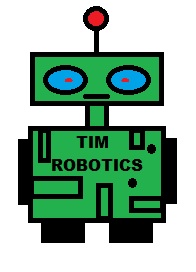
Modular Solar Array Cleaner

By TIM Robotics a subsidiary of TIM Tech



Submitted in partial fulﬁllment of the requirements of Draft Report(CST 472)

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# Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| Revision # | Editor | Revision Description | Revision Date |
| V1.0 | Timothy Wright | Initial First Draft | 5/17/2019 |
| V1.0.1 | Timothy Wright | Revisions for Final Initial Draft | 6/10/2019 |
| V2.0 | Timothy Wright | Revision for Draft Report (CST 471) | 11/8/2019 |
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| V3.1 | Timothy Wright | Revision for Final Report (CST 472) | 3/13/2020 |
| V4.0 | Timothy Wright | Revision for Final Submission | 6/8/2020 |
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# Signatory Page

This proposal is approved as part of the requirements for class CST374, Embedded Project Proposal.

Timothy Wright, Author

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Signature Date

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# Abstract

MSAC is a modular solar array cleaner. MSAC is being produced because there are very few solar array cleaning systems geared towards a residential style solar array. Typically, solar array cleaning systems are more geared towards industrial solar farms. MSAC is being produced for the residential market because solar arrays can lose as much as 25% of their energy output due to dirty solar panels. Many homeowners have installed solar arrays; however, they typically fail to install a cleaning system with said array. It is very difficult and expensive to install a piped water cleaning system after a solar array is already installed; this is where MSAC comes in. MSAC is a modular solar array cleaner that will mount on the side of most residential style arrays. This will allow a homeowner to install a cleaning system without moving the solar panels around, which can be very expensive. There are a few alternatives to MSAC, however, they typically clean much slower and not as often. This can lead to the solar array being dirty more often then it should be and in turn reduce the energy output of the solar array. This product will take around 600 hours to design and prototype. Development costs will be around $13,685.85, this includes ordering of parts, equipment rental, and costs of developing a prototype. An additional $60,000 will be needed for the cost of labor, this accounts for 600 hours at $100 an hour. The MSAC is projected to cost under $500 in parts once mass produced, this means that with a retail price of $799.99 only around 246 units need to be sold to recoup development costs. With solar energy being one of the more prominent and easily accessible forms of alternative energy for homeowners, this 246 unit break-even point should easily be reached.

# Project Management

## Table of Tasks

|  |  |  |  |
| --- | --- | --- | --- |
| Task | SubTask | Date: Start | Date: Est. Complete |
| Research Parts create comparison matrix |  | 9/17/2019 | 11/30/2019 |
|  | Limit Sensor | 9/17/2019 | 11/30/2019 |
|  | Motors | 9/17/2019 | 11/30/2019 |
|  | Microcontroller | 9/17/2019 | 11/30/2019 |
|  | Tempeture sensor | 9/17/2019 | 11/30/2019 |
|  | Wind sensor | 9/17/2019 | 11/30/2019 |
|  | Wirless communication | 9/17/2019 | 11/30/2019 |
| Mechanical Design Draft |  | 10/1/2019 | 11/1/2019 |
| Pinout |  | 11/1/2019 | 11/30/2019 |
| Test Program for all Parts |  | 11/1/2019 | 11/30/2019 |
| Mechanical Design Mockup |  | 11/1/2019 | 11/30/2019 |
| Select parts and order parts |  | 11/1/2019 | 11/30/2019 |
| Create UML |  | 11/1/2019 | 11/30/2019 |
|  | Robot | 11/1/2019 | 11/30/2019 |
|  | Base-Station | 11/1/2019 | 11/30/2019 |
|  | Website | 11/1/2019 | 11/30/2019 |
| Test All Parts Received by Dec 6th |  | 11/1/2019 | 12/6/2019 |
| Mechanical ReDesign(if needed) |  | 11/1/2019 | 12/13/2019 |
| OS and wind/temp program |  | 11/1/2019 | 12/13/2019 |
|  |  |  |  |
| Design Robot Base station communication |  | 1/7/2020 | 1/14/2020 |
| Implement Robot Software Design |  | 1/14/2020 | 1/28/2020 |
| Implement Base station Software Design |  | 1/28/2020 | 2/12/2020 |
| Implement Robot Base Station Communication |  | 2/12/2020 | 2/16/2020 |
| Test Communication |  | 2/16/2020 | 2/18/2020 |
| Test System |  | 2/18/2020 | 2/28/2020 |
| Redesign or Fix Errors |  | 2/18/2020 | 2/28/2020 |
| Design Website/Base station Communication |  | 3/9/2020 | 3/20/2020 |
| Implement Website |  | 3/20/2020 | 4/30/2020 |
| Implement Website Base Station communication |  | 4/1/2020 | 4/14/2020 |
| Test Website |  | 4/14/2020 | 4/30/2020 |
| Regression Testing |  | 4/30/2020 | 5/30/2020 |
| Error Fixing |  | 4/30/2020 | 5/30/2020 |
| Design Water Feeding System |  | 4/30/2020 | 5/30/2020 |
| Implement Water Feeding System |  | 4/30/2020 | 5/30/2020 |
| Final Documentation |  | 4/30/2020 | 5/30/2020 |

The above table shows the original overall schedule for all three terms. The items marked in green were completed on time. The items marked in yellow were completed, but were delayed. The items in red were not completed.

## Estimated Cost

This product would take around 600 hours to design build and develop. This leads to a labor cost of around $60,000. Development costs will be around $13,685.85, this includes ordering of parts, equipment rental, software purchases and costs of developing a prototype. The MSAC is projected to cost under $500 in parts once mass produced, this means that with a retail price of $799.99 only around 246 units need to be sold to recoup development costs. The cost breakdown can be seen in the table below.

Table 1: Development Costs

|  |  |  |  |
| --- | --- | --- | --- |
| Part | Cost | Amount | Total cost |
| Microcontroller | $35.00 | 5 | $175.00 |
| Limit sensor | $1.16 | 20 | $23.20 |
| Anemometer | $44.00 | 4 | $176.00 |
| Temperature sensor | $1.50 | 10 | $15.00 |
| Brush motor | $12.99 | 5 | $64.95 |
| x/y axis motors | $48.00 | 10 | $480.00 |
| wireless communication | $1.20 | 10 | $12.00 |
| Motor Driver | $10.00 | 10 | $100.00 |
| Battery | $119 | 5 | $595 |
| Additional Microcontroller | $75.00 | 2 | $150 |
| Additional Battery | $36.74 |  | $36.64 |
| Total Parts Cost |  |  | $1,823.29 |
|  |  |  |  |
| Solder | $5.00 | 5 | $25.00 |
| Flux | $5.00 | 5 | $25.00 |
| Soldering Iron | $100.00 | 2 | $200.00 |
| SDM3045X 4-1/2 Digit Digital Multimeter | $389.00 | 2 | $778.00 |
| Tektronix MSO2022B Mixed Signal Oscilloscope | $3,600.00 | 2 | $7,200.00 |
| SPD3303X-E Triple Output Power Supply | $389.00 | 2 | $778.00 |
| Plywood/wood for mockup | $100.00 | 1 | $100.00 |
| Snapmaker 2.0 A250 + Printing supplies | $2,000.00 | 1 | $2,000.00 |
| Plyers/strippers/drill/etc | $1,000.00 | 1 | $1,000.00 |
| steel cable(feet) | $100.00 | 1 | $100.00 |
| Electrical wire(multiple sizes, feet) | $50.00 | 1 | $50.00 |
| Total cost of development tools |  |  | $12,256.00 |
| Cost of Engineer (Hours) | $100.00 | 600 | $60,000.00 |
| Total Cost |  |  | $74,079.29 |

## Currently Selected Parts

Table 2: Microcontroller Comparison

|  |  |  |  |
| --- | --- | --- | --- |
| Microcontroller | | | |
|  | SAMC21J evaluation kit | Raspberry PI 4 | Arduino Mega 2560 Rev3 |
| Price(USD) | $35 | $35 | $38.50 |
| ADC | 4 (up to12 bit resolution) | 0 | 16 (10 bit resolution) |
| GPIO | 13 | up to 28 | 54 |
| PWM Channels | 2 | 0 | 15 |
| FreeRTOS | yes | no | no |
| Selected | X |  |  |
|  |  |  |  |
| Reason | Can run FreeRTOS and has all inputs needed | | |
|  |
|  |

The SAMC21J microcontroller was chosen due to the engineer’s familiarity with the product as well as the products ability to run FreeRTOS. Also it is the same price or cheaper then the alternatives. Since the cost of parts will be rolled into the purchase price the added cost of this part will not affect the bottom line.

Table 3: Operating System Comparison

|  |  |  |  |
| --- | --- | --- | --- |
| Operating System | | | |
|  | Linux | FreeRTOS | No OS |
| Familiar | no | yes | no |
| Real time | yes | yes | no |
| Multiple tasks at once | yes | yes | no |
| Selected |  | X |  |
| Reason | Developer is familiar with this OS. | | |
|  |
|  |

The FreeRTOS OS was chosen solely because the design engineer is familiar with the OS. Due to this the development time can be reduced as well as the cost of development can also be reduced.

Table 4: Limit sensor Comparison

|  |  |  |  |
| --- | --- | --- | --- |
| Limit sensors x/y and charge | | | |
|  | V-156-1C25 | Yeeco Micro Limit Switch | CL20 |
| type | SPDT | SPDT | SPDT |
| price per | 1.165 | 0.6495 | 0.699 |
| Amount | 6 | 20 | 10 |
| DC Current rating | 0.6A | 0.6A | UNKNOWN |
| Overall Price | 6.99 | 12.99 | 6.99 |
| Selected | X |  |  |
| Reason | Lowest price with know current limit | | |
|  |
|  |

The V-156-1C25 limit switch was chosen because of its affordability. The end product will contain a higher end waterproof limit switch. However, to reduce development costs it was decided to go with a cheep limit switch to test functionality. Later, when starting the manufacturing phase, a waterproof replacement can be swapped in place of the testing limit switch.

Table 5: Wind sensor Comparison

|  |  |  |  |
| --- | --- | --- | --- |
| Wind sensor | | | |
|  | Adafruit Anemometer | Wind Sensor Rev. C | Build your own |
| Price | $44.00 | $17.00 | UNKNOWN |
| Needs Calibration | no | yes, every time it looses power | no |
|
| Input | Analog | Analog | Analog |
| Selected | X |  |  |
| Reason | Does not need calibration, no need to construct my own, only premade anemometer available. | | |
|  |
|  |

The Adafruit Anemometer was chosen because it is the only prebuild anemometer on the market that uses a turbine instead of measuring temperature changes. Due to the way it senses the wind speed, accuracy is increased. Even though the Adafruit Anemometer costs more then the alternatives, the increased accuracy as well as the fact that no time will be spent on developing an anemometer from scratch, justifies the increased cost.

Table 6: Temperature sensor Comparison

|  |  |  |  |
| --- | --- | --- | --- |
| Temperature Sensor | | | |
| robotshop SKU | B-See-351 | RB-Spa-1078 | RB-Suf-27 |
| Price | USD $13.90 | USD $1.50 | USD $5.99 |
| Brand | SeeedStudio | Sparkfun Electronics | Sunfounde |
| Working voltage | 3.3V-5V | 2.7 V to 5.5 VDC | 3.3V-5V |
| Measurement type | Thermistor | Thermistor | Thermistor |
| Temperature measurement range | -50 to +600°C | −40°C to +125°C | UNKOWN |
| Selected |  | X |  |
| Reason | Price | | |
|  |
|  |

The temperature sensor was chosen due to its price. The accuracy of the temperature sensor does not need to be any more than 1 degree Celsius and all options that were considered were accurate to much more then that. They all also had a temperature sensing range much greater than is needed. Therefor the only determining factor was the price.

Table 7: Brush Motor Comparison

|  |  |  |  |
| --- | --- | --- | --- |
| Brush Motor | | | |
| robotshop SKU | RB-And-128 | RB-Dfr-670 | RB-Dfr-671 |
| Price | USD $32.75 | USD $12.99 | USD $12.99 |
| Brand | AndyMark | DFRobot | DFRobot |
| No Load Current [A] | 2.7 | 0.17 | 0.17 |
| Stall Current [A] | 133 | 2.19 | 2.19 |
| No Load RPM | 5310 | 100 | 50 |
| Rated RPM | 4614 | 93 | 45 |
| Output Shaft Diameter [mm] | 7.9502 mm | 6 mm | 6 mm |
|  | 0.313 in | 0.2362 in | 0.2362 in |
| Output Shaft Length | 31.623 mm | 15 mm | 15 mm |
|  | 1.245 in | 0.5906 in | 0.5906 in |
| Rated Torque | 0.3178 Nm | 0.6865 Nm | 0.8826 Nm |
|  | 45.0043 oz/in | 97.2166 oz/in | 124.9867 oz/in |
| Stall Torque | 2.4249 Nm | 4.1188 Nm | 4.9033 Nm |
|  | 343.3948 oz/in | 583.2712 oz/in | 694.3658 oz/in |
| Height | 63.5 mm | 37 mm | 37 mm |
|  | 2.5 in | 1.4567 in | 1.4567 in |
| Length | 110.236 mm | 58 mm | 58 mm |
|  | 4.34 in | 2.2835 in | 2.2835 in |
| Nominal Voltage [V] | 12 | 12 | 12 |
| Selected |  | X |  |
| Reason | The RB-Dfr-670 was chosen because it outputs the desired rotations per minute as well as having a low cost. Depending on the final weight of the robot a different motor may be chosen that has a higher torque. | | |
|  |
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The RB-Dfr-670 brushed DC motor was chosen due to its low cost and high torque. A brushed DC motor was chosen to remove the need for a motor driver. The RB-Dfr-670 was chosen over the RB-Dfr-671 due to the higher RPM. Too slow of an RPM and it would not clean the solar panels very well. However, to high an RPM and there would also be problems. Therefor an RPM of 100 was chosen. Using gears this RPM can be increased or decreased to fit the needs of the project, however, to reduce costs and remove gears a motor with an RPM close to the target RPM was chosen.

Table 8: Stepper Motor Comparison

|  |  |  |  |
| --- | --- | --- | --- |
| X/Y axis Motors | | | |
| robotshop SKU | RB-Phi-210 | RB-Phi-266 | RB-Phi-267 |
| Price | USD $44.00 | USD $74.00 | USD $48.00 |
| Brand | Phidgets | Phidgets | Phidgets |
| Rated Torque | 2.942 Nm | 23.5 Nm | 4.7 Nm |
|  | 416.6223 oz/in | 3333 oz/in | 667 oz/in |
| Nominal Current [A] | 1.7 | 2.8 | 1.7 |
| Height | 0 mm | 57 mm | 57 mm |
|  | 0 in | 2.2441 in | 2.2441 in |
| Length | 0 mm | 128 mm | 87.7 mm |
|  | 0 in | 5.0394 in | 3.4528 in |
| Nominal Voltage [V] | 12 | 12 | 12 |
| Weight | 503 g | 1496.8536 g | 564 g |
|  | 1.1089 lb | 3.3 lb | 1.2434 lb |
|  | 17.605 oz | 52.3899 oz | 19.74 oz |
| Width | 0 mm | 57 mm | 57 mm |
|  | 0 in | 2.2441 in | 2.2441 in |
| No. of Leads | 4 | 4 | 4 |
| Type | Bipolar | Bipolar | Bipolar |
| Selected |  |  | X |
| Reason | The RB-Phi-267 was chosen due to the reduced price with a high torque. | | |
|  |
|  |
|  |
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The RB-Phi-267 was chosen due to the high torque rating with a low cost. If need be gears can be used to increase this torque to fit the needs of the project.

Table 9: Wireless Communication Comparison

|  |  |  |  |
| --- | --- | --- | --- |
| Wireless Communication | | | |
|  | ESP8266 | Hoperf RFM75 V2.0 | Solu CC1101 |
| Frequency | WIFI | 2400-2483.5 | 387-464MHZ |
| Data rate | WIFI | 250kbps, 1 and 2Mbps | up to 600 kbps |
| Connection type | UART | spi | spi |
| Price per | 4 | 1.9 | 6.99 |
| crystal type | N/A | ±60ppm 16MHz crystal | UNKNOWN |
| voltage | 4.5V - 9V | 1.9-3.6 | 1.8-3.6 |
| Docs | Good | Good | Poor |
| Selected | X |  |  |
| Reason | The ESP8266 was chosen due to its ability to host a website. Due to the microcontroller change the micro is no longer able to host the website and is therefore the job of the communications device to do so. This is the main reason the ESP8266 was chosen. | | |
|  |
|  |
|  |

The ESP8266 was chosen due to its ability to host a website. Due to the microcontroller change the micro is no longer able to host the website and is therefore the job of the communications device to do so. This is the main reason the ESP8266 was chosen.

Table 10: Battery Comparison

|  |  |  |  |
| --- | --- | --- | --- |
| Battery | | |  |
|  | Ionic 12V12-EP | MIGHTY MAX BATTERY 12-Volt 8 Ah | MIGHTY MAX BATTERY 12-Volt 100 Ah |
| Price | 119 | 20.36 | 174.99 |
| Product Depth (in.) | 4 | 2.56 | 6.61 in |
| Product Height (in.) | 4 | 3.94 | 8.3 |
| Product Width (in.) | 5.9 | 5.94 | 12.17 in |
| Battery Capacity (mAh) | 12000 | 8000 | 100000 |
| Battery Power Type | Lithium Iron Phosphate | Sealed Lead Acid | Sealed Lead Acid |
| Battery Size | 12-volt | 12-volt | 12-volt |
| Brand Name | IONIC | MIGHTY MAX BATTERY | MIGHTY MAX BATTERY |
| Cell Type | Specialty | Specialty | Specialty |
| Discharge Cycle | Deep Cycle | Deep Cycle | Deep Cycle |
| Max Discharge Rate | 255A (5S) |  |  |
| Features | Rechargeable | Rechargeable | Rechargeable |
| Number in Package | 1 | 1 | 1 |
| Returnable | N/A | 90-Day | 90-Day |
| SLA Type | N/A | Absorbent Glass Mat (AGM) | Absorbent Glass Mat (AGM) |
| Safety & Security Product Type | Battery | Battery | Battery |
| Selected | X |  |  |
| Reason | The Ionic battery was chosen due to its low weight. | | |
|  |

Originally a mighty max battety was chosen, however when the battery arrived it was concluded that the weight of the battery would have been too much for the system. Therefore a new low weight battery was chosen. However, this comes at a much greater cost then the old battery. However, due to the microcontroller change which reduced the cost the total cost of the project is about the same.

Table 11: Stepper Motor Driver Comparison

|  |  |  |  |
| --- | --- | --- | --- |
| Stepper Motor Driver | | | |
| TB67S249FTG | TB67S249FTG Full Breakout | TB67S279FTG | TB67S249FTG Compact |
| Minimum operating voltage: | 10 V | 10 V | 10 V |
| Maximum operating voltage: | 47 V | 47 V | 47 V |
| Continuous current per phase: | 1.7 A | 1.2A | 1.6 A |
| Maximum current per phase: | 4.5 A | 2A | 4.5 A |
| Minimum logic voltage: | 2V | 2V | 2V |
| Maximum logic voltage: | 5.5 V | 5.5 V | 5.5 V |
| Microstep resolutions: | full, non-circular 1/2, 1/2, 1/4, 1/8, 1/16, 1/32 | full, non-circular 1/2, 1/2, 1/4, 1/8, 1/16, 1/32 | full, non-circular 1/2, 1/2, 1/4, 1/8, 1/16, 1/32 |
| Current limit control: | potentiometer | potentiometer | potentiometer |
| Reverse voltage protection?: | Y | Y | N |
| Header pins soldered?: | N | N | N |
| Price | 11.95 | 9.75 | 9.95 |
|  |  |  |  |
| Selected | X |  |  |
| Reason | The TB67S249FTG was chosen because its max current per phase matched the max current of the stepper motor that was chosen, the compact version will not work because the continuous current was only 1.6A and not 1.7A because of this same reason the 279 was not chosen since it can only output 1.2A | | |
|  |

The TB67S249FTG was chosen due to the continuous current per phase being equal to that of the stepper motor. Also this particular board was chosen due to the on chip active gain control (AGC). AGC is a hardware component that monitors the needed torque of the stepper motor and reduces the current being used. This reduces heat on the board and more importantly saves power.

Currently all parts have been ordered and all parts have arrived.

## Change Management Procedures

All engineering change requests (ECR) will be sent to the project advisor by email in memo format. All engineering change requests will be recorded in an excel spreadsheet. There will be data fields for the requested change, the reason for the change as well as the status on if the change has been approved, denied or is still pending approval.

If an ECR is approved, an engineering change order (ECO) will be drafted, this must happen within 7 days of the ECR being sent to the engineering advisor. If an ECR is not approved within this time period, the ECR is automatically disapproved with the reason being “timed out”. An ECR with a disapproval reason being “timed out” can immediately be re-requested. Once an ECR is approved and the ECO drafted, the ECO will then be sent to the project advisor for approval. All ECO’s will be saved with the project documents. A revision history for all ECO’s will be kept. There will also be an additional excel spreadsheet that will keep track of all ECO’s. There will be data fields for the associated ECR the current revision of the ECO and the status of approval.

Once an ECO is approved the change will then be put into effect and all necessary documentation will be updated if needed. As with the ECR a 7-day timeout period is in effect, meaning, if an ECO is not approved within 7 days it is automatically disapproved with the reason being “timed out”. An ECO with a disapproval reason of “timed out” can immediately be re-requested.

If an ECR or ECO is not approved for any reason except “timed out” there is a 10 day waiting period before it can be requested again.

## Status Reports

Status reports shall be sent to the project advisor weekly. They will contain the progress made during the week as well as the current plan for the next week. If the plan for the current week is not completed the status report shall include an explanation as to why the project is delayed as well as a plan to get back on track.

## Skills and Knowledge

The skills and knowledge required for this project include but are not limited to, C programming, soldering, mechanical engineering, wireless communication, Android development and an understanding on how to clean solar panels.

# Conceptual Overview

MSAC is being produced because there are very few solar array cleaning systems geared towards a residential style solar array. Typically, solar array cleaning systems are more geared towards industrial solar farms. MSAC is being produced for the residential market because solar arrays can lose as much as 25% of their energy output due to dirty solar panels. Many homeowners have installed solar arrays; however, they typically fail to install a cleaning system with said array. It is very difficult and expensive to install a piped water cleaning system after a solar array is already installed; this is where MSAC comes in. MSAC is a modular solar array cleaner that will mount on the side of most residential style arrays allowing homeowners to install a cleaning system on top of an existing array.

## Problem statement

As stated previously the problem this product is trying to solve is that not all solar panels were installed with a cleaning system which can then lead to the solar array getting dirty. A study from the National Renewable Energy Laboratories has shown that dirty panels can lead to a reduction in solar panel efficiency by up to 25%3. Dirty solar panels can lead to a significant decrease in energy output.

## Intended Audience

The intended audience for this project is any homeowner who has installed or plans to install a solar array. The solar array must be a continuous block of solar panels in a rectangular formation.

## Proposed Project

The Modular Solar Array Cleaner (MSAC) is a solution to the problem stated above. This system would autonomously clean the solar array according to a set schedule. The MSAC will also allow cleaning of the array manually through an android application. The system will consist of a base station and a robotic cleaning unit (RCU). The RCU will contain a rotary brush and traverse the solar array. The RCU will traverse the solar array from top to bottom to ensure the panels it has previously cleaned are not dirtied by the panels it still has to clean. After the RCU is finished cleaning it will return to the base station and dock. When docked the RCU will recharge its batteries.

The base station will be mounted in the top left corner of the solar array. It will communicate with the robot as well as the android application to control the movement of the robot. It will also provide a place for the robot to dock as well as supplying the robot with power to charge its batteries.

The Android application will control the robot through a simple interface. It will communicate instructions to the base station which will in turn communicate them to the robot. This allows the remote control of the MSAC.

The MSAC will follow a schedule that is preprogrammed by the user. The android application will allow the user to change this schedule. There will also be a button to start an autonomous cleaning outside the regular schedule.

## Existing Products

There are a couple existing products out there that accomplish the same thing that MSAC does, however they have their drawbacks. RAYBOT[1] is one such machine. However, it is very slow, waterless only and not currently available to buy. Another such machine is Scrobby[2] however it only cleans 3-4 times a year using water collected from rainfall. The E4/T4[5] as well as the Pleco[4] are more geared towards industrial solar farms. This means they come with advanced features that a typical homeowner would never use. Because of this the E4/T45 and the Pleco4 will be more expensive then what a typical homeowner will be willing to pay.

Table 12: Comparable Products Comparison

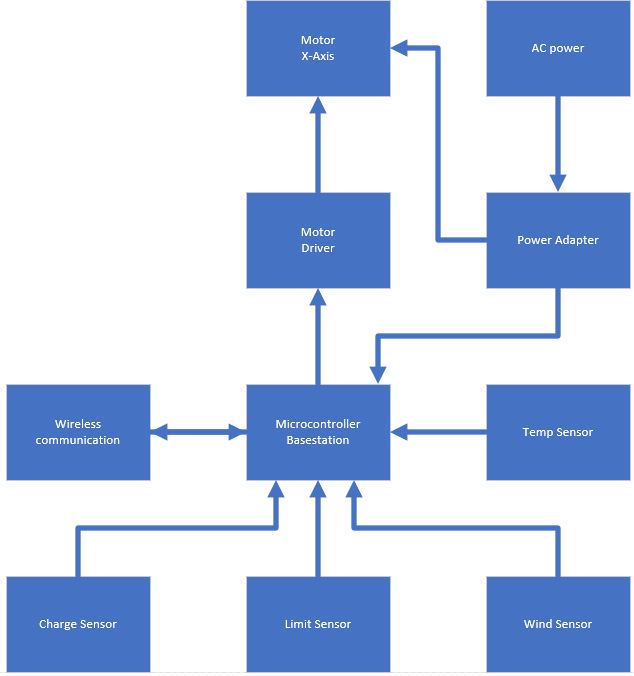
|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Name | Water | Cleaning Time | Cost | Tilt | Projected Users | Manual control |
| MSAC | Possibly | 3 in/sec | $799.99 | 45° | Homeowners | Yes |
| RAYBOT[1] | No | 5 solar panels/hour | N/A | 55° | Homeowners | No |
| Scrobby[2] | Yes (rainwater only) | 3-4 times a year | $348 (kickstarter) | 75° | Homeowners | No |
| E4/T4[5] | No | N/A | N/A | N/A | Industrial | No |
| Pleco[4] | No | N/A | N/A | 45° | Industrial | Yes |

## Final Deliverables

Once the MSAC is complete all documentation as well as all electronic copies of the source code will be provided to the project supervisor.

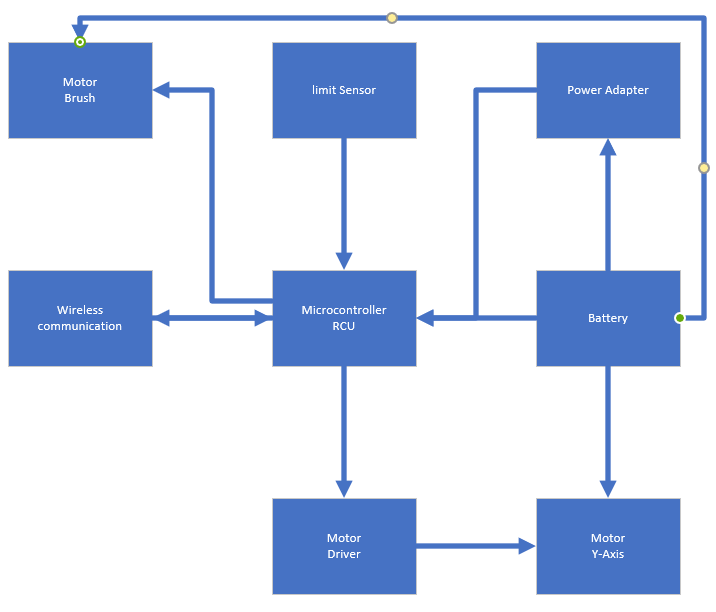
# System Decryption

## Base Station Block Diagram

Figure 1 

## Robot Block Diagram

Figure 2



## General Description

The system will detect the start of a cleaning, undock the RCU, turn on the brush and start traversing the solar array top to bottom. Once it has finished cleaning the array it will turn off the brush and return to the base station. It will then dock and wait for the next cleaning cycle. In manual mode the RCU will undock and wait for movement commands. Once it is out of manual mode it will redock the RCU. If the RCU is running low on while in autonomous mode, the RCU will save its position and dock at the base station. Once the RCU is charged it will continue the cleaning cycle where it left off.

## Major Subsystems

This product will have the following major systems each with their own subsystems.

Base Station – Charging subsystem, X-Axis subsystem, Communication subsystem, Sensor input subsystem, Scheduling subsystem

RCU – Y-Axis subsystem, Brush subsystem, Sensor input subsystem, wireless communication subsystem, Cleaning algorithm subsystem

Website – Scheduling subsystem

## Hardware Platform Description

Currently the plan is to use two of the same microcontrollers, one for the base station and one for the RCU. There will be two motors to control the x and y movement of the RCU as well as one motor to control the brush on the RCU. The RCU and the base station will each need a wireless communication card. There will be various sensors such as a temp, wind and limit sensor. Currently there has been no research done into the hardware. For information regarding the timeline of when hardware will be researched please see the Gantt chart.

## Software Platform Description

Atmel studio 7.0.122 will be the primary IDE for development of this project. This project will be written mostly in C. The website will be created using standard HTML.

# Requirements

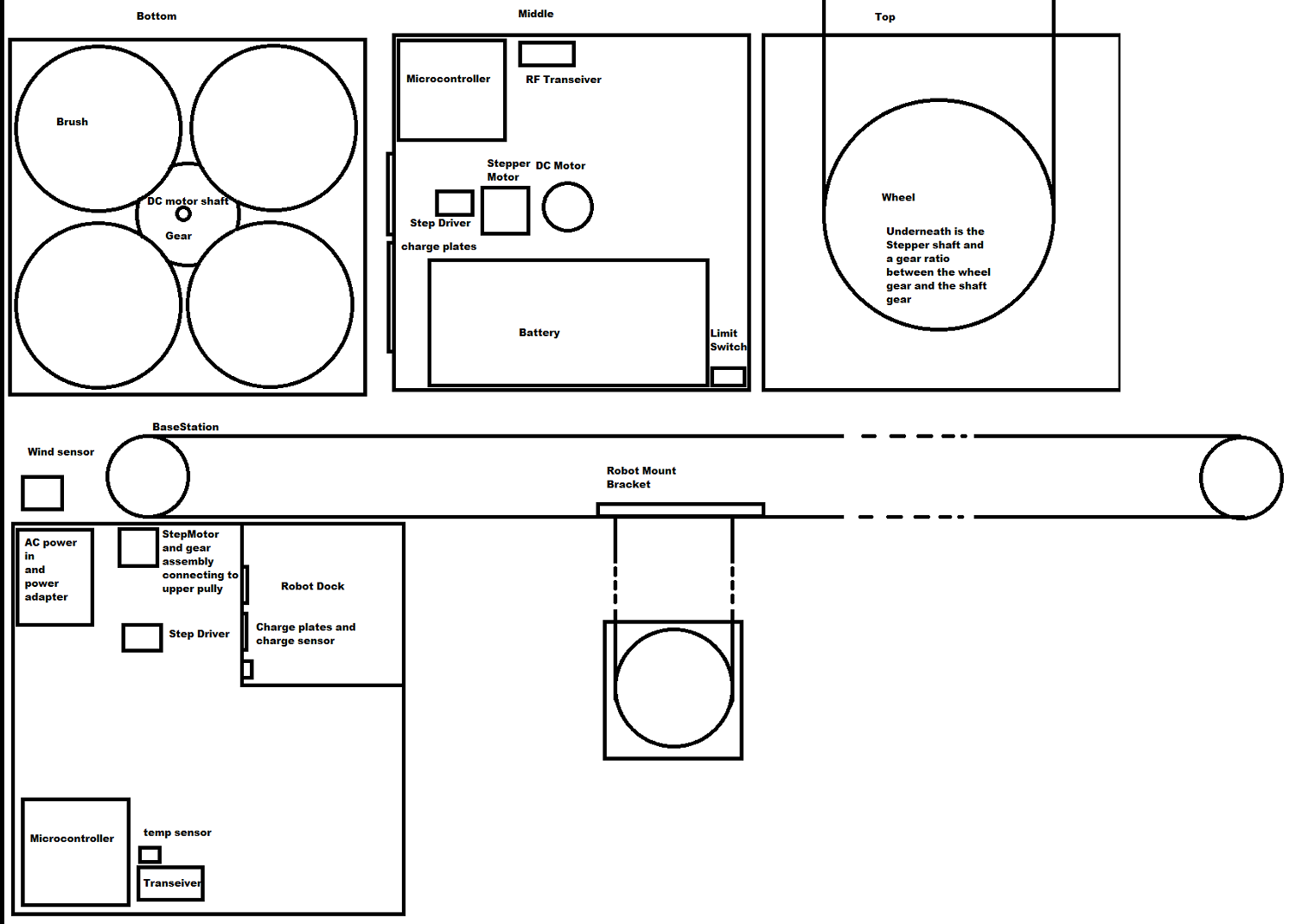
1. The system shall use two microcontrollers (one for the robot and one for the base station).
2. The two microcontrollers shall communicate with wireless technology (to be determined) capable of transmitting at a rate of 1kbps over a distance of 65 feet.
3. The system shall consist of a base station, a robot, a website and a controller.
   1. A base station is the part of the system that sits stationary and provides a docking station for the robot.
   2. The robot is the part of the system that traverses the solar panels and cleans them.
   3. The website will be the component the user connects to set the schedule.
   4. The controller is what will allow the manual control of the system.
4. The robot shall be powered by a battery capable of running the robot for at least 2 hours under normal operation.
5. The base station shall be powered by 120 v at 60 Hz converted down to meet system requirements.
6. The base station shall provide a way to charge the robot when docked.
7. If the robot’s battery is running low (low level TBD later) the system shall pause the cleaning, dock the robot, wait for the robot to recharge then resume cleaning.
8. The base station shall control the x-axis movement of the robot.
9. The robot shall control the y-axis movement of the robot.
10. The robot shall clean the solar panels using a brush at a rate of .1 inches per second.
11. The system shall provide a way to swap between manual and autonomous mode..
    1. Manual mode is when the robot is being controlled using the controller.
    2. Autonomous mode is when the robot is following the schedule.
12. The system shall include a controller that can control the robot.
13. The controller shall provide a way to control the x and y axis movement of the robot. (way of controlling TBD later)
14. The controller shall provide a way to turn on and off the cleaning brush.
15. The controller shall provide a way to automatically dock the robot. (Docking the robot is when it positions itself in the base station and starts charging)
16. The system shall automatically dock the robot if the user did not dock the robot in manual mode and has swapped into autonomous mode.
17. The system shall have the ability to follow a schedule based on the time of day and day of week.
18. The system shall provide a way for the user to set the schedule.
19. The system shall provide a way to initiate a cleaning outside the set schedule.
20. The system shall include a temperature and wind sensor.
21. The system shall postpone cleaning if the outside temperature is above a set value (Value TBD later).
    1. This is to prevent damage to both the electronics and the battery of the robot.
22. The system shall postpone cleaning if the speed of the wind is above a set value (Value TBD later).
    1. This is to prevent damage to both the robot and the solar panels due to high winds.
23. The system shall clean the solar panels by traversing left to right or right to left from top to bottom.
    1. This is to prevent the robot from dirtying previously cleaned panels.
24. The system may include a way to get water to the robot.
25. The system may include a water or water-less cleaning style.
26. The system may include an option to turn on and off the water, when in manual mode, via the controller.

All requirements except requirement 2 and 17 were completed 100%. Requirements 24-26 were also not completed, however, they were not required for project completion. Requirement 2 it states “The two microcontrollers shall communicate with wireless technology capable of transmitting at a rate of 1kbps over a distance of 65 feet.” The devices are capable of transmitting at this rate and can be demonstrated using a laptop and manually typing in the setrcu or setbs URL's, however the WIFI modules disconnect from the AP after every transmission. If a sufficiently large transmission was sent the transfer rate would be able to overcome this however, as memory on the device is limited this wasn't possible therefore a partial pass was given. The following web link <https://arunoda.me/blog/load-testing-an-esp8266> shows extensive testing done on the ESP8266 showing its possible transfer speed. Although the transfer speeds of M.S.A.C didn't reach this due to the client disconnecting after every transmission, this shows that the devices are capable of 1kbps. Therefore a 50% partial pass was given for requirement 2. Requirement 17 was not completed at all due to an error in the transferring of the schedule from the website to the Basestation.

# Design

This section includes all the design documentation up to June 8, 2020.

## Draft Design

The draft design is a mockup of what the final design may look like. M.S.A.C will be building its final design using this initial design.

## Code Snippets

**ADC Code**

void WindSensor\_PORT\_init(void)

{

// Disable digital pin circuitry

gpio\_set\_pin\_direction(PB09, GPIO\_DIRECTION\_OFF);

gpio\_set\_pin\_function(PB09, PINMUX\_PB09B\_ADC0\_AIN3);

}

void WindSensor\_CLOCK\_init(void)

{

hri\_mclk\_set\_APBCMASK\_ADC0\_bit(MCLK);

hri\_gclk\_write\_PCHCTRL\_reg(GCLK, ADC0\_GCLK\_ID, CONF\_GCLK\_ADC0\_SRC | (1 << GCLK\_PCHCTRL\_CHEN\_Pos));

}

void WindSensor\_init(void)

{

WindSensor\_CLOCK\_init();

WindSensor\_PORT\_init();

adc\_sync\_init(&WindSensor, ADC0, \_adc\_get\_adc\_sync());

}

The above code initializes the ADC. The CLOCK\_init function sets up the clock that the ADC will be using. The PORT\_init function disables the GPIO feature of the pin and sets it to use the ADC feature. Lastly the adc\_sync\_init function enables the adc. This is a change from what was happening in that the ADC function we ended up using is synchronous. This means there is no callback function. This would typically not be used due to the system having to wait for the read function to finish before continuing to execute code, however, due to the system not needing to be real time and the fact that the code executes very quickly, it was determined that this wasn’t necessary. Also, when using the callback method the program had to wait for the result anyway, therefore, it was decided to use the synchronous version instead of the asynchronous version.

**ADC Read Code**

int check\_sensors() //DONE

{

uint8\_t temp[2];

uint8\_t wind[2];

adc\_sync\_enable\_channel(&WindSensor, 0);

adc\_sync\_read\_channel(&WindSensor, 0, wind, 2);

double w = ((uint16\_t)wind[1] << 8) | wind[0];

w = (((w \* 3300.0 / 4095.0) - 400) / 1600) \* 50;

adc\_sync\_disable\_channel(&WindSensor, 0);

adc\_sync\_enable\_channel(&TempSensor, 0);

adc\_sync\_read\_channel(&TempSensor, 0, temp, 2);

double c = ((uint16\_t)temp[1] << 8) | temp[0];

c = c \* (3300/4095.0);

c = ( c - 500) / 10;

double f = (c \*9 / 5)+32;

adc\_sync\_disable\_channel(&TempSensor, 0);

if(f < 80 && w < 8)

return 0;

else

return 1;

}

This is the function that converts the value obtained through the adc\_sync\_read\_channle call and determines if the system can start executing a cleaning. This function has two parts, one for each ADC read. Each part functions as follows. The ADC channel is enabled. The ADC value is updated. Due to the system outputting the value into 2 8-bit values the final value must be calculated by shifting the upper bits 8 bit higher. This is done and saved in a variable. Calculations are then done on this value to obtain the wind speed or the temperature depending on which channel it is. Finally, the channel is disabled. The channel is disabled to conserve power.

**Button Initialization Code**

gpio\_set\_pin\_direction(Manual\_1, GPIO\_DIRECTION\_IN);

gpio\_set\_pin\_pull\_mode(Manual\_1,GPIO\_PULL\_UP);

gpio\_set\_pin\_function(Manual\_1, GPIO\_PIN\_FUNCTION\_OFF);

This is an example of a single GPIO being set up. First the pin direction is set as input. Second the pin is set as a pull up. This means that a read of the pin with the button not being pressed is 1 while a pressed read would be 0. Finally the peripheral function of the pin is disabled and set for GPIO instead.

**Button Read Code**

int readbtn(int btn)

{

return gpio\_get\_pin\_level(btn);

}

The read button function is very simple. All that happens is the button that is being read is passed in and a read function is called. Essentially this is just a rebranding on the name of the function, however, initially the function did more. The extra code was removed and replaced with what is currently there. However, to avoid having to refactor the rest of the code the function was left in place.

**Website Setup Code**

void setup() {

WiFi.softAP(ssid, password);

WiFi.softAPConfig(local\_ip, gateway, subnet);

delay(100);

server.on("/", handle\_OnConnect);

server.on("/led1on", handle\_led1on);

server.on("/led1off", handle\_led1off);

server.onNotFound(handle\_NotFound);

server.begin();

}

This code sets up the website access point. The first line starts the website with the current SSID and password. The second line starts the wifi access point. After a delay, this allows the website to start, the different website URL’s are bound to functions that will run when that URL is accessed. Finally the server is started at which point clients can connect to and access the website.

**WIFI URL functions**

void handle\_OnConnect() {

server.send(200, "text/html", SendHTML());

}

void handle\_setrcu()

{

rcu\_to\_bs = server.arg(0).c\_str();

Serial.print(rcu\_to\_bs + "\n\r");

server.send(200, "text/plain", "");

}

void handle\_setbs()

{

bs\_to\_rcu = server.arg(0).c\_str();

Serial.print(bs\_to\_rcu + "\n\r");

server.send(200, "text/plain", "");

}

void handle\_getrcu()

{

Serial.print("sending\n\r");

server.send(200, "text/plain", rcu\_to\_bs);

}

void handle\_getbs()

{

Serial.print("sending\n\r");

server.send(200, "text/plain", bs\_to\_rcu);

}

void handle\_invert() {

uint8\_t i = atoi(server.arg(0).c\_str());

uint8\_t j = atoi(server.arg(1).c\_str());

if(Times[i][j] == HIGH)

{

Times[i][j] = LOW;

}

else

{

Times[i][j] = HIGH;

}

server.send(200, "text/html", SendHTML());

}

void handle\_NotFound(){

server.send(404, "text/plain", "Not found");

}

The handle\_on\_connect and handle\_notfound functions handle what happens when a client initially connects to the web server. The getrcu, setrcu, getbs, setbs functions are used to set and get the parameters that the Basestation and RCU use to communicate with each other. The Invert function is what controls the schedule. When a button is pressed on the website the triggering button is inverted from off to on or vice versa.

**Website HTML function**

String SendHTML(uint8\_t led1stat){

String ptr = "<!DOCTYPE html> <html>\n";

ptr +="<head><meta name=\"viewport\" content=\"width=device-width, initial-scale=1.0, user-scalable=no\">\n";

ptr +="<title>LED Control</title>\n";

ptr +="<style>html { font-family: Helvetica; display: inline-block; margin: 0px auto; text-align: center;}\n";

ptr +="body{margin-top: 50px;} h1 {color: #444444;margin: 50px auto 30px;} h3 {color: #444444;margin-bottom: 50px;}\n";

ptr +=".button {display: block;width: 80px;background-color: #1abc9c;border: none;color: white;padding: 13px 30px;text-decoration: none;font-size: 25px;margin: 0px auto 35px;cursor: pointer;border-radius: 4px;}\n";

ptr +=".button-on {background-color: #1abc9c;}\n";

ptr +=".button-on:active {background-color: #16a085;}\n";

ptr +=".button-off {background-color: #34495e;}\n";

ptr +=".button-off:active {background-color: #2c3e50;}\n";

ptr +="p {font-size: 14px;color: #888;margin-bottom: 10px;}\n";

ptr +="</style>\n";

ptr +="</head>\n";

ptr +="<body>\n";

ptr +="<h1>ESP8266 Web Server</h1>\n";

ptr +="<h3>Using Access Point(AP) Mode</h3>\n";

if(led1stat)

{ptr +="<p>LED1 Status: ON</p><a class=\"button button-off\" href=\"/led1off\">OFF</a>\n";}

else

{ptr +="<p>LED1 Status: OFF</p><a class=\"button button-on\" href=\"/led1on\">ON</a>\n";}

ptr +="</body>\n";

ptr +="</html>\n";

return ptr;

}

This function dynamically creates the HTML that is sent to the client. Based on the value that is passed in different HTML code is generated. The code that is generated depends on the value of the LED. This value changes the appearance and text of a button that the client will see. If the LED is off the client will see a green button with the word on. Clicking this button will then turn on the on-board LED and change the HTML that is displayed to a gray button that says “off”. This code can be extended, and multiple parameters passed in to change the HTML in many different ways. This is how the website will be implemented.

**PWM\_Ramp**

void pwm\_ramp()

{

int pwm\_params[16] = {2000, 1333, 1000, 800, 667, 571, 500, 444, 400, 364, 333, 308, 286, 267, 250, 235};

pwm\_set\_parameters(&StepperDriver, pwm\_params[3], pwm\_params[3]/2);

pwm\_enable(&StepperDriver);

os\_sleep(10);

pwm\_set\_parameters(&StepperDriver, pwm\_params[4], pwm\_params[4]/2);

os\_sleep(10);

pwm\_set\_parameters(&StepperDriver, pwm\_params[5], pwm\_params[5]/2);

os\_sleep(10);

pwm\_set\_parameters(&StepperDriver, pwm\_params[6], pwm\_params[6]/2);

os\_sleep(10);

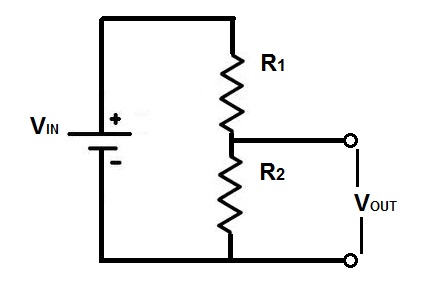
pwm\_set\_parameters(&StepperDriver, pwm\_params[7], pwm\_params[7]/2);

os\_sleep(10);//\*/

}

Due to the stepper motor used having a maximum acceleration a ramp function had to be used to allow the stepper motor to hit certain speeds. To accomplish this the PWM\_Ramp function is used. All this function does is output increasing frequencies over a period of time. Extensive testing was completed to find the fasted, yet still reliable, way of ramping the stepper motor to the max speed. The PWM\_Ramp function was the result.

**Battery Level Reading Circuit**



V­in = 14.6V max / 10.5 min

R1 = 47000Ω

R2 = 4700Ω

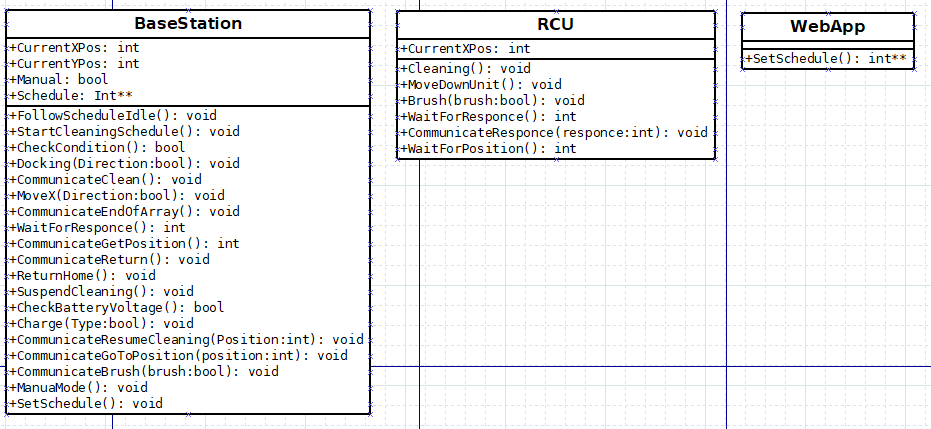
Ratio of R2 to R1 = 1/10 meaning R1 can be 4.3MΩ if R2 is 430kΩ

Vout = 1.33V max / 0.9595V min

1.1v read = 12.1v battery

The above figure is how the battery is read using the RCU’s ADC even though the RCUs ADC does not support 12v reads. Using a voltage divider with the shown values of R1 and R2 a value of less than 3.3v can be read in by the ADC. Calculations were preformed and it was determined that a 1.1v read results in a 12.1v current battery level. This is used to determine when the battery is a a level that it needs to be charged.

## UML



This is the current UML, this can only show what functions and variables are available, however there is a lot more information that can be seen when using the program to view the UML. This UML has been depreciated and replaced with other functions. However, it is being left in for reference as the current code implements the functionality of these function in less than what is shown. For instance all communication happens in a single function instead of multiple.

## Current Prototype

**RCU**

**A picture containing sitting, black, brown, table

Description automatically generated**

**Basestation**

**A picture containing computer

Description automatically generated**

**Current Solar Array Mockup**

A wooden table

Description automatically generated

## Pinout Connections

Below is the current pinout for the microcontrollers to the peripherals.

**Basestation**

PIN User Label Extension Functions Function SW component

|  |
| --- |
| PORT |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 11 | PB08 | Start\_Cleaning | EXT1 | ADC(-) | Digital input | P/11 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 18 | PA09 | Manual\_1 | EXT2 | ADC(-) | Digital input | P/18 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 19 | PA10 | Manual\_2 | EXT2 | GPIO1 | Digital input | P/19 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 20 | PA11 | Manual\_3\_old | EXT2 | GPIO2 | Digital input | P/20 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 27 | PB14 | Manual\_3 | EXT1 | IRQ/GPIO | Digital input | P/27 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 39 | PB16 | Manual\_7 | EXT2,DGI GPIO | IRQ/GPIO,GPIO1 | Digital input | P/39 |
| 41 | PA20 | Right | EXT1 | GPIO1 | Digital input | P/41 |
| 40 | PB17 | Direction | EXT2,DGI GPIO | SPI\_SS\_B/GPIO,GPIO2 | Digital output | P/40 |
| 42 | PA21 | Left | EXT1 | GPIO2 | Digital input | P/42 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 59 | PB30 | Manual\_4 | EXT2 | PWM(+) | Digital input | P/59 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 60 | PB31 | Manual\_5 | EXT2 | PWM(-) | Digital input | P/60 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 64 | PB03 | Manual\_6 | EXT2 | SPI\_SS\_A | Digital input | P/64 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| StepperDriver | | | | | | |
| 25 | PB12 | PB12 | EXT1,DGI GPIO | PWM(+),GPIO0 | Peripheral IO | WO/0 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 26 | PB13 | PB13 | EXT1 | PWM(-) | Peripheral IO | WO/1 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| TempSensor | | | | | | |
| 17 | PA08 | PA08 | EXT2 | ADC(+) | Analog | AIN/10 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| UART | | | | | | |
| 43 | PA22 | PA22 | EXT3,EXT2,EXT1 | UART\_TX,UART\_TX,UART\_TX | Peripheral IO | TX |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 44 | PA23 | PA23 | EXT3,EXT2,EXT1 | UART\_RX,UART\_RX,UART\_RX | Peripheral IO | RX |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| WindSensor | | | | | | |
| 12 | PB09 | PB09 | EXT1 | ADC(+) | Analog | AIN/3 |

## **RCU**

Pin# Pad ULabel Header Label Mode SW component signals

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Battery\_lvl | | | | | | |
| 12 | PB09 | PB09 | EXT1 | ADC(+) | Analog | AIN/3 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| PORT | | | | | | |
| 27 | PB14 | Direction | EXT1 | IRQ/GPIO | Digital output | P/27 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 28 | PB15 | Motor\_ON\_OFF | EXT1 | SPI\_SS\_B/GPIO | Digital output | P/28 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 41 | PA20 | up | EXT1 | GPIO1 | Digital input | P/41 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 42 | PA21 | down | EXT1 | GPIO2 | Digital input | P/42 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| StepperDriver | | | | | | |
| 25 | PB12 | PB12 | EXT1,DGI GPIO | PWM(+),GPIO0 | Peripheral IO | WO/0 |

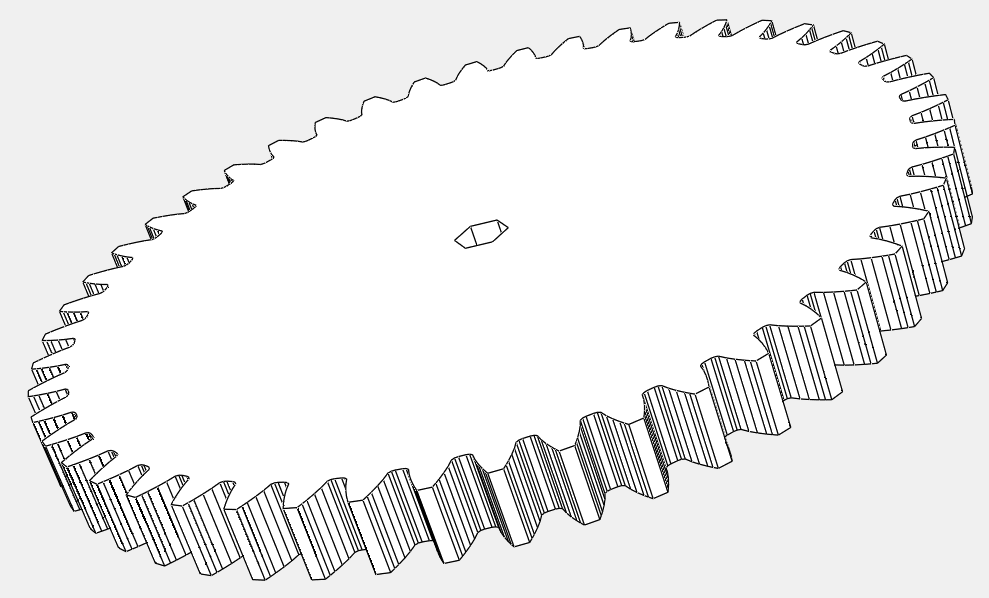
|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 26 | PB13 | PB13 | EXT1 | PWM(-) | Peripheral IO | WO/1 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| UART | | | | | | |
| 43 | PA22 | PA22 | EXT3,EXT2,EXT1 | UART\_TX,UART\_TX,UART\_TX | Peripheral IO | TX |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 44 | PA23 | PA23 | EXT3,EXT2,EXT1 | UART\_RX,UART\_RX,UART\_RX | Peripheral IO | RX |

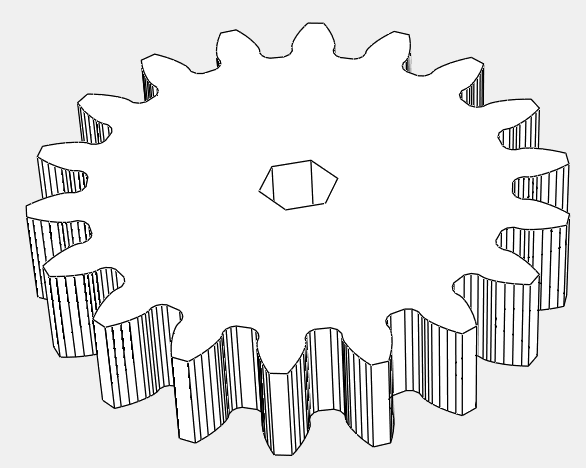
## 3D Designed Parts

**Brush Gear**



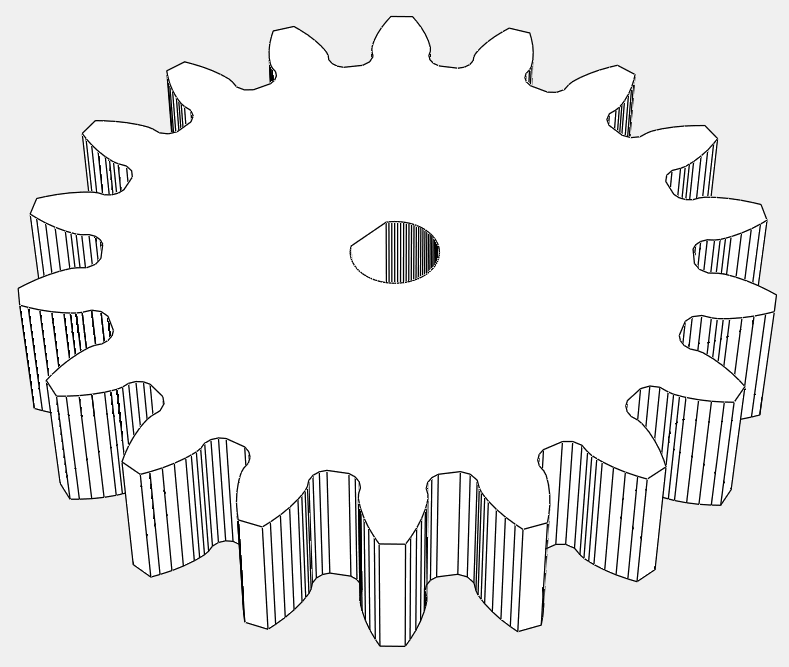
This is the gear that was designed to connect to the cleaning brushes. The hexagonal hole in the center matched the hexagonal shaft on the brushes. This allows the gear to snugly fit onto the brushes and when the gear is turned will also turn the brushes.

**Brush to DC conversion gear**



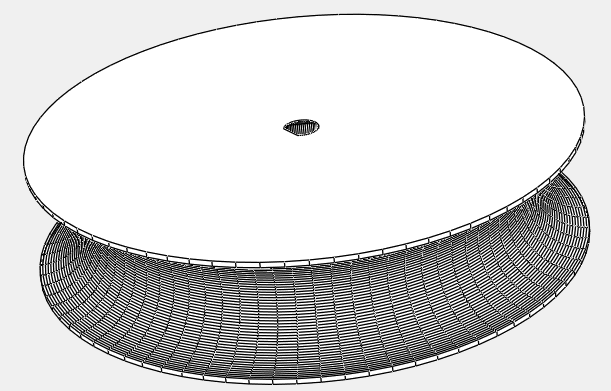
This gear also goes on the brushes however this gear will mount on the inside of the RCU and is what connects the brushes to the DC motor. The DC motor has an accompanying gear that it will have that will in turn rotate this transition gear. This allows the DC motor to have a smaller gear that will still translate the 100 RPM to the brushes.

**DC Gear**



This is the accompanying DC gear that was mentioned above, this gear will connect to the DC motor and turn the accompanying gear mounted on the brushes. The gear ratio from this gear to the above gear is 1 to 1. This translates into 100% of the RPM of the DC motor being given to the brushes. Therefor, the brushes themselves should turn at a rate of 100 RPM.

**Pully**



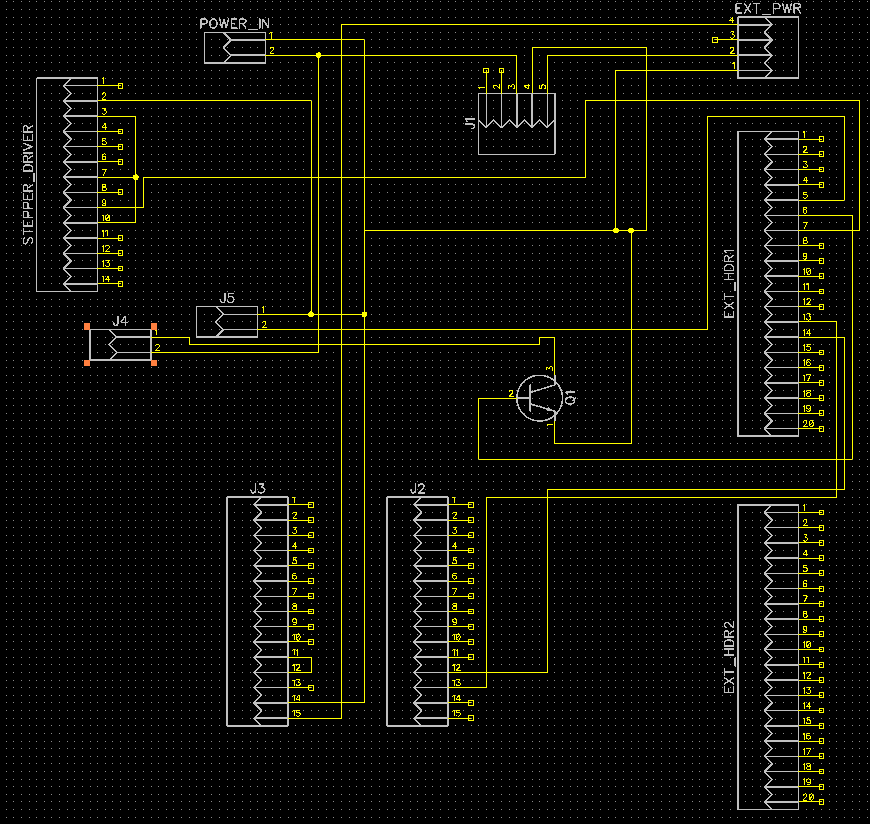
This is the new design for the pully. The pully is what wraps up all the extra cable that is not in use. Originally a 1/4 in cable was going to be used, however, after some research it was found that a 1/16 in cable is all that was needed. Therefore, the original design for the pully had to be reduced in size. Otherwise the pully would have been way to big and end up just taking to much room. Originally the pully was going to use a gear to drive it. However, after some redesigning that was switched to a direct drive solution.

**Future 3D changes**

Due to the inherent lack of strength of the 3D prints the method of attaching the prints to the gears and pullies will have to change. Currently the plan is to use half of a jaw coupling to give a better connection to the 3D printed parts. This will increase costs slightly, but it will in turn reduce the number of gears that are stripped and in turn reduce development costs.

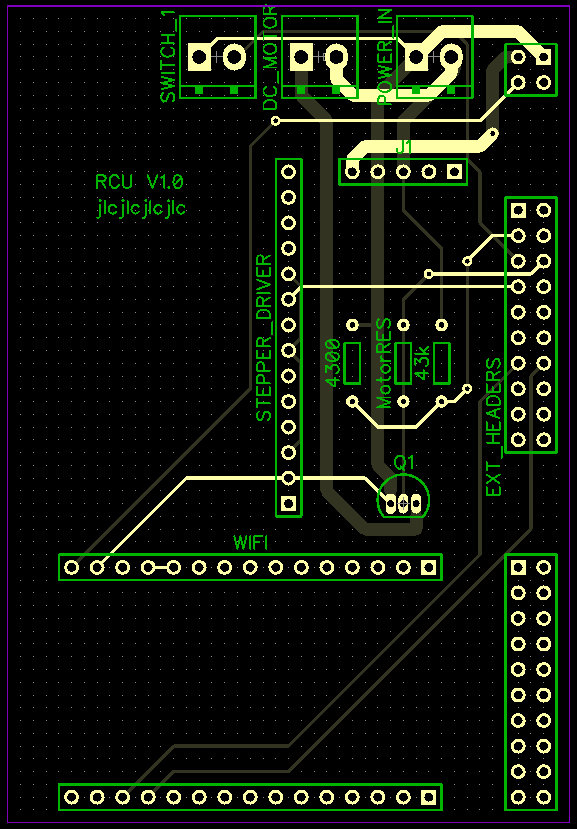
## PCB Design

**RCU**



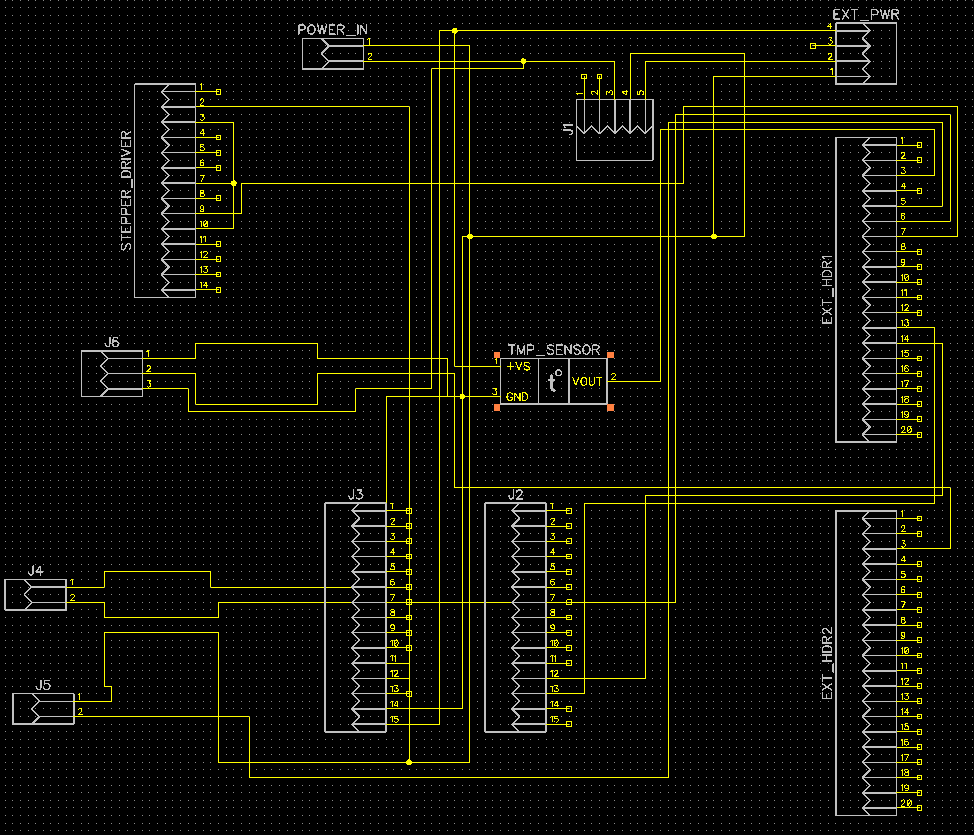
This is the schematic for the RUC. This will be translated into a PCB and then sent out to be constructed. Essentially this PCB is just a way of connecting components together without using jumper wires. However, there is still some components that are on here that are not just jumper wire connections.

**RCU PCB**



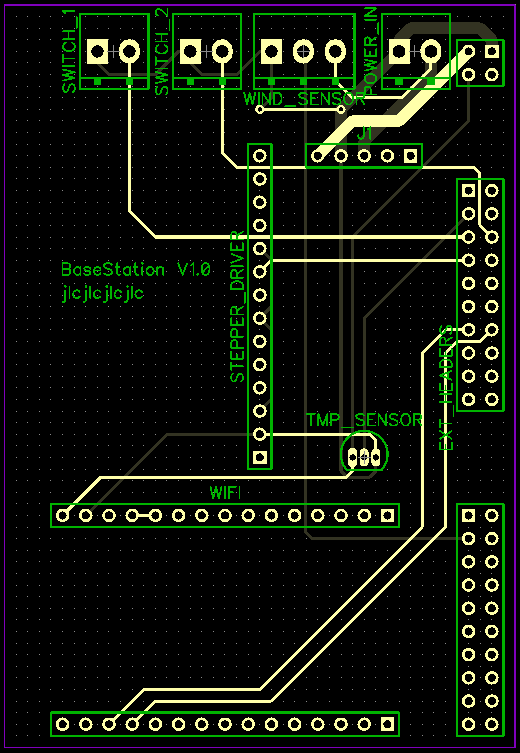
This is the PCB created using the RCU schematic. There is also a couple of components that were added in the final design that are not reflected in the schematic. These changes should be reflected in the later design schematic. There are also some additional changes to the PCB that will be reflected in later versions. During the next term the PCB will be redesigned again to accommodate a fly back diode to protect the circuit. Also, a direction pin will also be routed to the stepper motor driver.

**BaseStation Schematic**



This is the schematic for the BaseStation. This will be translated into a PCB and then sent out to be constructed. Essentially this PCB is just a way of connecting components together without using jumper wires. However there is still some components that are on here that are not just jumper wire connections.

**BaseStation PCB**



This is the PCB created using the BaseStation schematic. There is also a couple of components that were added in the final design that are not reflected in the schematic. These changes should be reflected in the later design schematic. In the next redesign of the Basestation PCB additional connectors will be used to allow the manual controller to be connected through the PCB. Also, an additional trace to allow direction control will be routed to the stepper motor driver.

Unfortunately due to a delay in the creation and shipping of the PCB M.S.A.C was unable to use this PCB. Future plans are to use it, however, currently a protoboard is being used.

**Website**

**![A screenshot of a computer

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RD4RXhpZgAATU0AKgAAAAgABAE7AAIAAAAPAAAISodpAAQAAAABAAAIWpydAAEAAAAeAAAQ0uocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAFRpbW90aHkgV3JpZ2h0AAAABZADAAIAAAAUAAAQqJAEAAIAAAAUAAAQvJKRAAIAAAADMjkAAJKSAAIAAAADMjkAAOocAAcAAAgMAAAInAAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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## Future changes

Currently there are no future changes that are planned for this project in the context of a senior project. Plans are to continue developing the project outside of school.

## Past Changes

MSAC swapped to a different battery due to the old battery being to heavy. MSAC swapped from using an Android application to using a website, this way iPhone users can also control MSAC. Also, this condenses the communication and the controls into one unit to reduce costs. MSAC also swapped to a new microcontroller that has the same functionality at less than half the cost.

# Glossary

AGC – Active Gain Control

Android -- an open-source operating system used for smartphones and tablet computers

Android Application – A program that runs on an android device

Android Device – A piece of hardware that runs the Android operating system

ECO – Engineering change order

ECR – Engineering change request

MSAC – Modular Solar Array Cleaner

RCU – Robotic Cleaning Unit

Solar Array – a linked collection of solar panels

Solar Panel – a panel designed to absorb the sun's rays as a source of energy for generating electricity

# Appendix

# References

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