

Weather-Adaptive Windows

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I. Introduction

A. Objective

Most windows installed in buildings today are manual. Once left in a state, open or closed, by a user, there is nothing that can be done about the state of the window until another user manipulates the window. This can lead to some negative consequences. If a person leaves the window open at night to reduce the temperature of his or her bedroom, a constant breeze could lead to adverse health effects. If windows are left open during a storm, water could enter the building, causing potential damage and flooding. If a window is left open and the weather gets too hot or cold (relative to the desired temperature), keeping the window open could lead to the opposite of the desired result. Last, but certainly not least, there's always the factor of human error; simple forgetfulness can lead to a window being open or closed when it's not supposed to be. This is why it's important to have a window that controls itself based on a couple of important weather conditions - temperature and rain. In addition, it's also important to give the user remote control over the position of the window.

We propose a building a Weather-Adaptive Window that also provides wireless user control via Wi-Fi. Sensors that monitor the ambient environment will alert the control system to inclement or undesired weather, and an open window will automatically shut itself. To protect homeowners as well as their pets and children, these windows will also respond to the presence of an obstacle and remain open.

B. Background

The rapid rise of the home automation market, which was valued at \$5.77bn in 2013 and is expected to grow at a CAGR of 11.36% between 2014 and 2020 [2], speaks to the increasing need of convenience and connectivity in people's lives. Nothing is more convenient than when something takes care of itself, and perhaps the second best option is to be able to control something from anywhere. A great example of this is the burgeoning Nest Learning Thermostat. The thermostat can be programmed via an app, which means that the temperature of one's house can be controlled from anywhere, potentially leading to massive power savings. After a week of use, the thermostat "learns" the typical behavior of the user and will begin programming itself [3]. Although the use of a smart thermostat can result in good power savings, even more drastic savings can be incurred by using the ambient outdoor temperature to regulate the temperature of indoor spaces. During mild seasons or in places with a temperate climate, being able to leverage this advantage is very important. Not only is the advantage in monetary savings, but it also reduces the carbon footprint of indoor spaces.

C. High-level Requirements

1. Window must be able to close and open itself based on a temperature threshold.
2. Window should close itself in the presence of rain.
3. User should be able to wirelessly control the window.

II. Design

The Weather-Adaptive Windows will operate using four modules, shown in Figure 1. The power module manages power supplied from standard American 60Hz 120V alternating current (AC) wall voltage so that the sensors are constantly operable. The sensor module receives feedback from the environment, processes the data where necessary, and communicates the information to the controller. The controller module will involve an integrated Wi-Fi chip and RF development board to provide control for the Weather-Adaptive Window as well as user interface. Finally, the motor drive module will receive input from the control module to open and close the window.

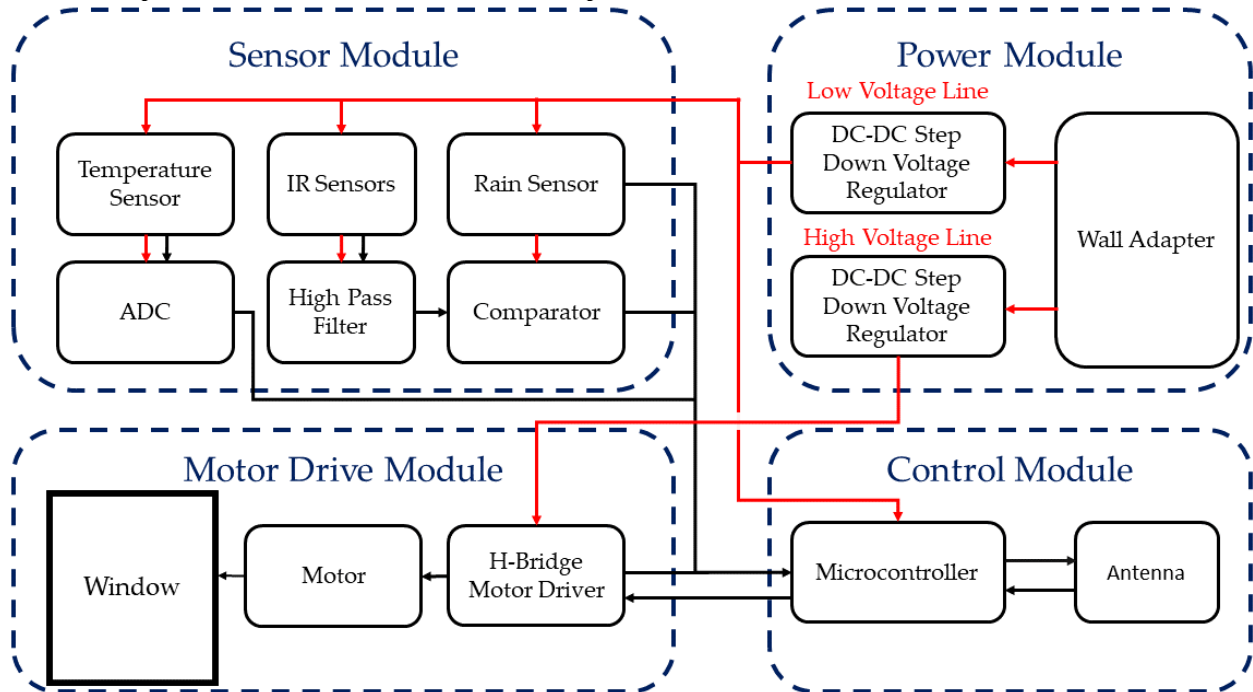


Figure 1. Block Diagram

A. Power Module

The purpose of the Weather-Adaptive Window is that it will close in any inclement weather conditions, meaning the sensors must always be operating. For this reason, we choose to power the window and its components from the wall.

1. Wall Adapter

The wall adapter is required to convert the voltage from alternating to direct current (DC) and step it down to a manageable voltage, for example 12V.

Requirement: Convert from 60V AC power to 12V DC power, with high enough current to power the motor, at least 1A

2. DC-DC Step Down Regulators

The DC-DC Step Down (buck) regulators are required to convert the voltage between intermediate rails, as the various components of the circuitry have different power requirements. Since the power comes from the wall, reliability is more important than efficiency.

Requirement: Reliably step down voltage from wall adapter, 12V, to intermediate power rails, 4.5-5.5V rails and 2.5-3.3V rails

B. Control Module

The control module will interface to the sensor module and the motor driver module to monitor the weather conditions and control the window mechanism. The control module will also have WiFi capability to allow remote control of the window.

1. Microcontroller

The microcontroller will host the software which controls the window based on the weather conditions read from sensor inputs. Additionally, the microcontroller will interface to WiFi. There are two ways to go about the WiFi implementation. The first is to use a single chip solution which incorporates the WiFi functionality as well as a microcontroller into the same IC. Solutions of this type exist such as the ESP8266 which is a WiFi equipped microcontroller. However, this particular example does not have abundant I/O resources, and is particularly lacking in ADC inputs which may be necessary for reading various sensors. The other solution solves this problem by using a separate wifi device and main microcontroller. The main microcontroller could be selected to meet all requirements except the WiFi capability, allowing a larger selection of devices to choose from.

Requirement: Microcontroller must have WiFi capability or be capable of interfacing to a separate WiFi peripheral according to IEEE 802.11 standards

Requirement: Microcontroller must have sufficient I/O capabilities to interface to the rest of the system (temperature sensor, IR sensors, rain sensor, motor driver, and WiFi peripheral).

2. RF Antenna

The RF antenna must be a 2.4GHz WiFi capable antenna which interfaces to the WiFi device. Due to the complexity in RF design, it is desirable to use an off-the-shelf module which incorporates the WiFi device and the antenna in one board or module.

Requirement: Antenna must work for 2.4GHz WiFi.

Requirement: Antenna must be incorporated into an off-the-shelf WiFi module so that no RF design work is required.

C. Sensor Module

The sensor suite gives feedback to the microcontroller to close the window in two events - the presence of rain, and temperature outside of the desired window. A rain and temperature sensor are used for these, respectively. In addition, the sensor module contains infrared (IR) sensors to determine whether the window is closed, and prevent the window from closing on an obstruction.

1. Rain Sensor

The rain sensor is a printed circuit board with exposed leads that act as a circuit that is completed in the presence of water. The rain sensor should pass a digital value to the microcontroller signalling when the variable resistance of the sensor passes a threshold.

Requirement: Sensor outputs a digital binary value to the microcontroller in the presence of rain.

2. Temperature Sensor

The temperature sensor should monitor the outside temperature to within $\pm 1^\circ\text{C}$. The analog output of the temperature sensor should be fed through an analog to digital converter (ADC) which can be read in by the microcontrollers.

Requirement: Sensor monitors temperature of ambient environment with accuracy $\pm 1^\circ\text{C}$

Requirement: ADC provides interface between sensor and controller so that temperature sensor outputs can be monitored with general purpose input/output (GPIO) pins

3. IR Sensor

IR sensors serve two purposes. The first is to detect the presence of an obstruction, so that the motor would stop closing the window in the interest of safety. The second is to detect the location of the window to know whether it is open or closed. To avoid interference from outside IR sources, the IR transceiver will pulse at a predetermined high frequency; the output will be high-pass filtered to ensure fidelity.

Requirement: IR sensors determine whether window path is obstructed or window is closed to shut off motor.

Requirement: IR sensors pulse at high frequency (at least 27MHz, that of a television remote control) and output is high-pass filtered.

D. Motor Drive Module

The motor drive module consists of the motor driver, the motor, and the mechanical interface to the window. This module will allow the control module to open and close the window as well as monitor the operation of the motor.

1. H-Bridge Motor Driver

The motor driver must be capable of driving a DC motor in two directions. One direction will be for closing the window, and the other direction will be for opening it. This means the motor driver should be an H-bridge design to allow the use of a single polarity power supply. Additionally, the motor driver should have the capability to measure the motor current for feedback purposes. PWM control will be planned for, but may not be necessary.

Requirement: DC motor driver capable of driving a DC motor bidirectionally.

Requirement: Motor driver must have current measurement capability for motor current feedback purposes.

2. Motor

The motor will be attached to the window and has the purpose of physically opening and closing the window. The motor must have enough torque, power, and speed to open and close the window in no more than 1 minute.

Requirement: DC motor must be capable of fully opening and closing the window no more than 1 minute.

3. Window

The window will be mechanically attached to the motor to facilitate opening and closing. The simpler this attachment is, the better. Windows with crank mechanisms for opening and closing (casement windows) present the simplest way to accomplish this goal, and as such are preferred, although sliding window types are also workable with additional mechanism.

Requirement: window must be capable of being opened or closed by rotating motion from the output shaft of a motor.

E. Risk Analysis

We believe that the greatest risk lies with the control module, more specifically the wireless communication portion of it. We have experience in most other things required for the completion of the project, but as a group, we have the least familiarity with this part. Because we have little knowledge of what problems may arise, it may take us longer to debug issues that we encounter when working on this part of the project. That's why we believe that the Wi-Fi portion of the control module may pose the greatest risk to the successful completion of our project.

III. Ethics and Safety

As with any automated system, there are safety concerns. In this case, the main safety concern is with closing the door on any living being, whether it be an unaware person or animal that may be occupying the window space as it attempts to close itself. To prevent harm to anything in the way of the window, an array of infrared sensors will be used as object detection. These will be used as logical input to the microcontroller, and the output of these sensors will be of the utmost importance when controlling the motor - even more

important than the weather indicators themselves. Also, infrared sensors will be used to gauge when the door has closed in addition with current sense at our motor. This prevents the motor from placing excessive stress on the window housing which could lead to shortened durability of the mechanism.

Another concern arises when dealing with electronics in an outdoors context. Our rain and temperature sensors will have to be outward facing. In order to ensure that only our sensors are facing on the outside, we will have to keep the bulk of the circuitry on the side of the window that faces toward the room. The sensors will likely need some sort of housing to ensure that none of the rain or humidity can reach the circuitry, which would cause undesired shorts. These shorts can lead to explosive results, which could cause harm to the end user.

In the lab, working with power conversion is always a concern. In a situation in which components or converters may not be properly connected, some parts could be overloaded and explode. In addition, when working with motors, there's always the concern that the motor could behave unexpectedly it isn't controlled properly which could lead to bodily harm.

Ethically, we believe that there are few concerns with our project. One promise that we will make over the course of our project is disclosing various aspects of our project that might endanger people or the world that people live in, which is in accordance with the first point of the IEEE Code of Ethics, "...to disclose promptly factors that might endanger the public or the environment," [1]. In addition, we have many prevention measures in place to ensure that we follow item nine on the Code of Ethics, "to avoid injuring others...by false or malicious action," [1]. Apart from these two concerns, we believe that there are few aspects of our project that might be of ethical concern.

IV. References

- [1] IEEE, "IEEE Code of Ethics," IEEE, 2017. [Online]. Available: <http://www.ieee.org/about/corporate/governance/p7-8.html>. [Accessed 20 September 2017].
- [2] Business Wire, "Research and Markets: Global Home Automation and Control Market 2014-2020 - Lighting Control, Security & Access Control, HVAC Control Analysis of the \$5.77 Billion Industry," Berkshire Hathaway, 19 January 2015. [Online]. Available: <http://www.businesswire.com/news/home/20150119005490/en/Research-Markets-Global-Home-Automation-Control-Market>. [Accessed 21 September 2017].
- [3] Nest, "Meet the Nest Learning Thermostat," 2017. [Online]. Available: <https://nest.com/thermostats/nest-learning-thermostat/overview/>. [Accessed 21 September 2017].