Arduino chip on the PCB. The chip will receive the config file data from the user from the WiFi module, communicated via UART. The PIC also has on-chip memory that can be used to store data such as the states of the shutters over each panel and the current experiment metadata.

Requirement(s)	Verification
1. Able to parse configuration file and activate correct servos	1A. Load configuration file into program locally (not via WiFi), note which servos should activate based on input file 1B. Run program, compare activated servos to expected servos to ensure they are equivalent
2. Receives configuration file from WiFi module, and activates corresponding servos	2A. Connect the microcontroller to the WiFi Module, to communicate over UART 2B. Send configuration file over WiFi to the controller, note which servos should activate based on input file 2C. Run program, compare activated servos to expected servos to ensure they are equivalent
3. Shuts off experiment if a motor disconnects	3A. Connect servos to controller (connect power from power supply and signal to controller) 3B. Simulate motor failure by quickly disconnecting servo wires or by mimicking failure in software testbench 3C. Ensure that the controller records the experiment as a failure and saves event in logs

2.3 Shutter Subsystem

The shutter subsystem is made of the motors which control the position (open/closed) of the shutters. Directions on when to switch positions comes from the control unit.

2.3.1 Gear Motor with Encoder

The gear motors will be used to open and close the shutters. With the uxcell Gear Motor, the shutters should be able to open and close with good speed as the motor functions at 200RPM.

Requirement(s)	Verification
1. Must have enough torque to open/close shutters	1A. Mount motors on shutters (work with ECE machine shop to do this) 1B. Run test program to rotate servo while connected to shutter and observe if torque is sufficient
2. Should be able to open/close shutters in under 2 seconds	2A. Mount motors on shutters (work with ECE machine shop to do this) 2B. Run test program to rotate servo while connected to shutter and record time taken for shutters to oscillate

2.4 Power Supply

The power supply is used to power the components in the system. These components are servo motors, encoders, and the WiFi IC. After realizing that we would not be able to change the batteries when we needed to along with the cost we decided to have the power supply consist of an AC to DC adapter.

2.4.1 Power Supply Unit

The power supply will be a 5V 15A 75W AC to DC adapter, and it will supply power to the motors and other components of the system.

Requirement(s)	Verification
1. The Power Supply must be able to supply a voltage of 5V.	1A. Measure the power supply with an oscilloscope and make sure it is within 5% of 5V.
2. The Power Supply must be able to supply a total current of 11.2 A for all motors to function simultaneously.	2A. Measure the power supply with an oscilloscope and make sure it is within 5% of 11.2A.

The power supply will have to power all 4 motors and encoders in parallel at the same time. Each motor and encoder will require 5V and 2.8A which is equal to 14 W as P=IV. With four motors this would account for 56W of power as $P_{total} = \sum P$. All four motors will require 2.8A of current, thus requiring 11.2A of total current as the motors will be in parallel. Both of these constraints will be satisfied by our power supply.

2.5 WiFi Module

The Wifi module will be used to receive information from the microcontroller via UART and then transmit that information across a wireless network in order to create a remote monitoring functionality. The power supply will power the WiFi IC with 3.3V.

2.5.1 WiFi IC

The WiFi IC will be implemented using the ESP8266 chip by Espressif Systems. The chip will be able to transmit data through a wireless network via TCP/IP connections.

Requirement(s)	Verification
1. Must be able to receive experiment configuration file (JSON) from server	1A. Connect the microcontroller to the WiFi Module, to communicate over UART 1B. Connect the WiFi module to remote server (via program) 1C. Send configuration file to the chip 1D. Check that the configuration file was received by the WiFi chip by having some acknowledgement action on the controller (rotate motor, light LED, etc.)
2. Be able to send log files with relevant data to the server after each experiment	1A. Connect the microcontroller to the WiFi Module, to communicate over UART 1B. Connect the WiFi module to remote server (via program) 1C. Send a test configuration file 1D. Execute experiment or have some wait time to mimic experiment running 1E. Wait for the log files to be received on the server after experiment completes and check for accuracy

2.6 Software

There are two sub-components to the software that runs across the system. The first part is the software on the controller itself. This is responsible for controlling the shutters, as well as recording the current state of the system.

2.6.1 Controller

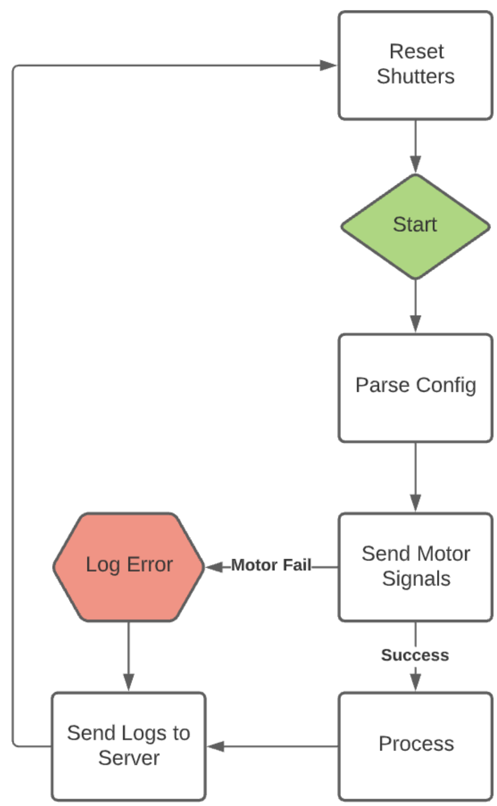

Figure 3. Controller Software Flow

2.6.2 Web Application

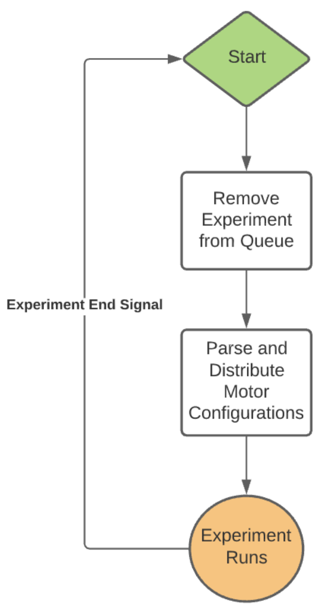

Figure 4. Foreground Thread

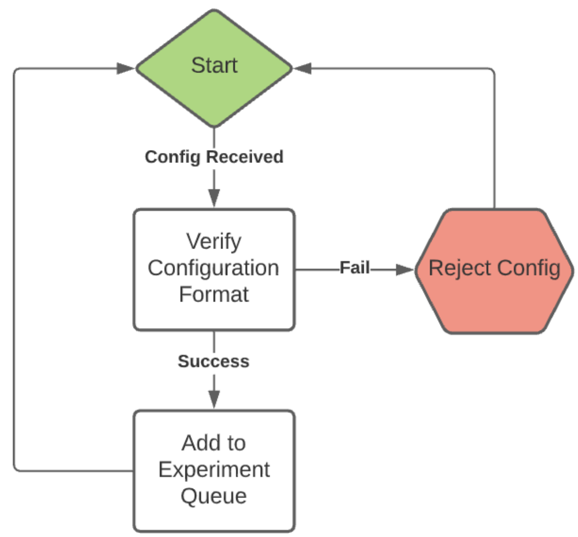

Figure 5. Configuration Acceptance Thread

2.7 Circuits

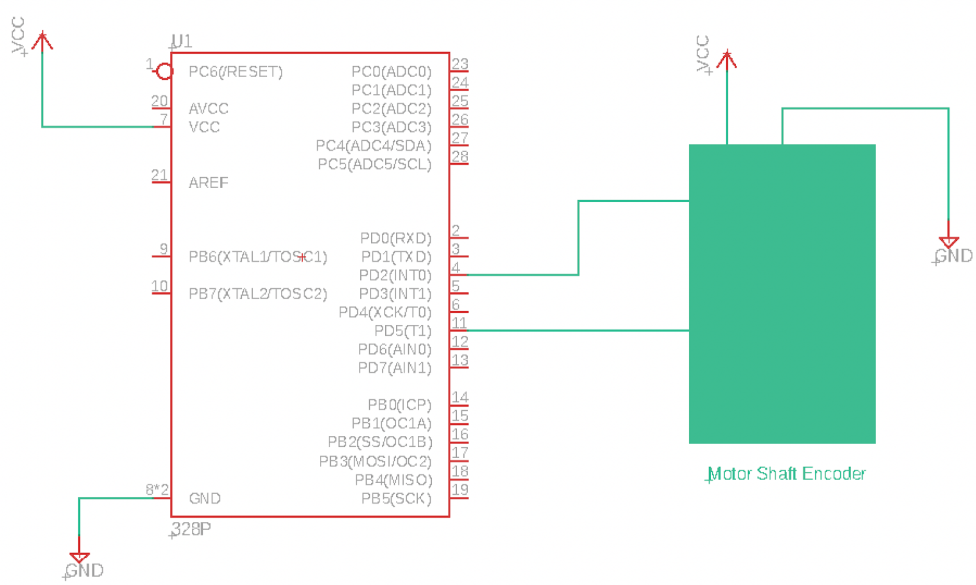

Figure 6. High-Level Shaft Encoder Circuit

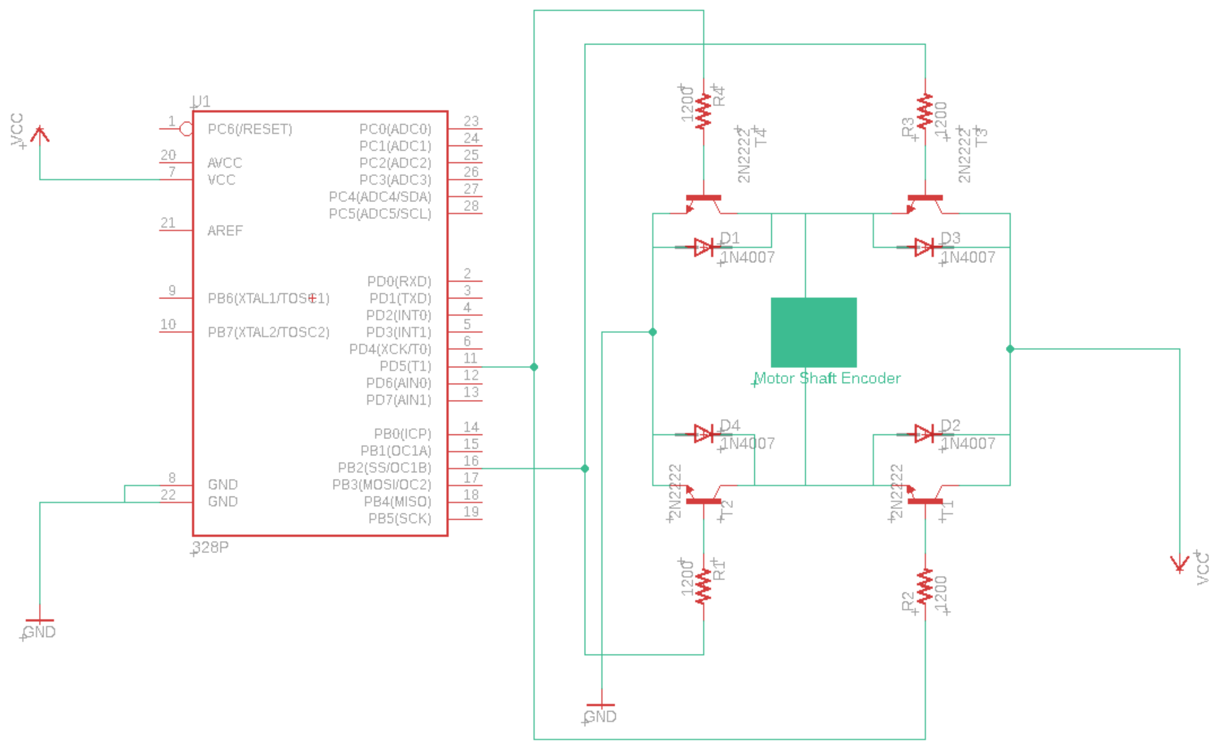

Figure 7. H Bridge Motor Driver

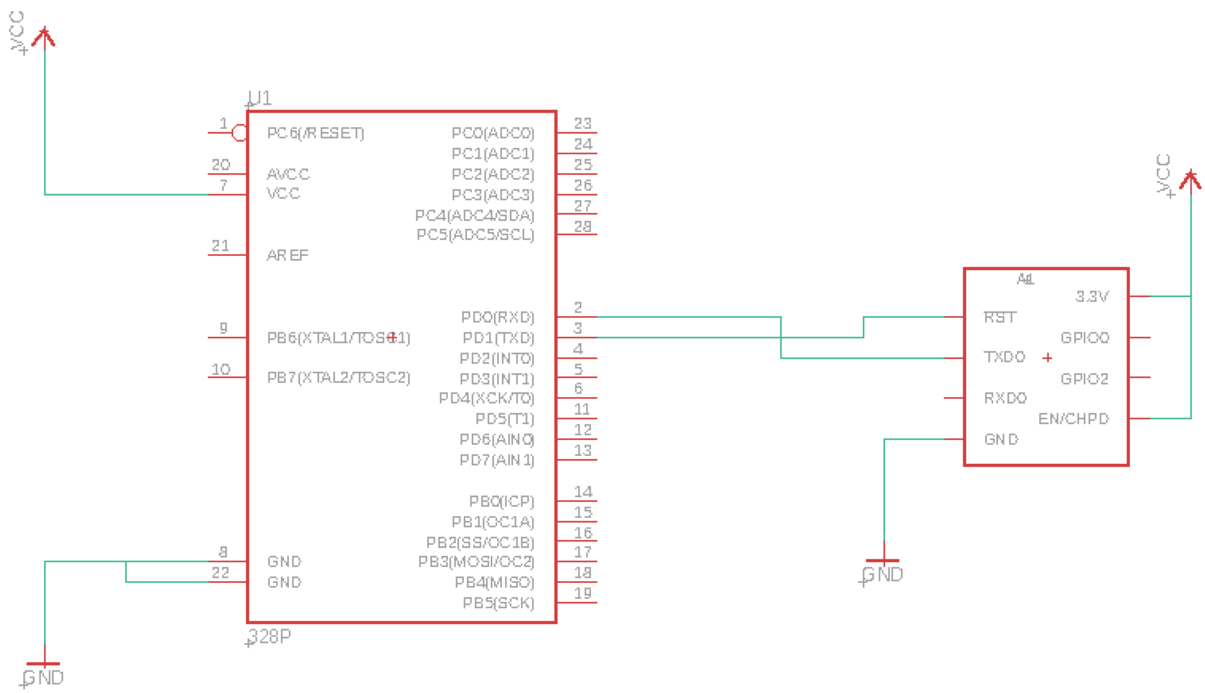

Figure 8. Microcontroller and WiFi Module Schematic

2.8 Risk Analysis

The Shutter subsystem will provide the greatest risk to the completion of our project. One possible source of failure is that the shutters will be too heavy for the gear motor to rotate efficiently. This may increase the time it takes for the shutters to open/close, and therefore reduce the response time for our overall system.

Another possible limitation is that the motors fail to close completely flush, thereby allowing sound to seep through the gaps. This source of error would most likely be caused by slight motor error or shutter design flaws. A large part of this problem will involve working with the design lab so that the shutter design allows it to be completely sealed when closed.

The last limitation that we will deal with in terms of the shutter system is the space constraint. Our design requires thin shutters that do not consume a large amount of space yet are capable of reflecting sound and serving as a wall. In terms of COVID-19, our team does not believe that will cause us many problems. All three of us are on campus and have been able to meet with each other. We have also been able to meet with the machine shop multiple times with zero problems.

2.9 Tolerance Analysis

The subsystem most critical to the success of our project is the shutter subsystem. The main concern is the requirement of the motors to be able to rotate the shutters open/closed. Torque requirements can be calculated based on the expected weight of the shutters. A set of aluminum shutters, when cut to the dimensions of a sound panel (1 ft. X 1 ft), at a tenth of an inch, the torque requirements are as follows:

$$\text{Mass of Aluminum} = 44.22526g / in^3$$

$$\text{Mass of shutters} = (44.22526g / in^3) * (12in * 12in * 0.1in) = 636.48g$$

$$\text{Rated Torque of Motors} = 0.2kgf.cm = 200gf.cm$$

$$\text{Stall Torque of Motors} = 0.8kgf.cm = 800gf.cm$$

Based on this analysis, the motor is expected to be able to rotate the weight of the aluminum shutters. However, this depends on the shutter coming out to the exact dimensions/weight as expected. Additionally, the motor would be close to stalling out at this weight. Consequently, an external gearbox of 4:1 would reduce the load on the motor by 4, making the load 159.12g, which is within the rated torque of the motors.

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

The labor rate from our team was calculated from the average salaries of Illinois ECE graduates [5]. Since the three members of the team are Computer Engineering, all the hourly rates were calculated based on the Computer Engineering salary, $96, 992. For the remaining 8 weeks in the course, the team expects to work 15 hours a week on design and construction of the system. This totals to 120 hours worked, and a total labor cost of $5595.6 per employee. The total labor cost is then 3*5595.6= $16786.8.

Employee	Rate	Hours Worked	Labor Cost
Rishi	$46.63	120	5595.6
Zachary	$46.63	120	5595.6
Rajat	$46.63	120	5595.6

Table 1. Personnel Labor Cost

3.1.2 Parts

In Table 2 (below), is the initial list of parts that is necessary to complete the project. This does not include cost of construction materials, but focuses on the electronic parts integral to each subsystem. The total cost of the parts is expected to be $110.68.

Module	Part	Quantity	Cost per Unit	Function
Control Unit	ATMEGA328P U	1	$2.40	Microcontroller chip which connects components and controls their state
Control Unit	TLC5940NT	1	$8.95	IC that allows expansion of PWM pins from

				ATMEGA, allows for scaling up
Shutter Subsystem	Gear Motor + Encoder	4	4x$7.40=$29.60	Controls shutter movement to open and close
Wifi Module	ESP8266	1	$6.95	Receives configuration file from internet server using WiFi
Power Supply	5V 75W Power Supply	1	$26.99	Provides power to entire system
Shutter Subsystem	Aluminum Shutters	1	$25.79	Provides a basic shutter mechanism build off
Other	Electronics (Resistors, capacitors, etc.)	N/A	*$10.00 *Estimated	Required to create safe, functional circuits

Table 2. Parts Cost

3.1.3 Total Cost

The total cost of the parts is $110.68 and the total cost of labor is $16,786.80 bringing our total cost to be 16,897.48.

3.2 Schedule

Week	Objective	Rishi	Zachary	Rajat
2/28 - 3/6	Design Document and Check, order parts	Complete Design Document, work with Zachary on motor design	Research motors and servos and finalize which parts to use, design circuit	Design Circuit Schematic for ESP8266 and ATMEGA
3/7 - 3/13	Design Review, start designing PCB for	Begin web application development,	Start PCB Design, work with Rajat	Start PCB Design, work with Zachary

	ATMega and WiFi Module	assist with PCB		
3/14 - 3/20	Finish initial designing PCB and place PCB order, make basic prototype with Arduino Board and parts, work with machine shop to mount motors to shutters	Continue web app dev, research connecting applications to ESP8266 WiFi Chip, assist with PCB design as needed, work with machine shop to mount motors	Complete PCB Design, add motors to PCB and any other necessary components, verify PCB design with TA, place PCB order	Work with Zachary on PCB Design, build basic prototype with motors and shutters on Arduino Board, verify torque requirements are met
3/21 - 3/27	Verify PCB order was correct, order again if not. Begin constructing entire system with arduino board	Compile components onto PCB board (soldering if needed), mount board to system, work with Zachary	Find way to neatly attach board to system and mount board, work with Rishi and Machine Shop	Mount motors onto shutters, find way to attach shutters together neatly, work with Zachary and Machine Shop
3/28 - 4/3	Test system to ensure functionality is as intended	Test system, address any issues/bugs that we observe	Test system, address any issues/bugs that we observe	Test system, address any issues/bugs that we observe
4/4 - 4/10	Provide progress reports, begin working on presentation, continue debugging	Work on presentation, continue debugging	Work on presentation, continue debugging	Work on presentation, continue debugging
4/11 - 4/17	Continue presentation work, plan demo	Create demo configurations to show functionality, continue working on presentation	Continue working on presentation, distribute responsibilities for presentation	Continue working on presentation, distribute responsibilities for presentation
4/18 - 4/24	Mock demo	Mock Demo	Mock Demo	Mock Demo

4/25 - 5/1	Final demo, and mock presentation and report due	Refine presentation, work on final report	Refine presentation, work on final report	Refine presentation, work on final report
5/2 - 5/8	Final presentation and report due	Complete final report and submit	Complete final report and submit	Complete final report and submit

Table 3. Weekly Schedule

4. Ethics and Safety

The sound shutter project is fully automated and is intended for unsupervised use, and there are a number of associated safety concerns associated with the system. Most of these concerns are related to the motion of the shutters and potential damages to the motors driving the shutters. This is especially a concern because the priority is to contain any potential damages that might occur to just our system, because the lab would be unsupervised.

The most likely failure situations are motor burnout or an obstruction that prevents the shutter from closing. The other concern is motors overheating, but the motor should turn off automatically if it gets too hot, which can be treated as an offline motor. Additionally, the likelihood of this event happening is very low, considering the motors are only rotating back and forth occasionally, and only with a range of 180 degrees.

To handle such situations, the shutter subsystem software will be designed to recognize when a shutter is unable to close, or has lost connection (burnout, offline motor). The program will then mark the experiment as a failure to run, and log the error, specific to the exact panel with a malfunction. This logging will also aid the lab staff in identifying the problem, and ensuring that the issue does not occur again. This is in accordance with IEEE Code of Ethics #5, to acknowledge and correct errors [6].

Additionally, due to the valuable nature of experimental data, results from experiments run using the system should only be accessible by the researcher who commissioned the experiment. This is intended to follow the ACM Code of Ethics, 1.6., to respect privacy [7]. While we cannot verify the intentions of the lab as a whole, our iteration of this system will follow this guideline, since it is our priority to maintain privacy when relevant. Our system would share system reports, configurations, and any gathered data privately with the researcher, to prevent data from spreading in the community.

5. References

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