Smart Home Conditioning System

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Abstract

Our project for ECE 445 senior design class is the Smart Home Conditioning System that achieves automatic opening and closing of the window and blind in different conditions. The project can help people with disabilities open or close the window and the blind when the environment is pleasant. In this paper, we covered our design in detail and how we successfully built the project based on our high-level requirements. We also included the requirements and verifications table, the cost calculation of the design, and our future plan for the project.

Contents

1. Introduction

1.1 Problem

The windows and blinds, which enable the exchange of air, light, and sound, are essential pieces of furniture that maintain the comfortable environment of a house. For people with physical disabilities who often stay at home for a long time, to maintain their mental health, it is particularly important to keep their home in exchange for fresh air and receive mild sunshine, which will help them build a connection with nature and the outside world. However, it might be inconvenient for them to open the window and blind when it's a pleasant day outside or to close them when it rains, fogs, smokes, or when it is too noisy or shiny outside. Therefore, we aim to design a Smart Home Conditioning System that automatically keeps the house in exchange for fresh air and mild sunshine on pleasant days and blocks the unpleasant weather outside for people with physical disabilities.

1.2 Solution

The Smart Home Conditioning System consists of a sensor module to detect humidity, temperature, brightness, air quality, and noise levels, a motor module to open/close the window and the blind, a control module to make decisions, a safety module to prevent safety issues, and a power module to supply constant voltage to all other components. The sensor module consists of two subsystems: indoor and outdoor. For the outdoor subsystem, we have the rain sensor, noise sensor, humidity and temperature sensor, and dust sensor to determine the temperature, noise level, and whether it rains, fogs, or smokes outside. For the indoor subsystem, we have the brightness sensor and noise sensor to measure brightness outside and indoor noise level. In the case when the temperature is not within a preset range, when it rains, fogs, or smokes, or when it is too shiny or noisy, the microcontroller will tell the motors to close the window or the blind. For the motor module, we have two motors to move the window and the blind separately together with a motor driver to control the direction and the time that the motors run. To address potential safety problems, we employ an IR (Infrared) sensor to detect whether there are any obstacles such as hands or pets between the window and the frame. Overall, this Smart Home Conditioning System consists of a sensor module with indoor and outdoor subsystems, a safety module with IR sensors, a microcontroller, a power module with a converter, and a motor module with a window motor, a blind motor, and a motor driver.

1.3 High-Level Requirements List

1. The window will close when the relative humidity outside is larger than 70%; when it is raining outside; when the dust concentration outside is larger than 300 μg/m³ (microgram per cubic meter, unit of concentration of an air pollutant); when the noise is larger than 70 dB (decibel, unit of measurement of sound); when the outdoor temperature is lower than 23℃ (degree Celsius) or higher than 27.5℃. In other cases, the window will remain open.

2. To ensure the privacy of our users, we want to check the brightness outside. The blind will be closed whenever the brightness level falls below 10 lux (unit of illuminance), indicating that it's night outside. In this case, the inside scene will be separate from the outside. Otherwise, the blind will be left open.

3. Safety is an essential consideration of our design. Therefore, the safety module should respond within 0.5 seconds when any obstacles appear within 10cm (centimeter) of the window. We also want to detect rain and noise levels every 30 seconds, outdoor humidity and temperature every 5 minutes, and brightness and dust level every 30 minutes.

2. Design

2.1 Block Diagram

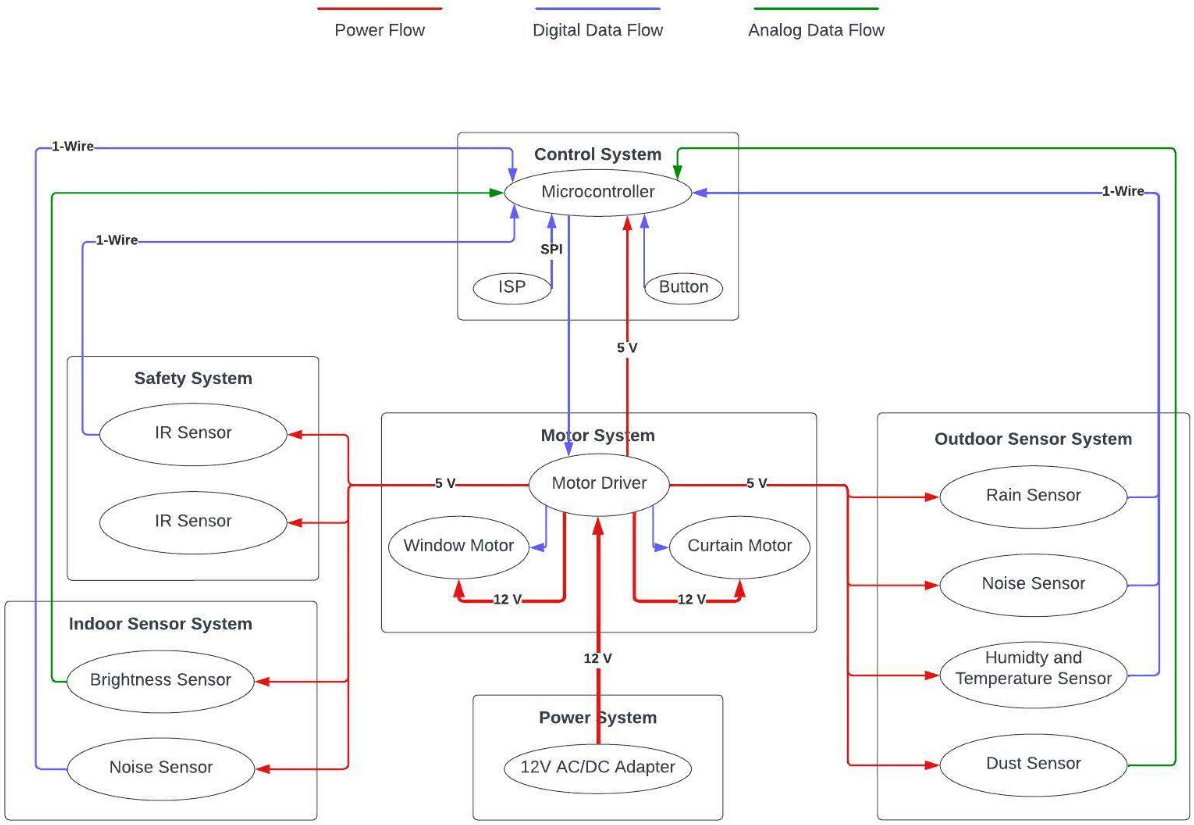

Figure 1. Block Diagram of the Project

2.2 Physical Design

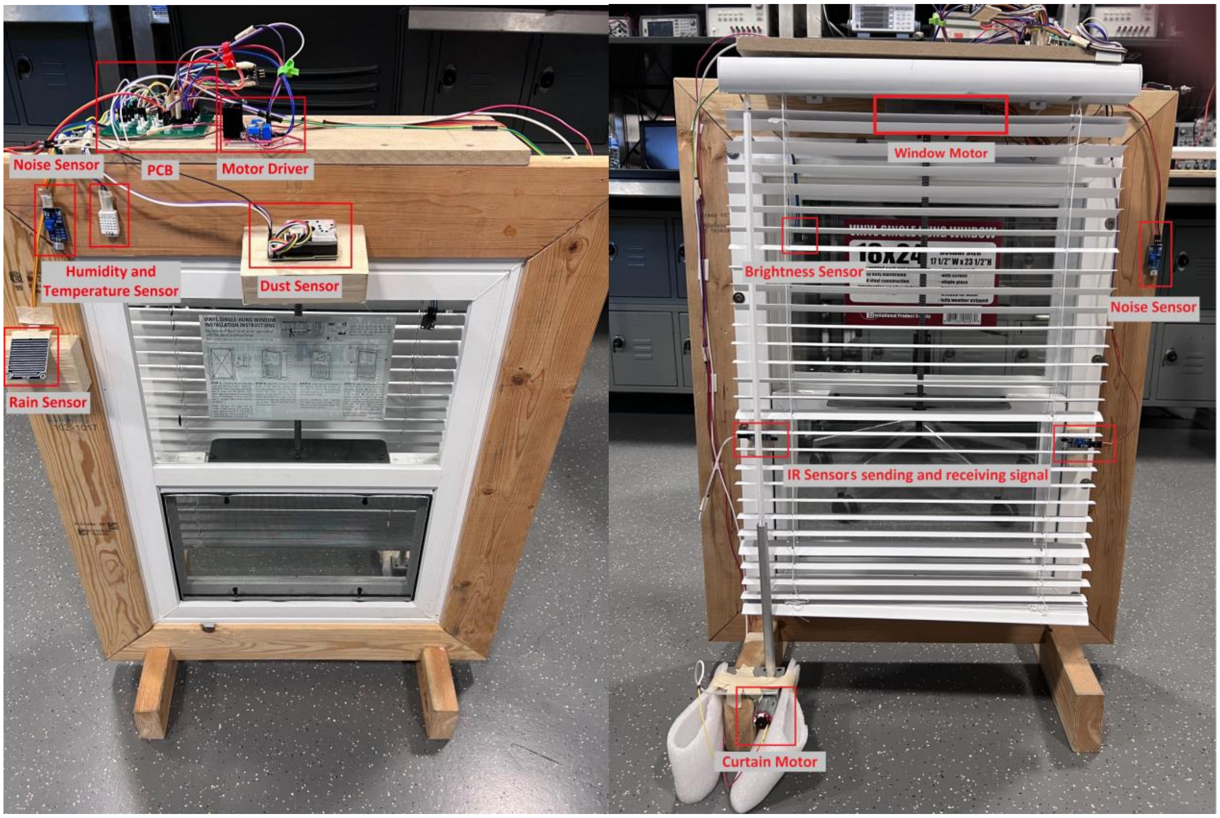

Figure 2. Front View and Back View

Our design for the Smart Home Conditioning System is built on a vertically sliding window, which has a frame size of 18*24 inches. The wood frame around the window has a dimension of 25.5*31.5 inches, and most of our designs are located on the wood frame. To be specific, the control system and the power system were attached to the top of the wood frame. The window motor was installed underneath our control module, which was also attached with a straight and long screw that was installed on the top of the bottom window. The safety system consisted of two IR sensors, which were located at the left and right of the wood frame. The outdoor system was located outside of the wood frame. The blind system has a mini blind installed on the top of the wood frame, and the blind motor was attached to the spinning stick that opens/closes the blind.

2.3 High-Level Flow Chat

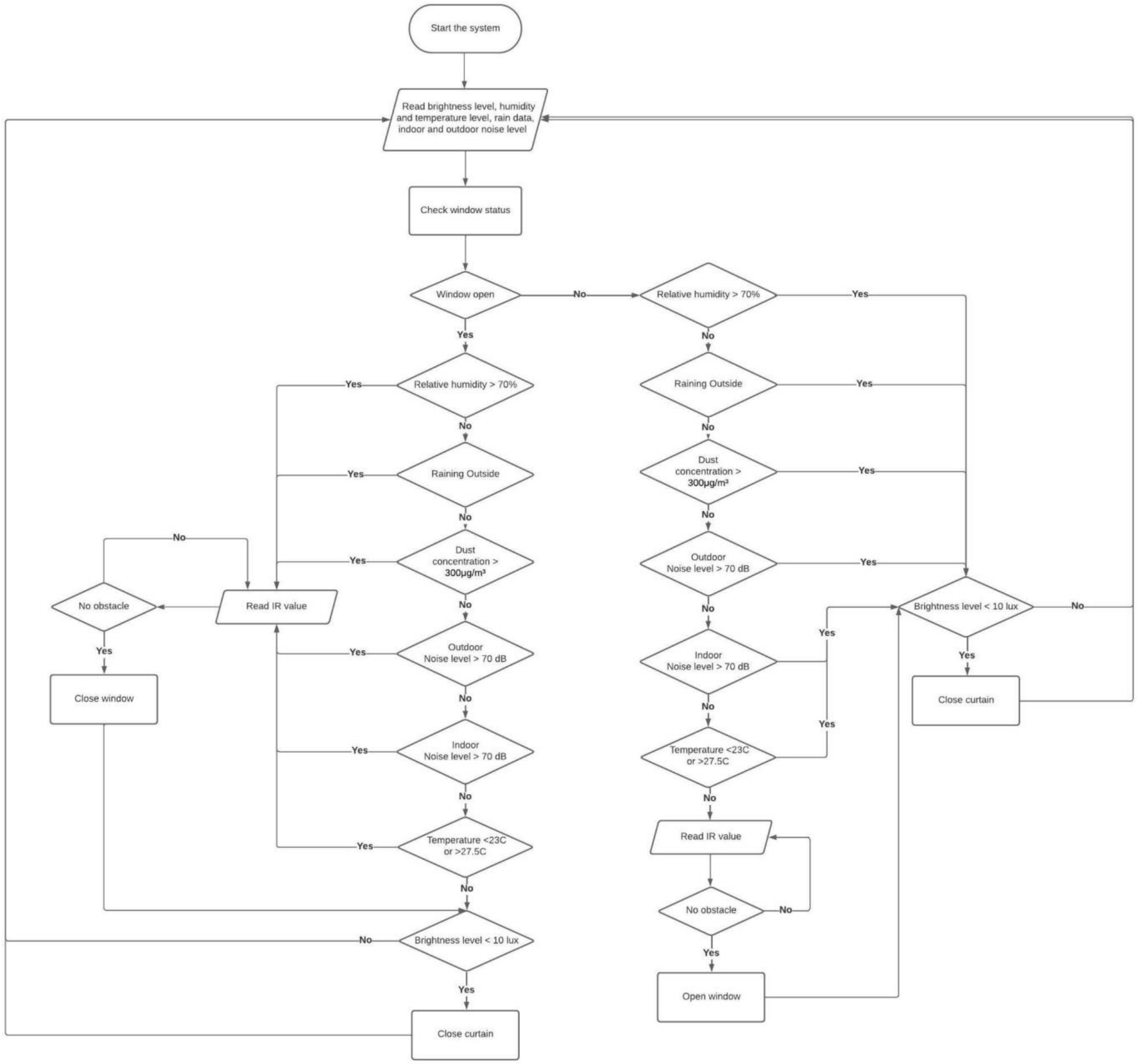

Figure 3. Flow Chart

2.4 Subsystems Overview

2.4.1 Power Subsystem

This subsystem supports the power needed by the motors to perform the opening and closing of the window and blind. The power system is able to supply power to all sensors and the microcontroller we are using in this project. With the wall adapter that converts the voltage from

AC (alternating current) to DC (direct current) 12V (Volt, unit of voltage) voltage and a Motor Driver to convert the 12V DC to 5V DC, it can successfully power up the system.

AC-DC Converter

For our AC-DC Converter, we used a 110V AC to 12V DC converter by inShareplus. The AC-DC Converter accepts AC voltage from 100V to 240V, which can satisfy our need for the design. The Converter pack also includes a 5.5/2.1mm (millimeter) DC Female Barrel Connector, which is convenient for the connection with the motor. The AC-DC Converter is also connected to the Motor Driver to provide 5V DC voltage, which is used by most of the components in our design. The maximum wattage is 24W (Watts, unit of power), which is enough to supply the power of every component.

Motor Driver

The Motor Driver converts 12V DC voltage from the AC-DC converter to 5V DC voltage. In our design, we chose the Motor Driver by HiLetgo. The reason we chose Motor Driver is that we want to limit the cost of our design, and our selection of Motor Driver has the option to provide 5V DC voltage from 12V DC input. In this case, we don't need an extra 12V to 5V DC converter in our design. The Motor Driver provides the power supply for most of the components, such as the microcontroller, the indoor & outdoor sensors, and the IR sensors. The selected Motor Driver can provide an output current of up to 2A (Ampere, unit of electric current), which is enough for our design.

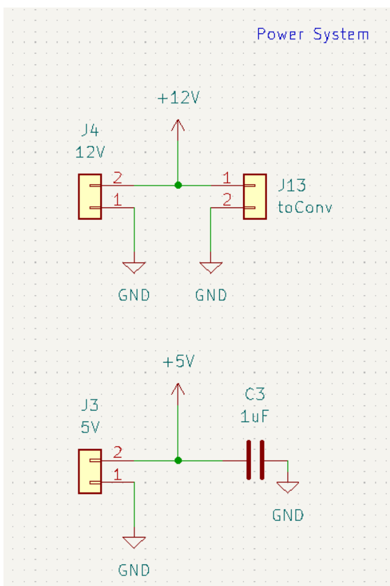

Figure 4. Power System Schematic

The Requirement and Verification table is in Appendix A Table A.1.

2.4.2 Control Subsystem

This subsystem consists of the microcontroller that reads in and processes the data from the sensors and then decides the action of the motors for the window and blind. The microcontroller should provide enough consideration of the current weather and generate decisive signals to the motors. The microcontrollers should also respond fast to data from sensors within 0.5 seconds.

Microcontroller

Atmega328P is the center of our design, and it is connected to our PCB (printed circuit board) to process the status of different sensors and motors. The data signals are sent to the PCB when the threshold is met or the data has changed, and the PCB passes the signal to the microcontroller for further analysis. The microcontroller in this step considers the current environment and preset conditions, which are combined to decide whether we need to open or close the window or blind. After processing, the microcontroller sends instructions to the motor driver, and the motor driver can achieve precise control on the motors. The motors then rotate to open/close the window or blind, which is precisely restricted by the microcontroller.

The microcontroller also handles the safety module, and since safety is the priority in our design, the microcontroller should always respond to the safety module before other operations. During the opening/closing of the window, the microcontroller always processes simultaneously with the safety module and will send out instructions to the motors immediately when unusual signals are received from the safety module.

PCB Design

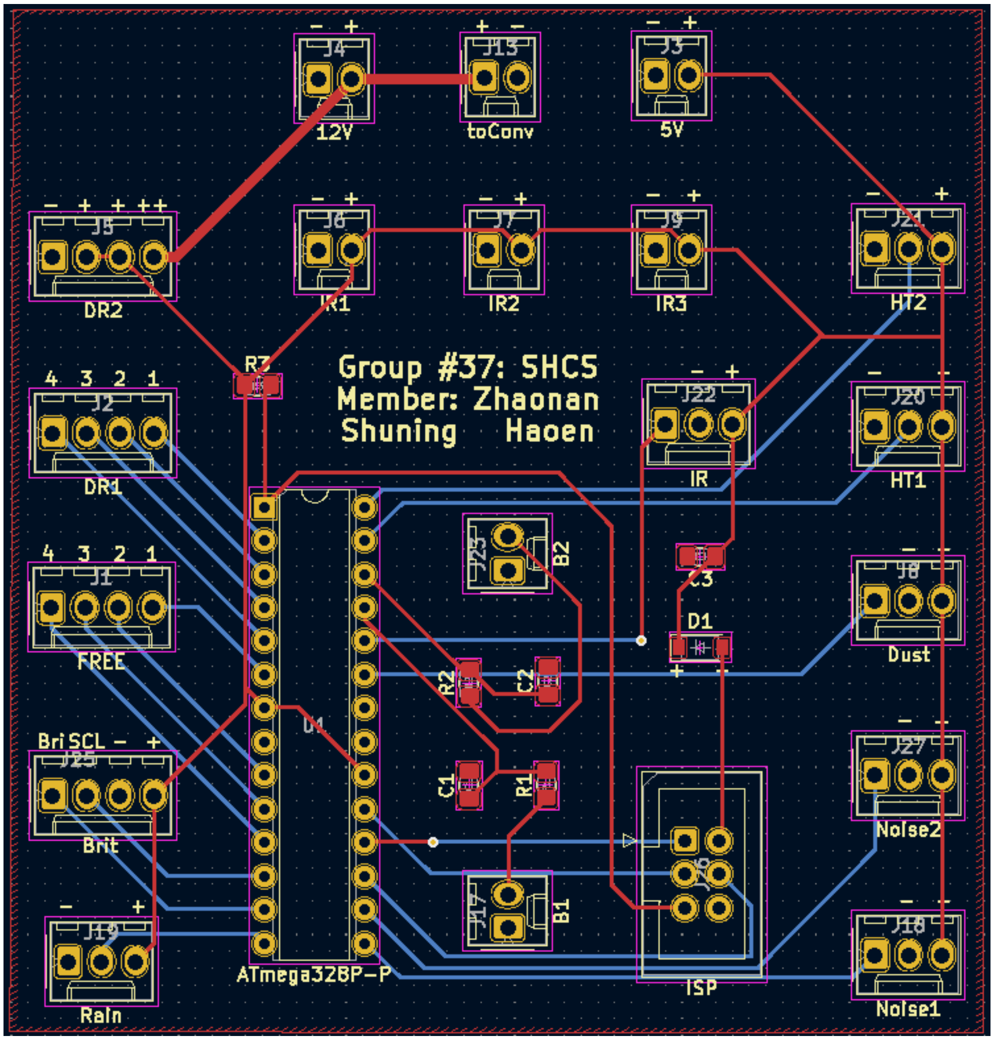

Figure 5. PCB Layout

The above figure is our PCB Layout, which consists of ISP, microcontroller, sensors, motor driver, and button connectors. The PCB receives different inputs from various sensors, and it sends those signals to microcontrollers to decide the status of the window and blind. Then, the decision will be sent to the motor driver to control the motors.

The Requirement and Verification table is in Appendix A Table A.2.

2.4.3 Safety Subsystem

This subsystem is a crucial part of our design as it prevents potential safety issues from happening. The safety subsystem consists of two IR sensors, one sending the infrared signal and the other receiving that signal. Normally, the IR sensor can receive the signal. However, when any obstacle appears near the window and blocks the light path, the IR sensor can no longer receive the signal.

The window motor will then be stopped, preventing users from getting injured when the window is opening or closing. The safety system requires the motor to stop within 0.5 seconds, and the IR sensor that detects obstacles should also be accurate when any obstacles appear within 10cm of the window.

IR Sensor

We put IR sensors on the left and right window frames to prevent people from getting hurt in the process of closing the window. The TSSP4038 sensor we selected is a compact infrared detector module. This sensor provides an active low output in response to infrared bursts at 940nm (nanometer), which results in a quick response time, allowing it to detect changes in its environment rapidly. With its rapid detection capabilities, the TSSP4038 sensor can quickly send back the data to the microcontroller for potential safety hazards, allowing for faster response times and ultimately reducing the risk of accidents.

The Requirement and Verification table is in Appendix A Table A.3.
The Schematic for the safety module is in Appendix C.

2.4.4 Motor Subsystem

In this subsystem, the microcontroller will control the direction of the window motor and the blind motor through the motor driver. The motors will then perform the close or open action, achieving the goal of our design to build a healthier indoor environment. This subsystem consists of a window motor, a blind motor, and a motor driver. When informed by the microcontroller and powered by the motor driver, the motor can fully open and close the window and blind.

Window Motor

We placed the motor on the top of the top window frame and attached them to a spiral iron Rod fixed on the top frame of the lower window. The motor rotates either clockwise or counterclockwise to pull up and down the window, depending on the decision made by the microcontroller. Given the weight for the whole window is 8lb and aiming to be able to lift the window up in roughly 30 seconds, we are choosing the motor that is powered by 12V DV, with 100 RPM (revolutions per minute) and a rated current of 0.6A.

Blind Motor

We placed the motor on the side and attached it to the blind's rotation rod. The motor rotates either clockwise or counterclockwise to change the blind position, preventing privacy issues for the users when night comes. Because the blind's rotation is lighter than the window, the motor we chose previously is able to support enough torque. With the ability to rotate more than 720 degrees, this motor is also able to fully change the blind’s position.

Motor Driver

The Motor Driver is important in our design since we use it to supply 5V voltage and control the movement of the motor. We placed the motor driver next to the PCB and received the signal from the microcontroller to control the motor. The motor driver will switch the Vcc (voltage common collector) and ground to change the direction of the motors when the microcontroller sends signals, which helps us open and close the window and the curtain. Our selected motor driver has two output channels, which can connect both the window motor and blind motor, and thus further limit the cost of our design.

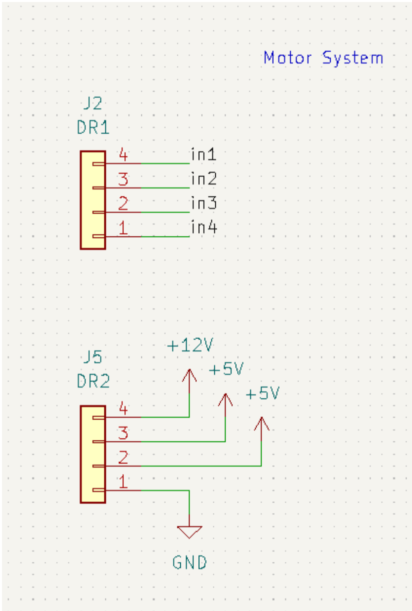

Figure 6. Motor System Schematic

The Requirement and Verification table is in Appendix A Table A.4.

2.4.5 Outdoor Sensor Subsystem

This module is powered by the power system, and it measures the rain, fog, smoke, temperature, and noise of the outside environment. It sends back the collected data to the microcontrollers which then decides if the data had exceeded the preset value. The outdoor sensor subsystem helps the microcontroller to determine if the window needs to be closed when the humidity sensor detects > 70% relative humidity [1]; when the dust sensor detects > 300 μg/m³ dust concentration [2]; when the rain sensor detects raindrops; when the noise sensor detects noise level exceeding 70 dB [3], or when the outdoor temperature falls out of 23.5℃ - 27℃ [4].

Rain Sensor

We need a rain sensor on the right side of the outside wood frame to detect if it is raining outside so that the microcontroller can tell the window motor to close the window when it is raining. Therefore, we chose the LM393 because it has a large raindrop board that is separate from the control board which makes wiring convenient. It also contains a potentiometer to adjust the sensitivity. LM393's control board can send digital output to the microcontroller, where high digital output indicates no rain while low digital output indicates rain.

Temperature and Humidity Sensor

We need a temperature sensor on the right side of the outside wood frame to detect the outside temperature for the microcontroller to analyze the overall temperature.
We also need a humidity sensor on the right side of the outside wood frame to detect if it is foggy outside by measuring the relative humidity so that the microcontroller can tell the window motor to close the window when relative humidity is larger than 70%.
Therefore, we chose the DHT22 because it consists of a humidity sensor and a thermistor, and this sensor can measure both the temperature in degree Celsius and humidity in relative humidity. Its accuracy can go up to ±0.5 ℃ and ±2% RH (relative humidity) and exhibits excellent long-term stability. DHT22 sends a digital signal from its data pin to the microcontroller in the format of "8-bit integral RH data+8 bit decimal RH data+8 bit integral T (temperature) data+8 bit decimal T data".

Dust Sensor

We need a dust sensor on the middle of the outside wood frame to detect if it is smoking outside by measuring the dust concentration so that the microcontroller can tell the window motor to close the window when the dust concentration is larger than 300 $\mu g/m^3$. Therefore, we chose the KS0196 which performs well in detecting delicate particles. KS0196 sends analog signals to the microcontroller with an output voltage linear to the dust density, so there is no need to make calculations. We want it to accurately measure dust concentration with the accuracy of ±30 $\mu g/m^3$.

Noise Sensor

We need a noise sensor on the right side of the outside wood frame to detect if the outdoor environment is too noisy by measuring decibels so that the microcontroller can tell the window motor to close the window when the outdoor noise level is larger than 70 dB. Therefore, we chose DAOKI which enables users to set a threshold. When the threshold is reached, it sends a digital output to the microcontroller. What's more, DAOKI also has a potentiometer for sensitivity adjustment. We want it to accurately measure the noise level with the accuracy of ±5 dB.

The Requirement and Verification table is in Appendix A Table A.5.
The Schematic for the outdoor module is in Appendix C.

2.4.6 Indoor Sensor Subsystem

This module is powered by the power system, and it measures the indoor noise level and outdoor brightness level. Data are returned to the control subsystem to decide if the data has exceeded the preset value. The indoor sensor subsystem helps the microcontroller to determine if the window needs to be closed when the noise sensor detects a value exceeding 70 dB [3] or if the blind need to be closed when the brightness sensor detects a value below 10 lux [5].

Brightness Sensor

We need a brightness sensor on the left side of the inside wood frame to detect if night comes by measuring the level of illuminance so that the microcontroller can tell the blind motor to close the blind when illuminance is smaller than 10 lux. Therefore, we chose the BH1750 which has a wide range and high resolution (1 - 65535 lux). It also shows little dependency on light sources and little influence by infrared. BH1750 sends digital signals to the microcontroller directly in lux, so there is no need to make calculations. We want it to accurately measure the brightness level with the accuracy of ±1 lux.

Noise Sensor

We need a noise sensor on the right side of the inside wood frame to detect if the indoor environment is too noisy by measuring decibels so that the microcontroller can tell the window motor to close the window when the indoor noise level is larger than 70 dB. Therefore, we chose DAOKI which enables users to set a threshold. When the threshold is reached, it sends a digital output to the microcontroller. What's more, DAOKI also has a potentiometer for sensitivity adjustment. We want it to accurately measure the noise level with the accuracy of ±5 dB.

The Requirement and Verification table is in Appendix A Table A.6.
The Schematic for the indoor module is in Appendix C.

2.5 Tolerance Analysis

In our design, there are three main aspects that require deep consideration.

The first aspect is the power and capability of each component. In our power system, the 110V AC power transfers into 12V DC and 5V DC as the power supply, and thus the converter would be important in our design to ensure that the maximum current does not exceed the limits. If the current exceeds the limit for converters, the design may lead to serious danger. In this case, we need to calculate the power needed for each sensor and motors, and decide if our choice of the converter is safe to use.

For the motor driver, the maximum current is 2A. For the components that are supplied by 5V DC power, the total current needed is shown in Equation (2.5.1), which is far lower than the maximum current of the motor driver. Thus, the Motor Driver is safe to use.

$$\begin{gathered} 0.2\text{mA(microcontroller)} + 2 * 5\text{mA(IR Sensor)} + 0.4\text{mA(Rain Sensor)} + \\ 2.5\text{mA(Temperature and Humidity Sensor)} + 20\text{mA(Dust Sensor)} + \\ 0.2\text{mA(Brightness Sensor)} + 2 * 0.4\text{mA(Noise Sensor)} \\ < 35\text{mA} = 0.035\text{A} \end{gathered} \tag{2.5.1}$$

For the AC-DC Converter, the maximum current is 2A. For the components that are supplied by 12V DC, the total current needed is shown in Equation (2.5.2), which is lower than the maximum current of the AC-DC Converter. Thus, the AC-DC converter is safe to use.

$$\begin{gathered} 0.035\text{A(2.5.1)} + 0.036\text{A(Motor Driver)} + 2 * 0.6\text{A(motor)} \\ < 1.28\text{A} \end{gathered} \tag{2.5.2}$$

The second aspect is the torque by the motor, and we need to make sure that our choice of the motor can lift the window and spin the stick on the blind. For this aspect, we also need to consider the case in which the motor is not spinning at the maximum torque, and we need to leave some room to ensure the success of our design.

We also required the motor to fully pull up the window within 30 seconds of receiving the signal from the microcontroller. This requires the motor to have enough torque and could operate at a relatively fast speed. Equation (2.5.3) shows the force we need to lift the 3.63kg (kilogram) window and considering the time limit, the total force needed is 38N (newton). The motor has a known radius of 2.7cm, and in this case, the torque as calculated in Equation (2.5.4) is 1.026Nm (newton-meter). To ensure success in the motor, we require the motor to have at least a torque of 3Nm [6]. Because the motor chosen has torque way above the value, thus we could confirm that the motor can successfully lift the window in 30 seconds. Because the blind is lighter than the window, thus we believe the same motor is also powerful enough to fully adjust the position of the blind.

$$F = m * a = 3.63kg * \frac{9.8m}{s^2} + 3.63kg * \frac{0.5m}{s^2} = 38N \qquad (2.5.3)$$

$$\tau = 38N * 0.027m = 1.026Nm \qquad (2.5.4)$$

The last aspect is the response time of our systems.

For our safety module, we want the time it takes for the IR sensor to react and the microcontroller to respond when any obstacles appear within 10cm of the window to be within 0.5 seconds for safety considerations. The IR sensor we chose can respond in 5ms (millisecond) for ranges from 10cm to 2m (meter). What's more, the microcontroller can respond within 2ms.

For the sensor module, with the information given in the datasheet, we confirm that the rain sensor can detect the environment every 30 seconds; the brightness sensor can detect the luminosity every 30 minutes; the dust sensor can check the environment dust concentration every 30 minutes; the humidity and temperature sensor can measure the surroundings every 5 minutes; and the noise sensor can receive the sounds constantly every second.

Therefore, the safety module and sensor module can satisfy our requirements.

2.6 Alternatives

We were able to fulfill most of the requirements mentioned in Appendix A. However, we failed to upload the code to the microcontroller. As an alternative approach to solving this problem, we used Arduino Nano, which consists of the same Atmega328P microcontroller and ISP (In-system programming) implemented on board. Through the Nano, we were able to upload our program and let it process all the data input from the sensor and make the right decisions.

3. Costs

3.1 Parts

Table 1 Parts Costs

Description	Manufacturer	Part #	Quantity	Cost($)
Motor System				
Motor	Fafeicy	Fafeicyogdbg 2c9up-03	2	16.13 x 2
Motor Driver (4pc)	HiLetgo	L298N	1	11.49
Power System				
110V AC - 12V DC Converter	inShareplus	ISP-NW-PS-12V-WP-UL-24W	1	8.89
Control System				
Nano with USB cable (3pc)	Lafvin	B07G99NNX L	1	22.99
PCB (10pc)	PCBway		1	30
Connector Headers	DigiKey		1	1.86
Safety System				
IR Sensor (6pc)	WWZMDiB	TSSP4038	1	7.99
Indoor/Outdoor Sensor System				
humidity and temperature sensor	Aideepen	DHT22	1	10.35
dust sensor	Keyestudio	Ks0196	1	10.00
sound sensor (5pc)	Daoki	TS-US-115-CA	1	6.29
Brightness sensor	DFRobor	BH1750	1	4.5

rain sensor (3pc)	HiLetgo	LM393	1	6.49
Other				
blind	Lumino		1	9.97
Total:			**$ 163.08**	

3.2 Labor

Assume the hourly salary for a newly employed Engineer is $45/hour and assume an average workload for this project is 10 hours per person per week. With a total of 12 weeks of work this semester, as the detailed schedule included in Appendix B, the total labor cost would be

$$\$45 \times 10 \text{ hours/week} \times 12 \text{ weeks} \times 3 \text{ people} = \$16200 \tag{4.2}$$

3.3 Total

The total cost for our project as including the parts cost from table 1 and labor cost shown in equation 4.2 is $16363.08

$$\$163.08 + \$16200 = \$16363.08 \tag{4.3}$$

3.4 Schedule

We follow the schedule we set in the design document, and every group member has finished their own parts before the deadline. The detailed schedule is in Appendix B.

4. Conclusion

4.1 Accomplishments

We are thrilled that we have successfully read data from six different sensors and used it to control the opening and closing of the window and blind under the appropriate environmental conditions, which fulfilled our high-level requirements for this project. Our sensor network collects data on temperature, humidity, dust, light, and noise level allowing us to make informed decisions about when to open or close the window and blind for optimal comfort and energy efficiency. Also with the IR sensors, we are able to ensure the safety of our users.

In addition to the success of building the sensor module, after doing some research we were also able to develop the motor control system with the motor driver. By connecting the motor driver to our microcontroller, we were able to control the direction and speed of the motor. Our motor control system is a crucial component in our overall project, as it allows us to operate our window and blind systems with precision and accuracy. With the motor driver in place, we can ensure that our window and blind systems are operating as accurately as possible.

4.2 Uncertainties

Originally, our project design did not feature any digital screen display and we stuck to our plan, which we later found out might be a disadvantage for the users as they won't be able to see the real-time sensor reading. During the testing process, we made sure that every sensor held the correct thresholds and returned the corresponding value. But when putting this in real-life usages, we could only assume that the sensors are still working correctly and report the right value to the microcontroller.

Another aspect we could improve is installing more IR sensors. We believe the two IR sensors we use for now will provide safety to the users, but with more sets of infrared red sensors installed, we would expand the coverage area along the window and provide an even greater level of protection to users.

4.3 Ethical considerations

Our design will only render limited Ethics problems, as we mainly focus on the mechanism and functionality. As our project comes to a close, it is important to address the limited ethical concerns that may arise due to the mechanism and functionality of the design. In accordance with the IEEE (Institute of Electrical and Electronics Engineers) Code of Ethics, our team is committed to upholding the highest standards of integrity, responsible behavior, and ethical conduct in our professional activities. To be specific, we prioritized "the safety, health, and welfare of the public". This guideline emphasizes that we should always place safety in the first place and ensure that anyone who uses our design will be safe and pleasant. We also "seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest, and realistic in stating claims or estimates based on available data, and to properly credit the contributions of others" in the process. At the same time, we always "maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations". Only after we equip ourselves with professional skills will we make the knowledge into practice, and this makes sure that we won't damage and hurt the equipment, labs, students, and even ourselves [7].

Besides ethics problems, our design may involve some safety concerns. Thus, we seriously designed our project so that we can make sure we eliminate those safety problems to a minimal degree. For our motor system, we checked that the closing/opening of the window stopped immediately when some obstacles appeared. This includes human arms, human hands, pets, and other objects like books, phones, and computers. The power system was also taken into serious consideration, since the electricity may lead to a severe fire risk and shorted risk. In addition, the components were well protected: no matter the outdoor system or the indoor system, the components were protected with shields and tapes, which can ensure that the design won't be affected by unexpected damage like weather and unintended touch.

In summary, our team adheres to the IEEE Code of Ethics and diligently addresses safety concerns in order to safeguard the ECE 445 lab environment, faculty, fellow students, and ourselves. Through consistent collaboration and adherence to our ethical and safety standards, we will continue to refine our design and present the best possible outcome.

4.4 Future work

There are a few ideas we have so that we can further commercialize our automatic window system and blind system.

1. We plan to develop a user-friendly app or interface that allows users to customize their preferences, such as temperature, humidity, or noise thresholds so that the system adapts to each user's unique needs and preferences. Meanwhile, we will make sure the app or interface is accessible for users with different disabilities by adding features such as voice guidance, large buttons, and high-contrast colors. We plan to integrate with popular smart home ecosystems like Google Home, Amazon Alexa, and Apple HomeKit. This will allow users to control the system using voice commands and integrate it with other smart home devices.
2. We also consider adding energy-efficient features, which could be using solar panels to operate the system or integrating with smart thermostats that will optimize energy consumption based on the comfort levels user defined through the app.
3. Finally, to ensure the competitiveness of the product, we will implement user feedback data collection, which collects feedback from users to identify areas for improvement and refine the product based on their needs and preferences.

References

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Appendix A Requirement and Verification Table

Table A.1 Power System Requirement and Verification Table

Requirements	Verification	Verification Status
The system must provide stable 12 ± 0.5V DC, 2 Amp power to motor system and motor driver	- Connect the Converter to the wall and use Voltmeters and Ammeters in the ECE 445 lab to measure the output voltage of the Converter, verify the reading is between 11.5 and 12.5 V - After 5 minutes, measure the output voltage and check it is still in the range of 11.5 - 12.5 V	Yes
The system must provide stable 5 ± 0.5V DC power to the sensors and microcontroller in this project	- Connect the motor driver to the 12V power supply and use Voltmeters and Ammeters in the ECE 445 lab to measure the output voltage of the motor driver, verify the reading is between 4.5 and 5.5 V - After 5 minutes, measure the output voltage and check it is still in the range of 4.5 - 5.5 V	Yes

Table A.2 Control System Requirements and Verification Table

Requirements	Verification	Verification Status
Could read in I2C data passed in from brightness sensor, 1-wire data passed in from noise, rain, IR, humidity, temp sensors, and analog data passed in from the dust and temperature sensors	- Simulate input signals for different pins: noise, rain, IR, humidity, and temp sensors can generate high/low signals, thus we can create high/low input to see if the microcontrollers work. - Check the microcontroller can print out the I2C data input coming from the brightness sensor on the monitor. - Simulate analogy data input for dust and temperature sensors.	Yes

Respond within 0.5 seconds to the different input signals, especially for IR sensors	- Simulate input signals and use the Arduino to measure the time for the Microcontrollers to respond - Provide the low/high signal for the assigned IR data reading pin that measures the microcontroller response time, verify it is less than 0.5 seconds	Yes
Microcontrollers should detect the environment in various time frames (detailed in high-level requirements) and check whether we need to change the status	- Use the Arduino to check whether the Microcontroller could process the data every 30 seconds / 5 minutes / 30 minutes: check if there is output to the motor when we change the testing environment after 30 seconds / 5 minutes / 30 minutes - Check if the Microcontroller would constantly read data for 30 seconds in a 1-minute duration: we will keep providing high readings to the Microcontroller for 30 seconds check if the motor position changes	Yes

Table A.3 Safety System Requirements and Verification Table

Requirements	Verification	Verification Status
Able to detect any obstacles appear within 10 cm of the window	- Place the book within 10 cm of the window frame and verify the sensor captures the abnormal behavior and sends a signal to the microcontroller	Yes
The IR sensor should respond and send the signal within 0.5ms to avoid safety problem	- Use the Arduino to check the response time for IR sensor and the time for the microcontroller to receive it, verify it is within 0.5ms	Yes

Table A.4 Motor System Requirements and Verification Table

Requirements	Verification	Verification Status
Window should be steadily opened within 30 seconds	- Attach a piece of paper to the motor and check if the motor spins with a constant Angular velocity: use a timer to see how many cycles the motor spins within 30 seconds. - Used an object with a similar mass as the window to see whether the motor can lift the object steadily - Use the timer to see whether the motor spins enough cycles within 30 seconds	Yes
Blind should be steadily opened within 30 seconds	- Attach a piece of paper on the motor and check if the motor spins with a constant Angular velocity: use a timer to see how many cycles the motor spins within 30 seconds. - Attach the motor to the blind rotation rod to see whether the motor can open the blind steadily - Use the timer to see whether the motor performs enough rotations within 30 seconds	Yes
Motor Driver should precisely control the spin of the motor	- Attached a piece of paper on the motor and check if the motor spins the desired direction - Used the timer to measure the time it takes to perform the rotation and check with the preset speed	Yes

Table A.5 Outdoor System Requirements and Verification Table

Requirements	Verification	Verification Status
Sensor should be able to work steadily under the 5V DC Power supply	- Connect the sensors to the 5V power supply and ground, and use the Arduino to check if the sensor is giving output - After 5 minutes, check again to see if the sensors are still able to give out the data output	Yes

Sensors should be able to respond within the corresponding time to the pre-set threshold correctly	- Rain sensor: Verify the sensor will correctly signal the microcontroller when it rains outside - Add 4 - 5 drops of water on the raindrop board and check the switch indicator, repeat the process for 20 times - Dust sensor: Verify the sensor will correctly signal when the environment around has 300 μg/m³ or higher dust concentration - Create 3 environments each with around 250 μg/m³, 300 μg/m³, 350 μg/m³ dust concentration, then measure the accurate dust concentration with another dust sensor with known high accuracy, and finally compare that to the data collected by the dust sensor we want to test. - Humidity sensor: Verify the sensor will correctly signal when the humidity of the environment around is 70% or higher - Create 3 environments each with around 50%, 70%, and 90% relative humidity, then measure the accurate relative humidity with another humidity sensor with known high accuracy, finally compare that to the data collected by the humidity sensor we want to test. - Noise sensor: Verify the sensor will correctly signal when the environment around is exceeding 70dB - Create 3 environments each with around 50dB, 70 dB, and 90dB, then measure the accurate decibel with Apple Watch noise-level detection application, and finally compare that to the data collected by the noise sensor we want to test	Yes

Table A.6 Indoor System Requirements and Verification Table

Requirements	Verification	Verification Status
Sensor should be able to work steadily under the 5V DC Power supply	- Connect the sensors to the 5V power supply and ground, and use the Arduino to check if the sensor is giving output - After 5 minutes, check again to see if the sensors are still able to give out the data output	Yes
Sensors should be able to respond within corresponding time to the pre-set threshold correctly	- Brightness sensor: Verify the sensor will correctly signal the microcontroller when the outside environment is below 10 lux - Place the brightness sensor in the environment of a cloudy outdoor, sunny indoor, typical office, and sunny outdoor with no direct sun, and compare the data collected by the brightness sensor to the standard light level chart [5] - Noise sensor: Verify the sensor will correctly signal when the environment around is exceeding 70dB - Create 3 environments each with around 50dB, 70 dB, and 90dB, then measure the accurate decibel with Apple Watch noise-level detection application, and finally compare that to the data collected by the noise sensor we want to test	Yes

Appendix B Schedule

Week	Task	Member
2/20 - 2/26	Design document; Select desired sensors and components; Specify detailed expectation for design;	All Members
2/27 - 3/5	Buy sensors and motors, and test whether the sensors and motors are functional	Shuning Zhang Zhaonan Shi
	Buy microcontroller and test whether the microcontroller fixes into our design	Zhaonan Shi Haoen Li
	Start PCB design, work on the component and contact with machine shop	All Members
3/6 - 3/12	investigate motor and encoder, program motor and test with the window	Shuning Zhang
	PCB assembly and test the functionality	Zhaonan Shi Haoen Li
3/13 - 3/ 19	Spring Break	All Members
	Finish any leftover job from previous week	
3/20 - 3/26	Implement rain drop sensor and brightness sensor with microcontroller and program basic induction for these sensors	Haoen Li
	Contact machine shop and install the motor and blind on the window	Shuning Zhang Zhaonan Shi
	Programming of the motors and encoder	Zhaonan Shi
	Install the Safety module	Shuning Zhang Haoen Li

3/27 - 4/2	Link indoor sensors to the microcontroller and connect to the PCB board; Test and debug the indoor system	Shuning Zhang Zhaonan Shi
	Link outdoor sensors to the microcontroller and connect to the PCB board; Test and debug the outdoor system	Haoen Li Zhaonan Shi
4/3- 4/9	Test out the exact location on the window frame for better measurement of the inside sensor module; Test and debug the indoor system for finalization	Shuning Zhang Zhaonan Shi
	Test out the exact location on the window frame for better measurement of the outside sensor module; Test and debug the outdoor system for finalization	Haoen Li Zhaonan Shi
	Connecting indoor sensors with outdoor sensors	All members
	Assemble all components, test the coordination of each component	
4/10 - 4/16	Finalized design, debug and test the design; prepare for the demo	All members
4/17 - 4/30	Mock Demo Final Demo Start writing Final Paper and Presentation	All Members
5/1 -5/3	Finalize Final Paper and Final Presentation	All Members

Appendix C Sensor Module Schematic