March 16th, 2015

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC, V5A 1S6

Re: ENSC 440W Design Specifications for the Automatic Windows Controller

Dear Dr. Rawicz:

The following report contains the design specifications for our product, the Automatic Windows Controller. We are aiming to invent an auto window system that will increase the users comfort and leisure while living in commercial buildings and home. The AWC will solve the problem of people who forget to close or open their windows before they leave their homes and will make their lives more convenient when they are using the space.

In this design specification report, we outlined how we will achieve each prototype deliverable in our Functional Specifications document for our Automatic Windows Controller. This document will allow our engineers and managers to follow the requirements when developing and presenting our prototype.

Smart Window Inc. is consisted of five engineering students: James (ChiaHung) Lee, Steven (Ho Chong) Zeng, Dong Hao Zhuo, Jie Wen Mai and Jing Xiang Hou. If you have any further questions or suggestions, please feel free to contact us by e-mail at dzhuo@sfu.ca. Alternatively, you may also contact us by phone (778)318-3662.

Sincerely,

Dong Hao Zhuo
Chief Executive Officer
Smart Window Inc.

Design Specifications

for Automatic Windows Controller

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Date Issued: March 16th 2015

Executive Summary

The design specification of our product Automatic Window Controller is described in detailed in this document. The main purpose of the design specification is to outline the development of our mechanisms for our prototype and clearly specify the functions and design with respect to the requirements **[Rn-I]** and **[Rn-II]** listed in our function specifications. A test plan is also provided to ensure that the performance of the AWC is satisfactory.

We described how the whole system functions and how the three motors and four different sensors are used to change the positions of the windows and curtains. Also, we outlined how we used an Arduino Uno microcontroller to control the motors and sensors while applying our logic to the system.

The prototype of our Automatic Window Controller is designed to have the following features:

- The electrical circuit and power components are hidden to improve aesthetics and safety
- The system can be controlled manually or automatically
- The gliding window, awning window, and curtains are adjustable to improve the quality of the living environment.

The Smart Window team aims to provide users these features through our Automatic Window Controller. We prioritize in creating a functional and safe product with a robust software design. Therefore, we follow the standards of CSA (Canadian Standards Association), AAMA (American Architectural Manufacturers Association), and WCMA (Window Covering Manufacturers Association) to fulfill the safety requirements.

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Glossary

AWC Automatic Windows Controller

EJ Exajoule

LDR Light Dependent Resistor

PCB Printed Circuit Board

Lux A Unit of Light Intensity

1. Introduction

The Automatic Window Controller (AWC) is a device used for ventilation in commercial buildings and residential homes. AWC controls the windows and curtains based on the indoor and outdoor environmental conditions. By sensing temperature, humidity, rain, and sunlight, the AWC can adjust the position of the window and curtain in a room to improve the living environment. The following sections contain the detailed design requirements of the Automatic Window Controller.

1.1. Scope

In this document, the designs to achieve the requirements listed in the functional specifications, **[Rn-I]** and **[Rn-II]**, are outlined. This document describes the design of the proof of concept model. The specifications for the production model are outside the scope of this document.

1.2. Intended Audience

The intended audience of this document includes all the members of the Smart Windows team and also any professional personnel assisting in the development of the AWC. The design specifications shall be used as a reference for testing the product to ensure that the AWC meets the company's safety and quality requirements

2. System Specification

The Automatic Window Controller provides a multifunctional automation system. All of the weather sensors are programmed using the Arduino software. The Automatic Window Controller is able to alter the position of the gilding window in two directions based on the current weather conditions. For the ventilation, the awning window can be flipped open allowing air to flow and preventing rain from entering. Also, the LCD screen displays the temperature and mode of the system. By using motors, the Automatic Window Controller can modify the level of light and living quality when users are not at home or sleeping. The rain sensor will be able to be disabled manually to allow cleansing of the window. This window is designed to be able to detect harmful gases. Once the detection of a smoke leakage is confirmed, the window will not be closed unless the system is shut down. The layout of system can be seen in the figure below.

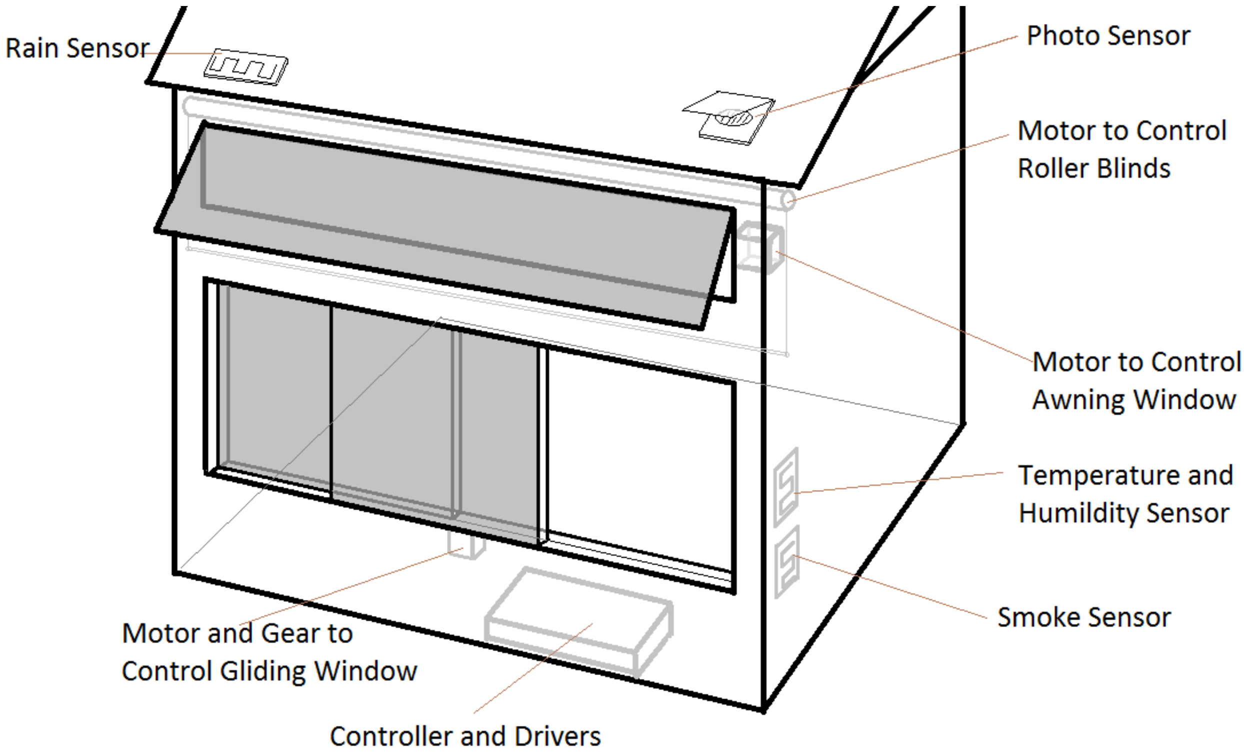

Figure 1: Layout of System Design

3. Overall System Design

In this section, the entire high level overview of Automatic Window Controller is provided. This section will explain the mechanism, circuit components, and software coding for the design. The details of each specific part will be shown and described in the following sections.

3.1. Mechanical Design

The following shows the mechanisms used to move the gliding window, awning window, and curtains. The dimensions of each component are listed in Table 1.

Table 1: Dimensions of Components

	Gliding Window	Awning Window	Roller Blind
Width (inch)	6	12	12
Length (inch)	4	3	10
Thickness (inch)	0.3	0.3	0.07

These dimensions are chosen to meet the requirements stated in the functional specifications.

3.2. Gliding Window

To satisfy **[R61-II]** the gliding window needs to consist of two screens, refer to figure 2. One of the screens is fixed while the other is moveable. A shaft that connects the gear to a motor is not shown in this figure. The moveable screen is placed behind the fixed screen and can be moved left and right**.** The window is moved using a single gear that is attached to a motor. The gear connects with a rack that is built into the bottom of the moveable screen. All these components are held together on a track that allows the window to slide with minimal friction.

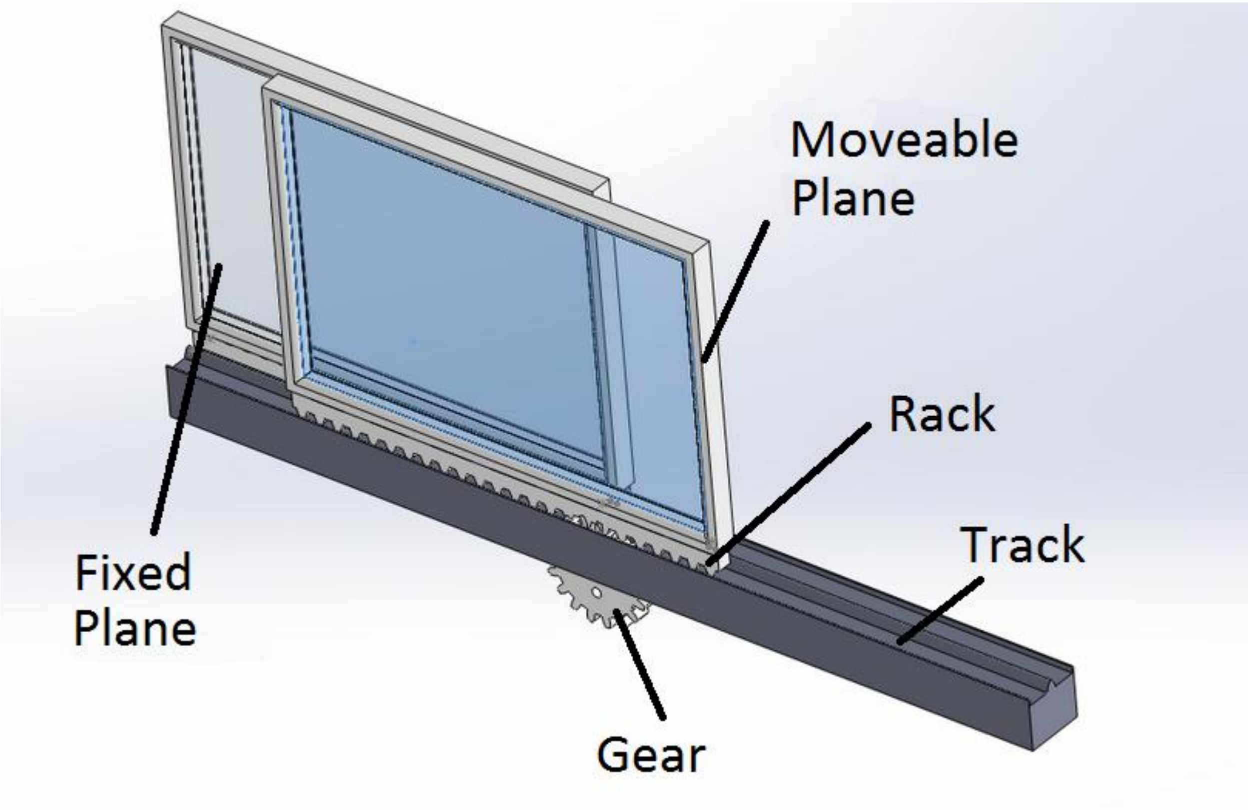

Figure 2: A SolidWorks Representation of the Gliding Window Mechanism

The purpose of using gears is that it requires the least amount of parts and is more precise compared to other drives such as traction drives and V-Belts. Also the gear ratio can be adjusted easily without having to change the mechanism. The gear mechanism that the gliding window uses is called "rack and pinion". The torque of the motors is transferred into a linear force that moves the screen in a straight line [1]. The linear motion that the gear, rack, and motor provide helps the window move uniformly as required by **[R62-II]**.

From Table 2, the stepper motor requires 200 steps to finish a circle, meanwhile, the gliding window will be moved by

$$L = 2\pi r = 2\pi \times 18mm = 113.1\text{mm}$$

The circle required to finish for the motor is 152.5/113.1= 1.35 circles

So we need 200×1.35 = 270 steps to fully open the gliding window.

3.3. Awning Window

The awning window consists of a single rectangular screen **[R86-II]** that has one of its sides (the longer top side) as a pivot point, refer to figure 3. The mechanism used to control the awning window consists of a shaft which has one end attached to the bottom on the screen and the other end attached to a belt. Both ends of the shaft are pivotable to accommodate for the position of the belt when it rotates. In order to ensure that the angle of the window when opened is less than 45 degrees as required by **[R78-II],** the length of the shaft (2.12 inches) is calculated using the following formula:

$$a = \frac{L}{\sqrt{2}},$$

where “a” is the length of shaft and “L” is the length of awning window (3 inches).

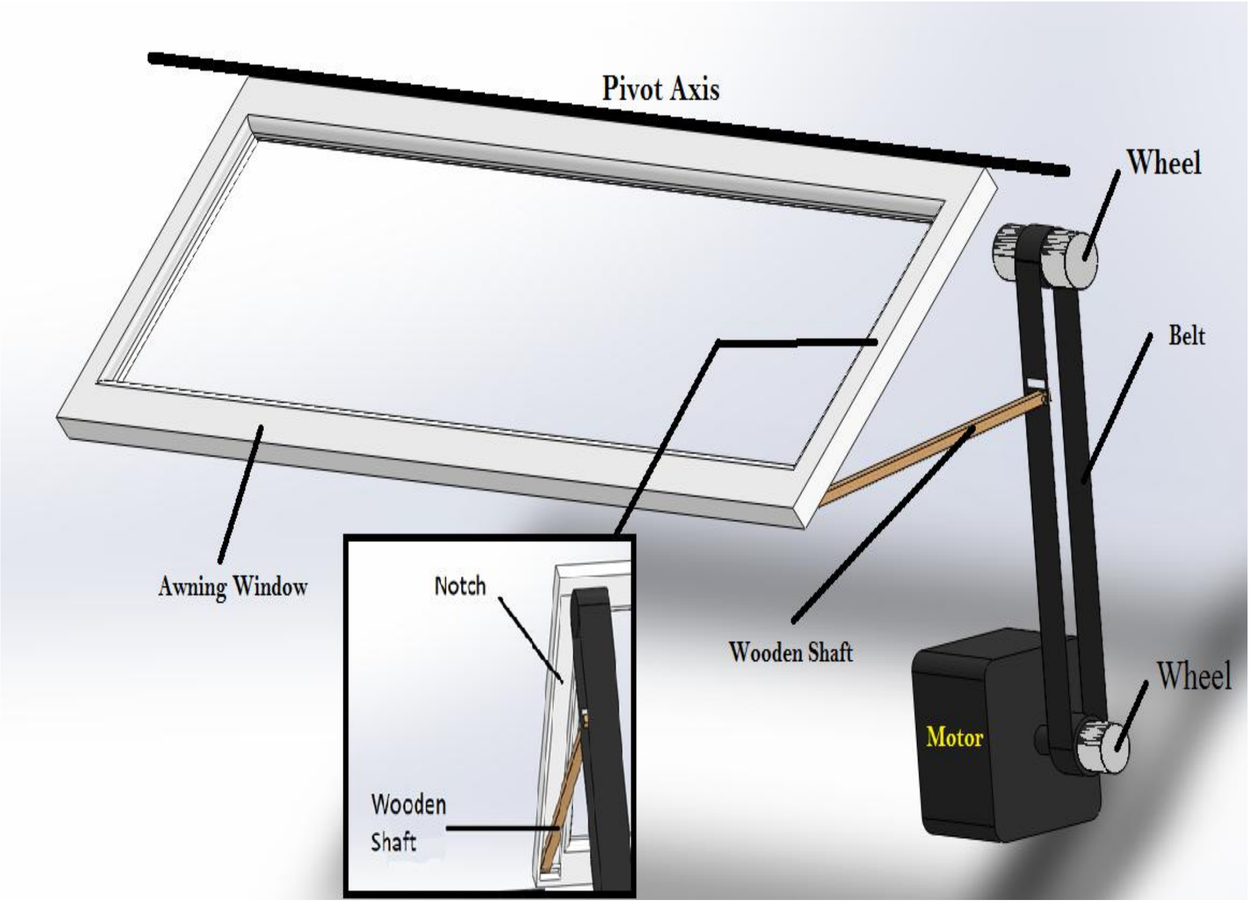

Figure 3: A SolidWorks Representation of the Awning Window Mechanism

The two wheels at each end of the belt can only move in a rotative motion. The shaft will either collapse into the notch or push out depending on the movement of the belt. The purpose of this design is to maximize the amount of torque generated by the motor. The formula for calculating torque is:

$$\boldsymbol{\tau} = \boldsymbol{r} \times \boldsymbol{F},$$

where $\boldsymbol{\tau}$, $\boldsymbol{r}$, and $\boldsymbol{F}$ are torque, distance from the pivot point, and applied force respectively. We focused mainly on "r" since it is the easiest parameter to control. We placed the shaft at the bottom of the window to maximize its distance from the pivot point and thus increasing the torque.

From Table 2, the maximum torque of the motor is 2.6kg*cm, and the radius of the wheel is 2.5mm, therefore the maximum force applying on the belt is 2600*10/2.5 = 104 N. Moreover, the mass of the awning window is calculated as 96.4g. The required torque for opening the awning window is 0.0359Nm. The maximum torque of the wooden shaft is 1.373Nm. Therefore, this system has enough power to open the awning window.

A simpler design can be made by placing the motor directly at the top of the window so that when the motor rotates the window would flip open or close. Although is design is simple, the torque is minimal because the value of "r" is zero. Thus, if the window is too heavy the motor will take on too much strain.

3.4. Roller Blinds

The roller blind consists of a rod that holds the fabric (Linen) of the curtains. This design is shown in figure 4.

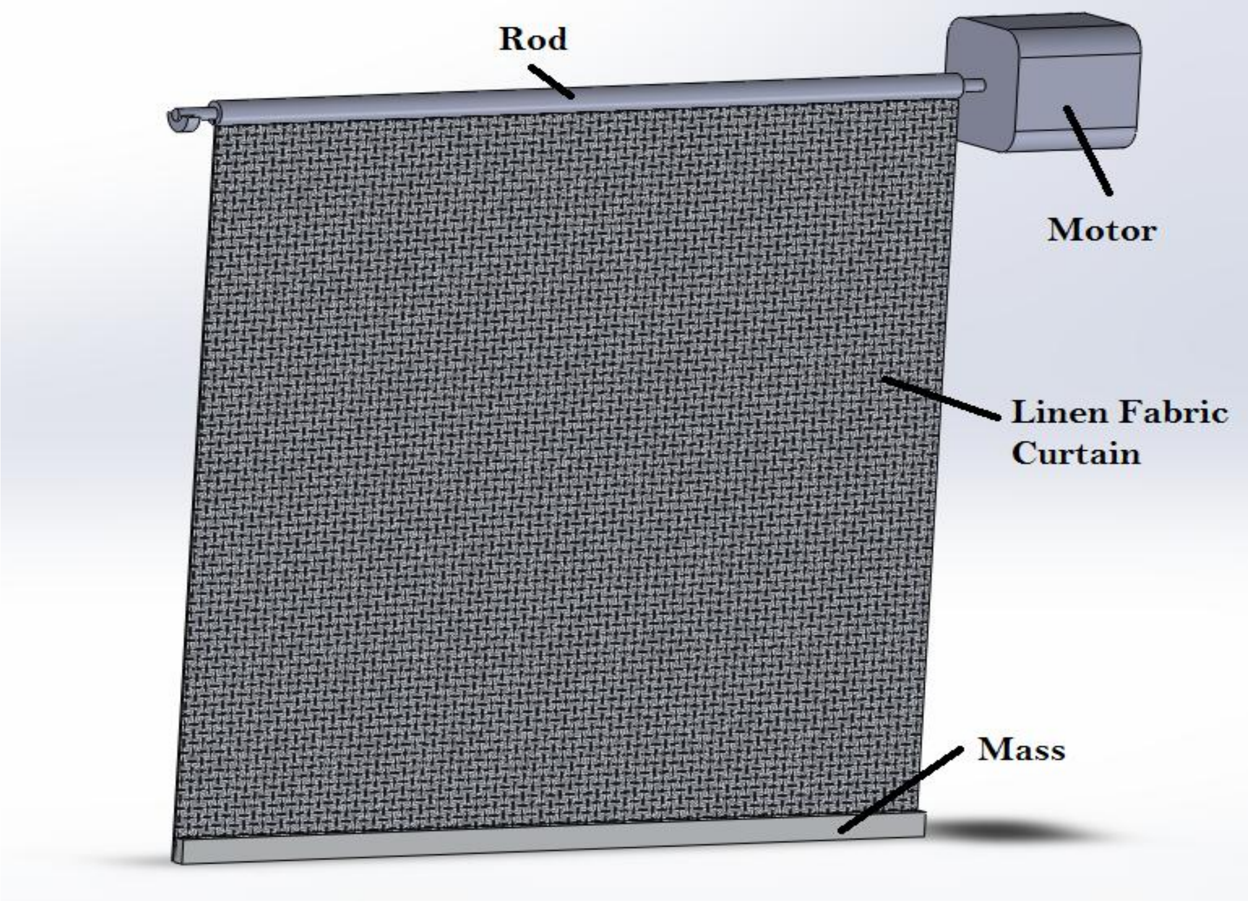

Figure 4: A SolidWorks Representation of the Roller Blinds Mechanism

The motor is attached to the pole and rotates to open and close the blinds. This design is simple because the curtains are light weight and the center of mass is located near the rotating axis of the rod. The motor only needs to be strong enough to rotate the rod. The changing radius of the rod plus fabric as the curtain opens and closes is negligible when calculating torque for this design.

4. High-level System Design

This section provides a visual overview of the high-level system design. It shows each of the modules interfacing with the brain (Arduino Uno) of the system. This system's inputs include rain sensor, temperature and Humidity sensor and smoke sensor. System output are the stepper motors which are connected to the motor drivers.

Figure 6 is a logic diagram of the high-level operations of the AWC. It shows the basic control stages of the system and how it reacts to different weather conditions.

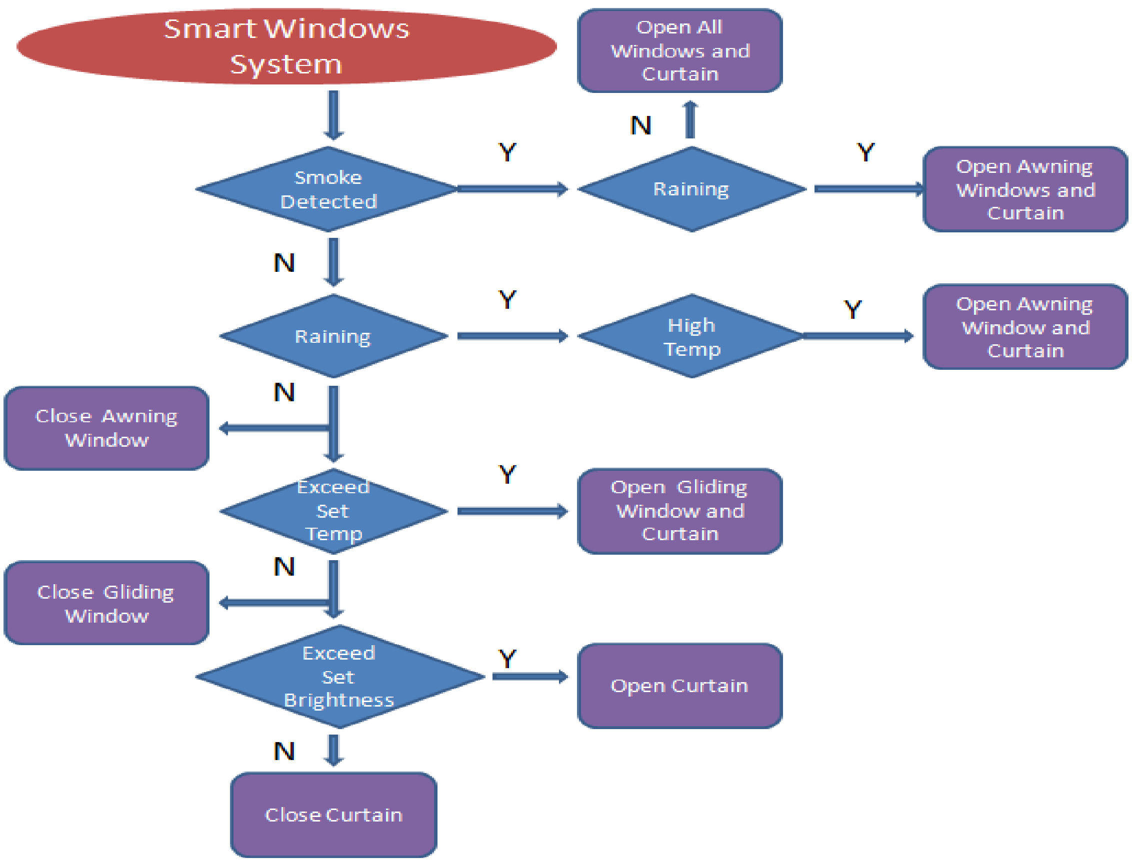

Figure 5: Logic Diagram of AWC

Note: The neutral position of the windows and curtains are closed, thus if nothing is detected by the sensors than all components remain closed.

5. Motors

Three motors are implemented in the Automatic Window Controller. For the gliding and awning windows, one motor is installed along with the window. Also, one stepper motor is used for adjusting the curtain. The specifications of the stepper motor NEMA17 is shown in the table below.

Table 2: Specifications Stepper Motor NEMA17 [2]

Model	42BYGHW208
Step Angle	1.8 °
Motor Dimension	34 mm x 42 mm x 42 mm
Rate Voltage	8 -20 V
Rate Current	0.4 A
Holding Torque	2600 g.cm
Phase Resistance	30 Ω
Motor Weight	0.2 Kg

6. Sensors

Four sensors are implemented in the Automatic Window Controller. The temperature and humidity, and smoke sensors are placed in the interior of the building. The rain sensor is installed on the roof to easily detect rain. Also, the position of the sun with respect to the photo sensor is shown in the diagram below.

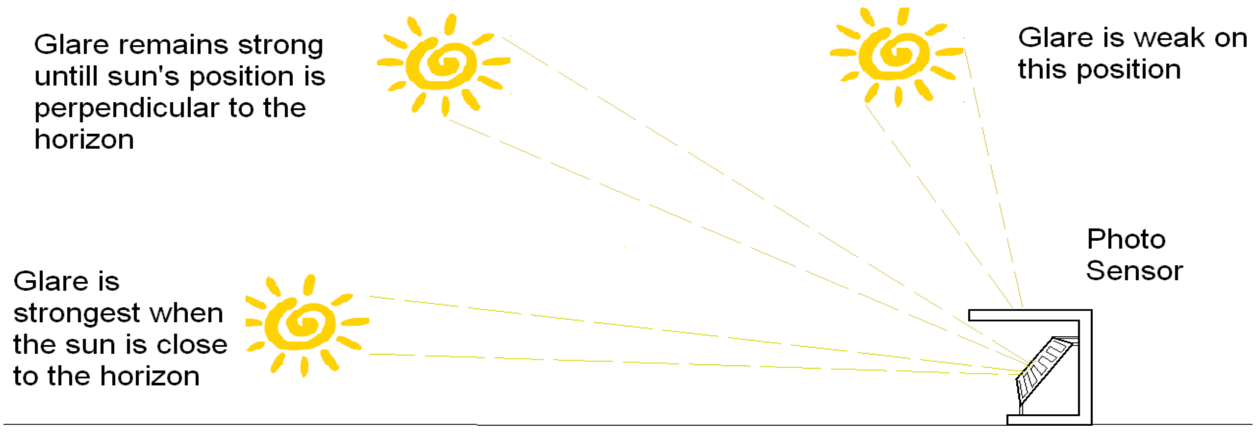

Figure 6: Sun's Position With Respect to the Photo Sensor

Table 3: Yearly Solar Fluxes and Human Energy Consumption [3]

Solar	3,850,000EJ
Wind	2,250EJ
Biomass potential	200EJ

$$\frac{dQ}{dt} = \Phi \qquad I = \frac{d\Phi}{dA}$$

Where I = Irradiance or Light Intensity is Flux Φ per area A (W/m^2)

And the radius of the light sensor is measured as 3mm, therefore, the area is

$$A = \pi 0.003^2$$

The resistance of the Light Dependent Resistor (LDR) varies according to the amount of light that falls on it. The relationship between the resistance R_L and light intensity Lux for a typical LDR is

$$R_L = \frac{500}{Lux} K\Omega$$

After the calculation, we obtained the value of LDR is about 4.54 ~ 8.94 when the light sensor detects sun light. Therefore, we set the boundary of the LDR input as 5, then if the LDR is less than 5, the curtain will close automatically.

7. Electronic Control System

Overall System Layout

The Figures 7 and 8 and Table 4 below show the connections for the sensors, motors, motor drivers, batteries, and Arduino microcontroller

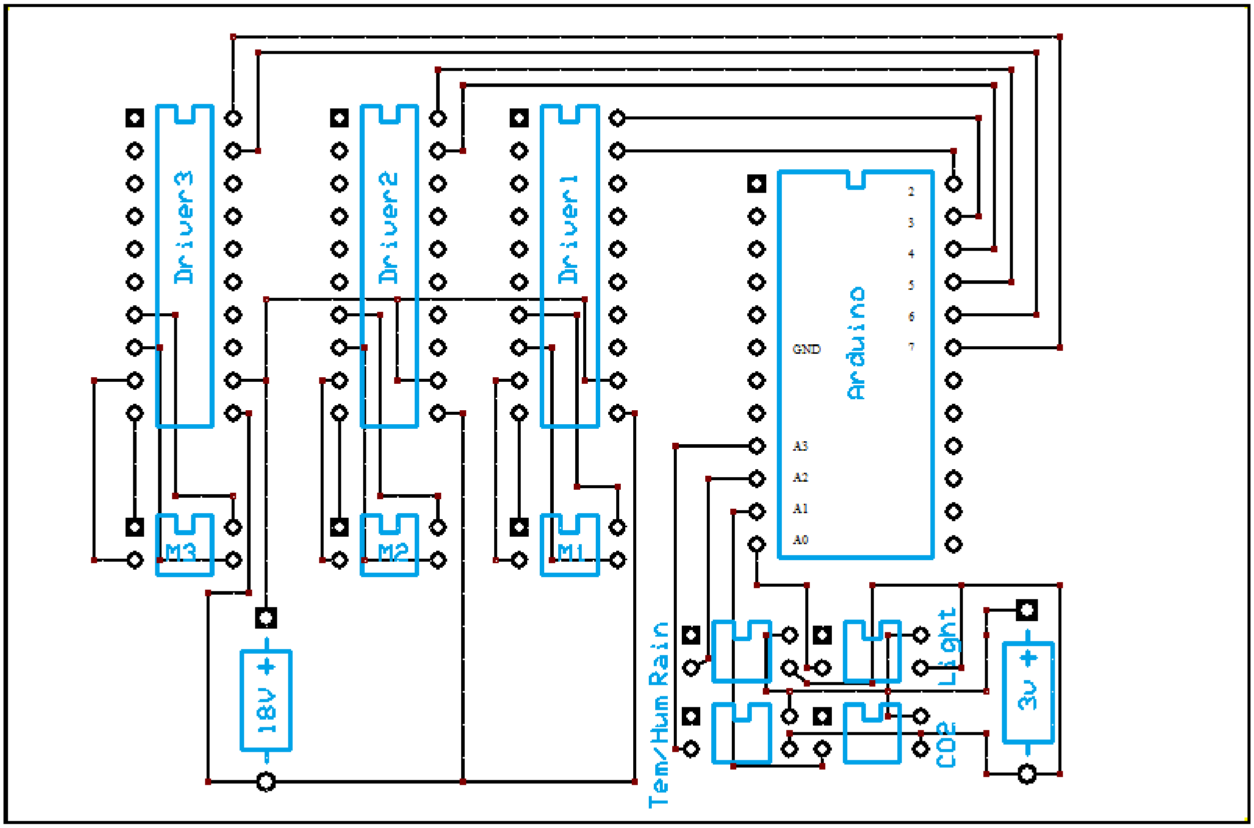

Figure 7: An ExpressPCB representation of Circuit

All of the sensors are powered by a 3V power supply while the motor drivers are powered by an 18V power supply.

From Table 6, the maximum DC current of the EasyDriver is 450mA, hence, the resistor of the wire inside the PCB is

$$R = \frac{18V}{450mA} = 40\Omega$$

And also the resistance of the wire can be determined as

$$R = \frac{\rho L}{A}$$

where ρ is the density of cooper, L is is the length of wire and A is the cross section area. Therefore the length and area can be determined when cutting the PCB.

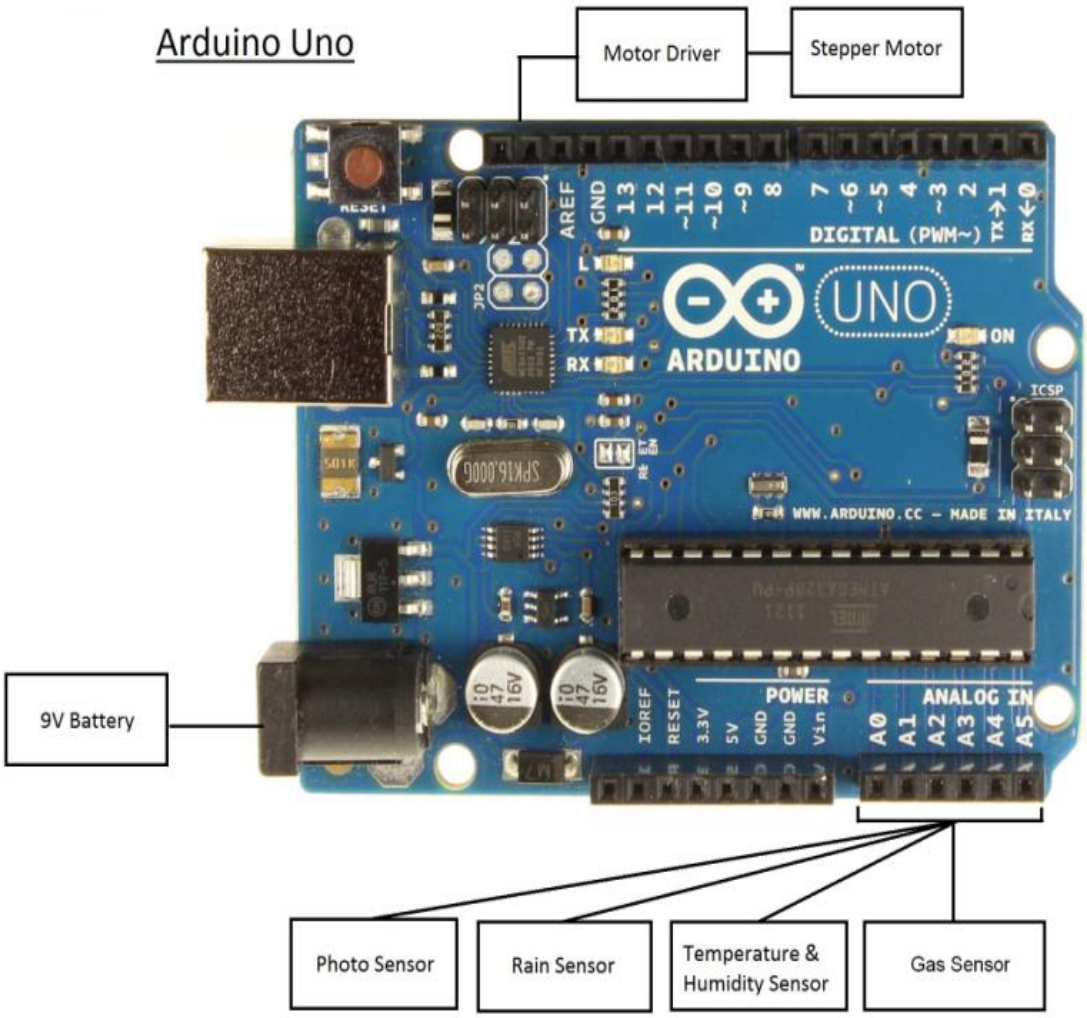

Figure 8: Arduino Connection Diagram [4]

Table 4: Port Connections

Arduino Pin	2	3	4	5	6	7	A0	A1	A2	A3	A4
Components	Motor Driver 1 (DIR)	Motor Driver 2(STEP)	Motor Driver 2(DIR)	Motor Driver 2(STEP)	Motor Driver 3(DIR)	Motor Driver 3(STEP)	Rain Sensor (A0)	Tem/ Hum Sensor (DATA)	Light Sensor (S)	CO2 Sensor (S)	Remote Sensor (DATA)

Arduino Uno R3

Arduino Uno R3 Microcontroller is the main board of Smart Window control system, issuing instructions by processing input data received from sensors. With the help of the driver board, motors that control the movements of physical output components are precisely given the instructions containing speed, direction and angular.

Table 5: Arduino Uno R3 Specification [4]

Operating Voltage	5V
Input Voltage (limits)	6~20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by boot loader
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

EasyDriver

The EasyDriver is a simple to use stepper motor driver, compatible with anything that can output a digital 0 to 5V pulse. It is the motor control circuit to control and power motors as well.

Table 6: EasyDriver Operating Conditions [2]

Voltage Supply Range	7~30V
Adjustable Current Control	150mA/phase ~750mA/phase

KY-018 Photo Resistor

Photo resistors, also known as light dependent resistors (LDR), are light sensitive devices most often used to indicate the presence or absence of light, or to measure the light intensity. In the Smart Window project, this light sensor detects the light condition to adjust the roller blinds.

Table 7: KY-018 Photo Resistor Specification [2]

Type	ICs
Voltage - Supply	0 V ~ 48 V
Operating Temperature	-40°C ~ 150°C
Mounting Type	Surface Mount

7039 Raindrop Sensor

7039 Raindrop Sensor uses DC 5V with a power indicator and LED indictor. Its drive capability is about 100mA that can directly drive relay, buzzer and small fan. The sensitivity can be adjusted by potentiometer. The LED will light up the high level as no rain; as rains, output low level, LED is on.

DH11 Temperature & Humidity Sensor

The DHT11 is a basic, ultra low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and spits out a digital signal on the data pin (no analog input pins needed). It’s simple to use, but requires careful timing to grab data.

Table 8: DHT11 Specification [2]

Operating Voltage	3 ~ 5 V
Max Current	2.5mA
Temperature Reading Range	0 ~ 50°C±2°C
Humidity Reading Range	20 ~ 80%+5%
Maximum Sampling Rate	1Hz

8. Test Plan

Tables 5 and 6 consist of the testes performed during and after the production of the proof of concept model.

Table 9: Equipments Testing

Unit	**Test Procedure**	**Expected Results**
Arduino Uno	Connect the Arduino to PC, and then test the board function on specialized software interface with our test program	The LED indicator would response correctly under the test program. Also the size of our code must fit within the Arduino`s 32kb memory
Sensors	Connect one of the sensors to the Arduino board, and the Arduino board to the PC. With the correct code and under specific environmental conditions, display the input data (temp, lighting, etc) on a text window. Observe the data	On the text window, the numbers indicating the input data should remain in a small range unless changes are detected by the sensor.
Motors	Connect the stepper motor to the Arduino and an 18V power supply. Upload our motor test program and observe results.	The motor should be able to rotate in any direction and for any degree and also provide enough torque to move run mechanism

Table 10: Testing Cases

Normal Case	Condition	Expected Outcome
1	Rain drops outside the house.	The gliding window will close to prevent rain from entering the building.
2	Too much sunlight passes through the window.	The curtain will be lowered to the bottom position to block the sunlight.
3	High natural smokelevels in the room.	The both windows will be open to ventilate the room.
4	Room temperature too high.	The gliding window and curtains should open when the temperature is too high (close if too low).
5	Room is too bright.	Curtains close to prevent light from getting in.
Special Case	**Condition**	**Expected Outcome**
1	Combination of normal case 1 & 4 (rain & temperature).	The awing window and curtains responses to the temperature change. The gliding window will remain closed.
2	Combination of normal case 1 & 3 (rain & smoke leakage).	The awning window and curtains shall open to ventilate the room and prevent rain from getting in.

9. Conclusion

The design specifications and features for the Automatic Window Controller are outlined in this document. The purpose of this document is to provide the Smart Windows Team a guideline to produce a functional and safe product. AWC controls the windows and curtains based on the indoor and outdoor environmental conditions. For the further development, the Smart Window team aims to develop an easy to use user interface that will allow the user to adjust the set temp and set brightness.

References

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