GNG2101

Design Project User and Product Manual

EZ-WNDW – Group E1.2

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List of Acronyms and Glossary

Table 1. Acronyms

Acronym	Definition

Table 2. Glossary

Term	Acronym	Definition

1 Introduction

Within the framework of our Engineering and Management project, we were presented with an exciting challenge: addressing the specific needs of a client with a disability. This individual, facing difficulties in manipulating her sliding window without external assistance, inspired us to design an innovative smart window controller: EZ-WNDW.

This User and Product Manual (UPM) provides the information needed for users of various backgrounds and abilities to effectively use the EZ-WNDW smart window controller and for prototype documentation.

This document aims to comprehensively present the operation of our product and the steps for its installation and usage. It is structured to guide potential users from the initial setup stages to troubleshooting any potential issues. Our goal is to make this technology accessible and easy to use for those who need it most. Additionally, we will also address the safety considerations associated with using EZ-WNDW, emphasizing that this device is specifically designed for domestic use and poses no risks related to high voltage.

This document is intended not only for end users but also for anyone interested in the development and application of innovative solutions to enhance the quality of life for people with mobility disabilities, or more generally people having sliding windows at home.

2 Overview

Our product is primarily targeted at individuals with mobility disabilities, who often face significant challenges in their daily lives due to their unique needs. Mundane tasks can become major obstacles when appliances and equipment aren't adapted to accommodate them. Take, for instance, the difficulty that those with mobility or strength issues encounter when trying to operate sliding windows. Moreover, in our case, our client faces unique health challenges that make it difficult for her to regulate her body temperature effectively, making this task even more crucial to ensure proper ventilation for her well-being.

This is precisely where our innovative device steps in. It's a cutting-edge system designed to streamline the process of opening and closing sliding windows by enabling remote manipulation via a smartphone. With our technology, users gain the ability to effortlessly control their windows' operation without the need for physical or external intervention.

Imagine the convenience of being able to open/close a window with just a simple touch on your phone, eliminating the need to leave your seat or rely on assistance. Our device not only provides individuals with disabilities with greater autonomy and freedom but also significantly enhances their daily comfort and well-being.

Furthermore, our product stands out from others on the market for several reasons. In fact, while traditional solutions exist, they often lack user-friendly interfaces and can be prohibitively expensive. Our smart window controller stands out for its intuitive smartphone app and affordability. By prioritizing user experience and accessibility, we offer a compelling alternative to current market offerings.

Our product offers a variety of features: it is compatible with iOS and Android handheld devices (smartphones, tablets, etc.), it is affordably priced and is much cheaper than other alternatives on the market, it is equipped with a temperature sensor for climate control, it includes voice control integration with Siri and Google Assistant, and it allows users to open/close the window at different interval lengths. Additionally, it boasts easy installation and uninstallation processes, while also allowing an easy switch between automatic and manual modes to allow users (e.g., caregivers) to manually operate the window if needed or in the case of a power outage.

Our solution consists of a mechanical aspect (for operating the window accordingly), an electrical aspect (power supply and electronics) and a software aspect (an app to be used by the client from her phone or iPad to remotely control the device).

The mechanical aspect involves a lead screw-driven linear actuator mechanism, mounted securely to the window frame on a base, with a latch-based connection for switching between automatic

and manual operation if needed. On the electrical side, we have a DC power connector, fuse holder, stepper motor, voltage regulator, and additional components like a microcontroller and sensors for precise control and monitoring. The software aspect utilizes the ESPHome Framework integrated with the Home Assistant Companion app, offering remote control via smartphone or iPad, with added Siri voice control for accessibility.

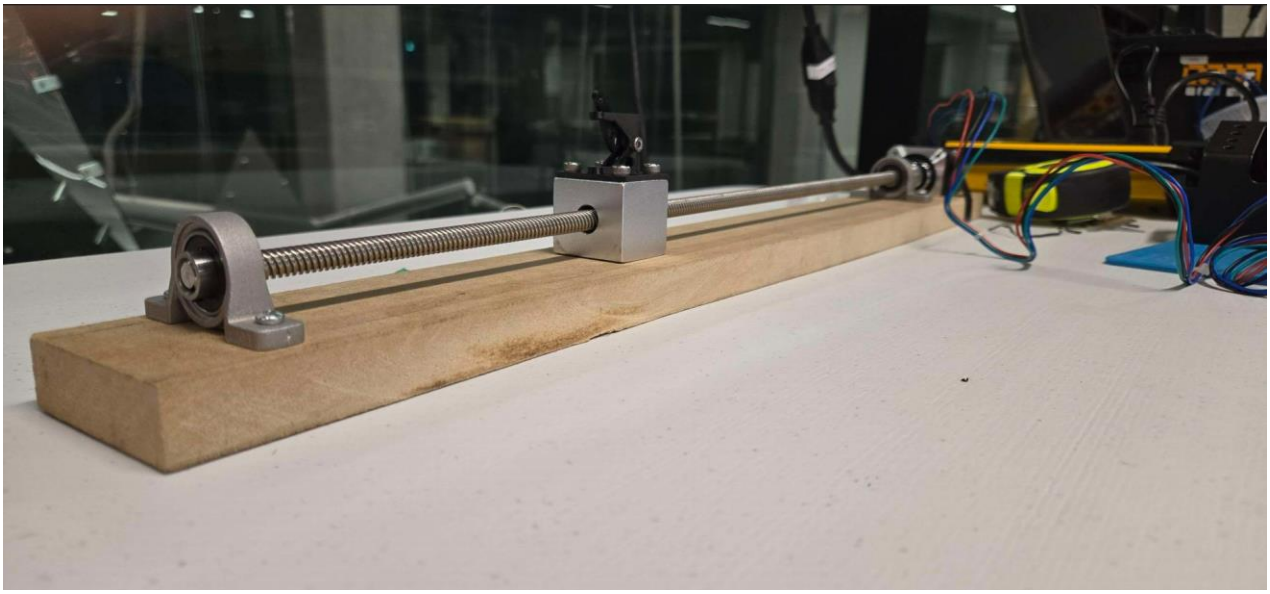

Figure 1: Final Prototype (Shroud Removed to Show Mechanism)

2.1 Conventions

N/A

2.2 Cautions & Warnings

Pay attention to the following points when using the EZ-WNDW smart window controller:

1. Moving Parts: Keep fingers and other body parts away from moving parts when the device is in operation. Contact with moving parts may result in injury.

2. Electrical Safety: This device is intended for use in a domestic environment. It should be connected to a power supply rated as specified on the device label. Improper connection may result in the risk of fire or electric shock.
3. Maintenance: Always unplug the device before cleaning or performing any maintenance. Never attempt to repair or disassemble the device yourself. If the device is not working properly, contact qualified service personnel.
4. Children and Vulnerable Individuals: Keep the device out of reach of children and individuals who may not fully understand the dangers associated with its operation.
5. Ventilation: Ensure the device is used in a well-ventilated area and is not covered or obstructed to prevent overheating.

Remember, safety first! Always read and understand all safety instructions before using the device.

3 Getting started

3.1 Configuration Considerations

On the hardware side, the mounting base for the device will need to be screwed onto the window frame, which will require creating screw placeholders in the window frame. Moreover, the window connection part (for switching between automatic and manual mode) will need to be properly attached to the window handle (e.g., using screws or heavy-duty double-sided tape). These mechanical configurations will be handled by one of our team's technicians when initially installing the device in the client's window.

On the software side, the user will need to be provided with the appropriate login credentials to the Home Assistant instance, which can be set by our team technician who will be installing the device or reconfigured by our IT administrator if needed. The same applies to the network settings to be used for the device's connection (which would normally be the user's home Wi-fi network). This is explained in more detail in the "Accessing/setting up the System" section below.

3.2 User Access Considerations

Since our product allows for both automatic and manual operation of the window (through a connection mode switch mechanism), there are a lot of users and/or user groups that could be using our prototype. This includes people with mobility disabilities (including our client in this case), caregivers (or other house staff such as cleaners), any adult with access to the window, etc. Automatic operation of the window can only be performed through the user's phone (owner of the device). This is because the device requires network connection to the user's device and the home assistant companion app is protected by login credentials which are provided to the user during initial installation.

3.3 Accessing/setting up the System

On the software side, it is required to set up the appropriate network for the device (Home Assistant server on the pi zero) to run on. In our final prototype, we set this up on one of our team member's local mobile hotspot, but normally this would be done on the user's home Wi-Fi network. This configuration will only need to be done once and can be done by one of our team's technicians when initially installing the device. More specifically, the network credentials (SSID and password) can be configured in the ESPHome configuration (.yaml) code through the Home Assistant Web GUI (assuming that the Home Assistant OS is running successfully and is connected to the ESP32 MCU through an EPSHome device integration on Home Assistant).

On the hardware side, the mounting base for the device will need to be screwed onto the window frame, which will require creating screw placeholders in the window frame. Moreover, the window connection part (for switching between automatic and manual mode) will need to be properly attached to the window handle (e.g., using screws or heavy-duty double-sided tape). These mechanical configurations will be handled by one of our team's technicians when initially installing the device in the client's window.

3.4 System Organization & Navigation

3.4.1 Mechanical Sub-system

On the mechanical side, our solution consists of a lead screw driven linear actuator mechanism to open/close the window, a mounting base to hold the mechanism and a latch-based window-to-device connection system (to allow for switching to manual operation of the window). More information on each of these components will provided below.

3.4.1.1 Connection of Window Handle to Linear Actuator

This subsystem connects the carriage of the linear actuator to the window to transmit the sliding motion from the carriage to the window so the window can slide open and close. The connection itself is temporary and does not require any tools to detach or to attach. It consists of a gate latch fixed on base that can slide horizontally and perpendicular to the axis of the lead screw and a 90 degrees bar fixed to the window. The mounting base and its guiding rail are customized 3D print parts. The rail is glued to the carriage as well as the 90-degree bar to the window.

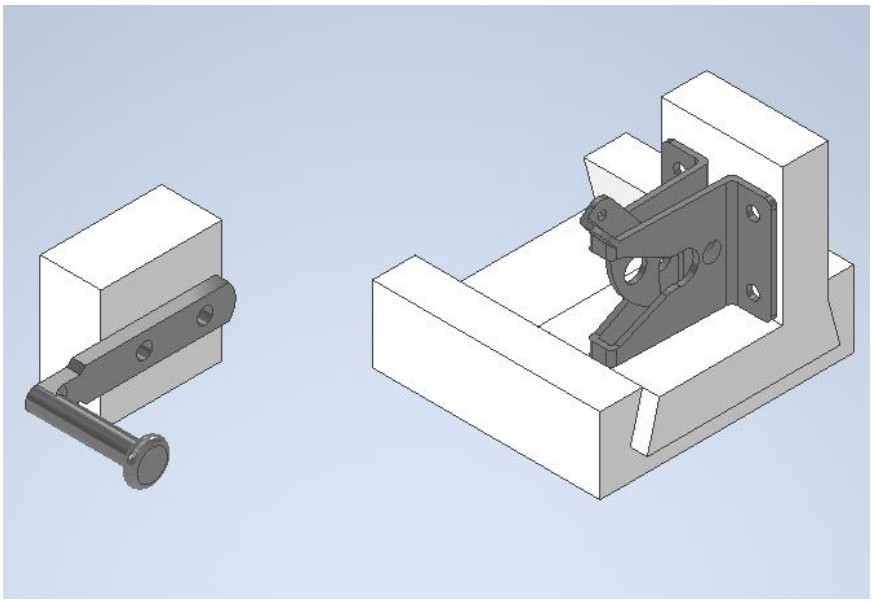

Figure 2: Window Handle-to-Linear Actuation Connection CAD Model

3.4.1.2 Screw Driven Linear Actuator

This subsystem converts electrical power to mechanical power in the form of a sliding motion. The subsystem consists of a motor coupled to a lead screw supported by roller bearings at each end and a carriage driven by the lead screw and moving along its axis guided by two linear rods. The carriage is glued to the rail mechanism that is part of the temporary joint to the window and all parts of the screw driven linear actuator are screwed to its mounting base.

Figure 3: Screw Driven Linear Actuator (Amazon Canada n.d.) & Stepper Motor (Amazon Canada n.d.)

3.4.1.3 Linear Actuator Mounting Base

This subsystem provides a base to hold the lead screw mechanism fixed and aligned and provide a single object to connect to the window frame installing the linear actuator. It also provides extra axial guidance to the carriage. The subsystem consists of a customized MDF board and screws to attach to the screw driven linear actuator subsystem and the window frame.

Figure 4: CAD model of Linear Actuator Base & Assembled Linear Actuator Base Prototype

3.4.2 Electrical Sub-system

This subsystem is composed of a DC power connector (DC barrel) to supply direct current from a mains connection to a device, a fuse holder (F1 Automotive fuse holder) to safely integrate fuses in electrical circuits, ensure a robust current path (prevent voltage from reaching other components), and provide a method to replace fuses once they handle overcurrent events as intended. It also includes a stepper motor (U7 Nema 17) with its integrated circuit (U2 TB67S249FTG) to achieve precise and controlled movement within the entire circuit, a voltage regulator (U3 LD33CV) to stabilize the input voltage to a steady output voltage, a WiFi and Bluetooth microcontroller ESP32 mounted on a circuit board, a humidity sensor (DHT22), and 2 LEDs. This entire subsystem is intended to serve for the electrical power supply of the device and its proper operation.

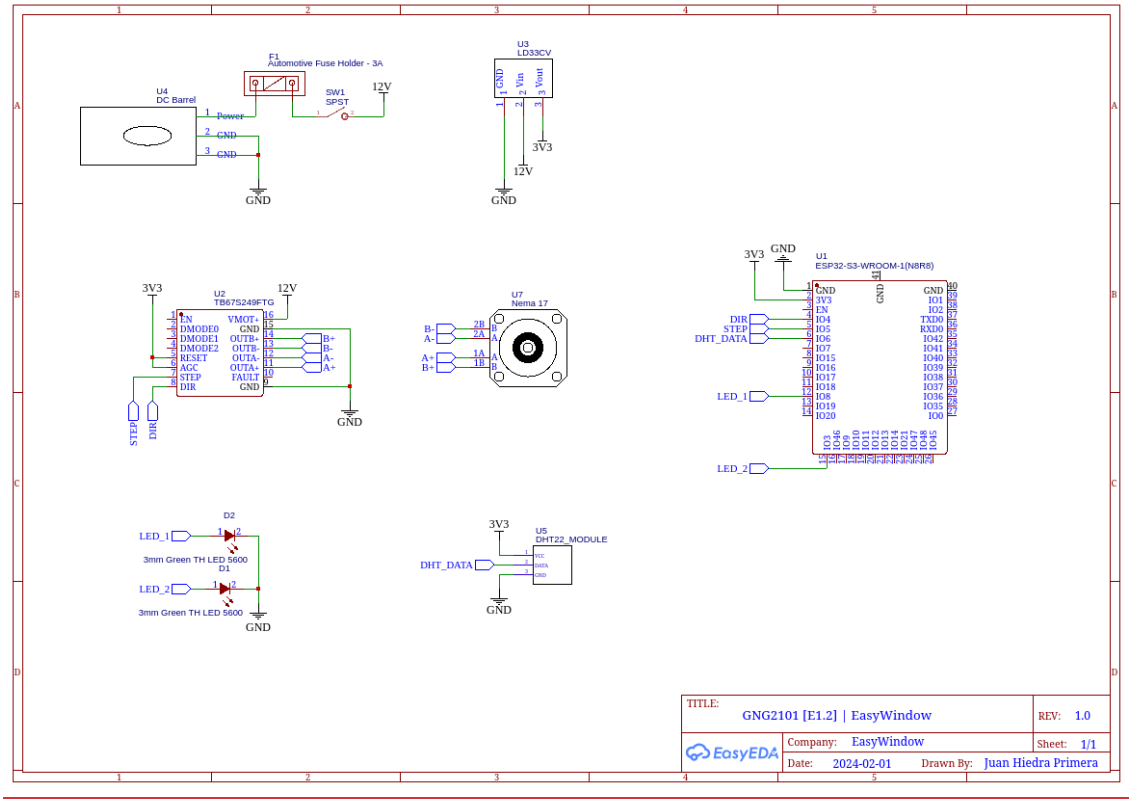

Figure 5: Electrical Sub-system Design Model

For our final prototype, this circuit configuration was appropriately assembled and soldered onto a protoboard for a cleaner and more permanent solution.

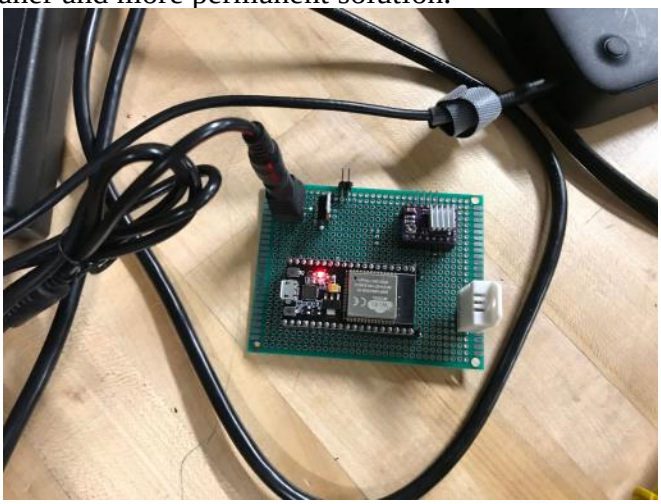

Figure 6: Image of Protoboard Circuit Configuration from Final Prototype

3.4.3 Software Sub-system

The software sub-system consists of a mobile application (compatible with iOS devices such as the client's iPhone or iPad) based on the Home Assistant Companion App. This also includes voice control integration (Siri/Google Assistant) to allow for a more accessible solution for our client. The application will consist of one main page with a button for opening/closing the window (quick access) and a detailed view button which allows them to also stop the window during its operation (for opening/closing at different lengths). It will also show the current room temperature reading in Celsius.

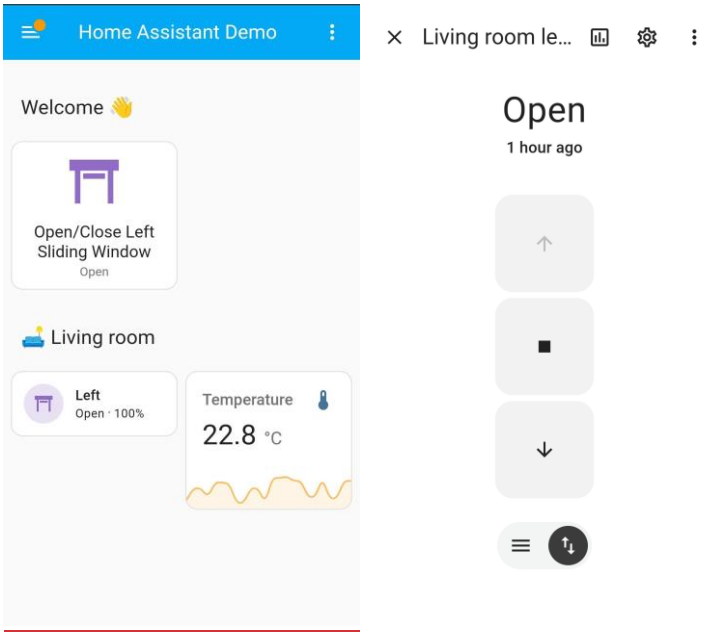

Figure 7: Software Application Design & Detailed View for Window Operation

3.5 Exiting the System

To exit the system, no need to bring the carriage back to its initial position. Make sure that the system is immobile, and the position of the carriage does not prevent the window to unlatch

form the mechanism. Simply unplug the power cord from the wall, unlatch the window from the carriage and remove the two screws holding the base to the window frame.

On the software side, no action is necessary. If you would like to explicitly shut down the home assistant server, simply unplug the device's power cord.

4 Using the System

The following sub-sections provide detailed, step-by-step instructions on how to use the various functions or features of the EZ-WNDW.

4.1 Automatic Window Operation (Open/Close)

This feature allows the user to automatically open or close the window (as well as stop it mid-way through an ongoing operation).

- Instruction:
  - To open/close the window, locate the open/close button on the Home Assistant Companion App UI. Simply click open or close to perform the applicable operation.
- Expected Behaviors:
  - When you press the open/close button, you will see the window open/close.
- Special Instructions:
  - Ensure that the mobile app is properly connected to the EZ-WNDW device before attempting to open or close the window.
  - Before initiating the operation, verify that the window's path is clear of any obstacles to prevent damage or obstruction.
- Exception:
  - In certain situations, such as communication errors, the window may fail to respond to the open/close command. If this occurs, troubleshoot the connection and power source before attempting the operation again.

4.1.1 Stopping Window Operation (Open/Close at Different Lengths)

The application also includes a stop button which will allow the user to stop the current operation being performed by the window. This will allow the user to open/close the window at different lengths by simply initiating the open/close action and stopping it at the length they would like the window to be at.

4.2 Temperature Sensor Readings

The temperature sensor function enables the EZ-WNDW system to monitor and provide readings of the temperature outside and in the surroundings of the device in a real-time basis.

- Instruction:
  - The temperature reading is typically displayed numerically in Celsius unit. On the interface, you will be able to distinguish the outside temperature and that of the room where the EZ-WNDW device is located.

- Expected Behaviors:
  - When the temperature sensor function is activated, the system will continuously monitor the ambient temperature and update the displayed reading accordingly. Users can observe fluctuations in temperature over time, and a history graph of the temperature readings.

4.3 Climate Control

Using the temperature sensor readings, the EZ-WNDW smart window controller is able to automatically open/close the window in order to heat/cool down the room based on preset temperature values by the user.

- Instruction:
  - There will be a scroll wheel with a minimum and maximum temperature setting. The user can simply slide the ends of the scroll wheel to adjust these two values accordingly. EZ-WNDW will then monitor the room temperature and compare it to the outside temperature to accordingly open or close the window (for ventilation) to keep the room temperature within the set minimum and maximum temperatures.

- Expected Behaviors:
  - When the temperature inside the room goes below the minimum temperature, and the temperature outside of the room is hotter than the room temperature, then the window will open until the temperature is no longer below the minimum temperature. Otherwise, the window will remain closed. Similarly, when the temperature inside the room reaches above the maximum temperature, and the temperature outside of the room is colder than the room temperature, then the window will open until the temperature is no longer above the maximum temperature. Otherwise, the window will remain closed.

4.4 Voice Control

The Home Assistant Companion App allows voice control integration with Siri or Google Assistant. The setup for this feature was not done in the case of our final prototype, but there are instructions online on how to perform it:

- For Siri:
  - HomeKit integration: https://www.home-assistant.io/integrations/homekit/
  - Siri Integration via Shortcuts: https://companion.home-assistant.io/docs/integrations/siri-shortcuts/
- For Google Assistant:
  - Google Home Setup: https://www.home-assistant.io/integrations/google_assistant/

As we have not fully tested this feature, we cannot provide instructions on its usage. Please simply follow the links above for more information.

5 Troubleshooting & Support

5.1 Error Messages or Behaviors

For any connection issues with the Home Assistant Server (through the Home Assistant Companion app), feel free to contact one of our IT administrators to troubleshoot the issue with you. Note that there are many useful forums and documentation sources online available for Home Assistant as it is an open source home automation suite.

System may be impossible to set back on automatic mode from the smartphone app due to the latch bar not being lowered down for automatic reset. In this situation, the carriage will go all the way through the length of the window and stop. To correct this, set the carriage back to its start position, lower the latch bar and repeat the automatic mode setting procedure.

System may block when moving along the lead screw. In this situation, the motor will automatically stop. To correct the issue, unplug the device and check for any interference in the race of the carriage and remove if any. If no visible interference is present, apply oil to the lead screw for eased motion.

5.2 Special Considerations

Always make sure that the device is unplugged before performing any trouble shooting on the device.

If parts of the devices are damaged or altered, restrain from using the product or trying to repair it by yourself.

5.3 Maintenance

Apply proper lubrication on window's rails and lead screw to avoid overworking of the device due to friction.

5.4 Support

For emergency assistance or system support, please contact our dedicated support specialist Mathis Turgeon-Roy. You can reach him via email at mturgeo3@uottawa.ca. When reporting a problem, please provide as much detail as possible about the issue, including the steps you took leading up to it, any error messages you received, and the specific area of the system where the problem occurred. This will help our specialist diagnose and resolve the issue more efficiently.

In case of a security incident, such as a fire hazard or unauthorized system access, please report it immediately to our specialist at mturgeo3@uottawa.ca. Include all relevant details, such as the time of the incident, what system was involved, and any hazardous activities you noticed. Our team will investigate the incident and take appropriate action in priority to protect your systems and your access. Remember, your security is our top priority.

6 Product Documentation

6.1 Software Sub-system

The software sub-system consists of a mobile application (compatible with iOS devices such as the client's iPhone or iPad) that will interface with our device's microcontroller for operating the device remotely. This is done through the ESPHome Framework to integrate with the Home Assistant Companion app for a trusted and accessible software solution for smart home devices. This allowed us to develop an easy-to-use application that can interface with our device remotely (as we are using an ESP32 microcontroller), and that includes voice control integration (Siri/Google Assistant) to allow for a more accessible solution for our client.

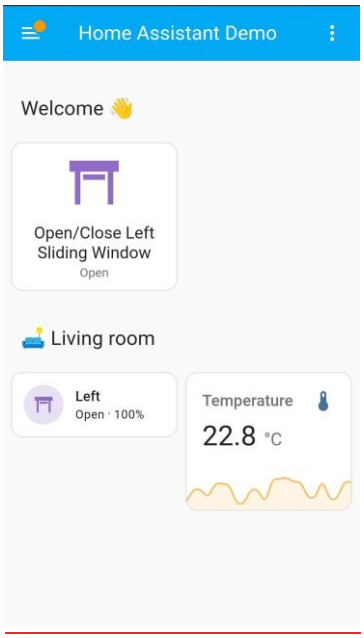

Figure 8: Software Application Design

6.1.1 BOM (Bill of Materials)

In terms of the materials used for the software side, no licenses our paid software services were necessary. This is because our software sub-system mainly relies on Home Assistant, which is a free open-source software, along with ESPHome which is also a free software firmware for microcontrollers to interface with Home Assistant.

6.1.2 Equipment List

The following tools were used to build/assemble the various components for this sub-system:

- Computer
- Home Assistant OS
- Pi zero
- Final Prototype Circuit Configuration (including ESP32 Microcontroller)
- ESPHome Firmware for MCUs

6.1.3 Instructions

First, follow the instructions on installing the Home Assistant Operating System on a Raspberry Pi: https://www.home-assistant.io/installation/raspberrypi#install-home-assistant-operating-system.

Then, follow the Home Assistant Onboarding procedure: https://www.home-assistant.io/getting-started/onboarding/. Finally, follow the onboarding procedure for integrating ESPHome into Home Assistant: https://esphome.io/guides/getting_started_hassio.html. Further configurations to the ESPHome configuration file can be done by following the appropriate component documentation on the ESPHome official website; https://esphome.io/#. You will mainly need a stepper component, a thermostat climate component, binary sensor components, temperature/humidity sensor components and the appropriate logic for handling temperature control as well as the end-stops for defining the window's start and end lengths (which can be specified with button components).

6.2 Physical (Mechanical & Electrical) Sub-system

6.2.1 BOM (Bill of Materials)

PART	COUNT	COST PER COUNT	TOTAL	PURCHASED	LINK/NOTE
Acrylic Sheet (24x12")	2	CA$14.00	CA$28.00	FALSE	https://makerstore.ca/shop/ols/products/acrylic-12-inch-x-24-inch
Linear motion kit	1	CA$40.99	CA$40.99	TRUE	https://www.amazon.ca/Linear-Motion-Support-Bearings-Couplings/dp/B09FXBGDX2/ref=sr_1_9?crid=2FCO5JS6D52RG&keywords=450mm+linear+rod&qid=1707412316&sprefix=450mm+linear+rod%2Caps%2C211&sr=8-9
NEMA 17 Stepper Motor	1	CA$17.99	CA$17.99	FALSE	https://www.amazon.ca/Stepper-1-8Degree-25-5oz-42x25mm-Extruder/dp/B07KZTWWRF/ref=sr_1

					_14?crid=3R7AQFACF5LPQ&keywords=Nema+17+motor&qid=1707412432&sprefix=nema+17+motor%2Caps%2C175&sr=8-14
Stepper Controller (5pc)	1	CA$17.49	CA$17.49	FALSE	https://www.amazon.ca/Bolsen-Reprap-Stepper-Aluminum-Printer/dp/B07G15Z31B/ref=sr_1_1?crid=F6S0TQU3PEBN&keywords=controller+pololu+stepper&qid=1707412469&sprefix=controller+polulu+stepp%2Caps%2C135&sr=8-1
Machine Screws (M4) Kit	1	CA$13.33	CA$13.33	FALSE	https://www.amazon.ca/Hilitchi-180-Piece-Stainless-Socket-Assortment/dp/B01MU4O1FJ/ref=sr_1_9?crid=3BVELP7AWYSLH&keywords=M4+screw+kit&qid=1707412755&sprefix=m4+screw+kit%2Caps%2C149&sr=8-9
Wood screws (#8 x 1")	1	CA$6.97	CA$6.97	TRUE	https://www.homedepot.ca/product/paulin--8-x-1-in-flat-head-square-drive-steel-wood-screws-zinc-plated-100pcs/1000141291

12AWG Wiring (2 x 10ft)	1	CA$17.98	CA$17.98	FALSE	https://www.amazon.ca/Electrical-Silicone-Flexible-Temperature-Resistance/dp/B0756TDTDM/ref=sr_1_10?crid=1ZVTNB8BB586Q&keywords=12awg%2Bwire&qid=1707412870&sprefix=12awg%2Bwir%2Caps%2C164&sr=8-10&th=1
Jumper cable set	1	CA$12.40	CA$12.40	FALSE	https://www.amazon.ca/IZOKEE-240pcs-Solderless-Breadboard-Arduino/dp/B08151TQHG/ref=sr_1_6?crid=2AOZF57VYR5UP&keywords=jumper+cable+set&qid=1707412931&sprefix=jumper+cable+se%2Caps%2C177&sr=8-6
ESP32 S3 MCU Development Board	1	CA$26.95	CA$26.95	FALSE	https://www.amazon.ca/Freenove-ESP32-S3-WROOM-Compatible-Wireless-Detailed/dp/B0BMQ8F7FN/ref=sr_1_2?crid=1KKZIFSG64Q0N&keywords=esp32-s3-box&qid=1707412971&sprefix=ESP32+box+%2Caps%2C150&sr=8-2

3D Printed Shroud	1	CA$2.00	CA$2.00	FALSE	No gram amount yet, so no accurate cost estimate can be made.
3D Printed Clamp	1	CA$2.00	CA$2.00	FALSE	No gram amount yet, so no accurate cost estimate can be made.
90° Gate Latch	1	CA$10.13	CA$10.13	TRUE	https://www.mcmaster.com/products/door-catches/gate-latches~/
Pi Zero 2 W	1	CA$21.00	CA$21.00	TRUE	https://www.pishop.ca/product/raspberry-pi-zero-2-w/
TOTAL			CA$229.12		
TOTAL BUDGETED			CA$110.00		
TOTAL EXPENSES TO TEAM			CA$90.98		
TOTAL EXPENSES TO TEAM AFTER TAXES			CA$102.81		

Table 4: Project Bill of Materials

6.2.2 Equipment list

The following tools were used to build/assemble the various components for this sub-system:

- Computer
- Soldering iron
- Bench saw

- Hand drill
- 3D printer
- Mill

6.2.3 Instructions

Then, the objectives of this prototype are to:

- Verify that the physical integration of all mechanical components respects the spatial constraints of the client's environment. Spatial constraints were measured as a rectangular box of 2 inches of depth, 3 inches of height and 48 inches long.
- Identify any problem with the mechanical interactions of components in the assembly that will get installed as a bloc to the window frame. Including
    - Motion of the lead screw relative to the motor
    - Motion of the lead screw relative to the bearing
    - Motion of the pillow block relative to the rest of the assembly
    - Fixed connection of the motor to the base
    - Fixed connection of the bearing to the base

The simplest and most useful way that we identified to reach those objectives is to design the base that is to be connected to the window frame and on which the lead screw's bearings, motor and electronic components are fixed on. By determining and marking the location for every connection and component on the base, we were able to visualize the minimum required dimensions for all components to work properly together. Then, we could cut the base to the minimum dimension and validate that the concept is able to be installed in the client environment. Finally, we machined the holes and slots previously marked and fixed all components to their respective placement. By doing so, we were able to achieve all of our objectives stated above. The material used to prototype the base was MDF and we used a mill to machined the holes and slots.

For the mechanical connection between the window and the pillow block, we are using a 3D printed gate-style latch; this provides an easy-to-use and intuitive connection mechanism that is intended to be familiar to caregivers. The latch portion attaches to the pillow block via M4 machine screws, and the shaft which latches on is attached to the window using 3M double-sided tape. In our testing, this proved to be a more than effective way to fasten the shaft to the window, since the force needed to open the window was less than that needed to break the tape connection.

Here are some photos of our prototype at different stage of the development:

Figure 9 - Measured and marked base for first validation and to help for manufacturing and assembly process

Figure 10 - Manufactured and assembled prototype

For the electrical components, upon gathering the electronics components (listed below) as well as soldering equipment, solder them together onto a protoboard according to the electronics schematic shown on Figure 4.

Electrical components needed:

- DHT22 sensor module
- Automotive blade-style fuse holder
- ESP32 S3 development board
- LD33CV 12V-3.3V linear regulator
- DRV8825 stepper motor controller
- 24G wire
- Female DC barrel jack to screw terminal connector

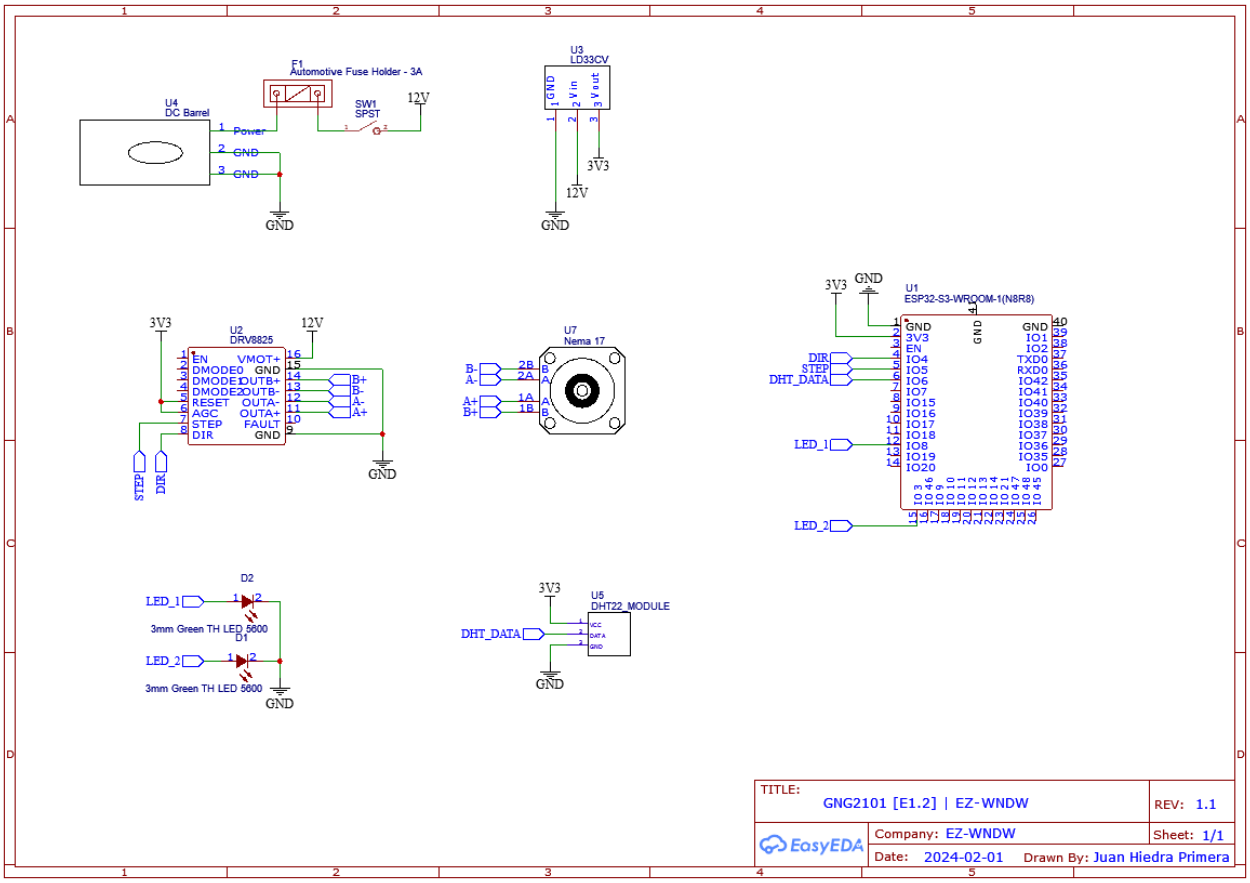

Figure 11 – Electrical diagram

Upon soldering all components together to the protoboard, gather the external components:

- NEMA 17 motor
- 12VDC AC Adapter

Once gathered, connect them according to the schematic.

6.3 Testing & Validation

The test performed on this prototype was simply to assemble the parts on the MDF base, run the motor and note any interference while the device is in motion.

Here are the results of the testing:

Assumption verified	Result
The physical integration of mechanical components respects the spatial constraints of the environment (as defined)	Yes
Number of interference or problem in the interaction between moving assembled components	0

Table 5: Prototype Testing Results Based on Assumptions To Verify

Here are the specifications of the prototype compared to our target specifications:

ID	*Metric*	*Specification*	*Prototype 2*	*Explanation*
1	Efficiency to open and close the window. as defined by the following equation:	**100%** It is the primary functional requirement. Device should only fail to open the window under exceptional conditions. On a small sample of 15 times, the device must be able to succeed 100% opening and closing.	Could not be tested	The prototype is not able to open the window yet, but the results show that the physical and mechanical parts should be able to fulfill their role in opening and closing the window
2	Percentage of device's actions that can be accomplished with a command given from the user's phone.	**90%** Actions that can not be commanded from the user's phone must not be part of the core functions of the device. Phone was requested by the client to be the main	Not applicable to the prototype	The software connecting to the smartphone is not part of this prototype.

		controller of the device, but some “nice to have” functions such as voice control or actions that can’t be controlled via smartphone by nature such as manual opening are accounted for.		
3	-Average required time to remove the device from a functional position to a position that allows cleaning of the window. -Average required time to reinstall the device in a functional position from a position that allows cleaning of the window.	**2 minutes for both** Represents the average time required by a member of the team to remove and install his windows at home. The device is removable to allow the windows to be removed and cleaned. It should not take longer to remove the device than to remove the window, so the current time required by the task is not doubled.	Could not be tested	Although this could not be tested, the prototype proved that the integration of all physical components pre-assembled as a bloc works and therefore can be installed and uninstalled as a single bloc. We are then confident that this target specification will be met with the final prototype.
4	Average time required by a new user to learn how to open the window manually.	**10 seconds** Twice the average time required by a member of the team to open a regular window rounded-up to the tenth. All caregivers should take only a few seconds of reflection before taking actions.	Could not be tested	The prototype being focused on testing functional constraints, this could not be tested. A more comprehensive prototype would be necessary to test this user experience specification.
5	Average time required to open the window manually	**6 seconds**	Could not be tested	The prototype being focused on testing functional constraints, this could not be tested. A more

		Twice the average time required by a member of the team to open a regular window. The action of opening the window manually must be fast to execute in case of an emergency the action should at most double the time required to open a regular window		comprehensive prototype would be necessary to test this user experience specification.
6	Percentage of the window area encumbered by the installed device	**5%** It is a reasonable assumption of the percentage at which the effect of the device on the visibility through the window will not be apparent to the user.	1%	The measurement of the assembled bloc enables the installation below the transparent area of the window. Therefore it won't encumber the window at all, but since not all components have been prototyped yet, we prefer to not set this as 0%.
7	Number of window opening lengths the device is set to operate to.	**3** Include the fully closed and fully open position which are essential to the core function plus one position in the middle to give flexibility to the user	Continuous	Prototype 1 already proved that we were able with the lead screw mechanism, motor and software to move the power screw's bloc to pretty much any length and not prototype 2 proves that these components as part of the complete assembly with the pillow block, the mounting base and the bearing assembly are still able to operate perfectly without mechanical interference.
8	Efficiency to open and close the window on user scheduled time.	**95%**	N/A	The software to schedule opening and closing is not part of this prototype.

		Does not need to be 100%, because it is not part of the core function, but should still be reliable if implemented for good user experience.		
9	RGB value of the casing's exterior	**235,235,235** Threshold determined subjectively by looking at RGB values of color tiles online and determined as a team which was the minimum values for which the color tiles were perceived white.	N/A	The exterior shroud is not part of this prototype.
10	Efficiency of the device to respond appropriately to set commands given by the user to Siri.	**80%** The option to give a command with the phone instead of voice is always present and voice control was only specified as a nice to have by the user, but the voice control should have enough reliability to not create frustration for the user.	N/A	The software connecting to Siri is not part of this prototype.
11	Cost of production	**100$ (Constraint)** This is a constraint imposed by the nature of the course.	about 50$	The prototype did not require any extra cost that was not part of the BOM for the final prototype.
12	Manufacturing time	**2 weeks**	3 days	The prototype took 3 days to be built

		This enables for multiple iterations to refine the prototype. Short iteration cycle are also required due to time restricted the nature of the course		
13	Product weight	**3 kg** Based on benchmarking	2.3kg	The prototype 2 represents most of the weight of the final prototype, so we can be confident that the final prototype weight won't exceed 3kg
14	Maximum force that the device can apply	**600-1000N** Approximate force needed to move the window with a safety factor of 2 and based on benchmarking. Upper limit was added to prevent the mechanism to be to strong and represent a potential hazard if someone get to put a part of their body in the way of the mechanism	Could not be tested	Although it was not tested, we used a static analysis to determine that our mechanism won't be able to move a load superior to 120N.
15	Product dimensions	**48"x3"x2" (constraint)** Based on the measurements of the window frame taken on site and benchmarked products	48"x2.5"x2"	This constraint that was previously a specification was the object of the main goal of the prototype. All component that needed to fit into the space were assembled and were able to run in an equivalent space smaller than the one available

16	Electrical power consumption	**70 W** Based on the power consumption of a medium sized fan which is also a device that can be used to bring fresh air into a room. Solution will then have a similar power consumption.	Was not tested	This was not part of the objective of the prototype, but according to the ratings of the motor, the power should only be around 2W

Table 6: Prototype Testing Results Against Target Specifications

7 Conclusions and Recommendations for Future Work

In summary, our project journey has been an invaluable learning experience, highlighting the importance of collaboration, iteration, and user-centric design. Moving forward, we recommend focusing on enhancing connectivity with other smart home devices and sensors to enable seamless automation of air and light control. Additionally, making the device adaptable to various window types would significantly broaden market opportunities. Furthermore, prioritizing improvements in the aesthetics of the device would enhance its appeal and integration into modern living spaces. If granted more time, we would delve deeper into these areas, ensuring comprehensive integration, universal compatibility, and refined design.

8 Bibliography

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- Amazon Canada (no date) *Nema 17 Stepper Motor.* Available at: https://www.amazon.ca/Stepper-1-8Degree-25-5oz-42x25mm-Extruder/dp/B07KZTWWRF/ref=sr_1_14?crid=3R7AQFACF5LPQ&keywords=Nema+17+motor&qid=1707412432&sprefix=nema+17+motor%2Caps%2C175&sr=8-14 (Accessed: 1 March 2024).

APPENDICES

9 APPENDIX I: Design Files

MakerRepo link to our project:
https://makerepo.com/MohanadAhmed123/1979.gng2101e12-ezwndw

Table 3. Referenced Documents

Document Name	Document Location and/or URL	Issuance Date

10 APPENDIX II: Other Appendices

N/A