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Blind-Automation Device

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Executive Summary

Our team set out to design and build a device to automatically move window covers. A series of interviews were conducted to determine project scope, customer needs, and target specifications. Based on the input of four interviewees, we designed six concepts for an inexpensive product that tilt twist-style blinds in response to ambient light levels and a time-based schedule. The concepts were scored and a single proof-of-concept prototype was created using a combination of 3D printing, basic analog circuitry, and an Arduino microcontroller. After parts were sourced and assembly began, we conducted an engineering analysis on the included blind stick and wall mounting system to ensure safe and consistent operation. Finally, through a week-long testing period, it was found that the prototype met or exceeded all performance goals and is a viable candidate for future development.
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1 INTRODUCTION AND BACKGROUND INFORMATION

1.1 INITIAL PROJECT DESCRIPTION
People forget to open their blinds in the morning and close them at night. Opening the blinds in the morning can be a cost-effective way of heating a room during the winter months, while closing them during the day can save energy during the summer. An affordable, easy to install automated blind actuator based on ambient light level measurement will eliminate these problems.

1.2 EXISTING PRODUCTS
Existing Product #1 – Somfy Ondeis Wirefree RTS Rain and Sun Sensor
This exterior mounted wireless sensor detects rain and sun and adjusts the blinds accordingly. Amount of sun or rain fall to trigger action is adjustable. Rain sensor intended to prevent damage to retractable awnings.

Figure 1: Somfy Ondeis wireless rain and sun sensor
**Existing Product #2 – Thermo Sunis Indoor Wirefree RTS Sun Sensor**

 Mounted on the inside of a window or window sill, this wireless sensor measures sunlight and temperature to determine optimal blind position.

![Figure 2: Thermo Sunis wireless sun sensor (indoor)](image)

**Existing Product #3 – HunterDouglas PowerView Motorization**

 Winner of the Red Dot design award, this attractive motorized blind interface focuses on the user experience. It allows programmable actions at specific times and automatic sunrise/set.

![Figure 3: Hunter Douglas PowerView Motorization](image)
1.3 RELEVANT PATENTS

**Patent #1 – US5760558A**

Solar powered, wireless, retro-fit-able. Intended for venetian blinds. This patent depicts a possible mechanism to point us in the right direction for initial concept generation. It’s useful to first think of what kind(s) of shades/blinds we want this device to be compatible for.


**Patent #2 –**

An interesting but wordy claim related to modeling the effects of sunlight on a buildings HVAC system for use alongside an automated blind system. The data they collect and analyze is interesting and could be a good starting point for our design.


1.4 CODES & STANDARDS

The codes and standards that have the possibility applying to our project are outlined in ANSI WCMA A100. These codes are primarily concerned with child safety, primarily restrictions on cord properties. These requirements influenced our decision in choosing how we decided which blinds to focus our project on.

1.5 PROJECT SCOPE

This project is intended to be a safe, easy, and inexpensive addition to window covers to maintain consistent indoor lighting by automatically adjusting blinds in response to ambient light levels.

Our target customers are homeowners/renters and business owners concerned about employee productivity and wellness. This product will allow homeowners, business owners, and building tenants to increase occupant productivity. Bright sunlight can cause glare, making employees uncomfortable and reducing their productivity, along with their health. The product will automatically adjust window blinds to maintain a comfortable interior lighting level, promoting productivity and the bottom line. The product can also reduce building energy consumption in the summer by reducing the amount of solar heat gain through the windows.

The main goals of our project are to ensure that we have a safe device that works with current blinds without modification, maintains comfortable interior light level, requires low maintenance and is quick to install. Our blind automation device will not be temperature dependent, move the blinds up and down or be solar powered. We are assuming that potential customers will already own twist style blinds and will agree with our definition of the acceptable light level.
1.6 PROJECT PLANNING

Below you will find our Gantt Chart which we used to plan how to complete this project in a timely manner. As you can see below, we stayed on our timeline for the majority of task. We fell slightly behind ordering parts, which made our time to build the prototype also slightly behind. We ultimately finished the first prototype by the ideal timeline.

![Gantt Chart Image](image-url)

1.7 REALISTIC CONSTRAINTS

1.7.1 Functional

Ideally the Blind Automation Device would connect to multiple sets of blinds. Because of the limited amount of power each motor can exert, the device must be attached to each set of blinds individually. Because of the individual attachment to each set of blinds, space becomes a limiting factor as some blinds will not have enough wall space to attach the device.

1.7.2 Safety

Our team considered the ANSI WCMA A100 standard concerning window covering safety. We found no concerns limiting our project.

1.7.3 Quality

The Blind Automation device would ideally allow the users to set their own definition for their ideal light level. To standardize and make sure the device is reliable, we decided to set the definition of the ideal light range.

1.7.4 Manufacturing

The Blind Automation Device would ideally use injection molding to make a casting that can be used for multiple materials. Instead we chose to use PLA due to its cheaper cost and accessibility.

1.7.5 Timing

The Blind Automation Device presents some challenges in the realm of timing. Ideally, the BAD would reliably reduce energy consumption with regular use. While energy savings will
probably still occur, our team did not have enough time to verify and refine the schedule to ensure energy savings. Even without ensuring that energy savings exist, the device will require several iterations to achieve a clean and compact version ready for market. This process could take several months. If a better user interface is desired, significant time will be invested to add a screen or wireless application. We produced only the first of these prototypes. While we are far from a manufacture-ready product, our design is scalable and, with some changes, would be easy and inexpensive to manufacture.

1.7.6 Economic

Because we wanted to create a prototype on a budget and also pass on a reasonable market price, we were very conscious of manufacturing costs. From our market analysis, we wanted to remain inexpensive. We chose to 3-D print our casing; ideally, we would want to use injection molded plastic for the case, but this would be unrealistically costly for a single prototype. An LED screen would provide a friendlier user interface, but would be more costly to implement. We were also unable to implement a wireless network of multiple linked blind controls because that would be too costly.

1.7.7 Ergonomic

Our team decided that the ultimate ergonomic interface is a smartphone app. We decided to pursue a simple manual interface using knobs, switches, and LEDs instead to limit price and development time.

1.7.8 Ecological

The first prototype of the device is not limited by ecological constraints.

1.7.9 Aesthetic

Ideally, we would want to place the light sensor on the ceiling above the blinds, as this is the location with minimal shadow and interference from people and other moving objects. This would involve lots of cords and would be ugly, therefore we decided to place the light sensor next to the window, by the box, in a position that is not as visually intrusive.

To make a less costly product, we could do away with the 3-D printed case we have designed; we would simply need anything to cover the electronics. However, for aesthetic reasons, we designed a custom printed case to contain the components of our device.

1.7.10 Life Cycle

The only moving parts in this device are the stepper motor and the universal joints. Both have extremely long life cycles, thus analysis was overlooked until later stages of manufacturing.

1.7.11 Legal

Extensive patent and legal research yielded no considerations that held back our design.

1.8 REVISED PROJECT DESCRIPTION

The Blind-Automation Device or “BAD” is a safe, easy, and inexpensive retrofit to window cover systems that maintains consistent indoor lighting. BAD functions by automatically adjusting blinds in response to ambient light levels.
2 CUSTOMER NEEDS & PRODUCT SPECIFICATIONS

2.1 CUSTOMER INTERVIEWS
In order to help us decide what factors are most important to our consumers, we asked our interviewees the following questions:

1. What kind of building would you use this product in?
2. What kind of window coverings do you use?
3. Do you open/close both your curtains and blinds?
4. What mechanism tilts your blinds (twist or pull)?
5. What is your preferred way of opening your blinds (tilt/raise)?
6. How much would you spend to automate your blinds?
7. How often would you be willing to change batteries?
8. How long are you willing to spend setting up the blinds?
9. How often do you move your window coverings?
10. When do you open your blinds?
11. When do you close your blinds?
12. Why do you open/close your blinds?
13. If you could automate your blinds, what would you want your schedule to be?

2.2 INTERPRETED CUSTOMER NEEDS
Based off the responses to the questions listed in the customer interviews, we determined that the customers had a wide range of needs. We took the fact that most of the people we interviewed lived in apartments to mean that our device shouldn’t cause permanent damage to the walls. We also took the fact that most people tilt their blinds to open them coupled with the fact that most blind systems were twist to tilt to focus our design on twist style blinds. Using the information for how much people were willing to spend to automate their blinds, we determined that the blinds need to be no more than $50 on average per device. With the interviewees expressing they would not be willing to change batteries more than 2-3 times a year to mean that we need to make sure our device has a very strong battery/ requires a small amount of power. Upon analyzing the data on why people use blinds and their usage patterns, we realized that this varies greatly person to person and that it would be best to pursue options where the user sets when the blinds automate and have the ability to quickly override this setting.
Table 1: Interpreted Needs

<table>
<thead>
<tr>
<th>Need Number</th>
<th>Need</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BAD is affordable</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>BAD is easy to install</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>BAD is low maintenance</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>BAD does not cause permanent damage to qalls</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>BAD is retrofittable to slatted blinds</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>BAD is retrofittable to curtains</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>BAD retrofittable to cloth screens</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>BAD raises and lowers blinds</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>BAD tilts blinds</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>BAD works with twist-to-tilt blinds</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>BAD works with pull-to-tilt blinds</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>BAD suits customer schedule</td>
<td>5</td>
</tr>
</tbody>
</table>

2.3 TARGET SPECIFICATIONS

Using the interpreted customer needs, we came up with the metrics to address their needs. These metrics and which needs they are associated with are provided in the table below.

Table 2: Target Specifications

<table>
<thead>
<tr>
<th>Metric Number</th>
<th>Associated Needs</th>
<th>Metric</th>
<th>Units</th>
<th>Acceptable</th>
<th>Ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Cost of components</td>
<td>dollars</td>
<td>&lt;100</td>
<td>&lt;50</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Time to install</td>
<td>minutes</td>
<td>&lt;30</td>
<td>&lt;15</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Number of months until battery replacement</td>
<td>Integer</td>
<td>&gt;4</td>
<td>&gt;12</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Removable and does not cause permanent damage to wall</td>
<td>Binary</td>
<td>pass</td>
<td>pass</td>
</tr>
<tr>
<td>5</td>
<td>8, 9, 10, 11</td>
<td>Opens blinds</td>
<td>Binary</td>
<td>pass</td>
<td>pass</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>User specified control</td>
<td>Binary</td>
<td>pass</td>
<td>pass</td>
</tr>
<tr>
<td>7</td>
<td>ANSI WCMA A100.1-2012 5.3.1.1</td>
<td>Height of “WARNING” label (in all uppercase letters)</td>
<td>inch</td>
<td>&gt;=5/16</td>
<td>5/16 inch</td>
</tr>
<tr>
<td>8</td>
<td>ANSI WCMA A100.1-2012 6.2.1.1.1</td>
<td>Service life of cord retraction device</td>
<td>cycles</td>
<td>&gt;5000</td>
<td>&gt;5000</td>
</tr>
<tr>
<td>9</td>
<td>Team defined</td>
<td>Stays securely attached</td>
<td>Binary</td>
<td>pass</td>
<td>pass</td>
</tr>
<tr>
<td>10</td>
<td>5, 6, 7</td>
<td>Retrofittable to existing blinds</td>
<td>Binary</td>
<td>pass</td>
<td>pass</td>
</tr>
</tbody>
</table>
3 CONCEPT GENERATION

3.1 FUNCTIONAL DECOMPOSITION

Functional Decomposition is the process of taking a complex process and breaking it down into its smaller, simpler parts.

![Function tree diagram]

Figure 5: Function tree
3.2 MORPHOLOGICAL CHART

![Morphological Chart](image)

Figure 6: Morphological Chart

3.3 CONCEPT #1 – “KNOBBY”
An ambient light sensor provides the input to this device. Using the input data, the microprocessor determines the desired angle of blinds and sends a signal to the motor. The motor then twists the blinds stick via friction fit clamp. The user can override the automation by pushing the knob and turning to the right or left to go up or down. The device is powered by a wall plug.
3.4 CONCEPT #2 – “INTERNET BLINDS”
This device has an internet connection that can look up the current sun angle and cloud cover. The microprocessor determines the desired sun angle and passes this along to the motor. The motor connects to the blinds handle through a drilled hole at the bottom of the handle. A three-position switch allows the user to override the automation. The device is powered by an internal battery.

3.5 CONCEPT #3 – “SOLAR BLINDS”
This device features a solar panel which charges an internal battery. A light sensor determines the lighting level, and the output from the sensor directly operates the motor. The motor twists a shaft which, via u-joint and socket, twists the blinds handle and changes the tilt of the blinds. Up
and down buttons allow for manual control. Hold both to toggle between automatic mode and override mode.

Figure 9: Concept 3 – “Solar Blinds”

3.6 CONCEPT #4 – “BLINDOSTAT”

The user schedules the device using the screen and up/down buttons, like a programmable thermostat. The microprocessor determines the desired blind angle and relays this to a rotating shaft exiting the box. The rotating shaft is connected to a universal joint which allows for angular transmission and twists the blinds stick via a socket joint. Override, up, and down buttons allow the user to manually control the blind angle. The device is powered via a wall socket.
3.7 CONCEPT #5 – “HIGH TECH”
An iPhone/Android app is used to communicate preferences to the device. A microprocessor powered by a battery will instruct a motor to move when appropriate. The motor, connected via a friction coupler, will drive the blind twist stick.
3.8 CONCEPT #6 – “LOW TECH”

Powered by a wall socket, this prototype uses an internal clock circuit to calculate the angle of the sun at different times of the year. Using this information, it moves the blinds to adjust the light level. The twist rod of the blinds is attached directly to the motor shaft with no coupling. A 3 position switch is available as an override - up for blinds open, down for blinds closed, and neutral for automatic operation.

Figure 12: Concept 6 – “Low Tech”

4 CONCEPT SELECTION

4.1 CONCEPT SCORING MATRIX

<table>
<thead>
<tr>
<th>Selection Criterion</th>
<th>Weight (%)</th>
<th>Rating</th>
<th>Weighted</th>
<th>Rating</th>
<th>Weighted</th>
<th>Rating</th>
<th>Weighted</th>
<th>Rating</th>
<th>Weighted</th>
<th>Rating</th>
<th>Weighted</th>
<th>Weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of components</td>
<td>12.00%</td>
<td>3</td>
<td>0.036</td>
<td>2</td>
<td>0.024</td>
<td>2</td>
<td>0.004</td>
<td>2</td>
<td>0.004</td>
<td>3</td>
<td>0.004</td>
<td>3</td>
</tr>
<tr>
<td>Ease of install</td>
<td>10.00%</td>
<td>4</td>
<td>0.040</td>
<td>3</td>
<td>0.009</td>
<td>4</td>
<td>0.004</td>
<td>4</td>
<td>0.004</td>
<td>5</td>
<td>0.005</td>
<td>3</td>
</tr>
<tr>
<td>Maintenance interval</td>
<td>12.00%</td>
<td>5</td>
<td>0.050</td>
<td>2</td>
<td>0.024</td>
<td>5</td>
<td>0.006</td>
<td>3</td>
<td>0.006</td>
<td>2</td>
<td>0.005</td>
<td>5</td>
</tr>
<tr>
<td>Accuracy of input data</td>
<td>7.00%</td>
<td>4</td>
<td>0.028</td>
<td>3</td>
<td>0.009</td>
<td>4</td>
<td>0.004</td>
<td>5</td>
<td>0.005</td>
<td>4</td>
<td>0.008</td>
<td>3</td>
</tr>
<tr>
<td>Removability</td>
<td>6.00%</td>
<td>5</td>
<td>0.030</td>
<td>3</td>
<td>0.009</td>
<td>5</td>
<td>0.003</td>
<td>5</td>
<td>0.003</td>
<td>5</td>
<td>0.003</td>
<td>3</td>
</tr>
<tr>
<td>Percent ability to existing blinds</td>
<td>8.00%</td>
<td>5</td>
<td>0.040</td>
<td>3</td>
<td>0.009</td>
<td>5</td>
<td>0.004</td>
<td>5</td>
<td>0.004</td>
<td>5</td>
<td>0.004</td>
<td>4</td>
</tr>
<tr>
<td>Safety</td>
<td>10.00%</td>
<td>3</td>
<td>0.030</td>
<td>5</td>
<td>0.005</td>
<td>3</td>
<td>0.003</td>
<td>5</td>
<td>0.005</td>
<td>3</td>
<td>0.005</td>
<td>3</td>
</tr>
<tr>
<td>Power consumption</td>
<td>8.00%</td>
<td>3</td>
<td>0.024</td>
<td>2</td>
<td>0.011</td>
<td>3</td>
<td>0.002</td>
<td>4</td>
<td>0.001</td>
<td>1</td>
<td>0.008</td>
<td>4</td>
</tr>
<tr>
<td>User interface</td>
<td>14.00%</td>
<td>5</td>
<td>0.070</td>
<td>3</td>
<td>0.042</td>
<td>2</td>
<td>0.028</td>
<td>3</td>
<td>0.008</td>
<td>5</td>
<td>0.007</td>
<td>2</td>
</tr>
<tr>
<td>Ease of construction</td>
<td>13.00%</td>
<td>3</td>
<td>0.039</td>
<td>2</td>
<td>0.024</td>
<td>2</td>
<td>0.009</td>
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| Total score                          | 0.0397     | 0.0371  | 0.035    | 0.005    | 0.0348   | 0.0335  | 0.0326 |
| Rank                                 | 1          | 3       | 2        | 4        | 2        | 5       |        |

Figure 13: Concept Scoring Matrix
4.2 EXPLANATION OF WINNING CONCEPT SCORES

Knobby wins the concept selection with a total score of .0397! This concept has the best maintenance interval out of all the options given that it uses an outlet for the energy supply instead of a battery. Not only that, but this has the best user interface by keeping the number of buttons to a minimum and only using a push knob to manually override the blinds. Not only that, but the user won’t be able to turn the knob when it is not in override mode which decreases the chances of the user accidentally changing the setup. This option has a 4 rating for the accuracy of input data by using an ambient light sensor. This sensor shows directly the amount of light in the room which is very accurate outside of slight changes due to objects walking by. The overall install of this is a 4 given that the user does not have to worry about installing battery, and only needs to place the light sensor without worrying about the set-up sets required for some of the other options like Wi-Fi. The only limitation to the ease of install is the availability of wall outlets and the length of the cord. The length of the cord also affects the safety of the product as it can pose as a choking hazard for children. This option earns a 3 in the power consumption category as the microprocessor is always working to take in the input from the ambient light sensor.

Figure 14: Winning Concept – “Knobby”
4.3 **EXPLANATION OF SECOND-PLACE CONCEPT SCORES**

Blindostat comes in at second with the best maintenance interval given essentially no maintenance since it uses a wall outlet as the power source. This option also boasts the best input accuracy as the microprocessor works based off of the time alone. The ease of install of this one is also one of the best with the only limiting factor being the cord and availability of outlets. The length of the cord also gives this concept a 3 in the safety rating as it poses a choking hazard. This Blindostat earns a 4 in the power consumption as it needs more energy to display the time on the clock. The Blindostat only earns a 3 in the user interface as the user would need to automatically remember to push the override button before pushing the up and down buttons. Finally, the Blindostat scores a 2 for the cost of components as the addition of a LED screen significantly increases the cost.
4.4 EXPLANATION OF THIRD-PLACE CONCEPT SCORES

Figure 16: Third place concept - "Solar Blinds"

The solar blinds scores a 5 in maintenance interval given that it comes with a rechargeable battery which significantly decreases the number of times the user will need to replace the batteries. The lack of the power cord brings this one to a 5 on safety as there are no choking hazards like the previous two options. Again as mentioned in Concept 1, the use of the ambient light sensor is almost perfect with the only limitations being temporary changes in light. Because of the light sensor, the accuracy of the input data can be slightly impacted giving this a 4 in that category. This scores a 2 in the user interface category as the user would need to remember how to enter override mode, before any changes to the slats can be changed. The use of the solar panel to recharge the battery makes the Solar blinds have a 2 in the ease of construction area. Construction of the blinds is inhibited by the user needing to determine the best place for the solar panel to maximize amount of gained power. Not only that, but the addition of the solar panel significantly increases the cost bringing the cost of components to a 2.

4.5 SUMMARY OF EVALUATION RESULTS

Overall, winning designs were one that had minimal user inconvenience and cost while maintaining the functionality of the blind automation device. We chose the “Knobby” design because it adjusts directly based on ambient light levels, without needing an internet connection. It has a simple user interface, without the need for a screen, which reduces the cost. Other options were costlier due to a screen or less accurate due to light level inputs from the internet rather than directly from the room.
5  EMBODIMENT & FABRICATION PLAN

5.1  ISOMETRIC DRAWING WITH BILL OF MATERIALS

Figure 17: Isometric CAD drawing
5.2 EXPLODED VIEW

Figure 18: CAD Exploded View
5.3 ADDITIONAL VIEWS

Figure 19: Front view with bill of materials
Figure 20: Top view
6 ENGINEERING ANALYSIS

6.1 ENGINEERING ANALYSIS RESULTS

6.1.1 Motivation
Our team wants to limit the torque of our Blind Automation Device (BAD) to avoid breaking the user’s blinds. We conducted preliminary research and analysis to determine the torque required to break the blinds. There are no applicable codes, but plentiful unhappy customers if the analysis is not conducted. We hope to not only limit the torque of the motor used in BAD, but possibly purchase a smaller and less expensive motor for future iterations. Another thing we want to do is make sure that the adhesive provided is strong enough to hold the box and not destroy the walls. We have decided to analyze how much 3M Extreme Mounting Tape to make sure that this is a feasible option for our users who are renting spaces or don’t want to damage paint jobs or drill into their walls.
6.1.2 Summary Statement of the Analysis

SOLIDWORKS Motion was used to calculate the maximum von Mises stress on the blind wand hook when the maximum motor torque is applied to the stick.

6.1.3 Methodology

6.1.3.1 Torque

Our team determined through experience and visual analysis that the weakest part of twist-style blinds exists where the blind stick attached to the turning mechanism. Specifically, we expect the hook on the end of the stick to snap in torsion. For future analysis, we would like to utilize destructive testing to confirm this hypothesis. We would take a set of blinds and measure the amount of torque required to break the hook. However, due to budgetary concerns, we were not able to test in this manner.

In the meantime, we modeled a blind stick with a hook in SOLIDWORKS and used Motion Simulation to apply a torque. After researching blind wand materials, we modeled the entire blind stick as PVC. With the material constraints, we can tell approximately how much torque is required to break the PVC hook and compare it to the maximum torque that the stepper motor can exert. It was approximated that the hook would interface with the ring on the c-shaped surface shown in green below; this face was fixed in the analysis. To simplify the
simulation, the length of the stick was not modeled, and the torque is applied at the bottom face of the hook. The torque applied was 0.48 N-m, the maximum possible torque the motor can produce.

Figure 23: SOLIDWORKS Motion methodology: fixed face and torque applied

6.1.3.2 Adhesive
To analyze the strength of the adhesive we got statistics from Scotch®. According to the information on the packaging, 60” of this tape holds 30lbs shear force, which means that each inch in length can support half a pound. We obtained the weight of the box to be approximately 7lbs. We want to make sure to have a factor of safety of at least 2 when analyzing the results.

6.1.4 Results
6.1.4.1 Torque
The ultimate tensile strength of PVC is approximately 52 MPa. When the maximum torque of 0.48 N-m is applied, the following von Mises stress distribution is the result. The maximum stress was 669.5 MPa, which exceeds the tensile strength of PVC.

6.1.4.2 Adhesive
With the box weighing 7 lbs and accounting for a factor of safety of 2, we need the tape to support a minimum of 14 lbs. With the current rating of half a pound per inch, we would need around 28 inches of tape. We will suggest using four 7 inch pieces of tape which should give us the proper coverage.

6.1.5 Significance
6.1.5.1 Torque
If the blinds were twisted past either end position and the motor continues turning at full power, the hook of the blind wand could potentially snap. We anticipated this issue by having a setting for the user to program the top and bottom stops of the blind device. The code is programmed so that the motor will not turn beyond these stops. In future prototypes, we could select a less powerful motor – one that provides just enough torque to twist the blinds will be enough. To stay within the ultimate stress of our blind hook,
we would want to select a motor with a maximum torque of 0.15 Nm. Alternatively, we could reinforce our hook with electrical tape. However, we felt that with our current software checks, we did not need to change our current design concept.

6.1.5.2 Adhesive

Considering the current amount of tape that would be required to ensure that it can safely support the weight of the box, we might consider other taping options. This amount of tape will essentially cover the back of the box, which seems excessive. With this in mind, we also think that this number is excessive because the tape itself has a built in factor of safety. We tested this with 10 inches of tape and it held the device overnight.

6.2 PRODUCT RISK ASSESSMENT

6.2.1 Risk Identification

1) Adhesive failure
   a. Description: If the adhesive fails, the box can fall off the wall. We are currently managing this by using strong adhesives.
   b. Impact – 2 If the adhesive fails, then the most that’ll happen is that the user will need to reattach device to wall.
   c. Likelihood – 3 This is likely if the adhesive weakens over time, or if the user does not properly install

2) Motor keeps spinning and breaks blinds
   a. Description: Malfunction of hardware can lead to the motor constantly spinning. Currently stopping and testing the code to minimize the possibility of code making this error.
   b. Impact – 4 The device will essentially not function as intended if this happens
   c. Likelihood – 2 We think this is unlikely, because we testing the code and error-proofed it.

3) Entanglement
   a. Description: User clothing/hair could get caught in u-joint.
   b. Impact – 1 This will personally effect the user, not the function of the device.
   c. Likelihood – 1 This is unlikely given that the user will not be near the device during most of the device lifespan

4) Water Damage
   a. Description: The box is not weatherproof. Water from a leaky window could enter box and destroy components
   b. Impact – 3 This could destroy the internal components which could effect how the device works
   c. Likelihood – 1 We think this isn’t likely that a user will put this on a leaky window

5) Fire
   a. Description: Excess heat from motor could cause fire.
   b. Impact – 5 This would be serious, because the device will no longer function and the safety of the user will be impacted
   c. Likelihood – 1 We used safe circuitry to minimize the chances of this happening.

6) Lacerations
   a. Description: User could injure self on box edges.
   b. Impact – 1 The user could potentially cut themselves, but the device will still work normally
   c. Likelihood – 3 This is average likelihood given that the box does not have rounded corner
6.2.2 Risk Heat Map

![Risk Assessment Heat Map](image)

**Figure 24: Risk Assessment Heat Map**

6.2.3 Risk Prioritization

We believe the heat map is very accurate for the risks mentioned. We would spend the most effort trying to resolve issues associated with adhesive failure and the motor continuously spinning and breaking blinds. We would spend more energy on those two items, because they would have the greatest likelihood and impact out of all the 6 options. Some of our ideas for minimizing the chances of the motor keep spinning include adjusting the stepper motor to make this impossible and possibly providing a custom stick based on our analysis. Some of our ideas for the adhesive failure include providing alternative mounting methods and reducing the weight of the box.

The fire due to excess heat from the motor is a low priority due to its’ low likelihood considering the motor limits motor run time. Water damage, lacerations, and entanglement are all low priorities due to their low likelihood, low impact, and controllability. These three items are dependent on factors outside of our control such as what the user is wearing, how the user handles the product, and the status of the user’s window. We can provide additional warning labels to lower the chance of entanglement and lacerations. We could also in future designs, round the edges of the box, to minimize chance of lacerations.
7 DESIGN DOCUMENTATION

7.1 PERFORMANCE GOALS

1. BAD will take less than 15 minutes to install
2. BAD knob positions worked correctly
3. BAD will change slat angle in response to complete darkness and bright light
4. BAD will automatically adjust blinds to appropriate angle within 1 minute of light level change
5. BAD will automatically keep blinds closed during user defined night time

7.2 WORKING PROTOTYPE DEMONSTRATION

7.2.1 Performance Evaluation

In the next video link you will see that our device met all of our performance goals. BAD took around 3 minutes to install so we are confident that the average user can install the device in 15 minutes. All the knob buttons worked correctly and the blinds responded complete darkness and bright light while also responding to the ambient light levels within 1 minute of the light level change. Finally, the user defined times worked correctly for the user.

7.2.2 Working Prototype – Video Link

https://youtu.be/GwnxGZlO6W0

7.2.3 Additional Photos

![Photo of prototype: Isometric view](image.jpg)

Figure 25: Photo of prototype: Isometric view
Figure 26: Photo of prototype: front view
Figure 27: Photo of prototype: front isometric view

Figure 28: Photo of prototype: side view
Figure 29: Photo of prototype: internal view
8 DISCUSSION

8.1 DESIGN FOR MANUFACTURING – PART REDESIGN FOR INJECTION MOLDING

8.1.1 Draft Analysis Results

Figure 30: Project enclosure before drafting

Figure 31: Post-drafting evaluation of the project enclosure

8.1.2 Explanation of Design Changes

The enclosure for our Blind Automation Device is a prime candidate for injection molding. To prepare for this process, our team used the SOLIDWORKS Draft analysis tool. The tool
found that 8 faces required drafting before injection molding is feasible. After applying several different draft angles, it was found that a -2-degree draft angle on all vertical surfaces produced a part that can be injection molded. See the Fig. 20 and Fig. 21 below for a side by side comparison of the test results before and after our changes.

8.2 DESIGN FOR USABILITY – EFFECT OF IMPAIRMENTS ON USABILITY

8.2.1 Vision
A vision impairment, such as red-green color blindness or presbyopia, may influence the usability of our device because much of our user interface is visually based. Labels on the knobs and switches are visual, and the LED is a visual indicator as well. Some of the labels, especially the ticks for the time knob and the labels for the five-position switch may be difficult to read with presbyopia. Red-green color blindness should not impair the usability of our device. We could improve usability for people with a vision impairment by providing physical raised ticks that can be felt with the hand, thicker lines, larger font, and knobs that are farther apart. We could also provide an auditory indicator to supplement the LED.

8.2.2 Hearing
A hearing impairment such as Presbycutia, would not affect the usability of our device. However, it may affect safety. A user without a hearing impairment may be able to hear an unusual noise or hum coming from the device if something were going wrong with the device. A user with a hearing impairment may not have this benefit.

8.2.3 Physical
A physical impairment such as arthritis, muscle weakness, or limb immobilization, may influence the usability of our device because the knobs and switches to control the device are relatively small and require a moderate amount of finger space. Individuals with physical impairments may have trouble gripping the small knobs and making the minute adjustments sometimes necessary to operate the device. We could improve the device by making knobs larger and easier to grip.

8.2.4 Language
A language impairment (i.e. speaking little or no English, in this case) may influence the usability of your device, as all our instructions and the position labels on the 5-position switch are in English. We could improve our product by providing instructions and labels in pictograph or in other common languages.

8.2 OVERALL EXPERIENCE

8.2.1 Does your final project result align with the initial project description?
Our final project aligned with the initial project description. Our goal was to maintain a comfortable ambient light level inside a room by adjusting the angle of Venetian blinds through a retrofit. We were able to do so.

8.2.2 Was the project more or less difficult than you had expected?
Some aspects of the project were more difficult, and others were less difficult than we had expected. The coding was much more difficult than anticipated. We spent most of the time coding, which was challenging because none of us were very familiar with Arduino. Once we
got the code to work and everything wired correctly, the mechanical components of this project were not too challenging.

8.2.3 In what ways do you wish your final prototype would have performed better?

It would be nice to have a better user interface. The current setup with three knobs and a switch is a little bit confusing. Ideally, we would have a screen and fewer knobs, but this was not feasible with our budget. We also burn through batteries quickly because the stepper motor is always powered. Ideally, our device would have some sort of “sleep mode” to minimize power consumption.

8.2.4 Was your group missing any critical information when you evaluated concepts?

We did not know that the stepper motor would need power even when it was not moving. If we had known this when we evaluated our options, we may have chosen a different motor or designed a way to power it only when needed.

8.2.5 Were there additional engineering analyses that could have helped guide your design?

An analysis of power consumption could have helped us with battery selection.

8.2.6 How did you identify your most relevant codes and standards and how they influence revision of the design?

We looked for codes and standards that blinds would have to follow. The majority of these were related to child safety, as blinds cords can be dangerous for small children. Because our device does not make any changes to the cords, the codes and standards were not relevant in our design.

8.2.7 What ethical considerations (from the Engineering Ethics and Design for Environment seminar) are relevant to your device? How could these considerations be addressed?

A possible ethical concern revolves around sourcing parts. This could be an issue considering child labor laws and unsafe work conditions for workers producing the parts. This will likely in future iterations not be an issue if we produce everything in house/ only use reputable sources.

8.2.8 On which part(s) of the design process should your group have spent more time? Which parts required less time?

We should have spent more time on the connections between the motor and the blind. We could have spent more time playing around with different universal joints and shafts and figuring out ideal placement of the device. We should have also spent more time on the markings/labels for the knobs. We should have spent less time working on making the motor work. We had a lot of difficulty with turning the stepper motor; we later discovered this would happen any time the batteries were low, not due to any error on our part. We should have connected our device to a power supply to keep consistent power and avoid this issue. We could have also spent some time designing a hinge system to attach the lid of the box.

8.2.9 Was there a task on your Gantt chart that was much harder than expected? Were there any that were much easier?

The Design for X and engineering analysis assignments were harder than expected. Most of the others were not too challenging because they were repetitive.
8.2.10 Was there a component of your prototype that was significantly easier or harder to make/assemble than you expected?

Certain aspects of coding were challenging. We had a lot of difficulty with turning the stepper motor; we later discovered this would happen any time the batteries were low, not because our code was wrong. The 3D printed box was surprisingly easy to make and turned out well.

8.2.11 If your budget were increased to 10x its original amount, would your approach have changed? If so, in what specific ways?

We would have designed a more versatile coupler system between the stepper motor and twist rod. Because universal joints are very expensive, we could only use ones that we had scavenged, one of which did not have a good range of motion. With a larger budget, we could purchase better universal joints. We would also change the user interface by using an LED screen and fewer buttons. We would choose lithium batteries, since ours ran out of power quickly. We would also think about how to connect several devices across a single room, so the user would only have to interact with one control box for all the windows instead of one box per window.

8.2.12 If you were able to take the course again with the same project and group, what would you have done differently the second time around?

We would have selected a better power source, considered attachments between the case and lid, and probably selected a smaller stepper motor. We would have also started prototype build earlier than the class timeline.

8.2.13 Were your team member’s skills complementary?

Yes. Dalton had more experience with the electronics. Melinda and Haley had more experience with coding.

8.2.14 Was any needed skill missing from the group?

No. With our combined skills, we were able to cover all skills needed, or quickly learn the necessary skills.

8.2.15 Has the project enhanced your design skills?

Yes. We learned how to design a product to meet user needs while staying within a small budget.

8.2.16 Would you now feel more comfortable accepting a design project assignment at a job?

Yes. This project was a good learning opportunity for design, product development, cost benefit analysis, group work, and engineering analysis.

8.2.17 Are there projects you would attempt now that you would not have attempted before?

Yes. We learned a lot about Arduinos and would now attempt future Arduino projects.
## APPENDIX A - PARTS LIST

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<td>Double sided tape to mount arduinos</td>
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Figure 33: CAD Model; Project Enclosure
Figure 34: CAD Model; Project Enclosure Lid

## APPENDIX C – ARDUINO CODE

For all code and associated libraries, see our project [GitHub](https://github.com).

On the following seven pages is an example of working code as of December 10, 2017.
Figure 35: Arduino code for prototype

```cpp
/*
  2017 MEMS 411 Blind Automation Device Code (Arduino)
  GROUP U – Melinda Lai, Haley Nichols, and Dalton Horweiler
*/
int light_calibration = 300; //WHAT IS YOUR CURRENT PERFECT LIGHTING?

#include <Time.h>
#include <Timelib.h>

//Declare pin functions on Arduino
digital pins
#define step 2
#define dir 3
#define MS1 4
#define MS2 5
#define MS3 6
#define EN 7
#define pos_knob_A 8 //rotary encoder InputA
#define pos_knob_B 9 //rotary encoder inputB
#define button 10
#define LED 13

//analog pins
#define light A8 // photo resistor
#define an_pm A1 // am/pm switch
#define time_knob A2 // time knob
#define five_ps_A4 // 5 position switch
#define five_ps_A5 // 5 position switch
#define five_ps_C5 // 5 position switch

//Declare variables for functions
int x; //stepper motor
int A3level;
int A4level;
int A5level;
int button_pos;
int counter = 0;
int counterMin = -9999;
int counterMax = 9999;
int counter_midpoint;
int current_time;
int light_level_1;
int light_level_2;
int difference;
int omhr;
int ommMin;
int ommsec;
int offhr;
int offMin;
int offSec;
bool clockIsSet = false;
bool onIsSet = false;
bool offIsSet = false;
int mode; //mode selected by 5 pos switch
int aState; //rotary knob
int aLastState = digitalRead(pos_knob_A);
int bState;
int bLastState = digitalRead(pos_knob_B);
```
```cpp
void resetBEDPins() //reset stepper driver to default state
{
  digitalWrite(stp, LOW);
  digitalWrite(dir, LOW);
  digitalWrite(MS1, LOW);
  digitalWrite(MS2, LOW);
  digitalWrite(MS3, LOW);
  digitalWrite(EN, HIGH);
}

void setup() {
  //initialize inputs and outputs
  //digital
  pinMode(stp, OUTPUT);
  pinMode(dir, OUTPUT);
  pinMode(MS1, OUTPUT);
  pinMode(MS2, OUTPUT);
  pinMode(MS3, OUTPUT);
  pinMode(EN, OUTPUT);
  digitalWrite(stp, LOW);
  digitalWrite(dir, LOW);
  digitalWrite(MS1, LOW);
  digitalWrite(MS2, LOW);
  digitalWrite(MS3, LOW);
  digitalWrite(EN, HIGH);
  pinMode(pos_knob_A, INPUT);
  pinMode(pos_knob_B, INPUT);
  pinMode(button, INPUT);
  pinMode(led, OUTPUT);
  pinMode(light, INPUT);
  pinMode(thknob, INPUT);
  pinMode(an_pn, INPUT);

  Serial.begin(9600); //Open Serial connection for debugging
  Serial.println("Serial initialized.");
  Serial.println();
  digitalWrite(EN, LOW); //unlock motor
}

/*
BEGIN FUNCTION DEFINITIONS
*/

//PHOTORESISTOR LIGHT LEVEL
void light_level() {
  light_level_1 = analogRead(light);
  delay(500000);
  light_level_2 = analogRead(light);
  difference = light_level_1 - light_level_2;
  Serial.println("light difference, 5s: ");
  Serial.println(difference);
  Serial.println();
  Serial.println("final light level: ");
  Serial.println(light_level_2);
  Serial.println();
}

int five_ps_mode()
{
  A3level = analogRead(five_psA);
  A4level = analogRead(five_psB);
  A5level = analogRead(five_psC);
  x=0;
  int threshold=0;
  if (A3level == threshold && A4level != threshold && A5level != threshold){
    x = 1;
  }
```
```c
137   else if (A3level == threshold && A4level == threshold){
138       x = 2;
139   }
140   else if (A1level == threshold && A5level != threshold && A3level != threshold){
141       x = 3;
142   }
143   else if (A4level == threshold && A5level == threshold){
144       x = 4;
145   }
146   else if (A1level != threshold && A5level == threshold && A3level != threshold){
147       x = 5;
148   }
149   return x;
150 }
151
152 // Flash LED
153 void flash_LED() {
154     digitalWrite(LED, HIGH);
155     delay(500);
156     digitalWrite(LED, LOW);
157     delay(500);
158 }
159
160 // Move stepper motor forward
161 void StepForwardDefault() {
162     if (counter >= counterMin && counter < counterMax) {
163         counter ++;
164         Serial.println("Moving forward at default step mode.");
165         digitalWrite(dir, LOW);
166         for(x=1; x<58; x++){ // Loop the stepping for 1/4 turn
167             digitalWrite(stp, HIGH); // Trigger one step forward
168             delay(1);
169             digitalWrite(stp, LOW); // Pull step pin low so it can be triggered again
170             delay(1);
171         }
172     }
173     else {
174         Serial.println("Error in endpoints -- step forward");
175     }
176 }
177
178 // Move stepper motor in reverse
179 void ReverseStepDefault() {
180     if (counter <= counterMax && counter > counterMin) {
181         counter --;
182         Serial.println("Moving in reverse at default step mode.");
183         digitalWrite(dir, HIGH); // Pull direction pin high to move in "reverse"
184         for(x=1; x<58; x++){ // Loop the stepping for 1/4 turn
185             digitalWrite(stp, HIGH); // Trigger one step
186             delay(1);
187             digitalWrite(stp, LOW); // Pull step pin low so it can be triggered again
188             delay(1);
189         }
190     }
191     else {
192         Serial.println("Error in endpoints -- reverse step");
193     }
194 }
195
196 void setCurrentTime() {
197     int runtime = analogRead(tknob);
198     bool pm = false;
199     int ampm = analogRead(an_pm);
200     if (ampm == 0) {
201         pm = true;
```
```c
int hr = realtime/12/1024;
if (pm==true){
    hr = hr + 12;
}
int mn = (((realtime=12+60/1024)%60)+60)%60;
int sec = (((realtime=12+60/1024)%60)+60)%60;
int x = hr;
int y = mn;
int z = sec;
Serial.print(" Now setting time to ");
Serial.print(x);
Serial.print(":");
Serial.print(y);
Serial.print(":");
Serial.println(z);
setTime(x,y,z,1,1,2017);
clockIsSet = true;
time_t t = now();
Serial.print("the hour is: ");
Serial.println(hour(t));
}

void setSchedOn (){  
int realtime = analogRead(tknob);
bool pm = false;
int ampm = analogRead (an_pmn);
if (ampm == 0){
    pm = true;
Serial.println("pm");
}

int hr = realtime/12/1024;
if (pm==true){
    hr = hr + 12;
}
int mn = (((realtime=12+60/1024)%60)+60)%60;
int sec = (((realtime=12+60/1024)%60)+60)%60;
onHr = hr;
onMin = mn;
onSec = sec;
Serial.print("on hour = ");
Serial.println(onHr);
Serial.print("on minute = ");
Serial.println(onMin);
Serial.print("on sec = ");
Serial.println(onSec);
}

void setSchedOff (){  
int realtime = analogRead(tknob);
bool pm;
int ampm = analogRead (an_pmn);
if (ampm == 0){
    pm = true;
Serial.println("pm");
}

int hr = realtime/12/1024;
if (pm==true){
    hr = hr + 12;
}
int mn = (((realtime=12+60/1024)%60)+60)%60;
int sec = (((realtime=12+60/1024)%60)+60)%60;
offHr = hr; //extra variable definition may not be necessary
offMin = mn;
offSec = sec;
Serial.print("on hour = ");
```

```cpp
Serial.println(hour);
Serial.println("on minute = ");
Serial.println(minute);
Serial.println("on sec = ");
Serial.println(second);
}

// Rotary encoder
void Rot_Knob () {
  aState=digitalRead(pos_knob_A); //This will read the current state of A
  bState=digitalRead(pos_knob_B);
  // If the previous and the current are different that means the knob has
  // moved.
  if (aState != aLastState) // pos_knob_B compared to pos_knob_A will tell you which direction the
    // encoder is going.
    // probably clockwise - check!
    if (bState!= aState){
      StepForwardDefault();
      // Serial.print("forward");
    }
    else {
      ReverseStepDefault();
      // Serial.print("backward");
    }
  Serial.println();
  Serial.printf("Counter: %d\n", counter);
  Serial.println();
  aLastState=aState; //This step updates the previous state with the new state
  bLastState=bState;
}

/*
MAIN LOOP

*/

void loop(){
  while (true){
    // Determine current position of 5 position switch
    if (five_ps_mode() == 0)
      {
        Serial.println("Error, device not configured yet");
      }
    // auto mode
    if (five_ps_mode() == 1)
      {
        if (clockIsSet && onIsSet && offIsSet == true){
          // make sure clock and schedule are set up
          int ontime = onHr*1000 + onMin;
          int offtime = offHr*1000 + offMin;
          int run = hour() * 1000 + minute();
          if (run > ontime && run < offtime){
            light_level();
          }
        }
        if (abs(difference) < 75) { // check to see if light is consistent
          // make sure light changed a reasonable amount
          if (abs(light_level - light_calibration) > 20) { // make sure light changed a reasonable amount
            if ((light_level < light_calibration) && (counter < counter_midpoint)){ // check counter
              StepForwardDefault(); // OPEN UP
              Serial.println("100 DARK");
            }
          }
        }
      }
```
```cpp
Serial.println("counter: ");
Serial.println(counter);

//check counter
else if (counter > counter_midpoint){
  ReverseStepDefault();
  Serial.println("Counter MIDPOINT");
  Serial.println(counter_midpoint);
  Serial.println("TOO DARK");
  Serial.println("counter: ");
  Serial.println(counter);
}
else
  Serial.println("TOO DARK");
Serial.println("Blinds already max open");

else if (light_level2 > light_calibration){
  if (counter >= counter_midpoint){ //MOVE UP
    StepForwardDefault();
    Serial.println("TOO BRIGHT");
    Serial.println("counter: ");
    Serial.println(counter);
  }
  else if (counter < counter_midpoint){ //MOVE DOWN
    ReverseStepDefault();
    Serial.println("TOO BRIGHT");
    Serial.println("counter: ");
    Serial.println(counter);
  }
  else{
    Serial.println("light is in comfy place");
  }

//OVERRIDE
if (five_ps_mode() == 2){
  Rot_Knob(); //take rotary encoder input
}

//set CT
if (five_ps_mode() == 3){
  delay(500);
  while (five_ps_mode() == 3){
    set_current_time();
  }
}

if (five_ps_mode() == 4){
  delay(500);
  if (five_ps_mode() == 4){
    Serial.println("Set time mode -- ON time (you have 5s)");
    Serial.println();
    unsigned long finishAtOn = now() + 5; //tells you what time to finish
    while (now() < finishAtOn){ //run setschedon for 5 seconds
      setSchedOn();
    }
    flash_LED(); //flash when on setting is set
    onIsSet = true;
    Serial.println("Set time mode -- OFF time (you have 5s)");
    Serial.println();
    unsigned long finishAtOff = now() + 8;
    while (now() < finishAtOff){ //run set_on for 8 seconds
      setSchedOff();
    }
  }
```
```c
409  digitalWrite(LED, HIGH);
410  delay(250);
411  digitalWrite(LED, LOW);
412  delay(250);
413  digitalWrite(LED, HIGH);
414  delay(250);
415  digitalWrite(LED, LOW);
416  delay(250);
417  offsSet = true;
418 }
419
420 // set stops
421 if (five_ps_mode() == 5){
422  // Serial.println("Now you will set the stops");
423  digitalWrite(button, HIGH);
424  delay(1);
425  button_pos = digitalRead(button);
426  Serial.println("now in position setting mode — UP");
427  while (button_pos != 0){
428    //Rot_Knob();
429    button_pos = digitalRead(button);
430  }
431
432  counterMax = counter; // may be max not min
433  Serial.print("UP position set. counterMax is: ");
434  Serial.println(counterMax);
435  Serial.println();
436
437  digitalWrite(button, HIGH);
438  delay(1000);
439  button_pos = digitalRead(button);
440  Serial.println("now in position setting mode — DOWN");
441  while (button_pos != 0){
442    //Rot_Knob();
443    button_pos = digitalRead(button); // exit while loop if clicked
444  }
445  counterMin = counter;
446  Serial.print("DOWN position set. counterMin is: ");
447  Serial.println(counterMin);
448  counter_midpoint = counterMax-((counterMax+abs(counterMin))/2);
449  Serial.print("MIDPOINT:");
450  Serial.println(counter_midpoint);
451
452  delay(5000);
453 }
454 }
455
```
12 ANNOTATED BIBLIOGRAPHY


