ECE 445: Senior Design Spring 2017
Project Proposal

Wi-Fi Enabled Motorized Windows for Automatic Climate Control

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1. Introduction

1.1 Objective

Climate change is one of the most important issues plaguing society today. Therefore, it is necessary to find new solutions to reduce the pollution caused by energy consumption. One such area that has not been significantly addressed is energy efficient climate control in buildings. According to the International Energy Agency, worldwide energy consumption in buildings accounts for about 40% of the world's total end use of energy, so the potential for savings in energy efficiency could contribute immensely to a global decrease in energy consumption [1]. Specifically, in developed countries HVAC (heating, ventilation, and air conditioning) systems account for almost 50% of energy consumption in buildings and around 10-20% of total energy consumption [2].

Our solution is an automatic climate control system that consists of a motorized window that automatically opens and closes to efficiently regulate the indoor temperature. Each window will have three sensors: moisture, temperature, and IR (for motion detection to prevent closing on objects). In addition, each window will have a microcontroller that processes the sensor data and a Wi-Fi module to send data to a hub. The hub is the central processing unit. It contains a temperature sensor to measure the indoor temperature, a microcontroller, and Wi-Fi module. A mobile phone application will be used to enable the automatic climate control, set the desired temperature range, and manually open and close each window. Each window will receive 120V 60Hz AC power from the grid. A power management system will provide the necessary DC voltages for the microcontrollers, sensors, and motor.

1.2 Background

Opening windows with weather dependent timing is an easy solution to allow natural ventilation to heat or cool a building. Opening windows reduces the total energy usage of a building by reducing the use of HVAC systems. Therefore, natural ventilation is of the utmost importance specifically in hot summers and the more moderate seasons [3]. In addition, many people would prefer to use natural climate control rather than air conditioning and heating as it is more environmentally friendly and allows fresh air to flow throughout the building.

However, there are several potential issues and inconveniences in opening and closing windows for temperature control in a building. First, it is cumbersome to continuously open and close windows throughout the day to maintain a comfortable temperature inside buildings. Many individuals are not home during the day to tend to the windows and most are sleeping throughout the night. Second, if a window is accidentally left open during inclement weather, a home could experience water damage near the windows. It is unrealistic to expect an individual to manually monitor the weather and open and close the windows accordingly which is why there is a critical need for an automatic system.

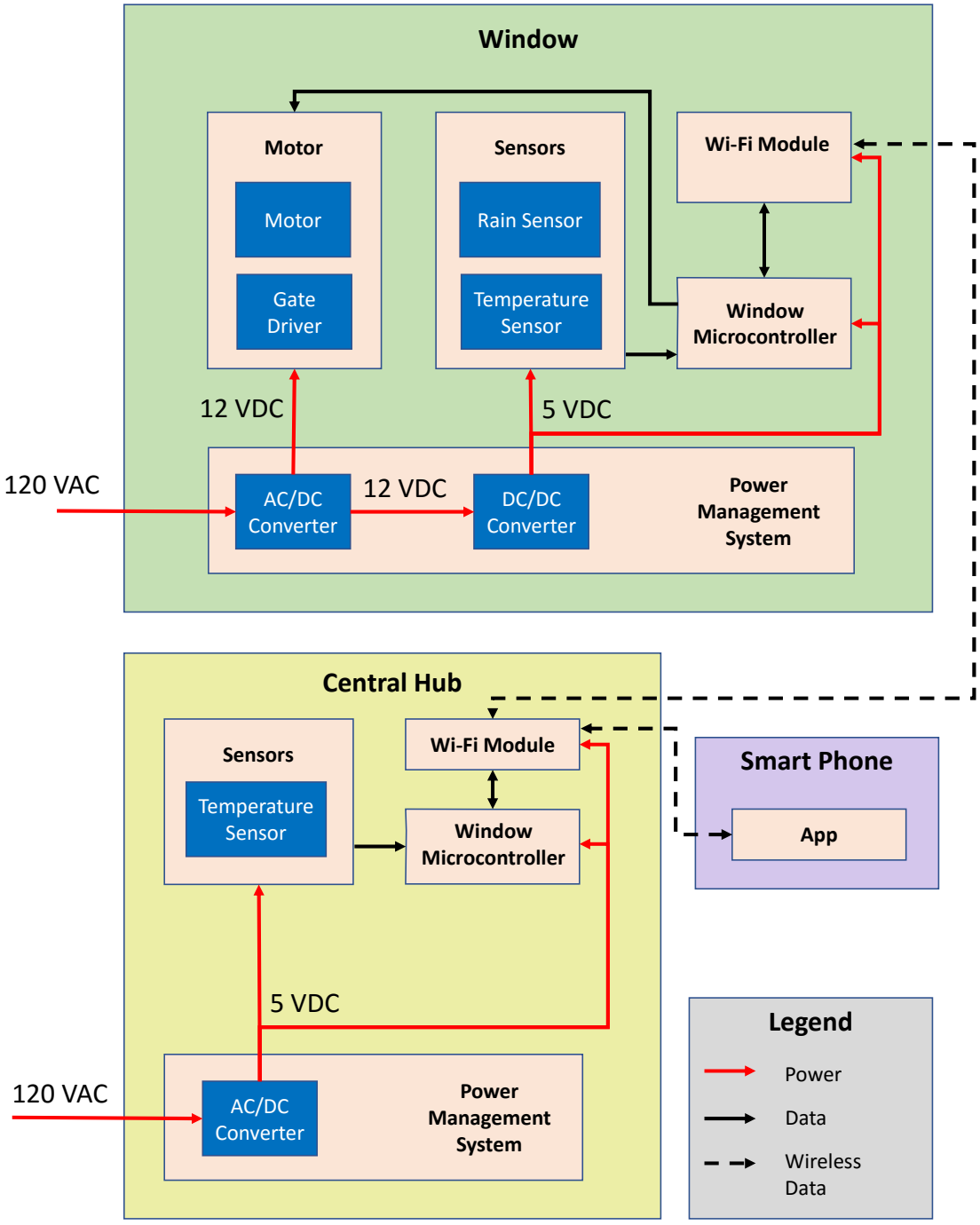
There are no commercially available products in the market that perform automatic climate control. There have been a few attempts at various pieces of the puzzle, but our system seeks to be a complete solution to automatic climate control. Shein, Tan, and Lim investigated a home temperature control system and proved that it could achieve a favorable cost efficiency compared to that of a traditional HVAC system [4]. Moreover, previous Senior Design students Cao, Nie, and Wan demonstrated a window that could automatically close in response to rain, decreased air quality, or an abrupt change in temperature [5]. Our system will be the first to utilize Wi-Fi communications with the capability of controlling multiple windows for synchronized automatic climate control.

1.3 High-Level Requirements List

- Each window will open or close in 10 seconds or less according to a local control system based on local sensors (close if raining, remain open if path is obstructed).
- The central hub can communicate data to and from window over Wi-Fi connection within 5 second.
- Each window will open and close according to the central hub control system based on local window temperature sensor and indoor temperature sensor

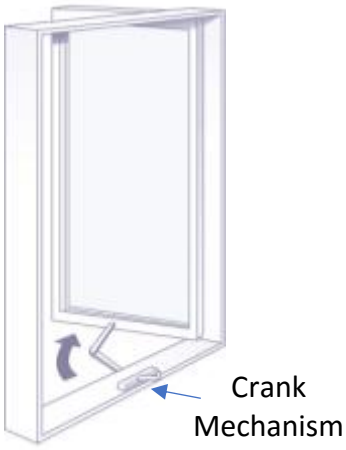
2. Design

2.1 Block Diagram



2.2 Physical Design

The window will be a side-hinged casement window. The motor will attach to the end of the cranking mechanism. There will be a mounted sensor array on the exterior frame of the window that contains the moisture sensor and temperature sensor. These will connect to a window control module that is mounted on the inner frame of the window. The window control module contains the microcontroller, Wi-Fi module, and power management system. The motor and motor driver will be attached to the cranking mechanism, and the IR sensor will be mounted on the motor facing outwards towards the window. The central hub will contain a microcontroller, Wi-Fi module, power management system, and temperature sensor in a casing.



Side-Hinged Casement Window [6]

2.3 Functional Overview

2.3.1 Sensing Module

The sensing module is responsible for receiving all external inputs to the system. By using a combination of sensors, information on the environment can be known and used to help the controller make decisions. Temperature, moisture, and movement data are collected and sent as signals to be the microcontroller to be processed.

2.3.1.1 Temperature Sensor

The temperature sensor will be located on the outside of the window and will monitor the temperature of the immediate environment. It will output an analog signal that is correlated to the measured temperature.

Requirement: Consistently measure temperature with an accuracy of +/- 1 Celsius.

2.3.1.2 Rain Sensor

The rain sensor will also be located on the outside of the window. This sensor will detect the presence of raindrops and send a signal to the microcontroller accordingly.

Requirement: Consistently detect the presence of rain droplets on the sensor.

2.3.1.3 IR Sensor

The IR sensor will detect if an object is in between the window and window frame so that the window does not close on something. This ensures that a user does not get their hand caught in the window as it closes. The sensor will be positioned facing the outside of the window so that it can detect objects in the path of the closing window.

Requirement: Reliably detects the presence of an object within 6 inches of the sensor's line of sight.

2.3.2 Power Supply

This module provides power to each area of the system. The power source for the controller will be from the power grid of the home. Since the different modules of the system require a variety of DC voltages an AC/DC Converter and DC/DC converter will be used to supply each module with the necessary voltage.

2.3.2.1 AC-DC Converter

This component will be used to take power from the grid and convert it into a DC voltage that can be used to power the motor.

Requirement: Convert 120 Volts AC to 12 Volts DC +- 5%.

2.3.2.2 DC-DC Converter

This converter will step down the DC voltage that is used to power the motor to provide a smaller voltage for the microcontroller and sensor modules.

Requirement: Convert 12 Volts DC to 5 Volts DC +- 5%.

2.3.3 Controller Unit

2.3.3.1 Microcontroller on the Window

The window microcontroller is responsible for reading all inputs, deciding the appropriate action, and then outputting signals to dictate those actions. Analog and digital signals from the sensor module are sent to the microcontroller along with digital signals from the Wi-Fi module. The controller will then, accordingly, send a control signal to the motor module to command the window to open or close and regularly send window position data to the Wi-Fi module.

Requirement 1: Accurately read in signals from sensors.

Requirement 2: Reliably communicate with Wi-Fi Module (both receiving and transmitting).

Requirement 3: Compute desired actions based on input signals.

Requirement 4: Send appropriate control signal to motor.

2.3.3.2 Microcontroller on the Hub

The hub microcontroller is the central processing unit. It provides a link between a phone and window, as well as tracking indoor temperature. Signals from the interior sensor module are sent to the microcontroller along with digital signals from the Wi-Fi module.

Requirement 1: Accurately read in signals from sensors.

Requirement 2: Reliably communicate with Wi-Fi Module (both receiving and transmitting).
Requirement 3: Compute desired actions based on input signals.

2.3.4 Wi-Fi Module

The Wi-Fi modules handle all wireless communication between the window system, the user, and the hub. This includes commands and preferences sent by the user via smart phone to the system and window position information from the controller to the phone. Communication is centralized in the hub, which then communicates with the appropriate controller depending on the user command. The communication will be encrypted using standard secure protocols.

Requirement: Successfully receives and transmits data between two microcontrollers, as well as with a smart phone.

2.3.5 Motor/Actuator Module

This motor module takes in a control signal from the microcontroller and moves the motor appropriately to open or close the window.

Requirement: Move motor according to received control signal.

2.4 Risk Analysis

The area of our project that is most essential for functionality is the motor module. This module has complete control over the movement of the window, which is the desired action. If this component fails, the product will do nothing regardless of the functionality of the other systems.

3. Ethics and Safety

There aren't any major ethical concerns with our system. In terms of safety, there are two main concerns. First, the system could accidentally close on someone or something that it is not supposed to. Second, someone could take advantage of the system to gain access to the house.

3.1 Safety

Since the windows will have the capability of closing automatically, there is the potential that they will attempt to close while a hand, the tail of a pet, or some other appendage is in the window. In order to avoid this, our IR sensors will be able to detect when a hand or tail is present, and override the system to remain in its current position until the object is removed.

3.2 Burglary

There are two main ways someone could break into a home because of our system. First, the system could automatically open the windows when the user isn't home in order to regulate the temperature, which could allow an intruder to enter. Second, someone could hack into the central hub and open a window to gain access to the home.

3.2.1 Opening the window automatically when nobody is home

This problem can be solved by having a "keep all windows closed" setting (or maybe "keep all first story windows closed"). An idea that might be out of the scope for this semester would be to automatically detect if the user was home based on their phone and then only activate the system if they are home.

3.2.2 Allowing someone to hack in and open the window

The second problem can be solved by using existing security protocols to encrypt the signals to the windows that open and close them, guaranteeing that only the owner's phone can control the windows.

Lastly, along with using the IR sensors for safety measures, they could be used to detect if someone is crawling through the window, which could then trigger a notification on the homeowner's phone.

4. References

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[4] Wai Wai Shein and Yasuo Tan and Azman Osman Lim, “PID Controller for Temperature Control with Multiple Actuators in Cyber-physical Home System,” in *International Conference on Network-Based Information Systems,* Melbourne, Vic, 2012, pp. 423-428.

[5] Jiaxi Nie and Xuanzhen Cao and Zhichun Wan, “Smart Window Responding System,” unpublished, Dec. 2016.

[6] Milgard Manufacturing, 2015, [Online]. Available: https://www.milgard.com/windows/style/casement-windows.