Smart Home Conditioning System

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Introduction

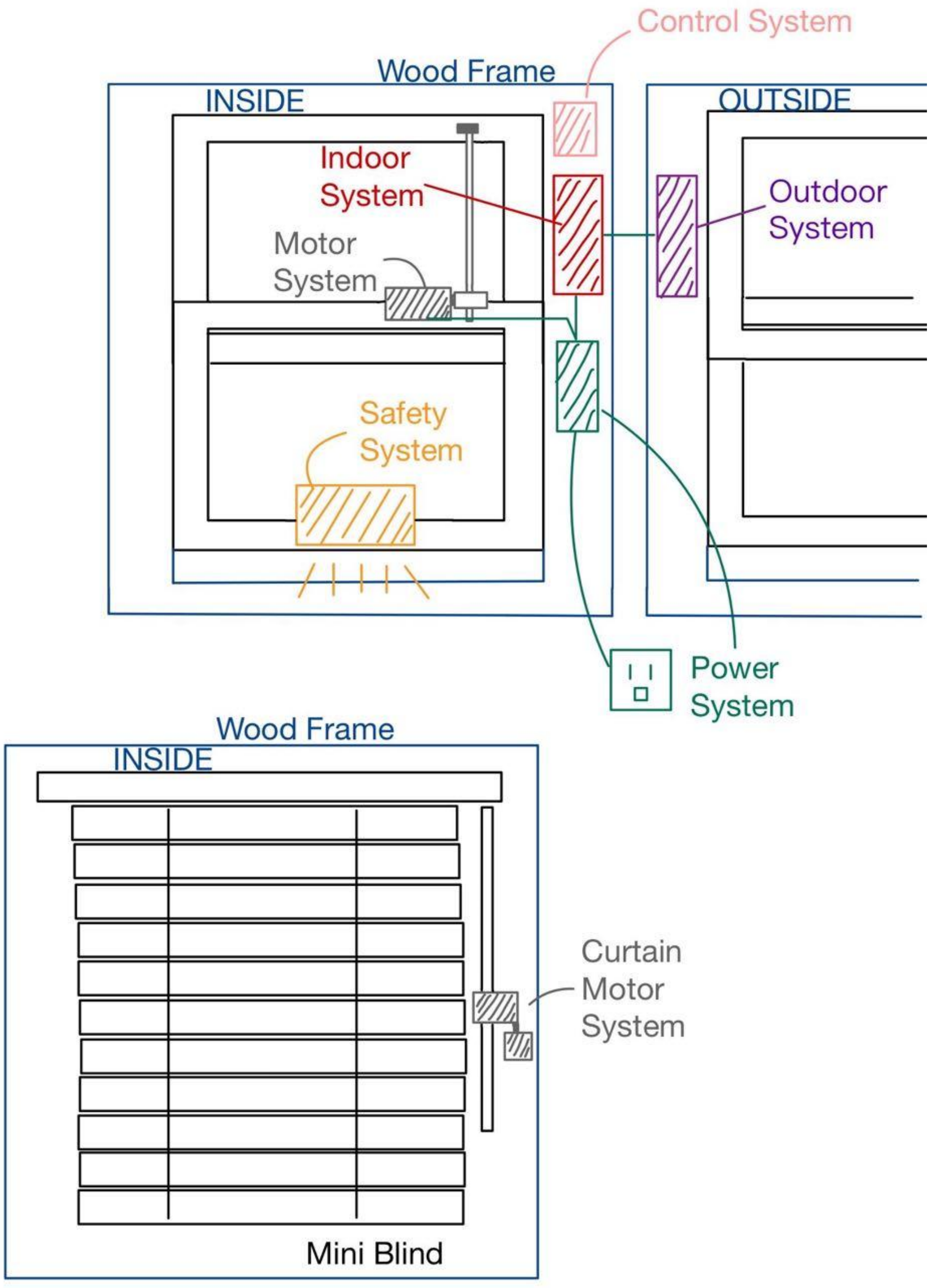
1.1 Problem

The windows and curtains, 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, for people with physical disabilities, it might be inconvenient for them to open the windows and curtains 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 disabilities.

1.2 Solution

The Smart Home Conditioning System consists of sensors to detect humidity, temperature, brightness, air quality, and noise levels, and two motors to open/close the window and draw the curtain. The sensor module consists of two subsystems: indoor and outdoor. For the outdoor subsystem, we will have the rain sensor, humidity sensor, and pm2.5 sensor to determine whether it rains, fogs, or smokes outside. For the indoor subsystem, we will have the brightness sensor and noise sensor to measure brightness and noise level. Additionally, we will also have two temperature sensors to measure indoor and outdoor temperatures. When the indoor temperature is lower than a preset value, and the outdoor temperature is high, the microcontroller will tell the motor to open the window. When the indoor temperature is higher than a preset value, and the outdoor temperature is low, the microcontroller will also tell the motor to open the window. In the case when the outdoor temperature is not within a preset range, when it rains, fogs, or smokes, or when it is too shiny or noisy outside, the microcontroller will tell the motors to close the window and draw the curtain. Besides, we will have a linear encoder for the motor to know whether the window and curtain are closed or opened. To address potential safety problems, we will employ an IR 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 an IR sensor, a linear encoder, a microcontroller, a window control module, and a curtain control module.

1.3 Visual Aid



1.4 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 PM2.5 concentration outside is larger than 300μg/m³; when the noise is larger than 70dB; when the indoor temperature stays between 23℃ and 25.5℃ while the outdoor temperature is lower than 21℃ or higher than 27.5℃. In other cases, the window will remain open.

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

3. Safety is an essential consideration of our design. Thus, we want to constantly detect the environment. We want the response time of our safety system, when any obstacles appear within 10cm of the window, to be within 0.5 seconds. We want to check if it is raining outside every 30 seconds, and if it is raining for over 30 seconds within 1 minute, we need to close the window. We want to check the indoor and outdoor temperatures every 5 minutes. We want to detect the noise level every 30 seconds, and if it is too noisy for 30 seconds within 1 minute, we need to close the window. Otherwise, our Smart Home Conditioning System will detect the environment every 30 minutes to limit the power the calculation needs.

Design

2.1 Block Diagram

2.2 Subsystem Overview

Power Subsystem: Support the power needed by the motors to perform the opening and closing of the window and curtains. Provide power for the sensors and microcontrollers to work.

Control 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 curtain.

Safety Subsystem: This subsystem is a crucial part of our design as it prevents potential safety issues from happening. Consists of linear encoders and one IR sensor, which will tell the microcontrollers if something is near the windows, and pauses the window motor. Prevent users from getting injured when the window is opening or closing.

Motor Subsystem: Giving direction by the microcontroller the window motor and the curtain motor will perform the close or open action, achieving the goal of our design to build a healthier indoor environment.

Outside Sensor Subsystem: This module will measure the rain, fog, smoke, and temperature of the outside environment. It will send back the collected data to the microcontrollers which will then decide if the data had exceeded the preset value.

Inside Sensor Subsystem: This module will measure the noise level, brightness, and temperature of the indoor living space. And send the data collected back to the control Subsystem which will then decide if the data had exceeded the preset value.

2.3 Subsystem Requirements

Power Subsystem: The power system should be able to supply power to all the motors, sensors, and microcontrollers we are using in this project. With the wall adapter that converts the voltage from alternating current (AC) to direct current (DC) 12V voltage and a DC-DC Step Down (buck) regulator to convert the 12V DC to 5V DC, it will be able to successfully power up the system.

1. AC-DC Converter
    a. Convert the 110V AC to 12V DC power
    b. Constantly supply 12V DC power to ensure the motor subsystem running correctly
2. DC-DC Step Down Converter
    a. Able to connect to the AC-DC Converter
    b. Convert the 12V DC to 5V DC power
    c. Constantly supply 5V DC power to ensure the sensors and microcontroller running correctly

Control Subsystem: The microcontrollers should provide enough consideration of the current weather and generate decisive signals to other motors. The microcontrollers should also respond fast to data from sensors within 0.5 seconds.

a. Stop the window or blind once the Safety system alerts
b. Process the data sent back from the Inside and Outside Sensor system, and decides the action of the Motor system
c. Process the data every 30 minutes to update the status

Safety Subsystem: The safety system requires the motor to stop within 0.5 seconds, and the IR sensor that detected obstacles should also be accurate when any obstacles appear within 10cm of the window.

IR Sensor:

a. Takes in 5V DC power
b. Successfully detect any obstacles between the closing window and the frame
c. Sent back the collected data to microcontrollers

Motor Subsystem: Consist of window motor and curtain motor. When informed by the microcontroller and powered by the power system it should be able to fully open and close the window and blinds.

1. Window Motor:
   a. Takes in 12V DC power
   b. Able to lock the window position
   c. High Torque to generate enough force to pull up the window
2. Curtain Motor:
   a. Takes in 12V DC power
   b. Able to lock motor position
   c. Perform 720 degrees of rotation to fully open and close the blinds

Outside Sensor Subsystem: The outside sensor subsystem will determine if the window needs to be closed when the humidity sensor detects a value that exceeds 50% or below 30%. Close the window when the PM2.5 sensor detects a value above 12 µg/m3 or when the rain sensor detects raindrops. And provide the current temperature to the microcontroller for further analysis.

1. Rain Sensor:
    a. Takes in 5V DC power
    b. Accurately detected if it is raining outside (>= 98%)
2. Humidity Sensor:
    a. Takes in 5V DC power
    b. Accurately measure the humidity level (+/-5% RH)
3. PM2.5 Sensor:
    a. Takes in 5V DC power
    b. Accurately measure the dust level (>= 95%)
4. Temperature Sensor:
    a. Takes in 5V DC power
    b. Accurately measure the temperature inside (+/- 0.5℃)

Inside Sensor Subsystem: The inside sensor subsystem will determine if the window needs to be closed when the noise sensor detects a value exceeding 70dB or close the blinds when the brightness sensor detects a value exceeding 300 nits. And provide the current temperature to the microcontroller for further analysis.

5. Brightness Sensor:
    a. Takes in 5V DC power
    b. Accurately measure the brightness level inside (+/- 10000lux)
6. Noise Level Sensor:
    a. Takes in 5V DC power
    b. Accurately measure the noise level inside (>= 95%)
7. Temperature Sensor:
    a. Takes in 5V DC power
    b. Accurately measure the temperature inside (+/- 0.5℃)

2.4 Tolerance Analysis

In our design, there are three main aspects that require deep consideration for the tolerance analysis.

The first aspect is the power and capability of each component. In our power system, the 110V AC power will transfer 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 will 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 decided if our choice of converter is safe to use.

For the DC-DC Converter, the maximum current is 3A. For the components that are supplied by 5V DC power, the total current needed is:

0.2mA(microcontroller) + 5mA(IR Sensor) + 0.4mA(Rain Sensor) + 2.5mA(Temperature and Humidity Sensor) + 20mA(PM2.5 Sensor) + 0.2mA(Brightness Sensor) + 0.4mA(Noise Sensor) + 0.012mA(Temperature Sensor) = 29mA = 0.03A, which is far lower than the maximum current of the Converter. Thus, the DC-DC converter will be safe to use.

For the AC-DC Converter, the maximum current is 2A. For the components that are supplied by 12V DC, the total current needed is:

0.03A(DC-DC Converter) + 2*0.6A(motor) = 1.23A, which is lower than the maximum current of the AC-DC Converter. Thus, the AC-DC converter will be safe to use.

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 spins 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.

The force needed to lift the window in our design is F = ma = 3.63kg * (9.8) m/s^2 = 36.162N, and to make sure that we can close/open the window within 30 seconds, we need more force F = ma = 3.63kg * (0.5) m/s2 = 1.82N. Thus, the total force needed is 38N. The motor we choose has a radius of 2.7cm, which is 0.027m. In this case, the torque needed is 38N * 0.027m = 1.026Nm.

With consideration for the energy lost, we will choose the motor with at least 3Nm to ensure the success of our design. The motor we choose has 5.4Nm, which is much higher than our need. Thus the motor will be safe to use.

The last aspect is the response time of our systems.

For our safety system, 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 5 ms for ranges from 10 cm to 2m. What’s more, the microcontroller can respond within 2 ms. Therefore, the safety system can satisfy our requirements.

For the rain sensor, we want it to detect the environment every 30 seconds, and based on the datasheet, the rain sensor can complete measurement in 5 seconds, and it can provide constant output that indicates rain for over 30 seconds. Thus, the rain sensor can fulfill our needs.

For the indoor temperature sensor, we want it to detect the environment's temperature every 5 minutes, and based on the datasheet for the temperature sensor, it can achieve a measurement time within 2 seconds. Thus, the selection of the temperature sensor can fulfill our needs.

For the sunlight sensor, we want it to detect the brightness every 30 minutes, and with the datasheet, the brightness can be measured from the sunlight sensor within 120 ms. Thus, the selection of the sunlight sensor can fulfill our needs.

For the P.M 2.5 sensor, we want it to detect the environment every 30 minutes, and based on the datasheet for the dust sensor, it can achieve a measurement time within 1 second. Thus, the selection of the P.M 2.5 sensor can fulfill our needs.

For the humidity and temperature sensor, we want the sensors to detect the environment's temperature every 5 minutes and humidity every 30 minutes. Based on the datasheet for the humidity and temperature sensor, it can achieve a measurement time for temperature and humidity within 2 seconds. Thus, the selection of the humidity and temperature sensor can fulfill our needs.

For the noise sensor, we want it to constantly detect the environment, and based on the datasheet for the sound sensor, it supports real-time data output. Thus, the selection of the sound sensor can fulfill our needs.

Ethics and Safety

Our design will only render limited Ethics problems, as we mainly focus on the mechanism and functionality. Based on the IEEE Code of Ethics, we, as a group, need to “hold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities” (IEEE, 2023). To be specific, we need to “hold paramount the safety, health, and welfare of the public” (IEEE, 2023). 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 should 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 credit properly the contributions of others" (IEEE, 2023). We need to keep promoting better design and listen to others' suggestions since they may have more professional consideration. At the same time, we must "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" (IEEE, 2023). Only after we equipped ourselves with professional skills will we make the knowledge into practice, and this will make sure that we won't damage and hurt the equipment, labs, students, and even ourselves.

Besides ethics problems, our design may involve many safety concerns and we need to make sure that we eliminate those safety problems to a minimal degree. For our motor system, we must make sure that the closing/opening windows stop immediately when some obstacles appear. This includes human arms, human hands, pets, and other objects like books, phones, and computers. The IR sensors should respond fast to ensure that the motor stops, and the encoder on the motor should also be precise to make sure that the motor stops when the windows or curtains are fully open or closed. The power system should also be taken into serious consideration, since the electricity may lead to a severe fire risk and shorted risk. In addition, the components should be well protected: no matter the outdoor system or the indoor system, the components should be protected with shields and tapes, which can ensure that the design won't be affected by unexpected damage like weather and unintended touch.

In conclusion, we will follow the IEEE Code of Ethics and eliminate any safety problems to protect the ECE 445 lab environment, professors and TAs, students, and ourselves. We will work together and meet frequently to improve the design, and we will keep our Ethics and safety standards so that we can present the best side of our design.

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