ENSC 405W Grading Rubric for Design Specification

Criteria	Details	Marks
Introduction/Background	Introduces basic purpose of the project.	**/05%**
Content	Document explains the design specifications with appropriate justification for the design approach chosen. Includes descriptions of the physics (or chemistry, biology, geology, meteorology, etc.) underlying the choices.	**/20%**
Technical Correctness	Ideas presented represent design specifications that are expected to be met. Specifications are presented using tables, graphs, and figures where possible (rather than over-reliance upon text). Equations and graphs are used to back up/illustrate the science/engineering underlying the design.	**/25%**
Process Details	Specification distinguishes between design details for present project version and later stages of project (i.e., proof-of-concept, prototype, and production versions). Numbering of design specs matches up with numbering for requirements specs (as necessary and possible).	**/15%**
Test Plan Appendix	Provides a test plan outlining the requirements for the final project version. Project success for ENSC 405W will be measured against this test plan.	**/10%**
User Interface Appendix	Summarizes requirements for the User Interface (based upon the lectures and the concepts outlined in the Donald Norman textbook).	**Graded Separately**
440 Plan Appendix	Analyses progress in 405W and outlines development plans for 440. Includes an updated timeline, budget, market analysis, and changes in scope. Analyses ongoing problems and proposes solutions.	**Graded Separately**
Conclusion/References	Summarizes functionality. Includes references for information sources.	**/05%**
Presentation/Organization	Document looks like a professional specification. Ideas follow logically.	**/05%**
Format/Correctness/Style	Includes letter of transmittal, title page, abstract, table of contents, list of figures and tables, glossary, and references. Pages are numbered, figures and tables are introduced, headings are numbered, etc. References and citations are properly formatted. Correct spelling, grammar, and punctuation. Style is clear, concise, and coherent. Uses passive voice judiciously.	**/15%**
Comments		

March 31, 2018

Mr. Steve Whitmore
School of Engineering Science
Simon Fraser University
Burnaby BC
V5A 1S6

Re: ENSC 405 Capstone Design Specifications: OptimSolar

Dear Mr. Whitmore,

The following document outlines the design specifications of a solar panel mounting production unit for ENSC 405W (Project Documentation, User Interface Design, and Group Dynamics) called OptimSolar. The project will involve constructing a universal solar panel mounting unit capable of solar tracking/concentration, cooling, and performance monitoring.

This document will outline in-depth design features of the proof of concept that will be presented and the prototype upon completion of ENSC 440W. OptimSolar has been broken up into three main sections: mechanical, power, and computing systems. Each of these systems will be analyzed. Also included in this document are several appendices. A test plan appendix will describe the expectations for the poster presentation demonstration, and a user interface appendix will describe the intended user interface for the prototype and proof of concept. Finally, an ENSC 440W plan appendix will be included to describe the final stages of the project.

If you have any questions about this document, please contact Cole Patterson by email at colep@sfu.ca.

Thank you,

Cole Patterson
Sam Swerhone
Jacob Cheng

OptimSolar

Design Specifications

OPTIMIZING SOLAR SYSTEMS USING CONCENTRATION AND COOLING, 3/31/2018

Group 15:

Sam Swerhone 301162949

Jacob Cheng 301194569

Cole Patterson 301222829

Table of Contents

List of Tables

List of Figures

Abstract
With renewable energy continuing to grow as an industry there are complementary markets that result from the rapid improvements in solar energy efficiency [1]. The OptimSolar product is a solar panel complement that improves solar panel power outputs and reduces installation inconveniences and costs. Hot climates can see up to a 65% improvement in power production, and colder climates could see up to a 40% improvement [2].

OptimSolar provides a universal mount that will encourage the growth of the residential solar industry. By implementing low power computing and optimizable tracking and cooling in a universal and easy-to-install companion product, homeowners and residential installers will have a 'go-to' product for solar system installations worldwide.

Introduction

With the effects of climate change becoming more apparent each year, there is a worldwide trend toward sustainable and renewable energy sources [3]. As fossil fuels continue to burn, the risk of permanent and irreversible damage to the planet increases [4]. Luckily, scientific advancements in photovoltaics are being made at an unprecedented pace, allowing us to move toward a world where renewable energy is the primary source of electricity.

The motivation for OptimSolar is simple, encourage more customers into the solar market by increasing performance and easing the installation process. OptimSolar can be described as a universally compatible solar energy optimization unit. Its capabilities include:

- Greatly increased performance of solar panels (up to a 65% increase in efficiency)
- Universal compatibility with standard residential panels
- Low installation efforts
- LCD user interface and control panel
- Performance display
- Low power consumption

This document is designed to identify and highlight the key concepts of the proof of concept and prototype versions of OptimSolar. Throughout the design specifications, an in-depth look at the implementation of: mechanical, computing and power systems will be discussed.

Background

Scope

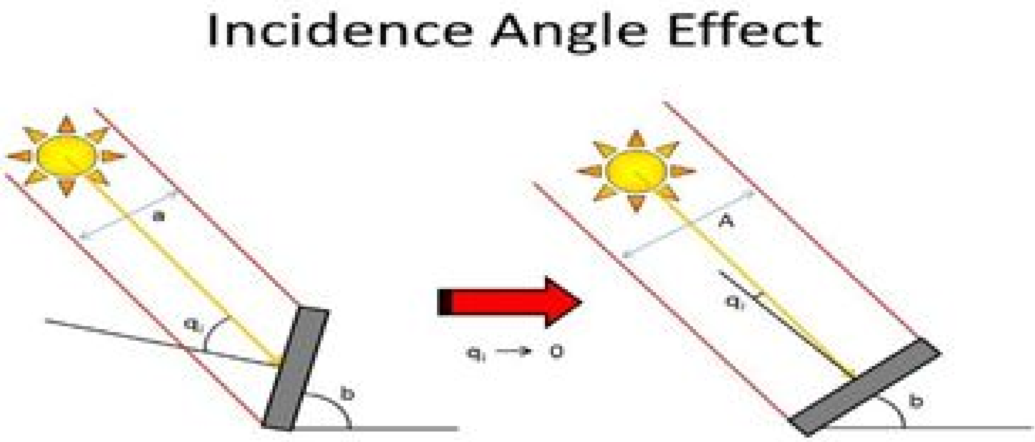
This design specification document illuminates the technical implementations for achieving the desired capabilities listed in the introduction. This document is intended as an internal reference for the upcoming stages of OptimSolar's development. There is a lengthy collection of appendices located at the end of this document that go into further detail of coding algorithms, test plans, the user interface of the prototype, and future development plans.

Theoretical Background

Understanding the science behind photovoltaics is key to improving the performance of solar panel systems. Photovoltaics primarily focus on taking advantage of the high speed movement of millions of photons (high energy subatomic particles that compose solar radiation). Photons are emitted from the Sun and collide with valence electrons in the outermost shell of a semiconductor. When these semiconductors are configured into a circuit, their electrons will leave their initial atom and bounce to the next atom, creating an electrical current [5]. As scientists and researchers improve photovoltaic materials and manufacturing, the technology will always be limited by the amount of solar radiation per area. After minimal atmospheric diffusion, the Sun can provide Earth's surface with $1000 W/m^2$ of energy [5].

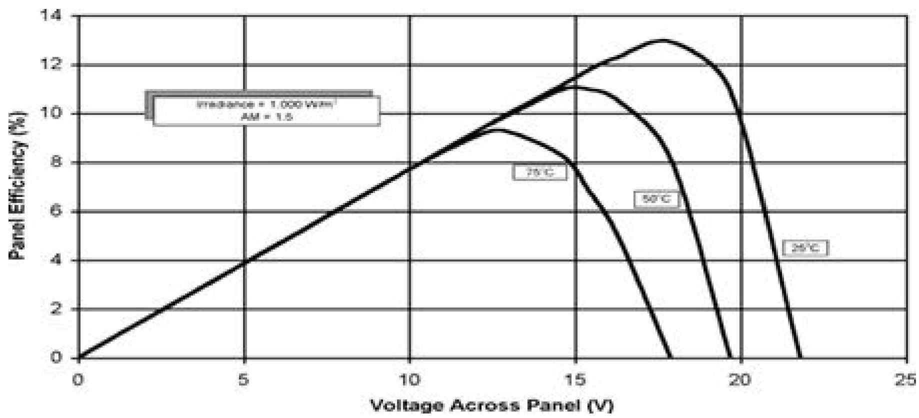
As the Earth rotates around the Sun, the powerful beams of solar radiation strike at different angles along the Earth's surface. As the incidence angle of the beams relative to a surface grows larger, less radiation is absorbed [6] (see Figure 1). This development is known as the Solar Incidence Angle Effect, and is the foremost motivation for the OptimSolar unit. OptimSolar is designed to maintain a solar incidence angle, q_i, of zero, by electromechanically articulating the panel orientation. Therefore, mounted solar panels will produce 40% greater average power output [7]. This is equivalent to having a solar panel that is 40% more efficient or 40% larger [8].

Figure 1: Incidence Angle Effect [9]



A negative side effect of maximizing or concentrating radiation is the extreme heat the radiated surface is subject to. Once solar panels reach above 75°C, the semiconductor material loses its ability to maintain voltage levels which in turn reduces the power production. At this temperature, the panels can even be subject to permanent damage [10]. Every solar panel has an optimum operating temperature, which usually lies between 15°C and 35°C. OptimSolar is designed to maintain solar panel temperature within this range by using a sprinkler system, avoiding up to 25% in decreased performance due to overheating [11]. Figure 2 depicts how panel voltages drop due to overheating.

Figure 2: Temperature Effects on Solar Performance[12]



Process Details

High Level System Overview

OptimSolar is a universal solar panel mount with solar tracking, cooling, and performance monitoring features. A simplified rendering of OptimSolar prototype is shown in Figure 3. Not shown in Figure 3 are all the electromechanical components that bring OptimSolar to life. The rest of this document will be outlining the internal workings of the design, as well as the structural dimensions and limits. OptimSolar's electromechanical design can be visualized as three separate but interacting subsystems: Computing System (CS), Power System (PS), and Mechanical System (MS). Table 1 presents the responsibilities of each subsystem, and Figure 4 depicts the system in a block diagram. The designs of each subsystem will be detailed in the following sections.

Figure 3: Simplified Rendering of OptimSolar

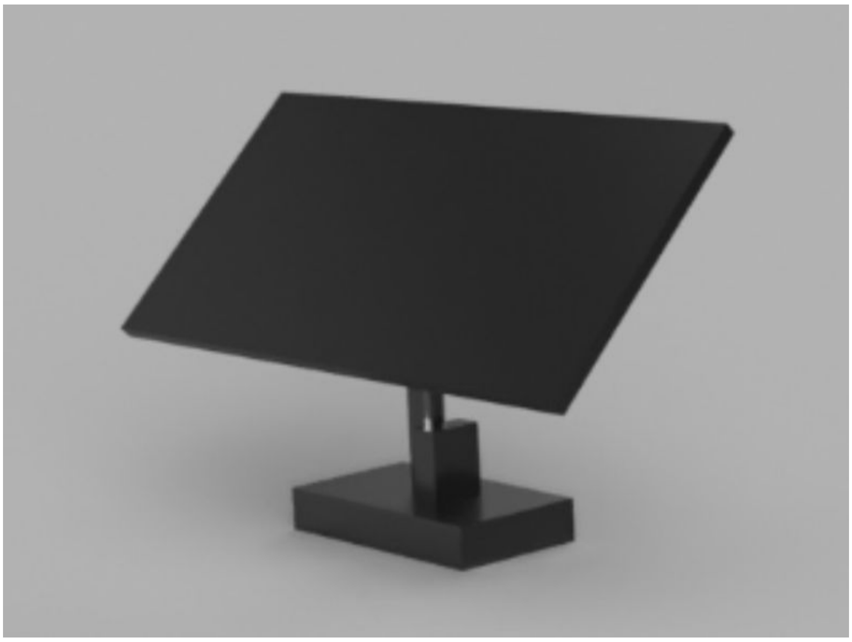
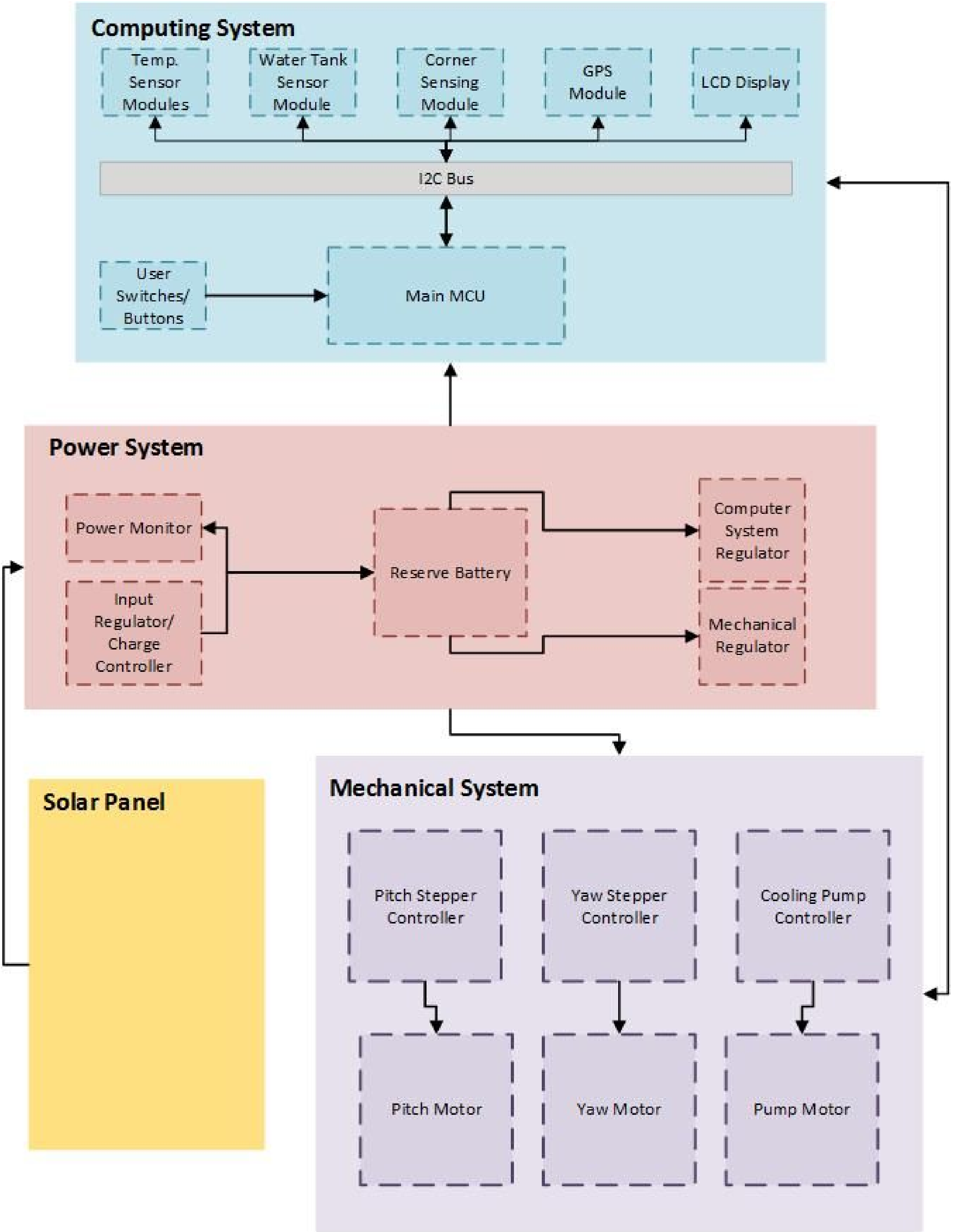


Table 1: Subsystem Definitions

Subsystem	Responsibilities
Computing System	User interfacing, sensing environment, enabling the motors, and low power optimization
Power System	Regulating input current/voltage and routing power to other systems
Mechanical System	Driving motors, locking rotations, mounting, and physical support

Figure 4: OptimSolar Block Diagram



Computing System

Optimsolar will boast a real time embedded computing system, emphasizing reliability and low power consumption. The computing system is responsible for enabling and optimizing tracking and cooling functionalities while supporting real time user interfacing. It encompasses multiple distributed MCUs and sensors, I^2C network, LCD screen, and a user control panel. The system must interface with stepper motor drivers that drive panel orientation and a hydroelectric pump actuating the cooling system. The computing system is also responsible for minimizing power consumption, and achieves this via controllable duty cycling and sleep/wake interrupts.

In the computing system, there are two kinds of microcontrollers: multiple distributed slave MCUs (ATTiny85) and the single master MCU (ATMega328). Tables 2 and 3 list all the port connections for the two devices. The slave MCUs have two separate subcategories of configuration: Corner Modules and the Water Level Module. Both of these subcategories operate with the same algorithm, but they read different sensors. The slave MCUs read sensors and transmit the sensor data to the master MCU upon request. The master MCU must control the LCD, control pitch and yaw rotations, and interface with UI inputs. The master MCU requires the sensor data from the slave MCUs to complete these tasks. All MCUs communicate under an I^2C protocol, where the master MCU initiates all communication and then requests data. Libraries for I^2C, LCD, and interrupts with the ATMega328 and ATtiny85 will be reused from open source libraries. These libraries include: Interrupts and Wire library by Arduino and the TinyWireS library by Github's Rambo. The pinouts for the two kinds of MCUs that OptimSolar employs can be found in Appendix VI.

Table 2: ATMega Port Mapping

ATMega 328p Pin Number	ATMega 328p Pin Name	Main MCU Connection
1	PC6	CS RESET
2	PD0	YAW EN
3	PD1	PITCH EN
4	PD2	NAV BUTTON INTERRUPT
5	PD3	CONTACT INTERRUPT
6	PD4	COOLING MOTOR EN
7	VCC	CS INPUT PWR
8	GND	CS COM
9	PB6	NOT USED
10	PB7	NOT USED
11	PD5	STEPPER DRIVER M1/M2 (TIED)
12	PD6	STEPPER DRIVER M3

13	PD7	YAW STEPPER DRIVER STEP
14	PB0	YAW STEPPER DRIVER DIRECTION
15	PB1	SELECT BUTTON INPUT
16	PB2	UP BUTTON INPUT
17	PB3	DOWN BUTTON INPUT
18	PB4	LEFT BUTTON INPUT
19	PB5	RIGHT BUTTON INPUT
20	AVCC	NOT USED
21	AREF	NOT USED
22	GND	NOT USED
23	PC0	PITCH STEPPER DRIVER STEP
24	PC1	PITCH STEPPER DRIVER DIRECTION
25	PC2	WAKE-UP SLAVES INTERRUPT
26	PC3	NOT USED
27	PC4	SYSTEM SDA
28	PC5	SYSTEM SCL

[13]

Table 3: ATTiny85 Port Mapping

ATTiny85 Pin Number	ATTiny85 Pin Name	Corner Module Connection	Water Module Connection
1	PB5	CONTACT SWITCH INPUT	NOT USED
2	PB3	PHOTORESISTOR INPUT	WATER LEVEL SENSOR
3	PB4	INDICATOR LED	INDICATOR LED
4	GND	CS COM	CS COM
5	PB0	SDA	SDA
6	PB1	WAKE-UP SLAVES INTERRUPT	WAKE-UP SLAVES INTERRUPT
7	PB2	SCL	SCL
8	VCC	CS INPUT PWR	CS INPUT PWR

[14]

Figure 4 shows a wiring schematic for the computing system. The computing system communicates via I^{2}C protocol, which requires low transmission capacitances of cabling. The computing system needs to overcome length of the wires for the prototype unit. This will not be an issue for the proof of concept as it maintains a small network footprint. However, the prototype will be much larger with the four sensing modules located at each corner of the solar panel. With the main MCU located in a central location (near the base), the wires can be up to 1.5m long. To overcome capacitance due to the length of the wires, a bus extender will be used to amplify the signals so they reach their destinations with full integrity. Figure 5 below shows a close up of the sensing module with the bus extender.

Figure 4: Wiring Diagram of Computing System

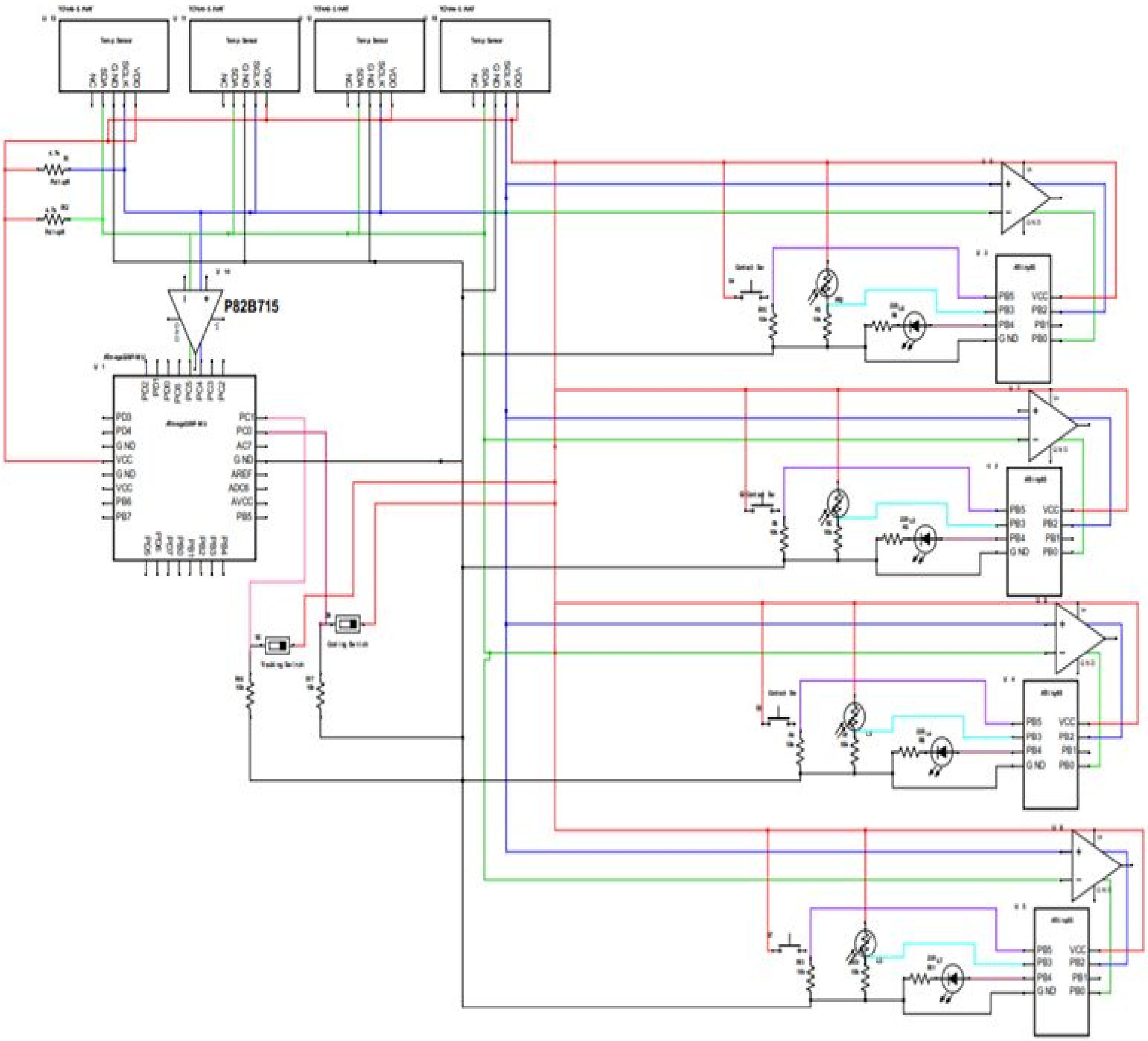
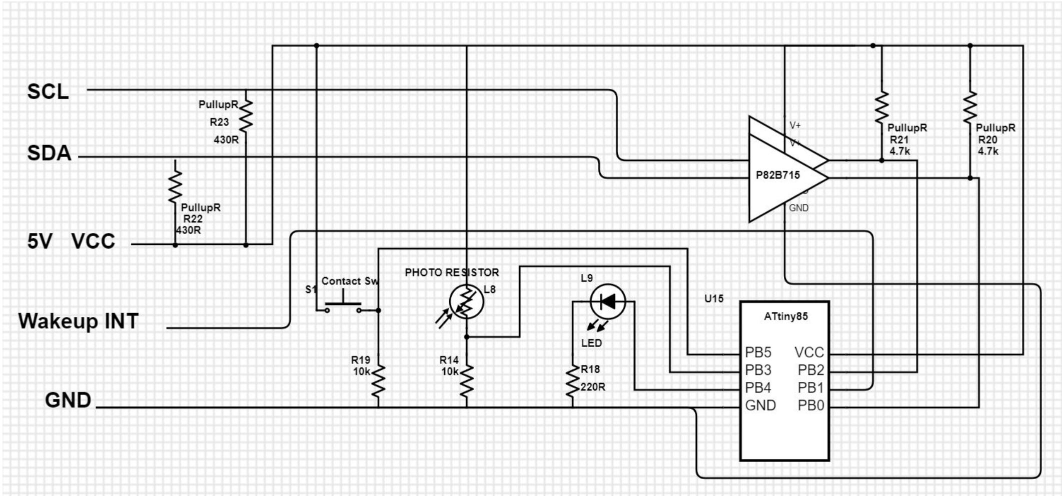


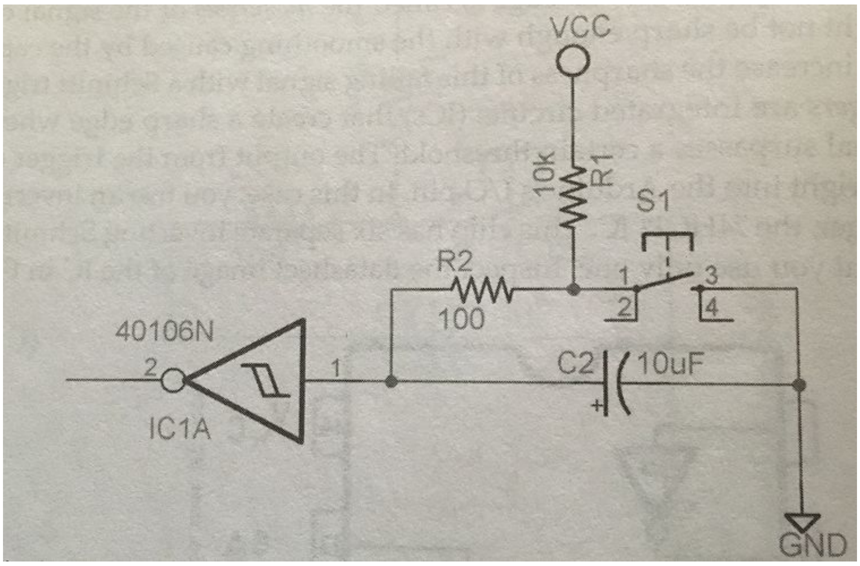
Figure 5: Close-up of Sensing Module



Interrupts play an important role in most embedded systems, and OptimSolar is no different. Interrupts are heavily used for user interfacing, duty cycling, for the wake-up of slave MCUs, and motion obstructions. Whenever a user presses a button or switch on the control panel, OptimSolar will jump to the user interrupt routine which: displays the first page of the LCD Screen, acquires updated sensor data, and waits up to the preset timeout duration for further user input. This requires a pin interrupt of the OptimSolar (this will be the highest priority interrupt). Controllable parameters will exist for duty cycling of the OptimSolar, so that the system will read sensors and/or adjust actuators periodically. This requires a timer interrupt in the master MCU. When this interrupt occurs the master MCU will interrupt slave MCUs for data transmission and then enable stepper drivers for motor actuation. This pin interrupt will wake-up the slave MCUs. Lastly, contact switches may be closed due to obstructions. This also triggers an interrupt that forces the master MCU to stop motor stepping, update sensor readings, and rotate to an unobstructed position.

The user interface will afford navigation of menus with a navigational push button pad (shown in Appendix III). These push buttons will be debounced for reliable usage. The circuit depicted in Figure 6 will be used for all five buttons within the navigational pad. The design requires a hardware debouncing of the push buttons, as opposed to software methods, because the program will not be able to implement any timing delays within the interrupt routines. The debounce circuit will use an RC circuit to filter out bounces in button signals and a Schmitt Trigger to sharpen edges of the RC output.

Figure 6: Hardware Debounce Circuit [15]



See Appendix I and Appendix II for detailed slave and master algorithms, respectively.

**The temperature sensors used by OptimSolar are manufactured with firmware supporting I^2C communication and a power saving mode. The LCD used by the OptimSolar also coming with firmware supporting I^2C and power on/off enabling.*

Sensor Location and Placement:

OptimSolar tracks the sun using data from four sensor modules located at the corners of the unit. Figure 7 shows the mounted solar panel with the four sensor modules. Previously stated, these modules include: the photoresistor to track the sun, contact switch for safety, and temperature sensor to monitor temperature of the solar panel. Figure 7 also shows the placement of the sprinkler unit for cooling. Similarly, Figure 8 shows the back side of the mount. This displays the wiring of all subsystems, mounting of the units, solar panel, and water storage unit.

Figure 7: Sensor Location on Solar Panel Font View

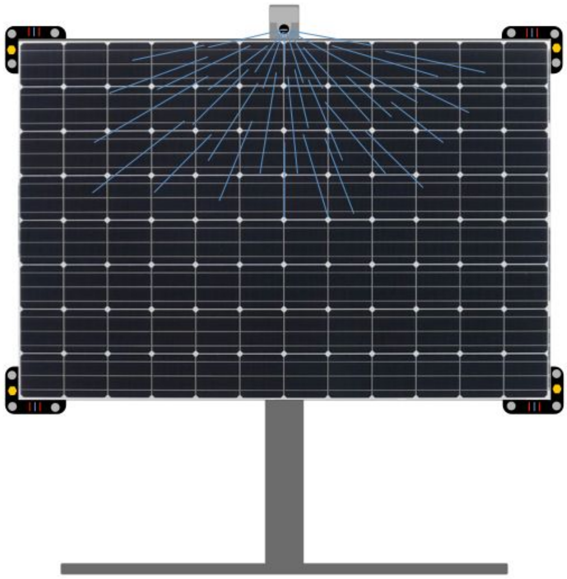
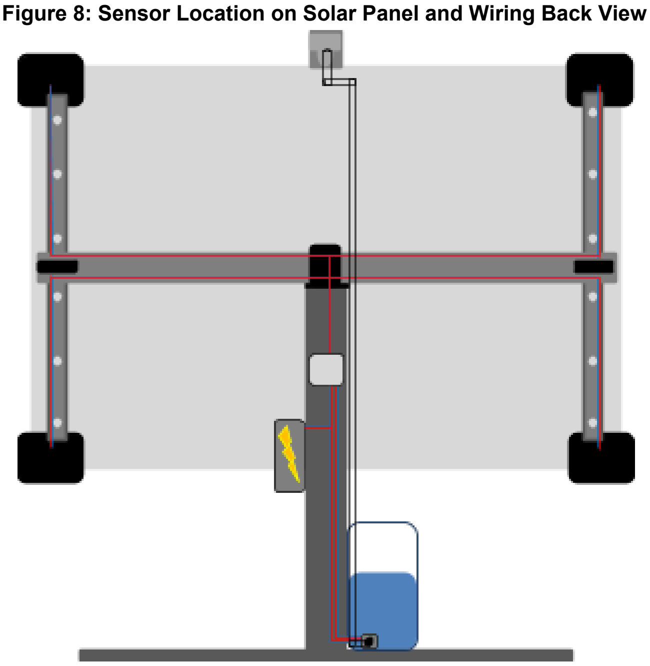


Figure 8: Sensor Location on Solar Panel and Wiring Back View

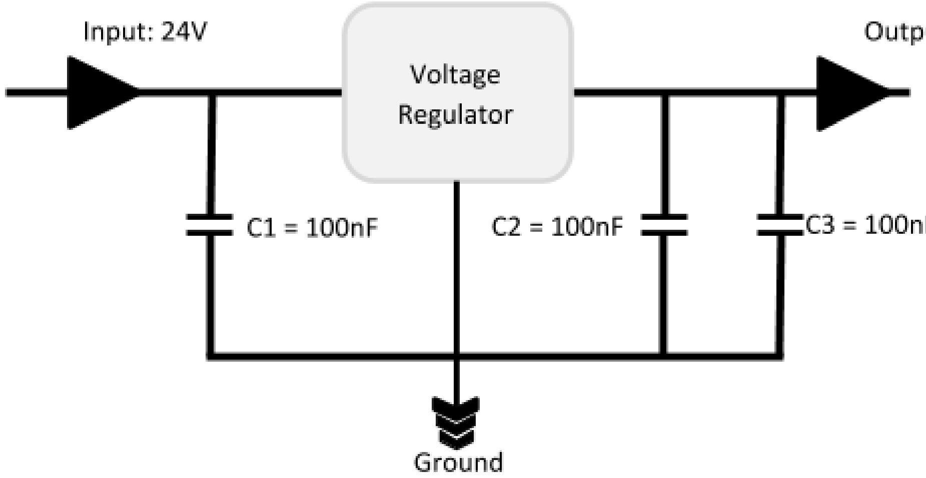


Power System

The power system routes power from the power supply to the rest of the OptimSolar subsystems, while protecting from surges and regulating voltage and/or current levels. OptimSolar's prototype will be powered via battery, and the design is yet to be formalized. The proof of concept unit will be powered from a wall plug in. The 220V wall source will be stepped down using an off-the-shelf wall converter.

The computing system runs off 5V whereas the power supply is 24V. Figure 9 shows the circuit used to regulate the 24V input down to 5V for the computing system. The proof of concept's mechanical system will be powered directly from the 24V wall converter, no step down or regulations required.

Figure 9: Voltage Regulator Circuit



Power Calculations

OptimSolar is designed to increase the efficiency of a solar panel by up to 65%. This is only achievable by maintaining extremely low power consumption with respect to the solar panels power production. OptimSolar requires power for two internal subunits: mechanical system and computing system. Combined, these units must consume less than 5% of the daily power improvement by the system. The following section will outline all components and their respective daily power consumption.

****Please note the following calculations are done under these assumptions:***

- unit is at 25°C
- 9 hours of usable sunlight/day
- Averaging 3.64kWh/m^2/day of solar radiation
- Using a 320W solar panel
- Dimensions of solar panel are 39”x77”
- Solar panels convert sunlight to electricity at 25%
- Components are not stressed and are running at typical performance
- Microcontroller (ATMega328) is run in power save mode at night
- Microcontroller runs in idle mode when no movement is necessary
- ATTiny85 is run in power down mode when not polling data

- Motors will only rotate a maximum of 360 degrees in one day
- Computing system is run off 5V
- Mechanical system is run off 24V
- Motor is a 2 phase, 276oz-in running at 2.6A/Phase
- Water pump will run for 1 hour/day

Energy Produced By Solar Panel Without OptimSolar

Daily power from solar panel: 3.64kWh/m^2/day x 1.94m^2 = 7.062kWh/day

25% efficiency: 7.062 x 0.25 = 1.767kWh/day

Energy Produced By Solar Panel With OptimSolar (65% improvement)

1.767 + (1.767 x 0.65) = 2.915kWh/day

Microcontroller Calculations

Table 4 below shows the current values of the main MCU used for the calculations of the power draw.

Table 4: Current draw of ATMega328

ATMega328	Average current draw	Max current draw
Active mode	5.2mA	9mA
Idle mode	1.2mA	2.7mA
Power Save mode	4.2μA	6μA

[13]

With 9 hours of sunlight/day on average, the ATMega328 microcontroller will be running on Power Save mode for 15 hours/day. With the microcontroller only polling data from sensors every 30 minutes for approximately 1 minute at a time, the ATMega will spend 30 minutes/day in active mode and the remaining 8.5 hours/day in idle mode. Table 5 below shows the respective power drawn by the main MCU in kWh/day.

Table 5: Power consumption of ATMega328

ATMega328P	Time/Day in mode	Current draw	Watts	kWh/day
Active mode	0.5 hours	5.2mA	0.026W	0.000013

Idle mode	8.5 hours	1.2mA	0.006W	0.000051
Power save mode	15 hours	4.2μA	0.000021W	0.000315

Sensor Modules

Table 6 below shows the current draw of the sensor modules MCU used in the power calculations.

Table 6: Current draw of ATTiny85

ATTiny85	Average current draw	Max current draw
Active mode	1.2mA	2mA
Power save mode	10μA	12μA

[14]

The sensor module includes four ATTiny85s that will run in Power Save mode for 23 hours/day and in active mode for 1 hr/day. The sensor module will require four bus extenders as well. These bus extenders (P82B715) will draw 25mA for 1 hr/day. The sensor module also includes 4 temperature sensors that will draw 350μA for 9 hr/day. Table 7 below shows the appropriate power calculations in the respective modes in kWh/day.

Table 7: Power consumption of ATTiny85

ATTiny85	Time/Day in mode	Current Draw	Watts	kWh/day
Active mode	1 hour	1.2mA	0.006W	0.000006
Power save mode	23 hours	10μA	0.00005W	0.00115

Bus Extender Calculations

Watts = Amps x Voltage = 25mA x 5V = 0.125W

kWh/day = (0.125W/1000) x 1 hr/day = 0.000125kWh/day

Temperature Sensor Calculations

Watts = Amps x Voltage = 350μA x 5V = 0.00175W

kWh/day = (0.00175W/1000) x 9 hr/day = 0.00001575kWh/day

Table 8 below shows the total power consumption of the entire computing system in kWh/day.

Table 8: Power consumption of Computing System

Component	Quantity	Power Consumption (daily)
ATmega328P	1	0.000379 kWh/day
ATtiny85	4	0.0046 kWh/day
Bus Extender (P82B715)	4	0.0005 kWh/day
Temperature Sensor (TC74A6-5)	4	0.000063 kWh/day

Total computing system power consumption = 0.005542 kWh/day

Table 9 below shows the total power consumption of the entire mechanical system in kWh/day.

Table 9: Power consumption of Mechanical System

Component	Quantity	Power Consumption (daily)
Stepper motor (276oz-in)	2	0.0223104 kWh/day
Stepper driver	2	0.000063744 kWh/day
Water pump	1	0.0042 kWh/day

Under optimal conditions, the stepper motors will only need to actuate 18 times/day for short intervals, and one final movement at the end of the day. This will yield a total operation time of at most 5 minutes. With the motor being a 2 phase stepper motor operating at 2.8A/phase and 24V, the following calculations show the total power used by the motors:

Current: 2.8A/phase x 2 phase = 5.6A

Watts = Amps x Voltage = 5.6A x 24V = 134.4W

kWh/day = (134.4W/1000) x 0.083hours/day = 0.0111552kWh/day

In order for the motors to work, they require stepper drivers. These stepper drivers will run at the same time as the motors, 5 minutes/day, and draw at most 16mA. The following calculations are for the power draw of the stepper drivers:

Watts = Amps x Voltage = 16mA x 24V = 0.384W

kWh/day = (0.384W/1000) x 0.083hours/day = 0.00003187kWh/day

The power consumption of the water pump will range depending on geographical location. Temperate climates may only run the water pump a few times each year, while extremely hot climates may require cooling every day of the year. The following calculation is based on the assumption that the water pump runs every day for 1 hour (during peak sunlight):

kWh/day = (4.2W/1000) x 1hours/day = 0.0042kWh/day

Total mechanical system power consumption = 0.0266 kWh/day

Grand total = 0.03212 kWh/day

Worst case assumptions were made for the previous calculations, likely resulting in overestimations. The computing and mechanical systems are designed to work harmoniously and seamlessly in an effort to maximize efficiency, while maintaining viable power consumption. Although a 65% improvement in overall efficiency of the solar panel is ambitious, we've designed a unit that will reach improvements near 65% with a total power consumption of only 1.1% of total daily power production.

OptimSolar must remain cost efficient, balancing power production improvements and financial cost. A solar panel sized at 39”x77” costs approximately $350. If we are capable of improving the efficiency of this solar panel by 65% it would be equivalent to buying a smaller (65% the size) solar panel for $228. PNW Energy envisions a universal solar panel mounting unit that will sell for around $150. At this price, if OptimSolar can improve the efficiency of the solar panel by 43% the buyer will break even. OptimSolar is not only a means of improving the efficiency of a single solar panel, but will save space, allowing for more solar panels to be installed. Existing stationary mounts sell for upwards of $400, and do not included the benefits seen by OptimSolar [16]. With this in mind, OptimSolar aims to be competitive in this market.

Mechanical System

Rotations

When it comes to the rotation mechanics, it is very important to understand the path the sun takes through the sky. Useful information can be found in Appendix VIII to understand the sun's Azimuth and Altitude angles as well as pitch and yaw.

There are two days in the year that are important to analyze when it comes to sunlight; the winter and summer solstices. June 21 and December 21 are the year's longest and shortest days, respectively. Since PNW Energy is located in the Pacific Northwest, Seattle Washington was analyzed for rotational calculations using [17].

Table 10: Measured Altitude and Azimuth Angles

Date	Peak Altitude Angle	Change in Azimuth Angle
June 21, 2017	64.09°	253.79°
December 21, 2017	17.59°	109.11°

These calculations show the difference in azimuth angle for a city in the Pacific Northwest, which is good to know when looking at yaw rotations required for OptimSolar.

In a simplified model, the yaw should have 180° rotation capability, and the pitch should have 90° rotation capability. This would allow the OptimSolar unit to have 100% coverage of the sun. In most locations, this is not needed. Although not needed for yaw, OptimSolar will included 180° rotation. For pitch, OptimSolar will have 60° pitch each way.

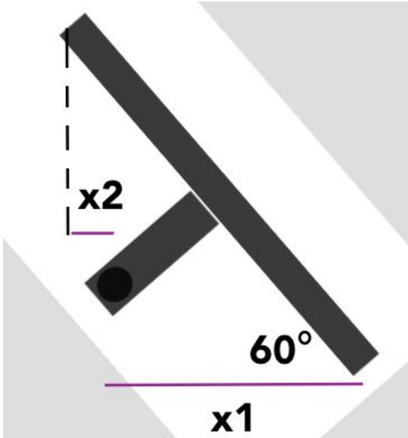
Mechanics

Now, with the defined pitch and yaw rotations, the torque required to move the solar panel must be analyzed. Accelerating an 80lb solar panel is no easy task.

By calculating the torque with an ungeared system at maximal torque levels

2.6122 in * 1280oz = 3343.6 oz-in.

Figure 10: Torque Diagram



Since the motors used for calculation are 260 oz-in, this would need to be heavily geared. By limiting the pitch rotation to 60° in either direction, the torque required is reduced to 1926.4 oz-in for the final prototype. With a bigger sized stepper motor (570oz-in), this can be geared up to the necessary ~2000 oz-in with ease. Figure 10 shows an approximate diagram of the solar panel at a tilted angle. Since the motor axle is in the middle, there are two sides that can act as a counterbalance.

Mechanical system

The mechanical system must work harmoniously with the computing system to have a product that runs smoothly and effectively. There are three mechanical components that will require direct wiring to the computing system: two stepper motors and a water pump. In order to control the stepper motors, stepper drivers are required. For the proof of concept and the prototype, OptimSolar will run with the same stepper drivers. However, they will be driving different motors to account for the size and load differences between proof of concept and prototype. Appendix VI shows the pin layout for the stepper driver (Big Easy Driver ROB-12859 ROHS). The stepper driver is the link between the main MCU and each motor. The wiring schematic for the main MCU, stepper driver and stepper motor can be seen in Figure 11. Finally, the mechanical system will need to run a water pump. Figure 12 shows the wiring schematic for the water pump.

Figure 11: Wiring Schematic for Main MCU and Stepper Motor

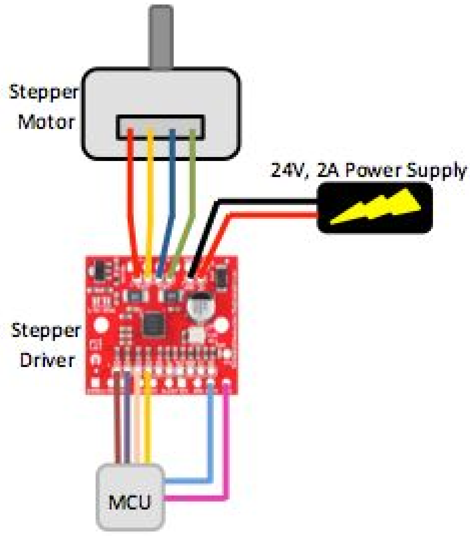
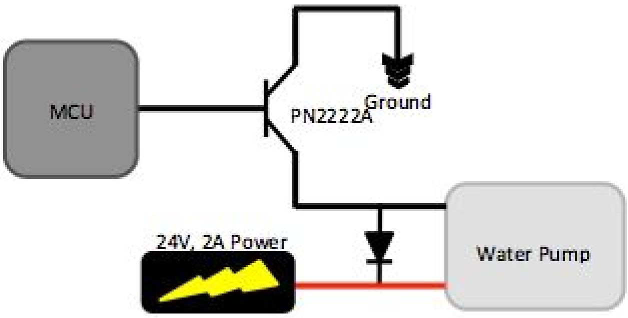


Figure 12: Wiring Schematic for Water Pump



Proof of Concept Mechanics

On top of the wiring and layout schematics, it is also valuable to understand the moving parts of OptimSolar. With dual-axis rotation, comes many challenges, especially at heavier loads. In the Yaw axis, an interplanetary gearing system has been chosen to move forward with.

Appendix VII contains the layout of the Proof of Concept, and the exact dimensions that are being used. It also contains the description of the interplanetary gearing system used to drive the yaw rotation of the OptimSolar unit.

Conclusion

PNW Energy is committed to designing a universally compatible solar panel mount, capable of providing dramatic performance improvements. OptimSolar recovers efficiency losses due to stationary panel mounting and panel overheating. The Design Specifications document, in conjunction with the 440 Plan Appendix, and User Interface Appendix, is one of the last tasks to complete for ENSC 405W. This document completely defines the methods used in the Proof of Concept for OptimSolar as well as future steps for this project. Next, comes a working Proof of Concept, which is the first realization of PNW Energy's goal to help grow small scale renewable energy.

All sections of this project have been well thought out, and have been tested before synthesis. This leaves PNW Energy to complete the structural design, and begin final testing. The tests described in the Test Plan Appendix will be used by PNW Energy to ensure that the poster presentation goes smoothly. Only basic functionality is included in the Proof of Concept, the next challenge involves implementing the requirements set out for the prototype in the Requirements Specifications document. PNW is excited to take on the challenges that come with progressing further with OptimSolar.

Appendix I: Slave MCU Algorithm (Pseudo C Syntax)

/*Note this particle pseudocode is for the Corner Modules, but is very similar to the Water Level Module code with the exception of some variables/pins and the read_sensors() function. */

```
#define SLAVE_I2C_ADDR  0x11                    //Values range from [0x11:0x1F] for
slave MCUs
#define CORNER_MODULE 1                         // either CORNER_MODULE or
WATER_LEVEL_MODULE
const byte LED_PIN =  6;
const byte PR_PIN = 1;
const byte INT_PIN = 3;
const byte CS_PIN = 2;
volatile byte data =  -1;
//Initialization Function automatically called upon reset
void setup() {
initialize_pinmodes();                    //Declare pins as inputs or outputs
initialize_IRQ(INT_PIN, listen_for_I2C);        //When INT_PIN is HIGH jump to
listen_for_I2C routine
initialize_I2C(SLAVE_I2C_ADDR);           //Initialize SDA and SCL pins for

flash_led();
}

Void loop {
    //sleeps for 20 seconds and power off some peripherials like ADC and Brown-Out
Detect
        LowPower.powerDown(SLEEP_2S, ADC_OFF, BOD_OFF)      ;
}

Void listen_for_I2C {
        enable_pins();      //turn back on all pins for reading and I2C communication

        Wait_for_Request(SLAVE_I2C_ADDR);  //Wait for specific address request
        data = read_sensors();                  //Read the specific sensor(s)
        transmit_data(data);                    //Send that data back to the Master
        flash_led();                            //Flash LEDs to indicate data transfer
        disable_pins();                          //disables all pins except INT pin
```

Appendix II: Master MCU Algorithm (Pseudo C Syntax)

**See Appendix III for in depth display/UI details, some functions and variables omitted for conciseness*

```
#define MASTER 1
const byte LT_TEMP_ADDR : 0x01;
const byte RT_TEMP_ADDR : 0x02;
const byte LB_TEMP_ADDR : 0x03;
const byte RB_TEMP_ADDR : 0x04;
const byte LT_CRNR_ADDR : 0x11;
const byte RT_CRNR_ADDR : 0x12;
const byte LB_CRNR_ADDR : 0x13;
const byte RB_CRNR_ADDR : 0x14;
const byte WATER_ADDR : 0x1F;
const byte LED_PIN =  6;            //External Indicator LED
const byte YAW_EN = …               //All control pins routing to stepper drivers, pump,
mechanical locks
…
..
const byte USER_INT = 2;
const byte OBSTRUCTION_INT = 3;
const byte SLAVE_WAKE = 4;
byte sleep_time = 15; //units
byte sleep_timescale =  3; //minutes

byte LT_Temp = 0;                       //Global variables for sensor data
byte RT_Temp = 0;
byte LB_Temp = …
…
…
byte water_healthy = 0;
volatile byte data =  -1;               //register for I2C data

void setup() {
        initialize_pinmodes();                  //Declare pins as inputs or outputs
        flash_led();
        initialize_IRQ(USER_INT, ui_routine); //When HIGH jump to listen_for_I2C routine
        initialize_IRQ(OBSTRUCTION_INT, read_sensors);
        initialize_IRQ(timer_routine);
        initialize_I2C();           //Initialize SDA and SCL pins for
        initialize_mech_sys();      //Initializes steppers to starting position and locks with
                                    //mechanical locks
```

```
        ui_routine();
}

void loop() {
    //sleeps for 20 seconds and power off some peripherials like ADC and Brown-Out Detect
        LowPower.powerDown(SLEEP_20S, ADC_OFF, BOD_OFF) ;
}
void ui_routine()
{
        time count;
        byte page = 0;
        byte x = 0;
        byte y = 0;
        read_sensors()                  //wakes all sensors, requests and receives data
        display_startup_screen()        //drives LCD to turn on and present 1st page
        count = get_time();
        while (get_time – count < 20seconds) //This is the main portion of the user interface
        {
                        If(button_1)            //Could be a button corresponding to temp settings
                        {
                                If(page == 0 && y == 1)
                                {
                                        … //more
                                }
                                … //more
                        }
                        else if(button_2)               //Could be a button corresponding to
                        {
                                … //more
                        }
                        else if… //more
        }
}

void timer_routine() {
        bool healthy = false;
        while(!heatlthy)
        healthy = read_sensors();       /*wakes all sensors, requests and receives data, can
return true if sensors and outputs are in proper state*/
        if(!heathy) update_actuators();         //using sensor data updates orientations and
}

bool read_sensors () {
        bool healthy = true;
        output(SLAVE_WAKE, HIGH);               //pin interrupt slaves
        delay(10);
```

```
        output(SLAVE_WAKE, LOW);
        for( every sensor) {        //get updated sensor data from each slave device
                requestFrom(*_ADDR);
                …
        }
        for( every temperature) {
                If( temp > temp_threshold) heathy = false;}
        if(RB_CRNR - light_threshold > LT_CRNR > RB_CRNR + light_threshold) {
                healthy = false; }
        if(RT_CRNR - light_threshold > LB_CRNR > RT_CRNR + light_threshold) {
                healthy = false;}
        if(water_level < water_empty_threshold) water_healthy = 2;
        else if(water_level < water_low_threshold) water_healthy = 1;
        else water_healthy = 0;

}

void update_actuators() {
        adjust_yaw(calculate_yaw_steps());  /*steps yaw motor proportionally to the
difference between left photoresistors and right photoresistors*/
        adjust_pitch(calculate_pitch_steps());/*steps pitch motor proportionally to the
difference between top photoresistors and bottom photoresistors*/
        adjust_cooling();  /*turns enables cooling system IFF temp sensors are past
temperature threshold and water_healthy != 2 (or empty)*/
}
```

ENSC 405W Grading Rubric for User Interface Design

(5-10 Page Appendix in Design Specifications)

Criteria	Details	Marks
Introduction/Background	Appendix introduces the purpose and scope of the User Interface Design.	**/05%**
User Analysis	Outlines the required user knowledge and restrictions with respect to the users' prior experience with similar systems or devices and with their physical abilities to use the proposed system or device.	**/10%**
Technical Analysis	Analysis in the appendix takes into account the "Seven Elements of UI Interaction" (discoverability, feedback, conceptual models, affordances, signifiers, mappings, constraints) outlined in the ENSC 405W lectures and Don Norman's text (*The Design of Everyday Things*). Analysis encompasses both hardware interfaces and software interfaces.	**/20%**
Engineering Standards	Appendix outlines specific engineering standards that apply to the proposed user interfaces for the device or system.	**/10%**
Analytical Usability Testing	Appendix details the analytical usability testing undertaken by the designers.	**/10%**
Empirical Usability Testing	Appendix details completed empirical usability testing with users and/or outlines the methods of testing required for future implementations. Addresses safe and reliable use of the device or system by eliminating or minimizing potential error (slips and mistakes) and enabling error recovery.	**/20%**
Graphical Presentation	Appendix illustrates concepts and proposed designs using graphics.	**/10%**
Correctness/Style	Correct spelling, grammar, and punctuation. Style is clear concise, and coherent. Uses passive voice judiciously.	**/05%**
Conclusion/References	Appendix conclusion succinctly summarizes the current state of the user interfaces and notes what work remains to be undertaken for the prototype. References are provided with respect to standards and other sources of information.	**/10%**
CEAB Outcomes: Below Standards, Marginal, Meets, Exceeds	1.3 Engineering Science Knowledge: 4.1 Requirement and Constraint Identification: 5.4 Documents and Graphic Generation: 8.2 Responsibilities of an Engineer:	

Appendix III: User Interface

Introduction

OptimSolar boasts a minimalistic UI, valuing simplicity and intuition. The system should require little oversight and operate autonomously under an intelligent embedded computing system. Although minimal, the system does offer a runtime system overview, parameter tuning, sensor readings, and power readings. These capabilities stand to provide feedback and performance optimization as well as troubleshooting.

This appendix will outline the current UI design for OptimSolar and is intended for internal usage, primarily developers. The scope of this document consists of general information, component definitions, user analytics, technical analytics, relevant standards, analytical usability testing, empirical usability testing, and graphical representations of the UI.

UI Components

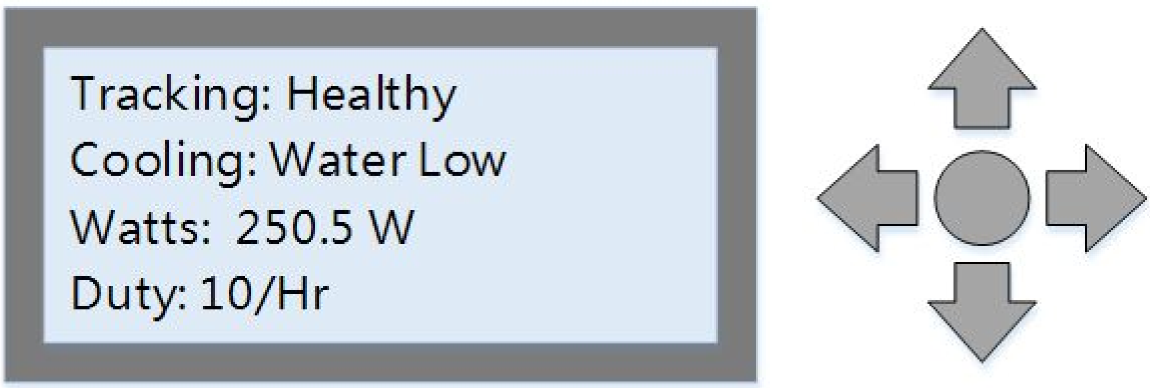
OptimSolar's UI will consist of four components: an LCD screen, navigation buttons, beeper, and on/off switch. Table 1 outlines the general functionalities of each button. Each component prioritize intuition, standardization, and feedback, so the user's first interaction will be positive and require no additional knowledge. The LCD screen will be 20x4 characters and be backlit to improve clarity in various lighting. The navigation push buttons will offer four directional arrow buttons and a center button, used for scrolling, toggling, selecting menu options, and display wake up. The interface will combine to look like Figure 1, with the On/Off switch located further away and the beeper hidden from sight.

Table 1: General Component Functionalities

Component	Function	Image
20x4 LCD Screen	Display readings/settings, visual feedback	 [18]
Center Button	Select	 [19]
Left/Right Buttons	Toggle Values	See Center Button image
Up/Down Buttons	Scroll selections	See Center Button image
Beeper	Provide audible feedback when buttons are pressed	Hidden from user
On/Off Switch	Main power switch	 [20]

*All push buttons function as wake-up display as well

Figure 1: OptimSolar's UI



User Analytics

PNW Energy has determined that users require limited UI functionalities with immediate feedback. There are two kinds of user’s: owner and installers. Users will likely be adult homeowners (male, female, other), between 20 to 65 years of age. Owners are expected to have little to no expertise. Installers will be assumed to have high level experience, and range from 25 to 50 yrs of age. For the proof of concept and prototype, PNW Energy will only support the interface in English, French and Japanese. These users require three main use cases for the UI: quick checking, tuning, and troubleshooting. Owners will want a quick check to make sure that their system is working as expected. Owners and installers will want to tune the system during installation by enabling tracking or cooling and operating parameters for individual optimizations. Lastly, owners and installers will want to see sensor data for troubleshooting purposes.

The general usage model is outlined using a flowchart shown in Figure 2, located below. If users would like to quick check, they simply need to wake up the display. If they would like to tune, they need to navigate to the “Tuning Page”. Alternatively, if they would like to troubleshoot or check sensor readings they will need to navigate to “Sensor Readings Pages” or “Power Readings Pages”.

Technical Analytics

Discoverability

The system will be easy to figure out without requiring a user manual. However, both an online and a hard copy user manual will be provided. The auto wakeup functionality and intuitive directional navigation allows for ease of use, and requires little to no prior knowledge.

Feedback

The system will employ two forms of feedback, visual and audible. It will also inform the user when the system is loading or computing sensor data.

Conceptual Models

Using intuitive language the menus should provide an accurate conceptual model. The user will receive immediate feedback, therefore reinforcing or redefining the users conceptual models. The only concern is that labels corresponding to certain tuning selections may be misunderstood, but due to immediate feedback and reading updates, the user should have enough information to learn. These labels will be defined in a user manual, as the LCD screen is constrained to 20x4 characters per page.

Affordances

OptimSolar, as a system, affords many things related to the mounting and optimization of solar panels. It has clear affordances, and the affordances will be advertised to potential customers/users. Specifically, the UI will afford runtime feedback, in the form of operational and performance data, and tuning of functionalities.

Signifiers

The LCD screen is a conventional signifier of a user interface, and provides an indication of available information by displaying human language. Additionally the device will light up, raising the user's attention. The navigation buttons are also a conventional signifier, indicating scrolling, toggling, and selecting.

Mappings

The navigation buttons will be mounted next to the LCD screen, indicating the correspondence of the two. The navigation buttons have a natural mapping, and will guide the user in directional control.

Constraints

The minimalistic UI is constrained in features and uses. The user can only make tuning changes, limiting mistakes and maintaining reversibility. Few constraints are necessary for this UI system.

Risks/Error Considerations

The main risk is that users may misunderstand labels within the menu and set inappropriate values. This risk will be mitigated by using immediate feedback and updating the OptimSolar mount via actuation of motors, as well as only affording tuning capabilities to revert and reset changes.

Additional Technical Information

The system will require immediate feedback, while limiting power consumption. The system's idle state will be a sleep state with a blank screen. The screen will only wake on user input. This will be accomplished by tying interrupts to the navigational buttons. It will also have a sleep timer, so that the display will sleep after a set inactivity timeout, returning to the extremely low power idle state. These methods will combine to provide immediate feedback while limiting power consumption.

The users will need to navigate the menus without frustration. The design team put much effort into using intuitive menu titles and button layouts. The wake up, navigation, and toggling functionalities will have a <100ms response time, effectively giving users an immediate response [21]. This response will be audible, followed by the visual display updates. There will also be limited reading, with no page taking more than 10 seconds for the average user to read [21].

The system also need to be reliable. There are two main concerns that the design team must account for. Each button must be debounced, avoiding the erratic behavior of push buttons. Secondly, there is the potential that users may set ineffective parameters. To avoid this, there will be a suggested value for each parameter in the user manual. There will also be a factory reset selection available in the "Options Page".

Engineering Standards

OptimSolar will follow the IEEE std 1621-2004 for User Interface Elements in Power Control of Electronic Devices Employed in Office/Consumer Environments as well as ISO standards for user interface.

Additionally, PNW Energy researched various minimalistic LCD-based UIs of embedded systems. These included solar performance monitors, 3D printers, air conditioning panels, and more. There are a few user interfacing conventions used by the OptimSolar UI: menu navigation with navigational pad, visual/audio feedback, and on/off rocker switch.

Analytical Usability Testing

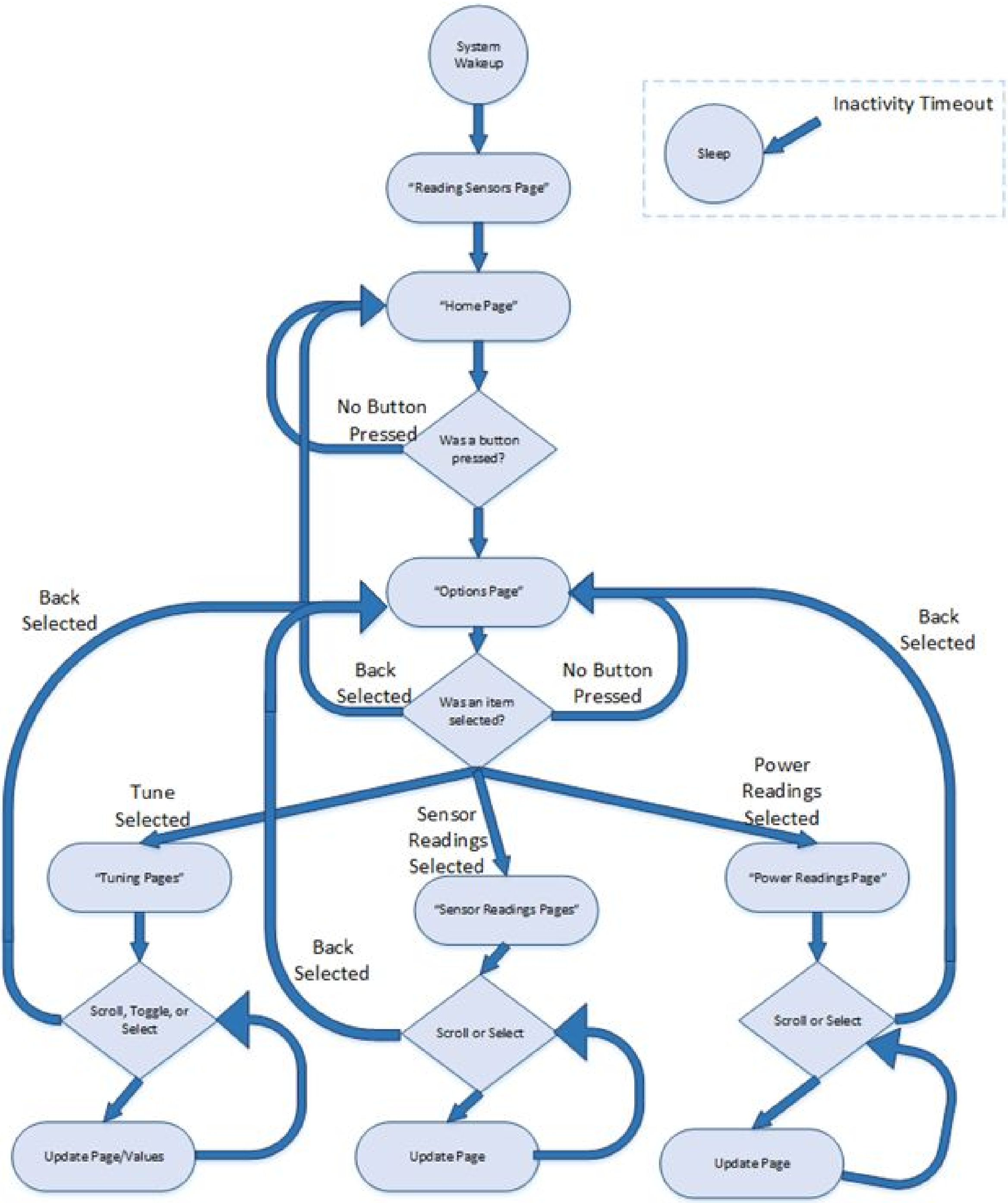
The PNW Energy team internally reviewed the current UI design. The proof of concept will not employ a UI, other than a power on switch and LED indicators. Therefore, analytical testing was a simple review of the planned navigation of menus. Since all three members contributed to the UI design, and the review was conducted by these members, the testing was likely biased. However, the team determined the navigation of menus to be intuitive.

During the prototyping of OptimSolar, the team will test the real LCD and navigation buttons, by scrolling through, toggling, and selecting all options. The team will be particularly interested in response time, using lab equipment and software tools to manually measure the response times of interrupts and button to MCU to LCD communications.

Empirical Usability Testing

As the proof of concept employs no LCD or navigation buttons, the team has presented mock ups of LCD screen layouts and navigation controls to relatives and friends. The mock ups were well received, but offer little unbiased information. The prototype will be empirically tested by setting up appointments with non-family persons, who fall under the expected user criteria outlined earlier. Four separate miniature trials will be run: uninformed use without solar panel mounted, uninformed use with solar panel mounted, unguided use, and guided use. Between each trial, test subjects will be ask to answer questions revolving around their understanding of OptimSolar. For the first trial, test subjects will be shown OptimSolar without the a solar panel mounted (this is important because the solar panel is a signifier of the intended use). The team will observe the users interaction with the device, taking note of where the users are easily drawn and their initial steps towards interactions. After, the solar panel will be mounted and the tests will be repeated for the second trial. For the next trial, the test subject will be informed of the affordances that OptimSolar intends to offer. The team will observe and take note of the test subject’s interactions. Lastly, the test subject will be taught expert usage. Each stage will be compared, and ideally test subjects require little to no teaching after the solar panel is mounted.

Figure 2: UI General Usage



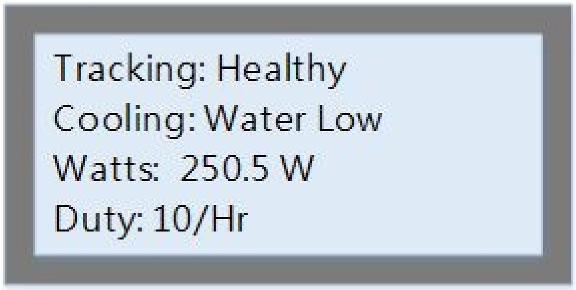
UI Display Pages

When the user wakes up the screen by pressing any of the buttons, the LCD screen will provide instant feedback by lighting up and displaying the "Reading Sensors Page", seen in Figure 3. This display state will remain until OptimSolar's computing system has read every sensor and holds updated data. The “Reading Sensors Page” will animate the ellipsis, notifying the user that the system is active and not frozen.

Figure 3: Reading Sensors Page

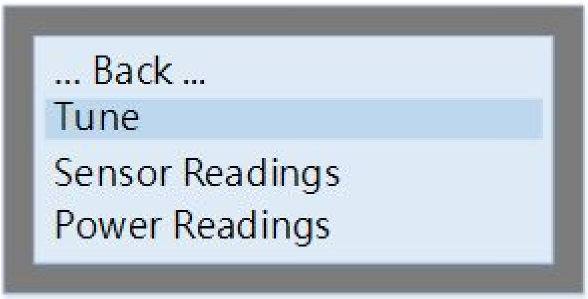
After the computing system has acquired updated data it will display the “Home Page”, seen in Figure 4. This page will remain until the user presses any button or the activity timeout is reached. The “Home Page” will display all the relevant data that an average user would be comfortable and/or interested with/in.

Figure 4: Home Page



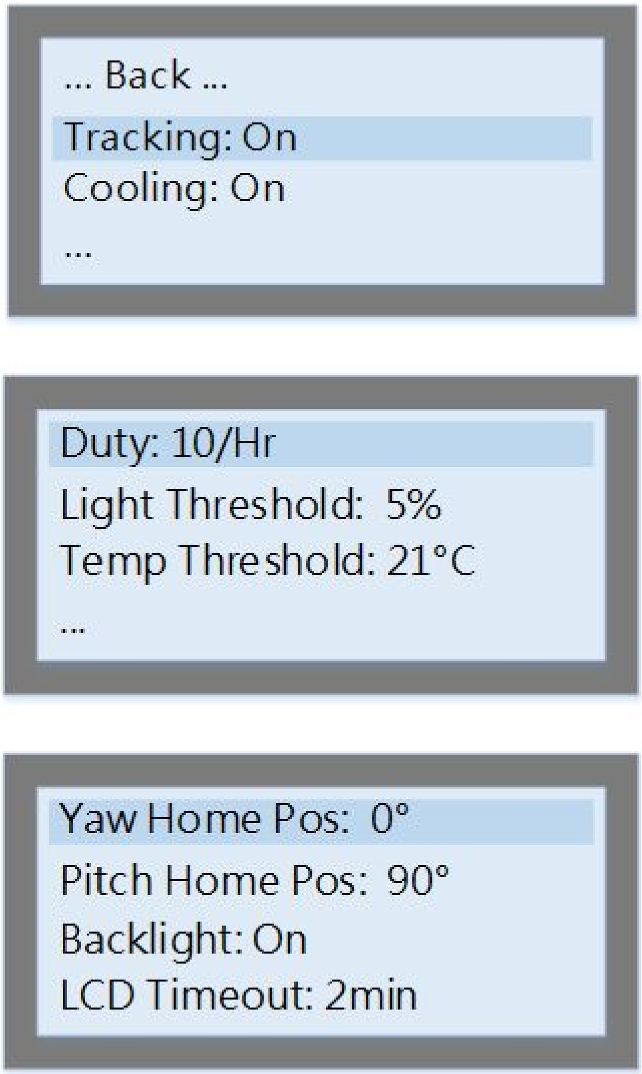
Once the user presses a button on the “Home Page”, the “Options Page” will appear. This is the first interactive page, where the user can scroll to the next desired page. The user can scroll using the up and down arrows, which is intuitive. Their scrolling will be indicated by the currently selected line being highlighted (slightly stronger color intensity). This is also the first page where a user has a “Back” option, which is a conventional method for informing the user that this option will direct them to the previous page. The user can select the “Back” option by highlighting it and then pressing the center button. The “Options Page” is depicted in Figure 5.

Figure 5: Options Page



If the user selects “Tune” from the “Options Page”, they will be brought to the “Tuning Pages”. These pages consist of a set of three concurrent pages, which make an intuitive list of selections. The user can scroll up and down the list using the up and down arrows. They can also change the values of their current selection by using the left and right buttons. If the user presses down or up, crossing the screen boundaries, they will be brought to the next portion of the list. This set of pages is depicted in Figure 6.

Figure 6: Tuning Pages



Alternatively if the user selects “Sensor Readings” or “Power Readings” from the “Options Page”, the user will be brought to the page sets depicted in “Sensor Readings Pages” and “Power Readings Page”, respectively. These pages are similar to the “Tuning Pages” except the left and right buttons will have no functionality. These pages are offered to provide more information to the user for troubleshooting or performance monitoring. The “Sensor Readings Pages” are shown in Figure 7 and the “Power Readings Page” is shown in Figure 8.

Figure 7: Sensor Readings Pages

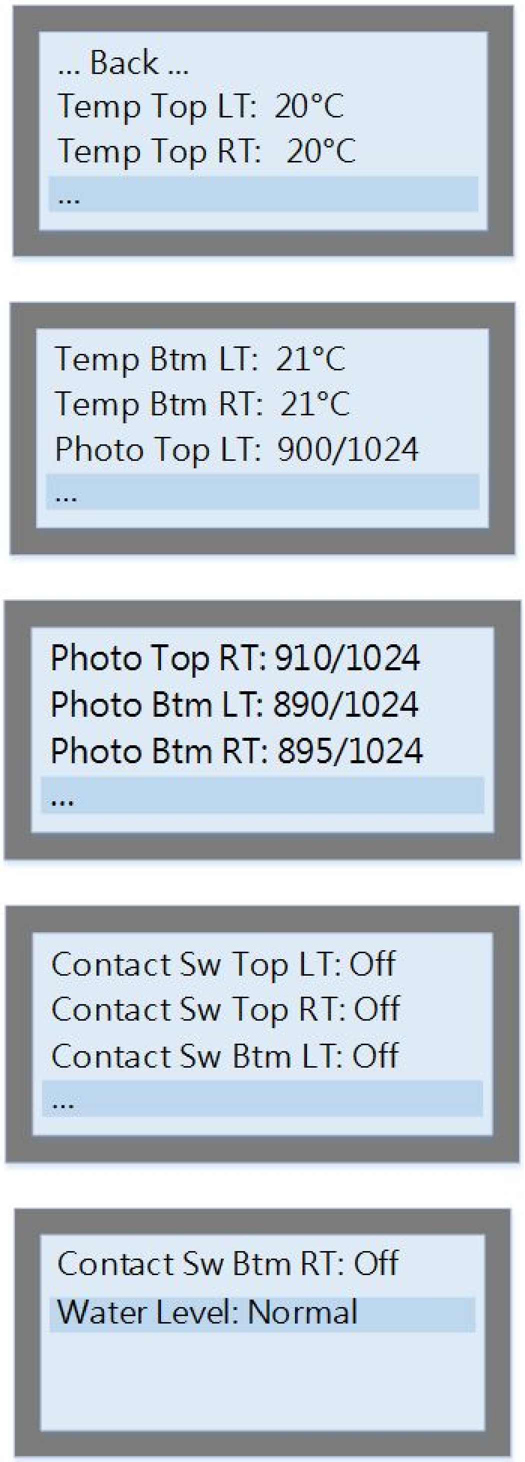
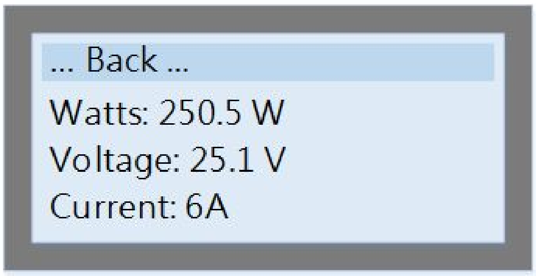


Figure 8: Power Readings Page



Conclusion

OptimSolar's UI affords easy performance monitoring and tuning. Design aspects were heavily motivated by Don Norman's "Design of Everyday Things". Developers sought to preserve the themes and suggestions presented by Norman. The user experience is paramount, and OptimSolar balances function with elegance. The design is intuitive and simplistic, yet effective and responsive.

The preliminary UI design outlined in this document will be used for the prototype, as the proof of concept will forgo all UI components other than a power switch. PNW Energy believe this design will be pleasant for all users and blend well with the rest of the OptimSolar system.

Appendix IV: Test Plan

With regards to the test plan, OptimSolar has specific goals it must meet to be considered successful. These goals were created by PNW Energy in order to stay on target for a prototype delivery in August 2019. The requirements for this Proof of Concept are less ambitious than those of the Prototype, but will allow the team to sort out small issues and rudimentary design issues before progressing to the prototype.

Testing day procedures will include shining a flashlight around the OptimSolar unit and watching the reaction in real time. The OptimSolar will orient itself towards the light source in a timely manner.

Mounting

The Proof of Concept will meet the design dimensions as defined in Appendix VII and be fabricated out of wood and 3D printed material.

Efficiency

The Proof of concept will be using an efficient algorithm to reduce the power used by OptimSolar. The advertised improvement in efficiency will not be testable on the Proof of Concept, since the solar panel will not be wired into the electronic circuitry.

Structural

Structurally, the Proof of Concept will not be tested under harsh conditions or by the weather.

Item to Test	Test Description	Result
Motor movement will not affect balance	While tracking the light source, the body of the PoC will not tip over or move	
Reviewed By		

Movement

Item to Test	Test Description	Result
Yaw and Pitch rotations must allow the panel to have 360 degree coverage (non continuously)	A flashlight can be rotated about the PoC. The panel must remain normal to the light source, but will never complete full circles due to wiring constraints	
Reviewed By		

Item to Test	Test Description	Result
The pitch must be able to rotate the panel 60° each way	While the light source is stationary in the yaw axis, the light source must be moved and rotated about the pitch axis. The panel must remain normal to the light source	
Reviewed By		

Item to Test	Test Description	Result
Unit must not over-rotate. When the yaw rotation has reached its limit, the unit must reorient itself to continue tracking	The light source must take the unit to its limit in the yaw axis and then move past it. The unit should rotate to yaw limit and flip the pitch to ‘catch up’	
Reviewed By		

Tracking

Item to Test	Test Description	Result
The MCU should orient the panel towards the light source at an accuracy of ± 10°	When a light source is stationary, the panel should orient itself perpendicular to it	
Reviewed By		

Item to Test	Test Description	Result
When two light sources can be 'seen', the board should orient itself towards the stronger source	A ceiling light can be used as a weak source. When the unit is 'locked' onto this source, a handheld flashlight should be able to move the panel away from the weak source and get the panel to track the flashlight	
Reviewed By		

Cooling

Item to Test	Test Description	Result
The temperature sensor will be wired to an LED, and when a preset temperature is reached, the LED will light up to indicate sprinkler activation	Warm the temperature sensor up, watch the LED	
Reviewed By		

Safety

Item to Test	Test Description	Result
Contact with OptimSolar will not cause any harm to a person	No sharp edges exist. No risk of shock exists.	
Reviewed By		

ENSC 405W Grading Rubric for ENSC 440 Planning Appendix

(5-10 Page Appendix in Design Specifications)

Criteria	Details	Marks
Introduction/Background	Introduces basic purpose of the project. Includes clear project background.	**/05%**
Scope/Risks/Benefits	Clearly outlines 440 project scope. Details both potential risks involved in project and potential benefits flowing from it.	**/10%**
Market/Competition/ Research Rationale	Describes the market for the proposed commercial project and details the current competition. For a research project, the need for the proposed system or device is outlined and current solutions are detailed.	**/10%**
Personnel Management	Details which team members will be assigned to the various tasks in ENSC 440. Also specifically details external resources who will be consulted.	**/15%**
Time Management	Details major processes and milestones of the project. Includes both Gantt and Milestone charts and/or PERT charts as necessary for ENSC 440 (MS Project). Includes contingency planning.	**/15%**
Budgetary Management	Includes a realistic estimate of project costs for ENSC 440. Includes potential funding sources. Allows for contingencies.	**/15%**
Conclusion/References	Summarizes project and motivates readers. Includes references for information from other sources.	**/10%**
Rhetorical Issues	Document is persuasive and demonstrates that the project will be on time and within budget. Clearly considers audience expertise and interests.	**/10%**
Format/Correctness/Style	Pages are numbered, figures and tables are introduced, headings are numbered, etc. References and citations are properly formatted. Correct spelling, grammar, and punctuation. Style is clear, concise, and coherent.	**/10%**
Comments:		

Appendix V: ENSC 440W Plan

Introduction/Background

OptimSolar aims to entice more customers into the solar market by increasing performance of solar panels. OptimSolar can be described as a universally compatible solar energy optimization unit. It will greatly increase the performance of a solar panel for a small additional cost. The product will have a universal mount compatible with most residential panel sizes. It will greatly improve solar harnessing by maintaining the solar panel plane perpendicular to the Sun's solar rays, a process known as tracking or concentration. The tracking ability can improve performance by up to 45% [22]. The OptimSolar unit will also offer cooling and temperature regulation using hydro-cooling techniques. Overheated systems can rapidly degrade performance (by as much as 25%) and shorten the lifespan of solar panels [23]. Lastly, the OptimSolar system will have an add-on performance display option, which will inform users of the current power output and notify them of any drop-offs due to unexpected issues. It should be noted that this display will not always be situated on the solar panel; it can be moved to easily accessible areas or implemented as a smart phone application.

Most of the information provided in OptimSolar documents have been relating to both the proof of concept and prototype designs. The next step in this project's lifespan is to move towards the prototype stage. The class ENSC 440W is the second successive Capstone project class and is meant to help move groups from a proof on concept stage to the prototype stage. This appendix will discuss some of the added functionalities to the project as time goes on.

Scope/Risks/Benefits

Scope

Building off of the OptimSolar Proof of Concept, the scope of the OptimSolar prototype can be broken down into sections. Since the Proof of Concept was rather basic in terms of functionality, the prototype must obviously build upon that. New topics for the project include a universal mount, a performance increase to existing solar panels (and a performance monitoring system to prove this), and lastly to integrate the water cooling.

Universal Mount
The mount will contain a slide-to-fit mechanism that is capable of holding onto a variety of sized solar panels. OptimSolar can be either attached to roofs or ground.

Performance increase
The prototype will include the solar panel's output for power generation. Now, the solar panels power must be increased enough to offset the added electronics of the OptimSolar unit.

Monitoring System
A monitoring system will be included in the OptimSolar in order to show the performance increase seen after installing OptimSolar. This will be done by way of an LCD screen. Later on, if time permits, this may also be included in a smartphone application to enable remote monitoring.

Water Cooling
Water cooling will be included in order to keep the solar panel at optimal temperature levels for electricity production. This requires the entire system to be waterproof, which introduces added complexity to the project. On top of the cooling system, the weather of the PNW and being outside means the system must be weatherproof.

Risks

Introducing a new product to the market is never an easy task, there are many risks associated with this. Aside from safety concerns, many of the risks involve recouping an initial investment and serving as a valid use of time. Some of these topics are: product effectiveness, longevity and marketability.

To analyze the effectiveness of a product, a consumer often looks at the cost-benefit ratio. For OptimSolar to succeed in the residential solar market, OptimSolar must have a price point comparable to that of another solar panel. On top of this, the benefits of OptimSolar must be very pronounced. With a potential 70% increase in power generation, we believe OptimSolar has the opportunity to be successful.

Another risk that is seen by outdoor devices is longevity. With any mechanical aspect to a product, there is the worry of longevity. Wear and tear is often encountered when parts move. Without proper maintenance, OptimSolar could deteriorate rapidly. This is multiplied by the fact that OptimSolar is always outside. Rain, wind, snow and sun can speed up this process by an order of magnitude.

On a similar topic as longevity, comes maintenance and installation. In a perfect world, any user would be capable of installing the unit by themselves and there would be minimal maintenance. Saying that OptimSolar would not require any maintenance would be naive. A user manual accompanying the product would be distributed and detail the installation process. Although maintenance is a reality, there are still steps that can be taken in the manufacturing process to combat excess amounts of maintenance.

All of the above factors contribute to the marketability of OptimSolar. By identifying the risks that are involved in this ambitious project, PNW Energy can brainstorm solutions to these potential issues.

Benefits

There are many benefits to solar tracking systems. According to [22], the benefits can include up to 70% increase in power generation. This is because of the maximization of solar incidence with the panel. Another issue experienced by solar panels is that of overheating - often in hot climates. When a solar panel is raised past a certain temperature (usually 35℃), the efficiency of the panel decreases. This results in a loss of potential power produced, which is very detrimental especially considering that the hottest temperatures usually come with the most sun (which is optimal solar panel weather).

The beauty of a product such as OptimSolar is the increase in self sufficient homes. With OptimSolar, the goal is to increase the amount of the solar panel enthusiasts as well as act as an introduction kit to new solar panel owners. With such an increase in power production, it may lean the customer who is on the fence with regards to solar panel systems.

Market/Competition/Research Rationale

Solar accounts for an estimated 303 GW of energy worldwide, and is growing at a rate much faster rate than traditional sources [22]. Notable companies like SunRun and SolarCity are rising in stock, and are pushing the boundaries of solar [24]. The renewable market was being held back by batteries, as throughout history the charge capacity and efficiency of batteries were inadequate for most power applications [25]. Experts are remarking that modern batteries have improved so much that they are hitting their physical limits [26]. Now that batteries have improved to allow electric cars and supercharging stations, all kinds of newly feasible electrical applications are arising, and older applications such as solar are becoming more economical[27]. In fact, solar panels are becoming so economic that they are now being installed in oceanic climates similar to that in the Pacific Northwest Region [27]. Allowing PNW Energy to expand our market worldwide.

The improvements of batteries are stimulating the solar market, by encouraging more households off the grid and governments to implement more renewables on the grid [28][29]. It seems most companies in the solar industry are either manufacturing solar panels, batteries, or installing solar systems. There are few companies who make retail mounts with automation or performance boosting and monitoring capabilities. Through PNW Energy's market research, no products currently exist which are pre-manufactured to offer solar panel mounting, solar tracking, and panel cooling. There are a few products which are manually or remote controlled articulating mounts, but automated solar trackers are seemingly left for installers to build, or to government plants and space applications.

As mentioned in the power calculations section, OptimSolar is equivalent to purchasing a second solar panel roughly half the size of the one being mounted to the unit. Based on the cost of materials, and the savings that large scale production would ensure, PNW Energy is confident that OptimSolar could be priced around the $150-$200 range. Comparing this price to other standard non-tracking solar panel mounts, PNW Energy has the potential to up this price to around $300-$500. As mentioned in the power calculations, standard non-tracking mounts are being sold for for upwards of $400 [16]. Selling OptimSolar at a competitive price to stationary mounts gives PNW Energy the opportunity to take over the market and be the top provider in solar panel mounts.

Once consumers understand the performance boosting capabilities of OptimSolar, the product will disrupt the current solar companion industry and make current mounts obsolete and overpriced. Within the solar industry, OptimSolar has little to no market competition. It has mostly market "companions". As the solar industry continues to grow and more solar panels are being purchased, PNW Energy expects more demand for OptimSolar.

PNW Energy believes solar power is the way of the future. The team has researched alternative renewable energy methods for households and currently no other harvesting systems make economical or spatial sense for households or small scale applications. Wind is much more unpredictable and reaches useable speed only 10% of the time, bringing down the average daily energy totally for a much more expensive and spatially costly system [30]. Wind turbines are extremely expensive and only are cost effective when they are massive and receive extremely high wind speeds[31]. BCC reiterates the belief that wind will never be an effective small scale solution: "In most UK locations micro wind turbines will never generate significant amounts of electricity" [32]. The next opponent of solar is hydro power. In order to have any considerable power from hydro turbines, home owners must have a moderate sized body of running water on their property as hydro is highly dependent on total volume of water [33]. PNW Energy is confident that solar energy will be the only economical small scale energy technology for the foreseeable future and if OptimSolar can obtain patents for its universal and performance boosting panel mount, it will collect incredible profit margins for many years to come.

Personnel Management

With the size of our project and with the small group size, it is crucial that PNW Energy is efficient with our planning and time management. To be successful with the proof of concept, our group implemented three techniques that have allowed us to work seamlessly and effectively.

1. A three strike system: to avoid conflict and to keep each other accountable strikes are given out for the following reasons: Late for meetings, late for inter-group deadlines and lack of communication. These strikes will be used when giving peer evaluations and will ultimately affect our grade.
2. A bi-weekly leader: As all three members of the group have strong personalities and enjoy the leadership role, PNW Energy operates on a bi-weekly leader, where every two weeks the leadership role switches. This allows each member to take charge throughout the project and eliminates conflict.
3. Specialty segregation: It is important that we are as effective with our time as possible and follow our strict timeline. In order to be more effective, we separated our project into three categories (computing, electrical and mechanical) and each member was assigned the one that best fit their abilities.

With the effectiveness of these three techniques, PNW Energy will continue to implement them throughout the duration of ENSC 440. However, as ENSC 440 will take a lot more manufacturing and assembly certain parts will be done by all members. The following table (Table 1) shows a general rubric of what is left to do and who will be doing these tasks.

Table 1: Tasks Remaining for ENSC440W

Task	Group member
Finalize Stepper Motor selection and purchase	Cole
Finalize algorithm	Sam
Finalize power supply	Jacob

Order Materials for fabrication	Cole
Design Waterproof enclosure for Computing system and sensor modules	Sam
Design waterproof enclosure for Power supply	Jacob
Water proof all electrical components and connections	Jacob
Design PCB for sensor modules, computing system, power regulation	Sam, Jacob
Finalize Prototype design	Cole
Order necessary materials for fabrication	Cole, Jacob, Sam
Fabricate mount	Cole, Jacob, Sam
Combine all components	Cole, Jacob, Sam
Test all systems throughout the progression of OptimSolar	Cole, Jacob, Sam

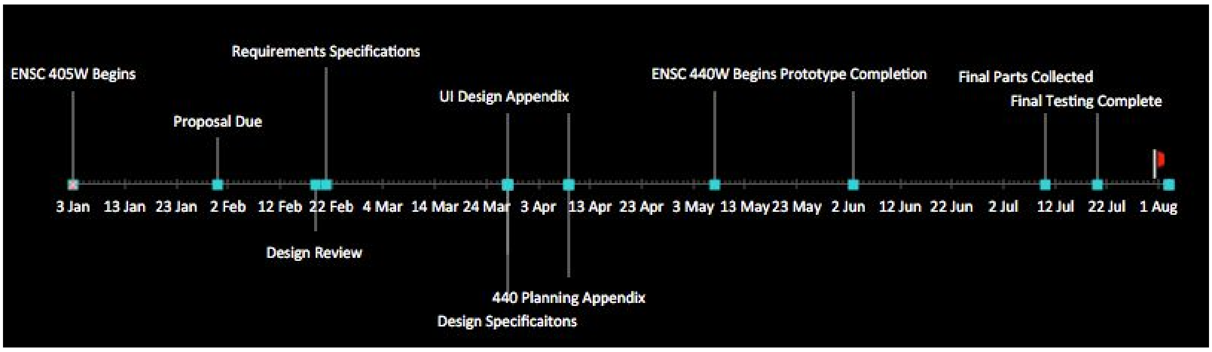
Although we are confident in our ability to accomplish this project, we are aware of the scope and realize we will need some assistance from individuals who are more experienced with certain aspects of the project. That being said, we have already been in contact with, and will continue to seek assistance from Dr. Ash Parameswaran and from Dr. Bob Gill. Both have been valuable assets when discussing design and have helped us refine our work so far. To accomplish some of the mechanical feats, it will require some skills that we do not have. We will be outsourcing our welding to a family friend who has graciously volunteered to assist us with our project.

Time Management

Time Management is an integral part of any successful project. Since the capstone project is upwards of eight months long, there must be necessary steps taken to ensure that time management very important to all team members. Throughout the course of the last four months, there have been many deadlines set by the members of PNW Energy.

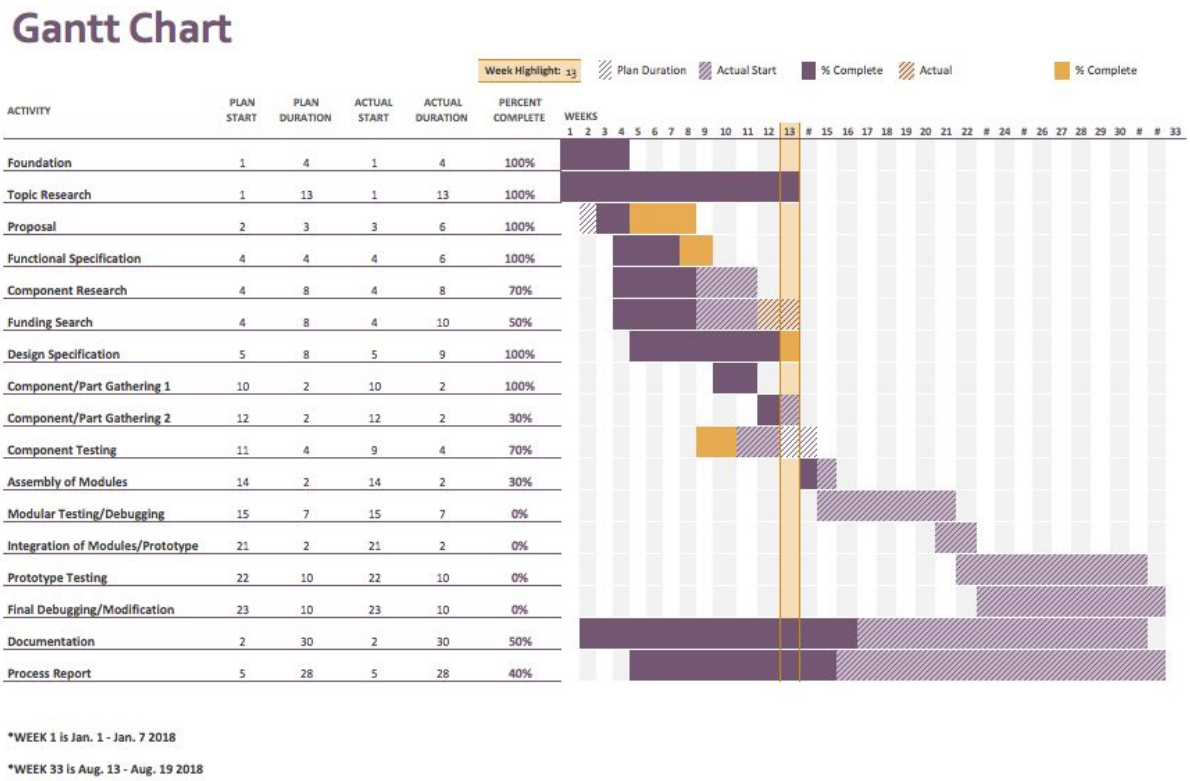
In the following section, a milestone chart will outline the previous deadlines as well as some of the known deadlines with respect to ENSC 440W.

Figure 1: PERT Chart



Next, an updated Gantt chart is provided.

Figure 2: Gantt Chart



Up until this point, PNW Energy has planned for setbacks by allocating extra time for each task.

Budgetary Management

PNW Energy has been as efficient as possible with our budget thus far. We ensured that as many parts as possible for the proof of concept can be transitioned over to the prototype for ENSC 440W. We have already purchased quite a few key components that we are using for the proof of concept and for the prototype at the end of ENSC 440W. In Table 2 below you can see a list of parts already purchased.

Table 2: Items Already Purchased

Component	Price
Computing System	$75
Sensor Modules	$25
Stepper Driver (x2)	$40
3D Printing Material	$25
Test Power Supply	$20
Miscellaneous (wires, screws, tape, etc.)	$15
Total:	$200

Highlighted in yellow is every component that will be transitioned over to the prototype for the end of ENSC 440W. With quite a few key elements already purchased, table 3 below shows the remaining parts as well as the cost associated with them.

Table 3: Remaining Parts

Component:	Price:
Water Proofing Material	$50
Stepper Motor (x2)	$140
Power Supply	$60
Water Pump	$20
Piping	$10
Sprinkler	$10
Steel	$250
Gears	$100
Bearings	$50
Miscellaneous (brackets, screws, sealant, etc.)	$30

Contingency	$100
Total:	$820

For contingency planning, every monetary value was rounded up to the nearest $10 and an additional $100 was added to account for any additional parts that need to be purchased. With an overall budget of $1015 PNW Energy is reaching out to established energy companies for funding, namely BC hydro, Fortis BC, Vancouver Renewable Energy, Canadian Energy, and Rev Engineering. The hope is to acquire either full funding for the project, partial sponsorship or donation of parts and components necessary for the design. We have already received a partial sponsorship from Idea Works Computer Solutions who has committed to lending us a large solar panel to do all our testing and fitting with. We are hoping that the other companies will step up and provide similar sponsorships. As well as reaching out to some big companies for sponsorship, PNW Energy will be applying for the ESSS Endowment fund and the Wighton Endowment fund. PNW Energy is fully aware that it is possible that we will not receive additional funding. For that reason, our initial budget is set within a range that our founding members are willing to split evenly amongst ourselves.

Conclusion

After ENSC 405W, PNW Energy will have more time to focus on the prototype for ENSC 440W. As defined in previous documents, the prototype will be a much more in-depth project than the Proof of Concept. There are many more considerations to be made for all aspects of the OptimSolar project. Power systems, and mechanical systems all must be greatly re-evaluated for a production-type product. Most of this comes from the fact that the prototype must hold and accelerate an 80lb solar panel. Along with the obvious increased torques of moving a heavy panel like this, there are engineering standards to be considered. Safety standards must be implemented in the final design to ensure a customer can safely use OptimSolar. Mechanically, mounting is also a large aspect of the project. Considering that the prototype will be mounted on household roofs, there are many design constraints with respect to mounting.

After completing the proof of concept, PNW Energy is in good position to complete the prototype on schedule for ENSC 440W. The basic version will have been completed, and next, the more difficult tasks will be attempted.

Appendix VI: Pin Layouts

Figure 1: ATMega328 Pinout [34]

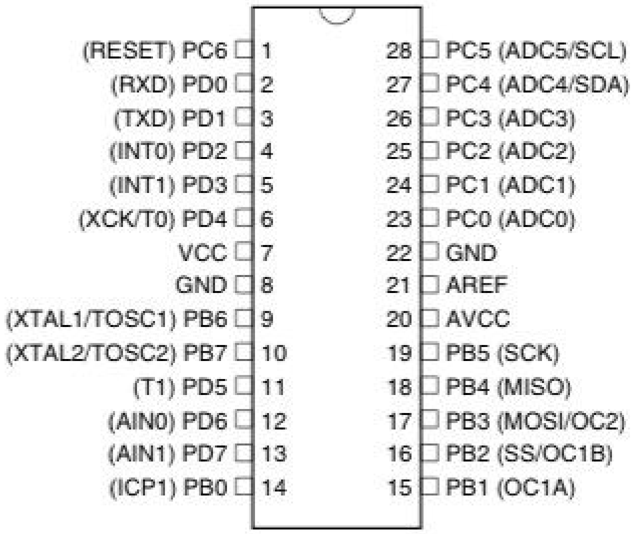


Figure 2: ATTiny Pin Out [35]

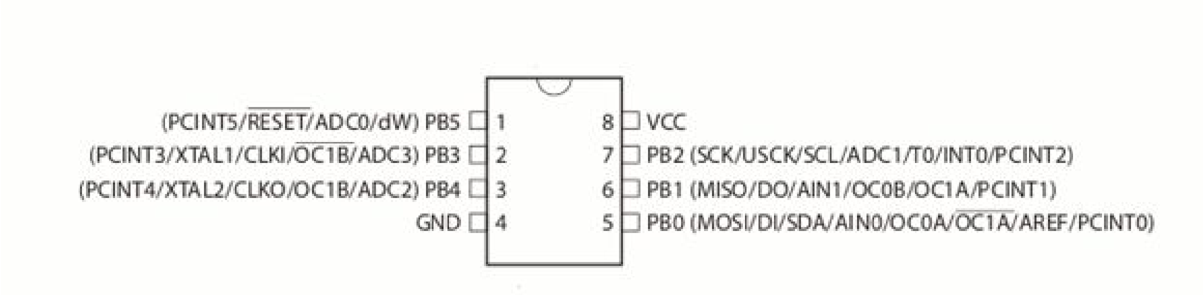
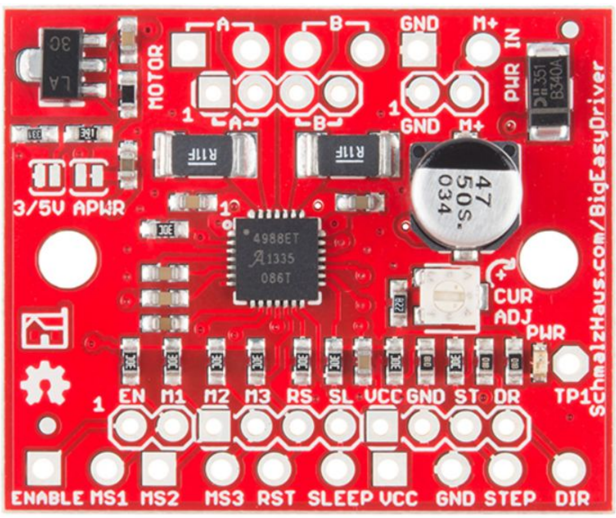
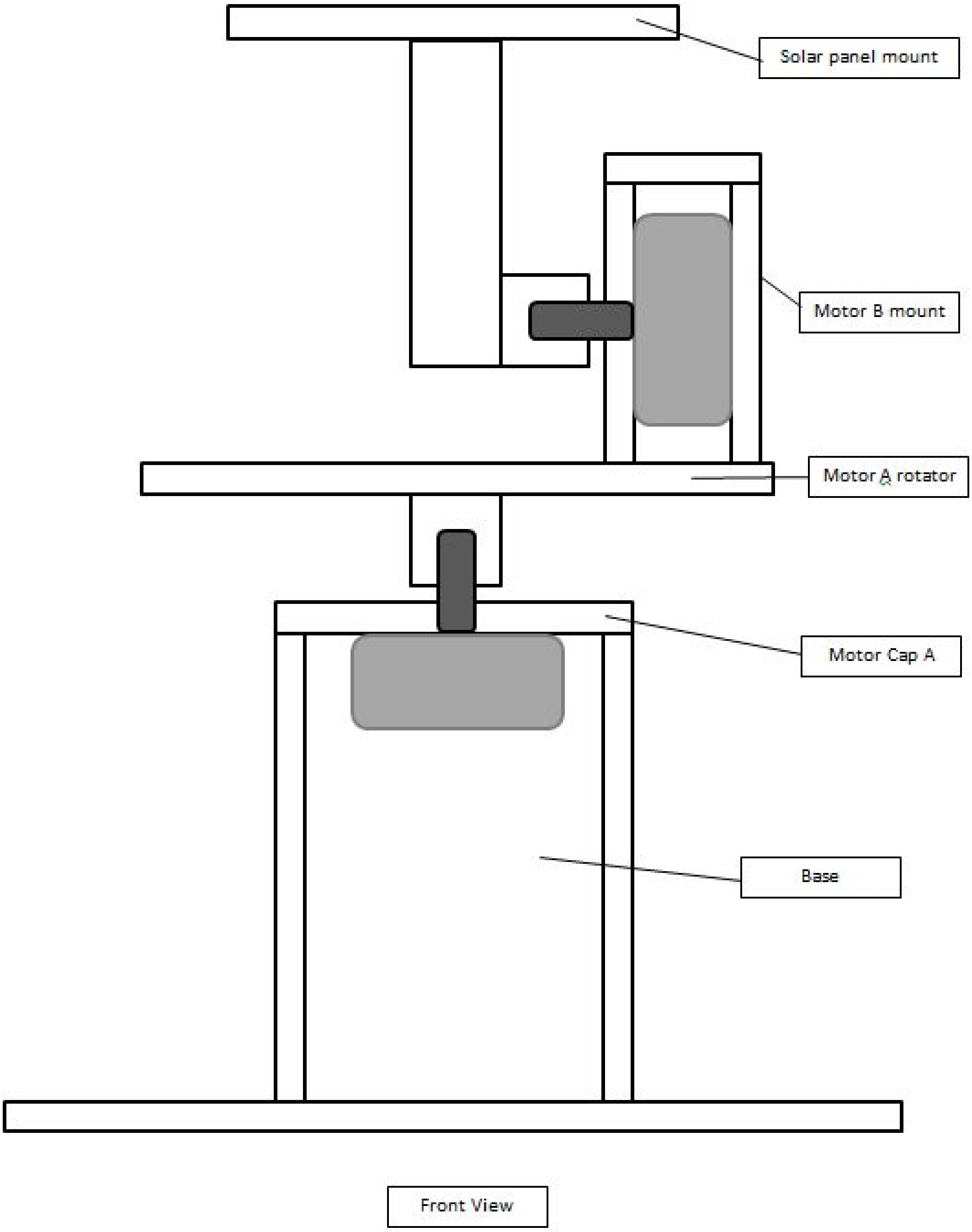
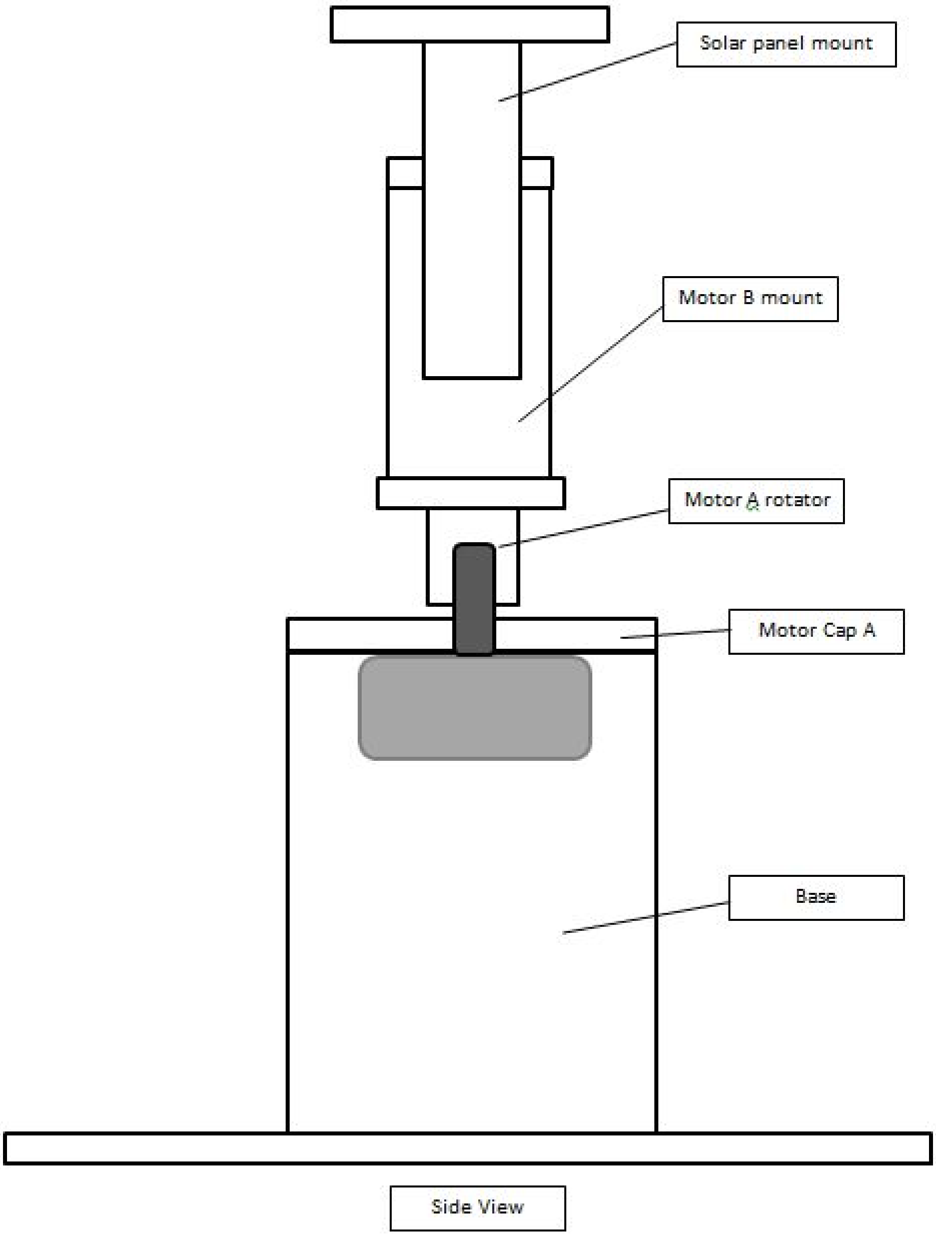


Figure 3: Stepper Driver Pinout [36]

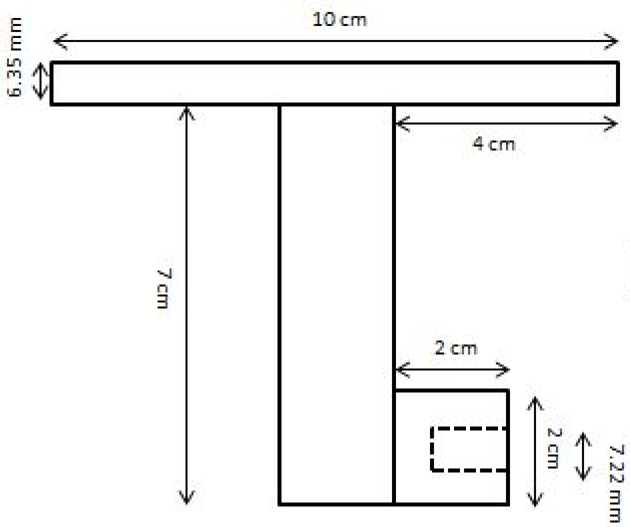


Appendix VII: Design Schematics

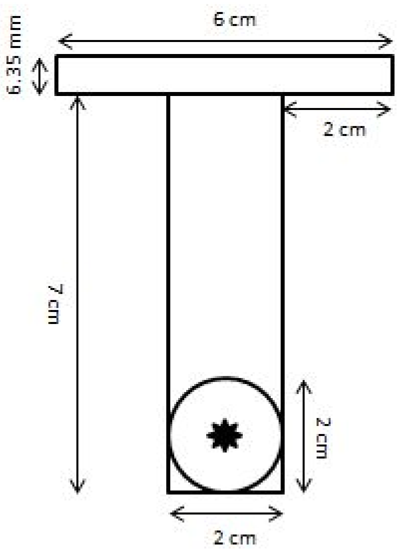



Solar panel mount
Motor B mount
Motor A rotator
Motor Cap A
Base
Side View

Solar panel mount: 3D print (6.35 mm = ¼")

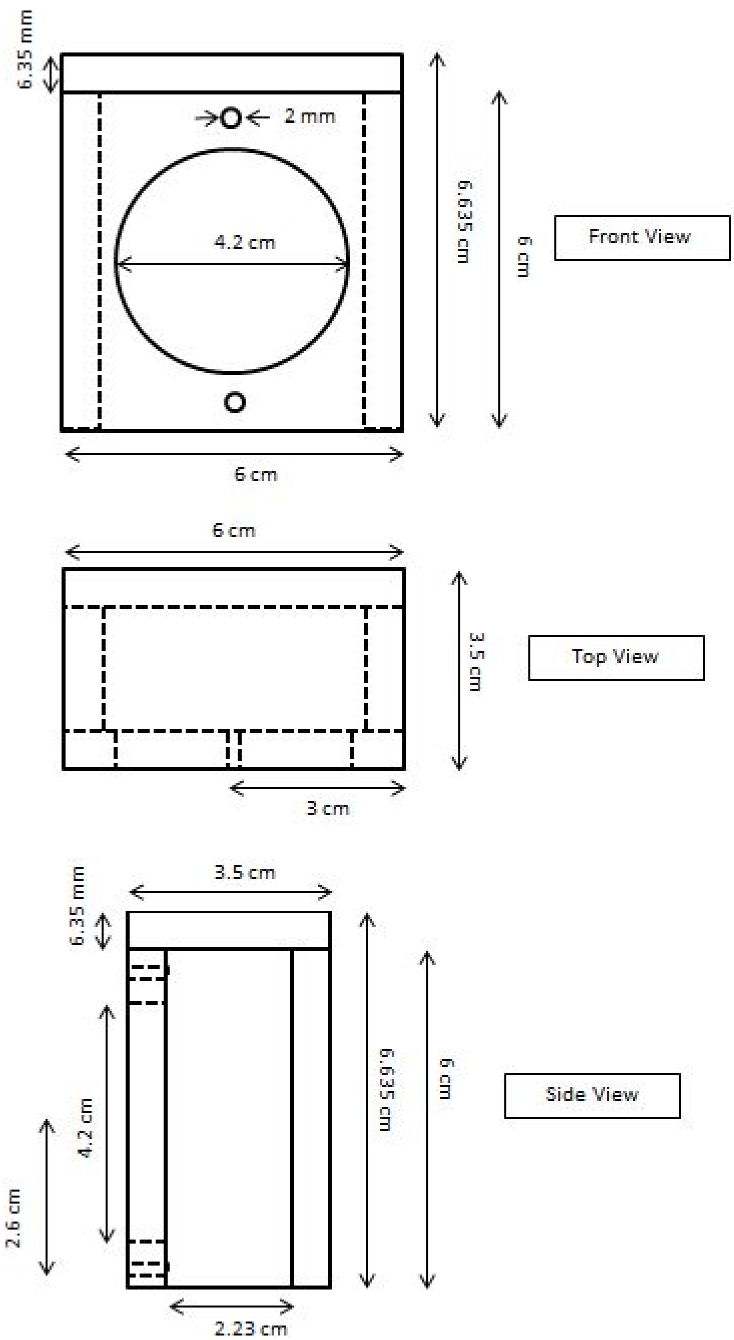


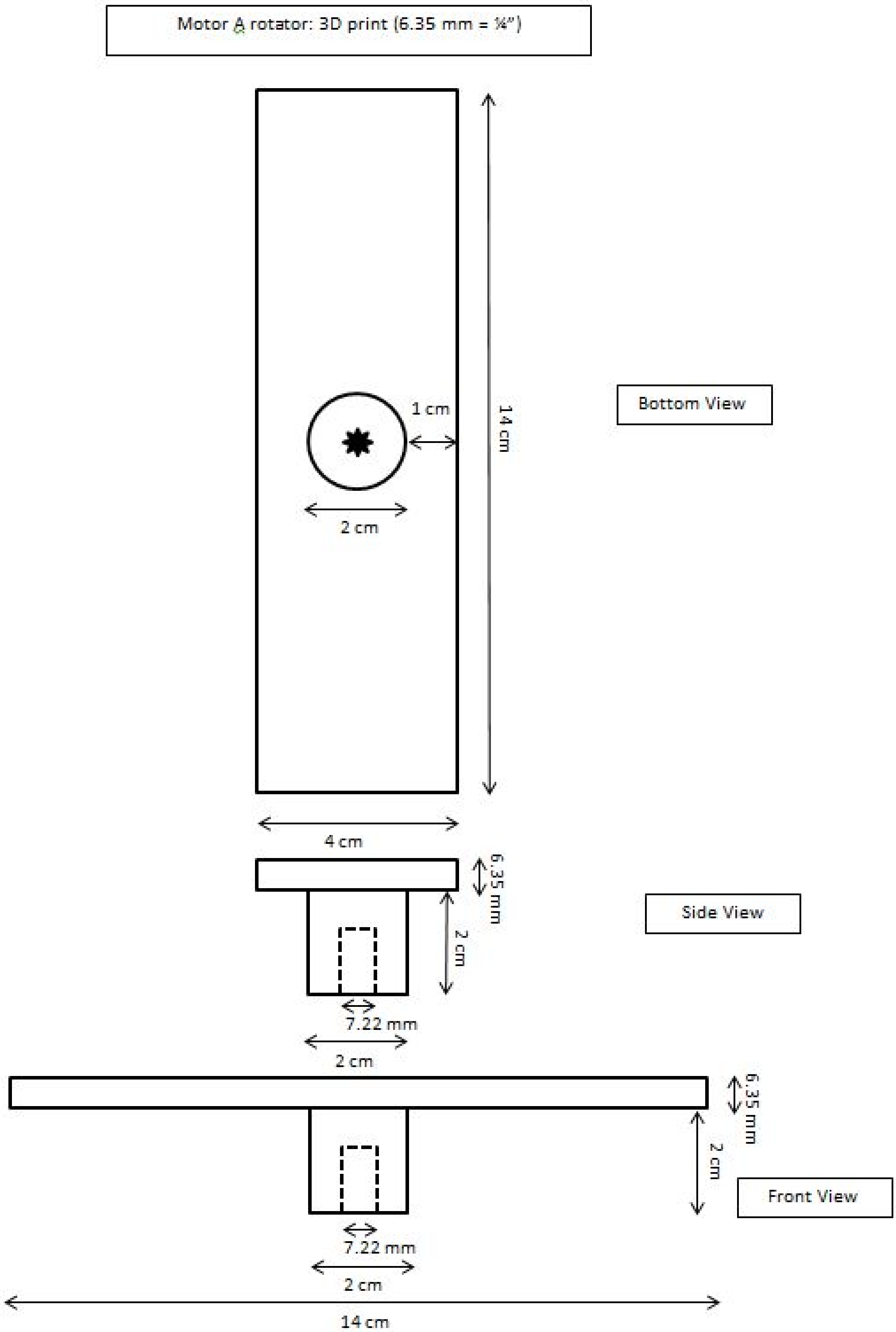
Front View



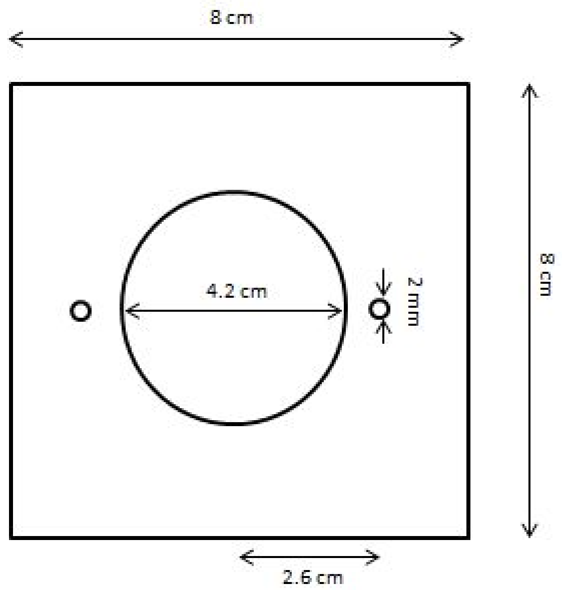
Side View

Motor B mount: Wood (6.35 mm = ¼")

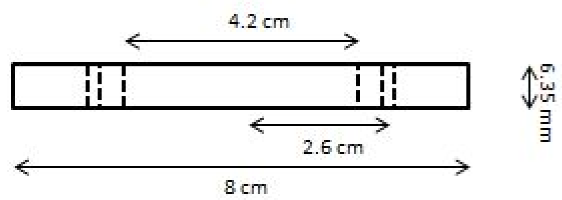



Motor A rotator: 3D print (6.35 mm = ¼")
Bottom View
1 cm
14 cm
2 cm
4 cm
6.35 mm
Side View
2 cm
7.22 mm
2 cm
6.35 mm
2 cm
Front View
7.22 mm
2 cm
14 cm

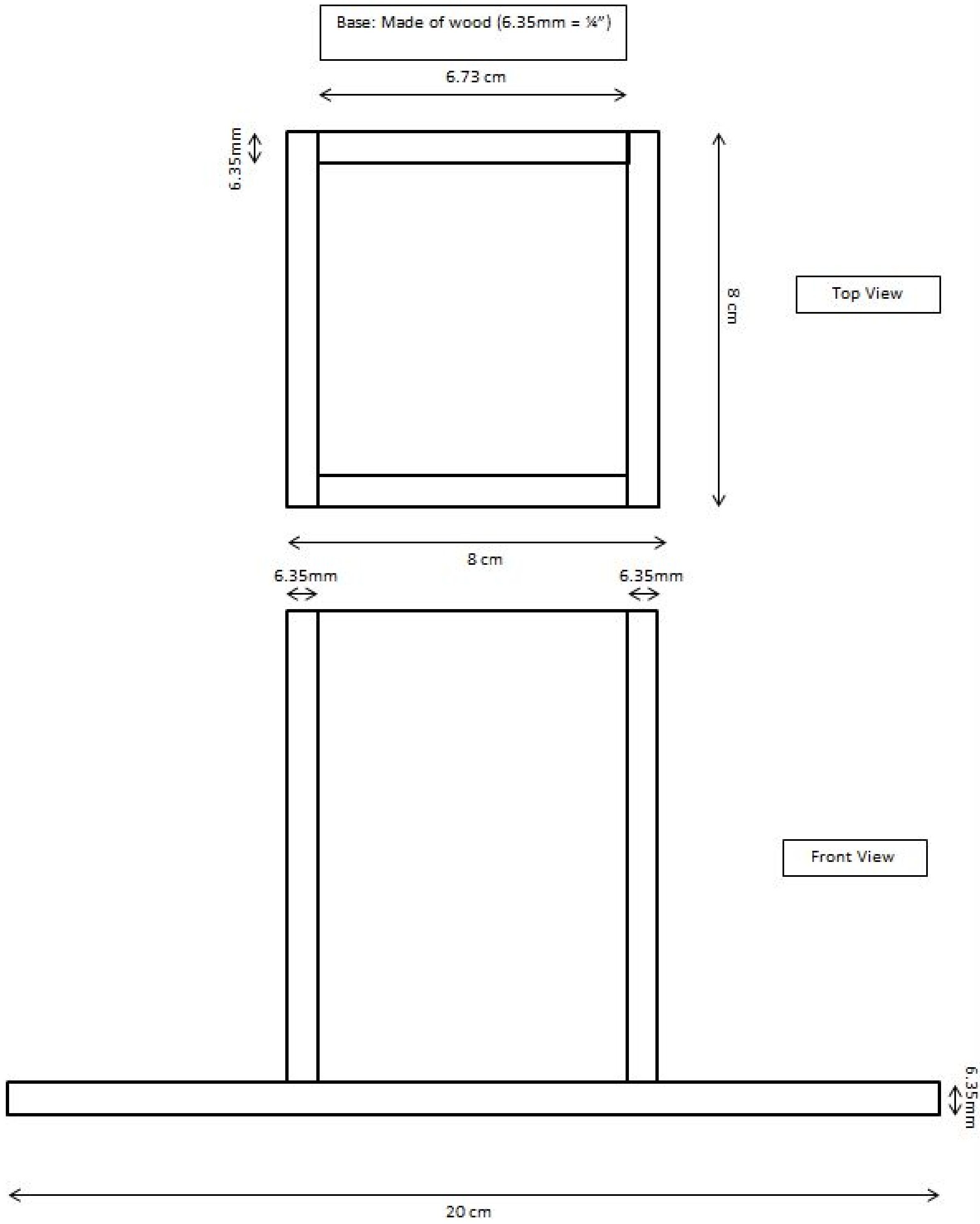
Motor cap A: Made of wood (6.35 mm = ¼")

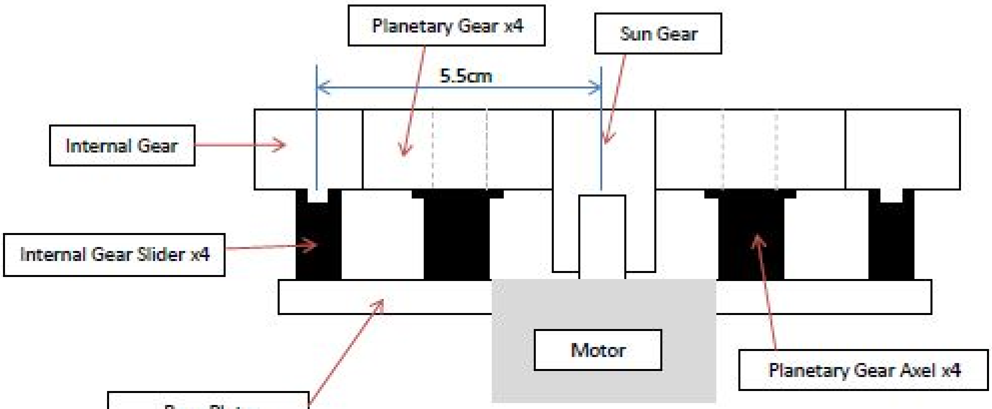


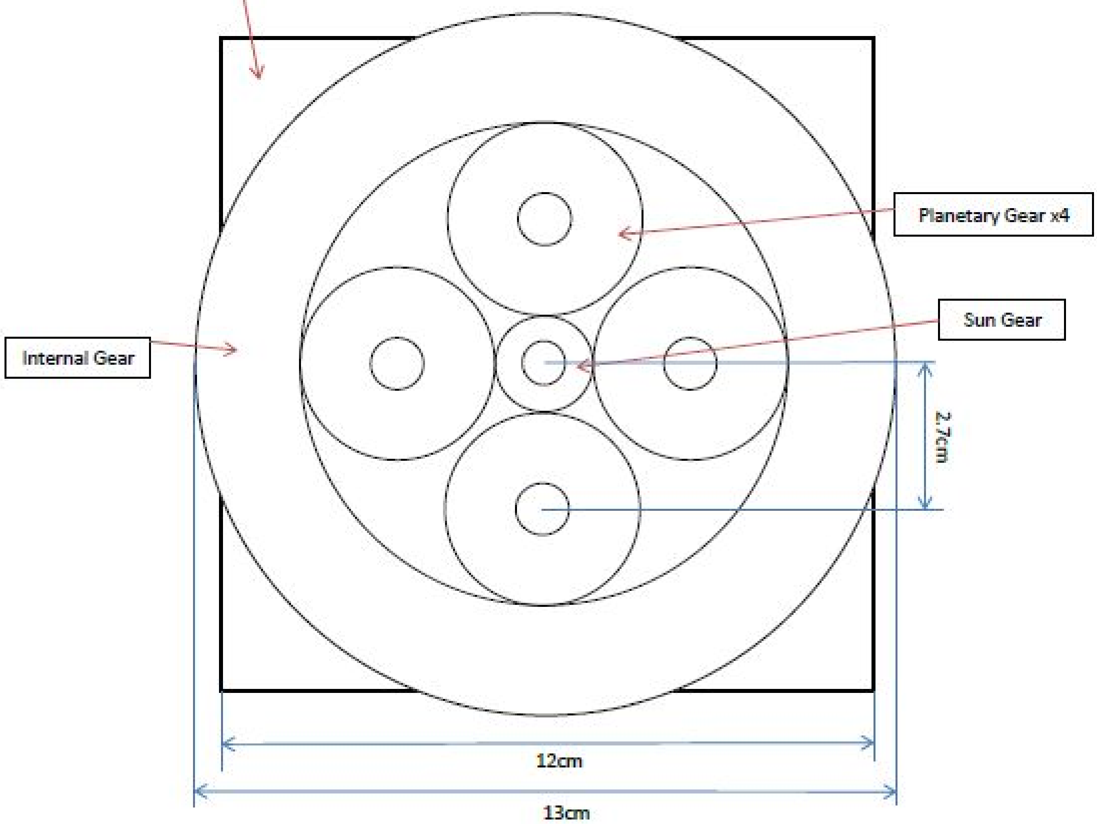
Top View



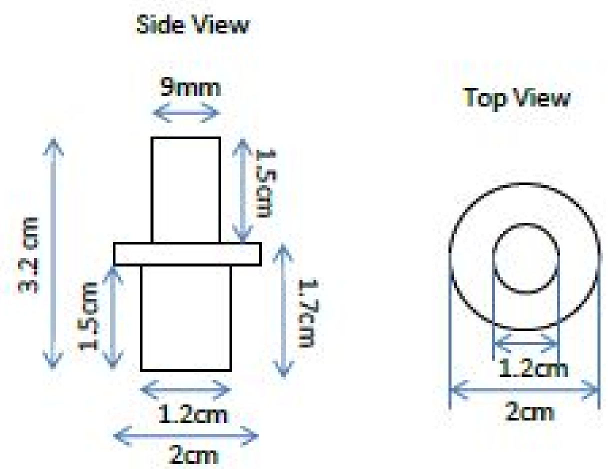
Side View


Base: Made of wood (6.35mm = ¼")
6.73 cm
6.35mm
8 cm
Top View
8 cm
6.35mm
6.35mm
Front View
6.35mm
20 cm

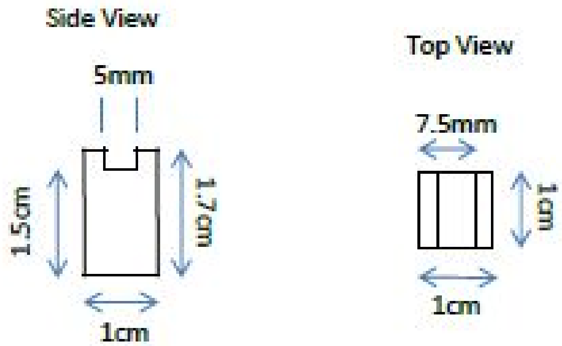

Planetary Gear x4
Sun Gear
5.5cm
Internal Gear
Internal Gear Slider x4
Motor
Planetary Gear Axel x4
Base Plate


Planetary Gear x4
Sun Gear
Internal Gear
2.7cm
12cm
13cm

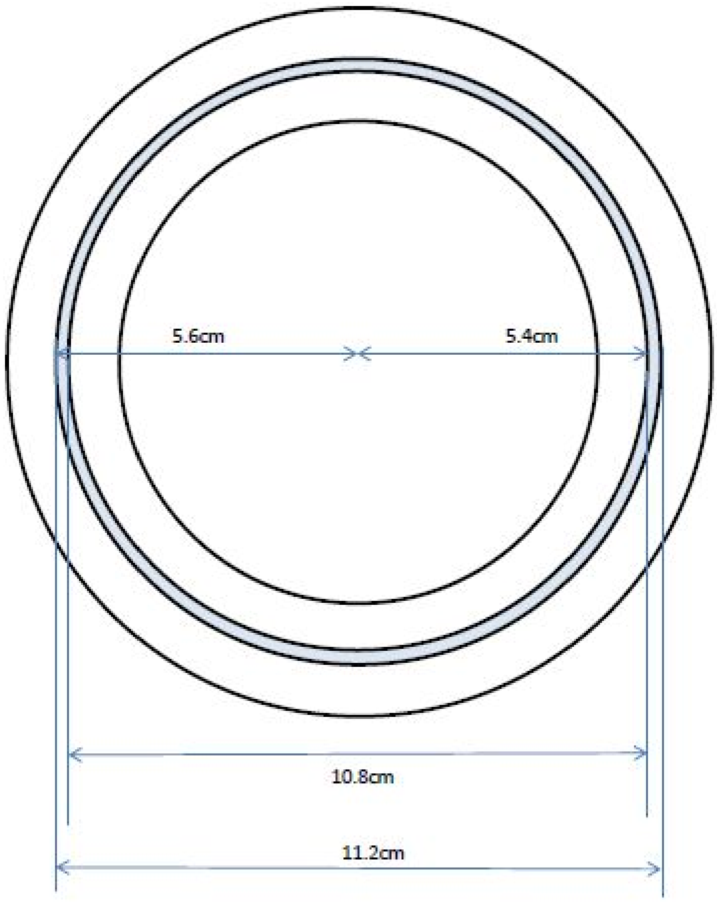
Planetary Gear Axel
Need 4 printed



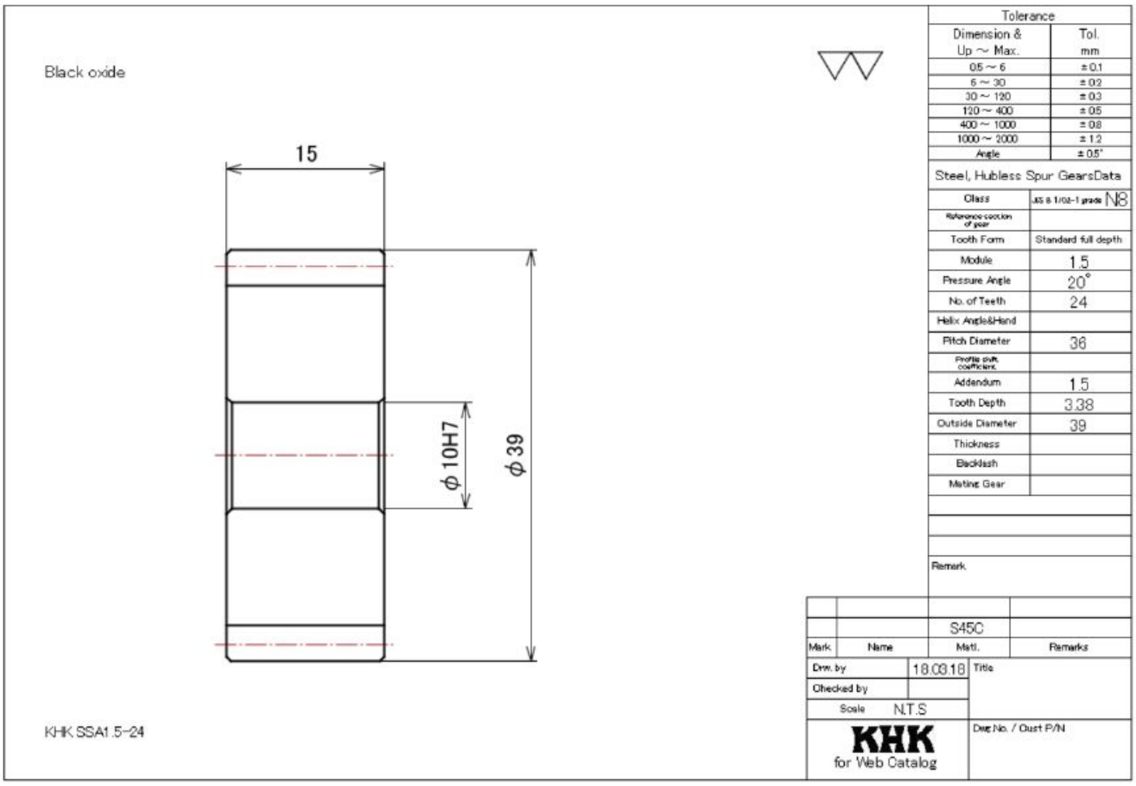
Internal Gear Slider
Need 4 printed

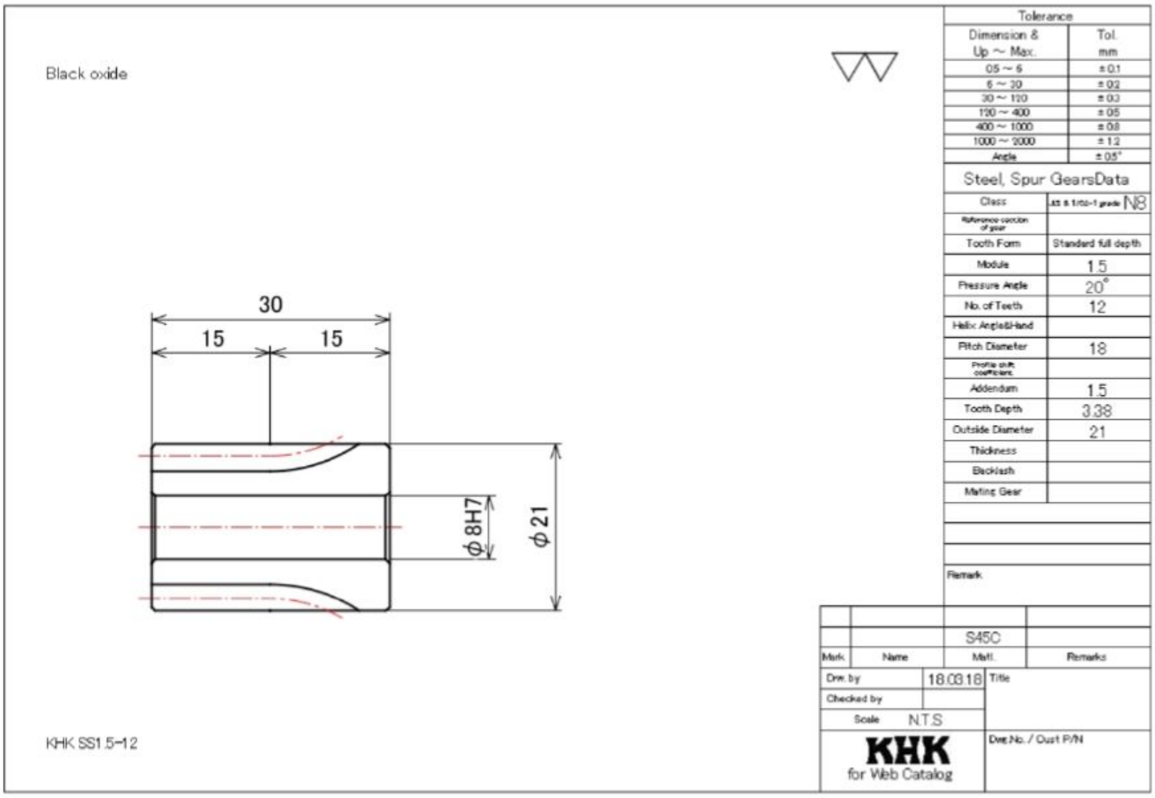


Internal Gear: Needs blue shaded part added in cad drawing.
It is 2mm thick and 2mm extruding. This part will along sliders



This appendix references a data sheet found in [37]





Appendix VIII: Pitch and Yaw

From a mechanical system standpoint yaw and pitch are shown below in Figure 1. Astronomical angles are shown in Figure 2. Yaw correlate to the “Azimuth” angle and pitch correlates to the “Altitude” angle.

Figure 1: Mechanical Rotations [38]

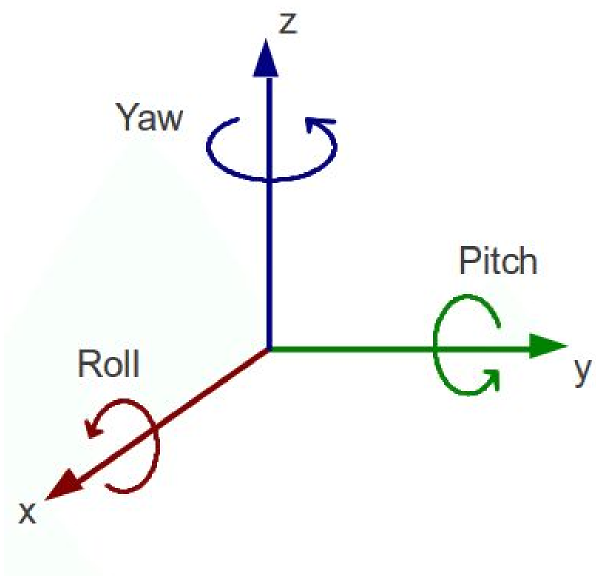
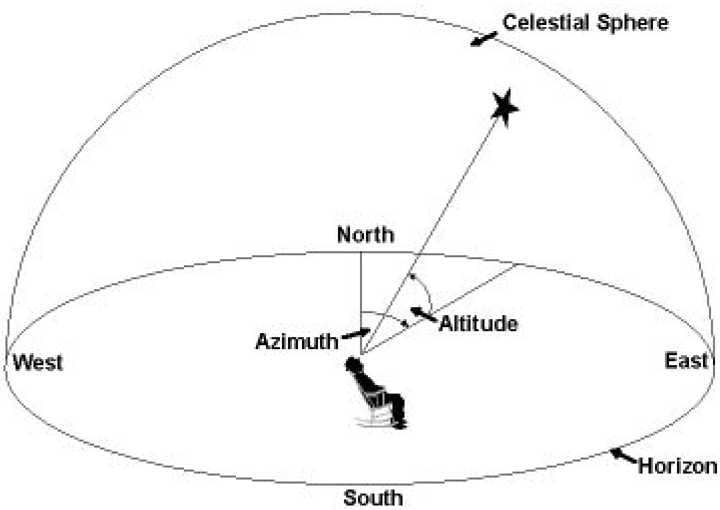


Figure 2: Azimuth Angle [39]



Glossary

MCU	Microcontroller Unit
I^2C	Inter-Integrated Circuit
CSA	Canadian Standards Association
UI	User Interface
CS	Computing System
MS	Mechanical System
PS	Power System
PCB	Printed Circuit Board
GPS	Global Positioning System
LCD	Liquid-Crystal Display
LED	Light-Emitting Diode
VCC	Rail Voltage
GND	Ground
SDA	Serial Data
SCLK	System Clock
IEEE	Institute of Electrical and Electronics Engineering
YAW	See Appendix VIII
PITCH	See Appendix VIII

References

[1] “Solar energy on the rise as popularity and cost-effectiveness of renewables continues to increase”, Energy Digital, 2017. [Online]. Available: http://www.energydigital.com/renewable-energy/solar-energy-rise-popularity-and-costeffectiveness-renewables-continues-increase. [Accessed: 19- Feb- 2018].

[2] “Are Solar Panel Tracking Systems Really Necessary”, Energy Informative, 2013. [Online]. Available: http//energyinformative.org/solar-panel-tracking-systems. [Accessed: 19- Feb- 2018].

[3] ”Solar energy on the rise as popularity and cost-effectiveness of renewables continues to increase”, Energy Digital, 2017. [Online]. Available: http://www.energydigital.com/renewable-energy/solar-energy-rise-popularity-and-costeffectiveness-renewables-continues-increase. [Accessed: 19- Feb- 2018].

[4] ”The Hidden Costs of Fossil Fuels”, Union of Concerned Scientists, 2017. [Online]. Available: https://www.ucsusa.org/clean-energy/coal-and-other-fossil-fuels/hidden-costof-fossils#.WouArEDwaUk. [Accessed: 19- Feb- 2018].

[5] “Pico-solar Electric Systems”. Hoboken: Taylor and Francis. Keane, J, 2014.

[6] ”The Solar Resource”, McEn Sustainable Energy., 2011. [Online]. Available: http://mcensustainableenergy.pbworks.com/w/page/20638192/The%20Solar%20Resou rce [Accessed: 19- Feb- 2018].

[7] ”Solar energy on the rise as popularity and cost-effectiveness of renewables continues to increase”, Energy Digital, 2017. [Online]. Available: http://www.energydigital.com/renewable-energy/solar-energy-rise-popularity-and-costeffectiveness-renewables-continues-increase. [Accessed: 19- Feb- 2018].

[8] ”Solar energy on the rise as popularity and cost-effectiveness of renewables continues to increase”, Energy Digital, 2017. [Online]. Available: http://www.energydigital.com/renewable-energy/solar-energy-rise-popularity-and-costeffectiveness-renewables-continues-increase. [Accessed: 19- Feb- 2018].

[9] ”The Solar Resource”, McEn Sustainable Energy., 2011. [Online]. Available: http://mcensustainableenergy.pbworks.com/w/page/20638192/The%20Solar%20Resou rce [Accessed: 19- Feb- 2018].

[10] ”How Does Heat Affect Solar Panel Efficiencies?”, Civic Solar, n.d. [Online]. Available: https://www.civicsolar.com/support/installer/articles/how-does-heat-affectsolar-panel-efficiencies. [Accessed: 19- Feb- 2018].

[11] ”How hot do solar panels get? Effect of temperature on solar performance”, Energy Sage., n.d. [Online]. Available: https://news.energysage.com/solar-panel-temperatureoverheating/ [Accessed: 19- Feb- 2018].

[12] ”How hot do solar panels get? Effect of temperature on solar performance”, Energy Sage., n.d. [Online]. Available: https://news.energysage.com/solar-panel-temperatureoverheating/ [Accessed: 19- Feb- 2018].

[13] ”ATmega328P Data Sheet”, Atmel., n.d. [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-42735-8-bit-AVR-Microcontroller-ATmega328-328P_Datasheet.pdf [Accessed: 19- Mar- 2018].

[14] ”ATmel 8-bit Data Sheet”, Atmel., n.d. [Online]. Available: http://www.mouser.com/ds/2/268/Atmel-2586-AVR-8-bit-Microcontroller-ATtiny25-ATti-1065586.pdf [Accessed: 19- Mar- 2018].

[15] “”Exploring Arduino: Tools and Techniques for Engineering Wizardry”. Indianapolis: John Wiley & Sons, Inc. Blum, J, 2013

[16] ”Fast Racking”, We Go Solar., n.d. [Online]. Available: http://www.wegosolar.com/categories.php?category=Solar-Panel-Mounts-/Fast-Racking[Accessed: 21- Mar- 2018].

[17] ”Solar Position Calculator”, NOAA., n.d. [Online]. Available: https://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html [Accessed: 31- Mar- 2018].

[18] “Silicon Technolabs 20x4 Line LCD Display With Blue backlight HD44780 for ALL Arduino,Rasp Pi,AVR,ARM,8051 (Blue)“, Amazon, 2018. [Online] https://www.amazon.in/Silicon-Technolabs-Display-backlight-HD44780/dp/B00XT7S5KS [Accessed: 30-Mar-2018]

[19] “Mamebook”, Mamebook, 2009. [Online] http://mamebook.blogspot.com/ [Accessed: 3/30/2018]

[20] “Travis Industries Gas Stove On/Off Rocker Switch (250-02013)”, Stove Parts Unlimited, 2018. [online] https://www.stove-parts-unlimited.com/travis-industries-gas-stove-on-off-rocker-switch-250-02013-p/250-02013.htm [Accessed: 3/30/2018]

[21] “Response Times: The 3 Important Limits”, Jakob Neilsen, 1993. [Online]. Available: https://www.nngroup.com/articles/response-times-3-important-limits/ [Accessed: 3/30/2018]

[22] ”Are Solar Panel Tracking Systems Really Necessary?”, Energy Informative, 2013. [Online]. Available: http://energyinformative.org/solar-panel-tracking-systems. [Accessed: 19- Feb- 2018].

[23] ”How Does Heat Affect Solar Panel Efficiencies?”, Civic Solar, n.d. [Online]. Available: https://www.civicsolar.com/support/installer/articles/how-does-heat-affect-solar-panel-efficiencies. [Accessed: 19- Feb- 2018].

[24] ”Top 3 Solar Stocks as of February 2018”, Investopedia., 2018. [Online]. Available: https://www.investopedia.com/investing/top-solar-stocks/ [Accessed: 19- Feb- 2018].

[25] ”How Batteries and Solar Power Are Disrupting Electricity Markets”, BCG., 2017. [Online]. Available: https://www.bcg.com/publications/2017/energy-environment-how-batteries-and-solar-power-are-disrupting-electricity-markets.aspx [Accessed: 19- Feb- 2018].

[26] ”Batteries are hitting physical limits”, DW., 2017. [Online]. Available: http://www.dw.com/en/batteries-are-hitting-physical-limits/a-19449790 [Accessed: 19- Feb- 2018].

[27] ”Solar and Wind Power Cheaper Than Fossil Fuels”, Independent., 2017. [Online]. Available: http://www.independent.co.uk/environment/solar-and-wind-power-cheaper-than-fossil-fuels-for-the-first-time-a7509251.html [Accessed: 19- Feb- 2018].

[28] ”Efficient Solar Energy Storage”, The Australian., 2017. [Online]. Available: https://www.theaustralian.com.au/news/inquirer/efficient-solar-energy-storage-a-game-changer-in-going-off-grid/news-story/230f5f483c98dc3bd7139a8bb25bc153 [Accessed: 19- Feb- 2018].

[29] ”Alternative Housing: Off-Grid Living And Tesla Energy”, BuildDirect., 2015. [Online]. Available: https://www.builddirect.com/blog/alternative-housing-off-grid-living-and-tesla-energy/ [Accessed: 19- Feb- 2018].

[30] ”Energy from the Wind”, University of Oregon., 1996. [Online]. Available: http://zebu.uoregon.edu/1996/ph162/l14.html [Accessed: 19- Feb- 2018].

[31] ”Small Wind Guidebook”, United States Department of Energy., n.d. [Online]. Available: https://windexchange.energy.gov/small-wind-guidebook [Accessed: 19- Feb- 2018].

[32] ”Why micro wind turbines don't work”, British Broadcasting Corporation., 2009. [Online]. Available: http://www.bbc.co.uk/blogs/ethicalman/2009/12/why_micro_wind_turbines_dont.html [Accessed: 19- Feb- 2018].

[33] ”Microhydro Myths & Misconceptions”, Home Power., 2012. [Online]. Available: https://www.homepower.com/articles/microhydro-power/design-installation/microhydro-myths-misconceptions [Accessed: 19- Feb- 2018].

[34] ”Arduino Bootloader”, VWLowen., n.d. [Online]. Available: http://www.vwlowen.co.uk/arduino/bootloader/bootloader.htm [Accessed: 19- Mar- 2018].

[35] ”attiny85”, ArduinoProjects4U., n.d. [Online]. Available: http://arduino-projects4u.com/attiny85-arduino/ [Accessed: 30- Mar- 2018].

[36] ”Big Easy Driver Hookup Guide”, SparkFun., n.d. [Online]. Available: https://learn.sparkfun.com/tutorials/big-easy-driver-hookup-guide?_ga=2.6604017.272209580.1520528801-1700285772.1519245339 [Accessed: 30- Mar- 2018]

[37] ”Internal Gears”, KHK Gears., n.d. [Online]. Available: https://khkgears.net/product-category/internal-gears/ [Accessed: 24- Mar- 2018]

[38] “Pitch, roll and yaw”, Research Gate, n.d. [Online]. Available: https://www.researchgate.net/figure/Pitch-roll-and-yaw-of-the-tag_fig7_322408155. [Accessed: 27- Feb- 2018]

[39] “Heavens Above Glossary”, Heavens Above, n.d. [Online]. Available: http://www.heavens-above.com/glossary.aspx?term=azimuth. [Accessed: 28- Feb- 2018]