MECE E3028 Mechanical Engineering Laboratory II
Professor Qiao Lin
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Experiment E*5*: Arduino

LABORATORY Lab REPORT

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Contents

Acknowledgements

Our TA for this experiment was Terence Conlon, working under the direction of Professor Qiao Lin. Our team comprised 6 members. Vittorio Bottoli, Sean Dugan, and Justin Donovan worked on one half of the results of the experiment. And Aidan O'Hara, Rushawn Childers, and Derek Jackson worked on the later half of the results of the experiment. Most of the paper beyond that was written, peer reviewed and edited by everyone in the group.

Abstract

The objective of this lab was to design, build and implement a solar cell array tracking system. Our system worked by using a photocell attached to a stepper motor to find the angle with the highest intensity of light. Once this angle was know we used a DC motor, that is attached to a potentiometer and a solar cell by a shaft, to move the solar cell to the angle with the highest light intensity. All of these components were connected to an Arduino board with a motor shield attached to the top. We applied an Arduino code that allowed to us to find the angle with highest intensity and move the solar cell to this angle. A limit switch was also applied to the stepper motor part of the device, this limit switch was used to move the stepper motor all the way to the beginning of its cycle so that the motor could move through its cycle again. Our device worked very well, to the point that when a light most intense at a certain angle the photocell recorded this angle and moved the solar cell to the angle with highest light intensity.

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1 Intro

1.1 Background and Motivation

In this experiment we will be using the open-source platform Arduino, which is used to build electrical and electromechanical systems based on a circuit board with a microcontroller. Arduino is an extremely popular platform mainly due to three reasons. The apparatus is fairly cheap, it operates successfully on a wide variety of systems, and it is easy to use. Arduino attracts a large community of individuals whether they are students, teachers, engineering professionals, or hobbyists. They all share their own projects (wiring, code, etc.) online for others to see, replicate, and potently further build off of. This allows new and inexperienced users to quickly learn and build their own systems. A large amount of information on Arduino is available on the Arduino website, GitHub, online forums, YouTube channels, etc. [3]

The circuit board in the Arduino platform is called an Arduino board and the Arduino Uno is the most widely used board. [4] The Arduino executable code can be written in an integrated development environment (IDE) known as the Arduino IDE. The Arduino boards can read several inputs from sensors and turn input signals into outputs based on a program written and compiled in the Arduino IDE. [5]

The motivation for building a full electrical circuit and mechanical apparatus around Arduino is to get familiar with the product that is so popular as well as to design, construct, and code a full project from the ground up. A solar tracker is not only extremely useful in the sustainable energy business today, but it can teach us the importance of design intent, planning, executing, and then debugging all as a team. An extra piece of motivation is to also learn about the components we will be implementing in the overall design of the solar tracker. We will be able to get familiar with different types of motors as well as learning about the Arduino apparatus.

1.2 Experimental Objectives

For this experiment, the objectives are to design and build a working Arduino-based solar cell array tracking system. It will consist of a system or motors, and sensors that find a light source with a photo resistor. This will be used to position a solar cell directly towards that source. During the fabrication process, we will be using cardboard, since we don't have access to 3D printing, machining or laser cutting. Additionally, we will get familiar with the Arduino platform as a controller and interface for various types of sensors and motors on both the coding and mechanical design fronts.

2 Theory

This entire experiment is build around Arduino, a programmable circuit board and software that can be used to provide electrical power while collecting and interpreting data outputs from various sensors. Arduino uses a Java-based Interactive Development Environment that compiles written code in C++, but its main appeal lies in that fact that it's an open-source platform, with many libraries and functions to control different kinds of sensors.

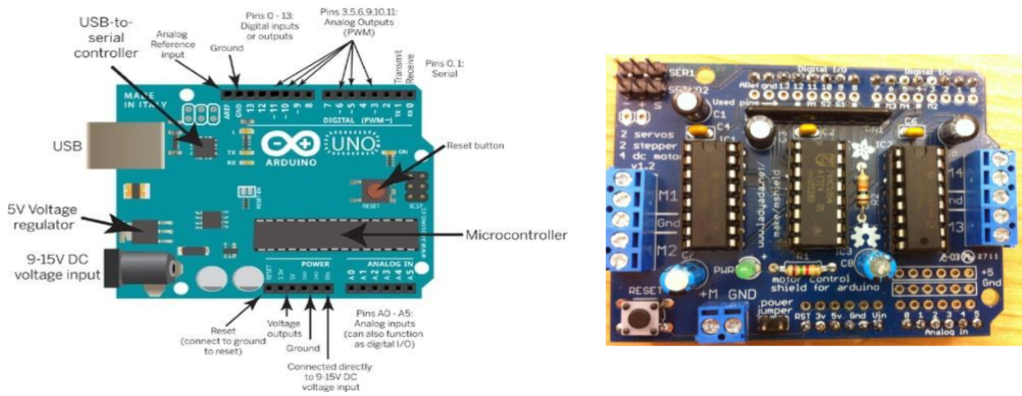


Figure 1: (a) Arduino Uno Board w/ components, (b) Adafruit Motor Shield

The Arduino Uno and Adafruit Motor Shield are shown in Figure 1, which we will combine to use as the brain for our apparatus. The Arduino Uno has a microcontroller at its center that will read our compiled program to execute prescribed commands. The Adafruit Motor Shield connects the Arduino Uno Board's digital I/O (PWN pins) and Analog pins; additionally it can control up to 2 servo motors, 2 stepper motors, and 4 DC motors simultaneously. The Uno board comes with a power supply and has a USB port for uploading code from our computers. The pins will be used to read signals from sensors.

In order to control both motors, the motor shield should be used in conjunction with the Arduino board, as the motor shield is able to power the motors using a separate power supply. To accomplish this, we soldered them together using a conductive epoxy, making sure we had access to the analog I/O, 5V, and ground pins in particular. Using the motor shield allows us more control over the DC and Stepper motor speed and voltage each motor receives, but the Arduino Adafruit_MotorShield.h library must be installed to do so. We also needed to Wire.h to assist with communication between devices.

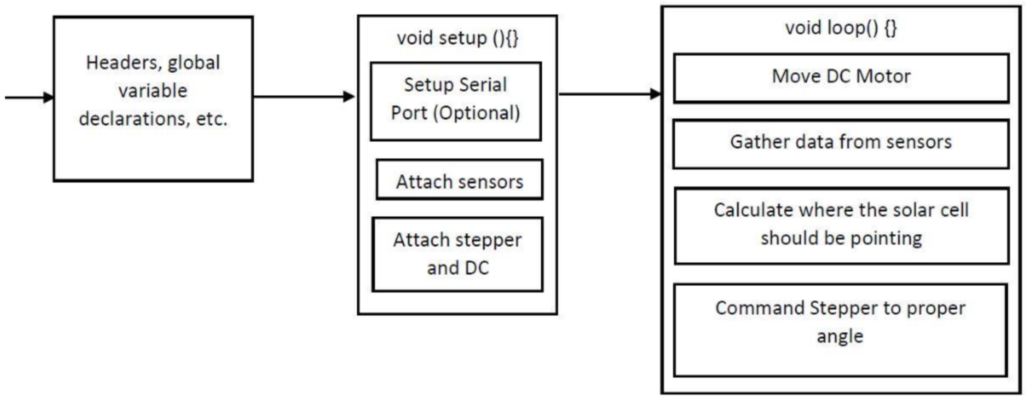
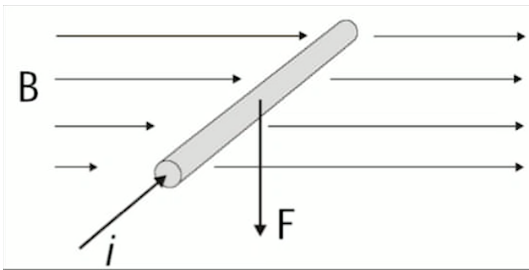


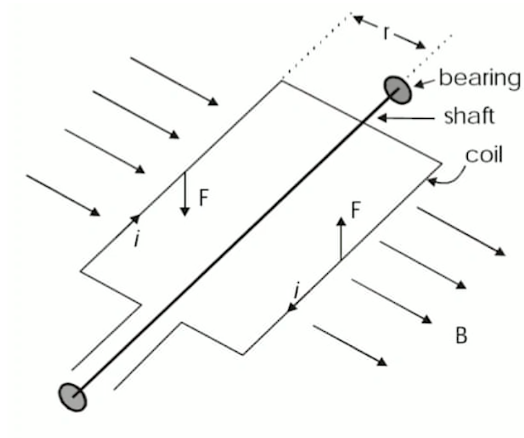
Figure 2: Helpful programming steps to take when making the code.

Arduino coding goes hand in hand with mechanical experiment design; we need the code for this experiment to initialize and calculate the solar cell's position etc., but we must have an idea of the physical layout and the role each sensor plays before we can tell it what to do. Typical functions an Arduino code is used to carry out include collecting and printing data from sensors periodically and controlling quantities such as motor speed or power supplied to a circuit. One thing worth noting is that in order to utilize the Arduino, we need to pay attention to the pins we connect each component to (i.e. 5V power vs. analog input etc.). As for the code itself, figure 7 shows a helpful guide on how to take steps when creating the code that we will upload in to the Uno board. For more helpful information on coding, we looked at the "Arduino_2_getting started" pdf available on coursework.

A major motivator in our experiment design lies in the respective operating principles for our two motors, DC and stepper. In this experiment, we focus on the permanent magnet DC motor in particular. The permanent magnet DC motor generates torque with a current carrying wire wrapped in a coil, the rotor, and a stationary permanent magnet, the stator, which creates a magnetic field. The field strength, B, is a characteristic of the magnet, and when a wire of length L carrying a current i passes through the field, (assuming an orthogonal relationship) a magnetic force is experienced by the wire:



(a) current carrying wire in magnetic field



(b) torque-producing armature

Figure 3: Magnetic force produced in DC motor

$$\overline{\mathbf{F}} = \overline{\mathbf{B}} iL$$

Then to produce torque, our current carrying wire is wrapped in a coil, forming our aforementioned rotor or armature. The coil will reach some distance r from the axis about which it is wound, resulting in the following torque on the armature:

$$\overline{\mathbf{T}} = \overline{\mathbf{F}} \times \overline{\mathbf{r}}$$

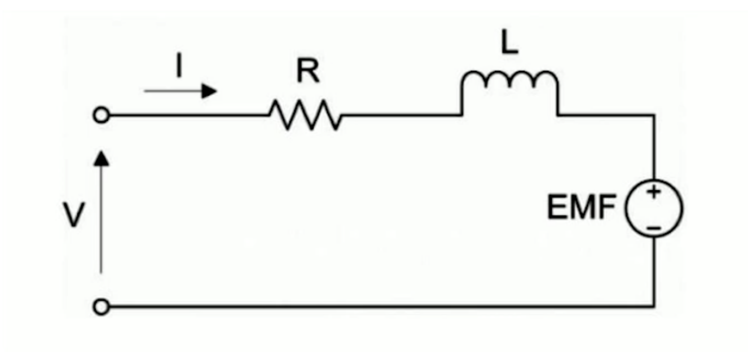


Figure 4: simplified DC motor circuit

The DC motor circuit can be approximated to the above, allowing us to express the voltage drop across the motor and the overall torque as such:

$$V = IR + L\frac{dI}{dt} + EMF$$

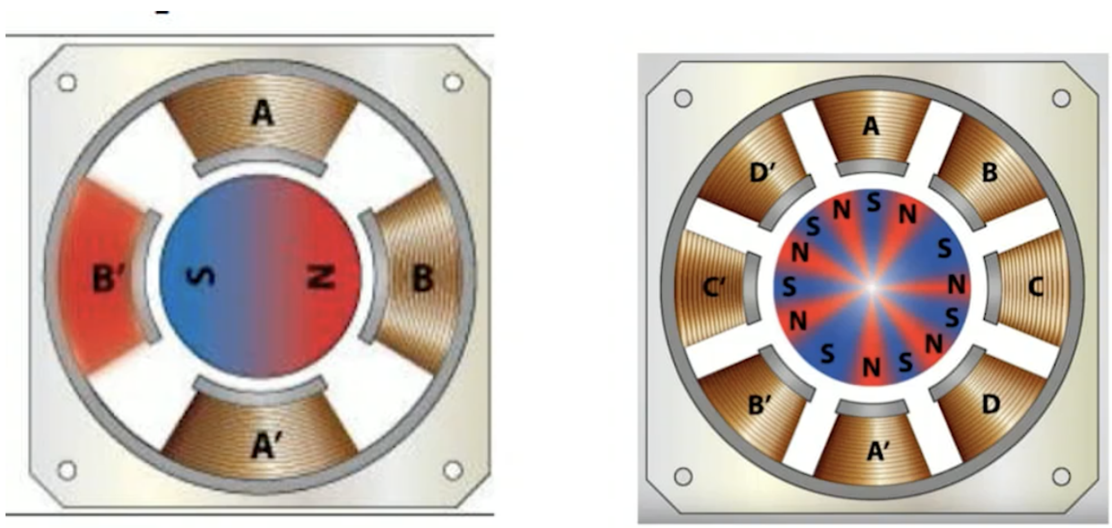
$$T = K\phi I$$

where ϕ is the flux per pole of the magnet and K is a characteristic constant of the circuit. Then if we assume a constant current and load, we observe the following relationship:

$$V = \frac{T}{K}R + K\omega \;\leftrightarrow\; \omega = \frac{V}{K} - \frac{T}{K^2}R$$

In other words, increasing the voltage received by the motor in turn increases the angular velocity at which it operates. This phenomenon is useful when the DC motor is used in conjunction with the potentiometer due to the potentiometer's variable resistances/voltages.

The DC motor is simple to use and inexpensive but does not have the same degree of accuracy as the stepper motor. Another appealing aspect of DC motors is the linear relationship between speed and voltage, but they suffer from being high maintenance and boast a low lifespan.



(a) Diagram of a stepper motor. The rotor is the permanent magnet at the center. The electromagnet poles at the sides comprise the stator.

(b) Stepper motor with more rotor and stator poles. This motor will have a much smaller step angle than the former.

Figure 5: Two different stepper motor designs. The smaller step angle of the latter makes it more accurate.

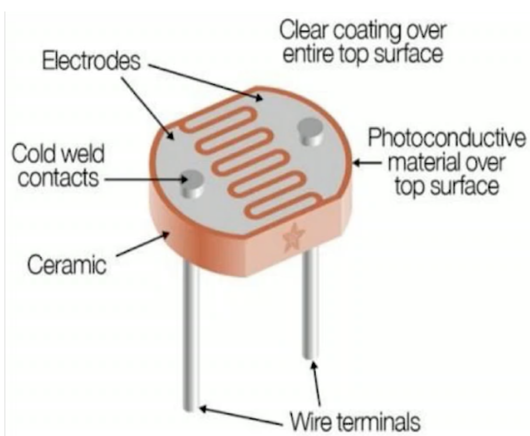
In a stepper motor, the rotor is a permanent magnet bordered by the stator, which can be multiple poles of electromagnets. The rotor rotates due to the magnetic force caused by turning poles on and off and phasing them. We can quantify the position of the rotor in terms of the step angle:

$$\text{Step Angle } = \frac{360^\circ}{\text{Number of Steps per Revolution}}$$

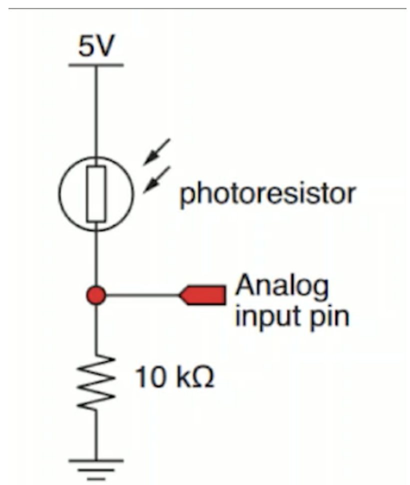
We could theoretically improve the accuracy of the stepper motor (i.e. reduce the step angle) by adding more poles to the rotor and stator. Resolution can also be increased further by using half-steps or micro-steps that are smaller than a single normal step.

Stepper motors may appear superior to DC motors due to their accuracy as well as their excellent low speed torque and longer lifespan, but they are inhibited by their low efficiency, inability to rapidly accelerate loads, and susceptibility to resonances, noise, and torque ripple. Additionally, stepper motors have high positional accuracy/control, but the initial position must be homed; this can be done with a limit switch that flips upon reaching a certain step angle. Due to these constraints, our apparatus will aim to establish the reference 0 angle using the limit switch then use the stepper motor in conjunction with the photoresistor to locate the point of maximum light intensity. The DC motor will then take the information gathered from the photoresistor and rotate the solar cell to match its angle.

The photoresistor, also known as a photocell or light dependent resistor (LDR), is a resistor whose resistance decreases as light intensity increases. This phenomenon occurs because its sensitivity changes depending on the wavelength/frequency of light. The specifics of the detectivity response to wavelength depends on the material of the photocell surface. The photocell used in this experiment uses CdS, but this is unimportant since our use for the photocell is largely qualitative. This is largely due to the fact that we cannot immediately consider resistance measurements into a meaningful output for our purposes; instead, we can express our output as a variable voltage by creating a voltage divider.



(a) Diagram of a photoresistor.



(b) voltage divider created with the photoresistor and a load resistor

Figure 6: The photoresistor's resistance scales with light intensity. We can take advantage of this property by creating a voltage divider.

In the depicted circuit, the photoresistor is placed in series with a load resistor, in this case 10k ohms. Regardless of the photoresistor's resistance value, 5 volts must drop off between it and the load resistor before reaching ground. Resistors in series behave linearly, so measuring the voltage between the two tells us how much the voltage dropped over the photoresistor only. More generally, this value will be proportional to the photoresistor's contribution to the total series resistance. If we replace the 5V term above with an arbitrary V_x, then we can express the analog voltage V_a as such:

$$V_a = V_x \left(\frac{R_{load}}{R_{load} + R_{photoresistor}} \right)$$

Now that we can measure voltage readings corresponding to positions of the photoresistor, we need only to locate the point at which the voltage peaks, as this will be the point with the highest light intensity.

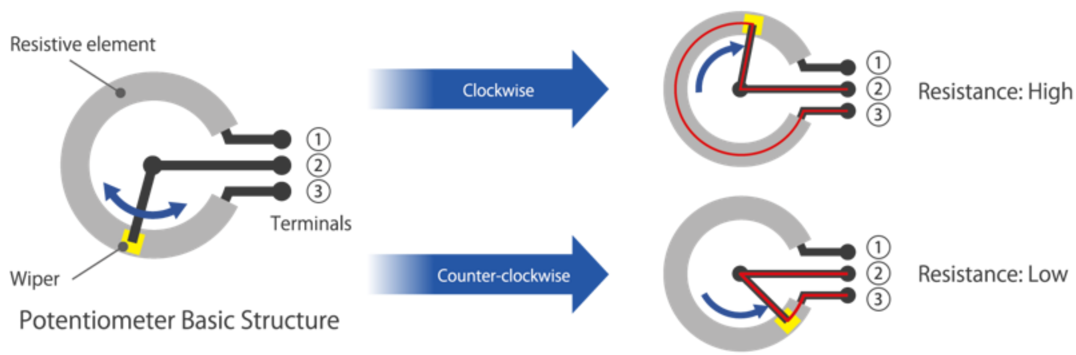


Figure 7: potentiometer diagram. The potentiometer resistance can be adjusted by a constant rate through rotation.[1]

Similar to the photocell, the potentiometer is a type of variable resistor. However this is where the similarities end; the potentiometer operates like an adjustable voltage divider of sorts by itself. The potentiometer has three terminals: two maintain a constant voltage difference between them while the third inhabits the space between them, splitting it into two segments. This third terminal, the "wiper," can be moved to any point between the ends, essentially controlling the respective voltage drops over each segment. Since the two segments act as resistors in series, their effect is proportional to the distance to the wiper; in other words, there is a fixed amount the voltage will change as the wiper moves. Since the physical mechanism through which we can move the wiper is via rotation of a hub on the back surface, then we can also find a constant voltage drop per rotation. Thus, upon calculating this relationship, we can connect the potentiometer to the shaft of the DC motor. Then through controlling the voltage seen by the motor, we can in turn control its rotational position, and by extension, that of the solar cell to which it will be connected. For convenience, the initial setup should have the potentiometer halfway between the ends and the physical device at a known angle to ease translation of the result found from the photocell.

3 Apparatus and Approach

3.1 Apparatus

The appropriate components that we will use for the creation of our solar cell array tracking system listed in the Table below (Table 1), provided from our Arduino Components Kit(s). We are responsible for designing and fabricating our mechanical components. The items numbered below can be visualized in Figure 8.

Item	Description	Company/Website
1	Solar Array	http://www.bgmicro.com/PWR1241.aspx
2	10k ohm, 10 turn potentiometer	https://www.mpja.com/10K-Ohm-10-Turn-Variable-Resistor-Linear-Taper/productinfo/32080%20VR/
3	6V DC motor	https://solarbotics.com/product/gm4/
4	5V Stepper motor	https://www.mpja.com/5V-Gearhead-Stepmotor-and-Driver-Board -ULN2003-for-Arduino/productinfo/31592%20MP/
5	Arduino Uno starter kit	https://www.mpja.com/Arduino-UNO-Compatible-Starter-Kit/productinfo/30297%20MP/
6	Adafruit Motor Shield	https://www.mpja.com/Multi-Motor-Drive-for-Arduino-Compatible-Shield/productinfo/30292+MP
7	10 position header	https://www.mpja.com/Header-Connector-Long-Pin-10-Position/productinfo/31053+HC
8	8 position header	https://www.mpja.com/Header-Connector-Long-Pin-8-Position/productinfo/31052+HC/
9	6 position header	https://www.mpja.com/Header-Connector-Long-Pin-6-Position/productinfo/31051+HC
10	Cadmium Resistor (Photocell)	https://www.adafruit.com/product/161?gclid= CjwKCAiAmNbwBRBOEiwAqcwwp SvP8s67wZ_vuQE6hBaIhOzU8sRUcLHviypU GMIxcztcePNCv54nRhoC_nwQAvD_BwE
11	Breadboard	

Table 1: Table of relevant components to be used in this experiment.

3.2 Procedure

For this lab we will construct and mechanical device that will allow use to measure the highest intensity of light and move a solar cell to the point of highest light intensity. To do

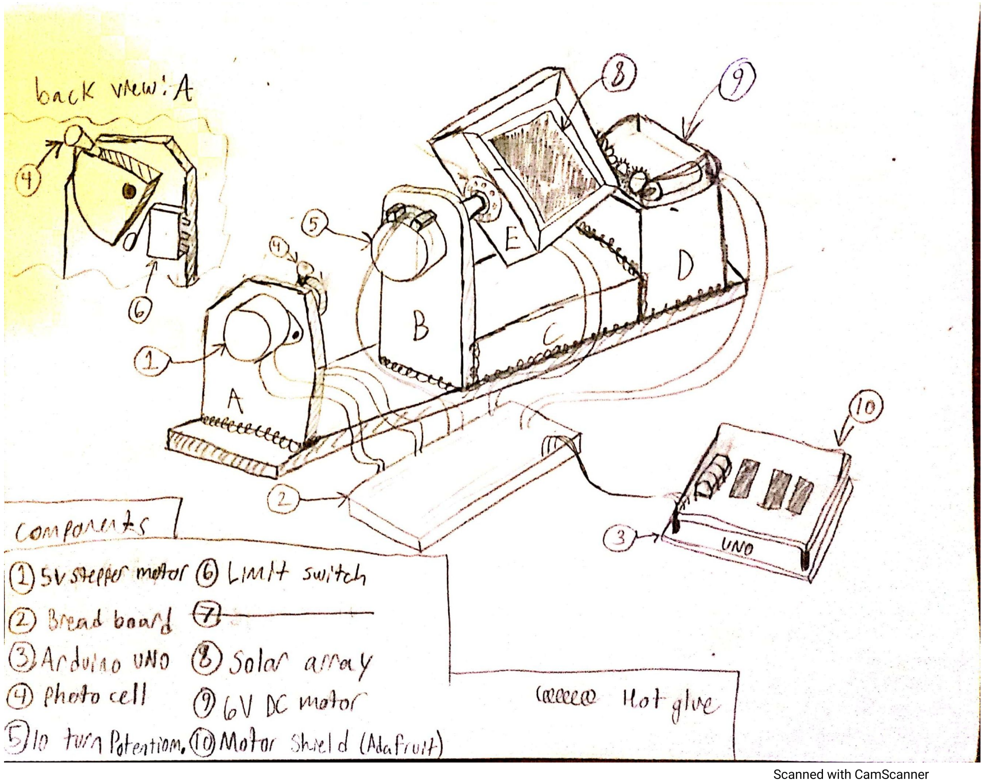


Figure 8: Full isometric sketch of apparatus with all components.

this we will create a mechanical design, develop an electrical circuit, and create a code in Arduino that will allow us to complete the goal mentioned above.

3.3 Methods

3.3.1 Design and Fabrication of Mechanical Components

Mechanical components for this experiment were fabricated using cardboard, hot glue, and an exacto knife, all of which were included in our design kits. All the components needed for our electrical circuit and data collection were provided in our lab kits, so our cardboard parts were only necessary to connect and physically support the others. Our fabricated components served as platforms used to hold each part at its prescribed height and accompanying rib supports for added strength. Figure 8 is an isometric sketch on what we planed to do for our final design, and a picture of the complete and final apparatus can be seen in Figure 13.

3.3.2 Electronics

1. The photocell can be treated as a resistor, which changes in resistance at different intensities of light. This will be used to find the angle at which the light is the brightest.

2. The photocell can be connected in series with another resistor to form a voltage divider. If a constant voltage is applied across both the resistors, the photocell's change in resistance at different light inputs can be measured. Here we will apply a voltage and read a voltage into Arduino by using an Analog I/O pin as the analog read pin to measure the change in voltage of the photocell circuit.

3. To control both motors, we will make use of the Adafruit Motor Shield. First, we will solder headers on to the Motor Shield to access the analog I/O pins as well as the 5V and ground pins on the Arduino Uno board underneath. To use the built-in functions for the Adafruit Motor Shield, we will have to use the AFMotor.hlibrary in the software. [6] Additionally, the Adafruit Motor Shield has the capability of powering up the motors using an external power supply so that we can run the motors at our desired voltage level, to do this we will use batteries that were provided to us and hook these up to the Adafruit Motor Shield. [7]

4. The stepper motor will be used to rotate the photocell back and forth to detect a strong light signal.The stepper motor will be wired to the Motor shield In order to power the stepper motor. We will say that each step of the motor corresponds to a distance moved by the photocell and we can find the new angle of the photocell. [8]

5. The DC motor with the potentiometer will be used to control the rotation of the solar cell array. Once the maximum intensity of light is found, the DC motor will rotate the solar cell to the appropriate position. The potentiometer will be attached to the shaft of the DC motor/solar cell so that a change in voltage across it can be used as position feedback. The potentiometer will be used to command the DC motor to move and stay at a certain rotational position. The potentiometer's voltage response as a function of the angular position will be analyzed and used to find the optimum position of the solar cell. [9]

6. The limit switch will be used to home the stepper motor, in other words when the stepper motor hits the limit switch it will move back to the starting position of the motor.

3.3.3 Implementing the Arduino Solar Tracking System

Once we have the mechanical design and the electronic components of the device created and put together we will then write an Arduino code for our device. Our Arduino code will use the stepper motor and photocell to find the angle at which the intensity of light is the greatest. The code will then use the potentiometer and the DC motor to move the solar cell to the angle at which the intensity of light was the greatest. Throughout this experiment we will have to apply the code and it might not work correctly so we will have to debug and trouble shoot the code many times before we get the device working correctly. For this we might also have to alter certain parts of our mechanical design or our electronic configuration in order to make our code work flawlessly with our created device.

3.3.4 Solar Panel Test

As the final confirmation we will measure the voltage across the solar cell using a voltmeter connected across the solar cell. When we do this we should see that when the solar cell is positioned at the angle at which the highest light intensity was measured the measured voltage should be high. If the solar cell is not at the angel with the highest light intensity the voltage across the solar cell should be lower. This is how things should go if we created the device correctly, therefore, this will tell us if the device works correctly.

4 Results

The finished solar cell array tracker and demonstration was completed successfully. We were able to demonstrate that our device could determine which direction the highest light intensity was coming from and rotate the solar cell array to the corresponding angle, within at $\pm$ 5 degree accuracy The device was able to track a light source that changed positions at different point in time. The photoresistor would pulse at 5 degrees at a time based on the degrees that we set the stepper motor to rotate each step. We set our accuracy factor for the angle of the solar cell to ± 5 degrees because an accuracy greater than this would need a significant slowing of the dc motor which would make the apparatus run much less efficient. We also chose ± 5 degrees because the voltage output from the solar cell would change a minimal amount at these varying degrees.

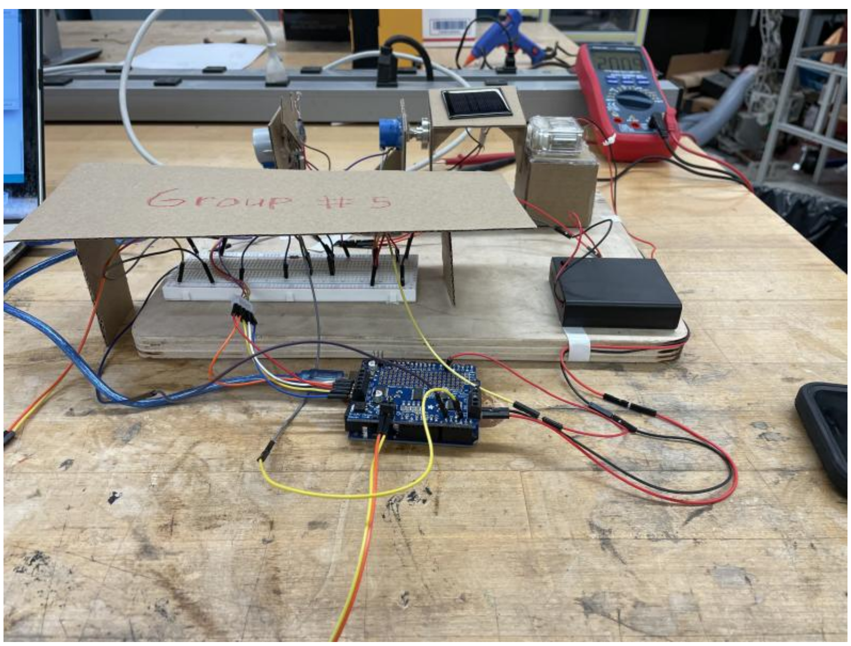


Figure 9: Front portion of our completed solar tracking apparatus.

Other photographed angles of the apparatus can be found in the appendix as figures 13, 14, and 15.

5 Discussion

In this experiment we did indeed use the stepper motor with the photocell connected to it. We opted out of attempting to just use the solar array for taking the light intensity readings. We thought it would have been counter intuitive. Since we want the solar array to be at the optimum angle to absorb the most sunlight, and only move when that angle has changed significantly. If it had to constantly move to search for the sun we could waist most if not more of the power we would collect.

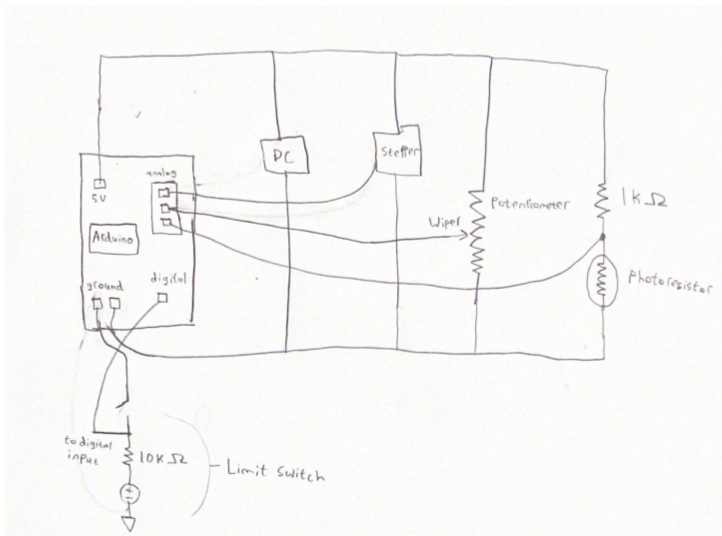


Figure 10: Drawn electrical schematic; the Arduino represents both the Uno and Motorshield.

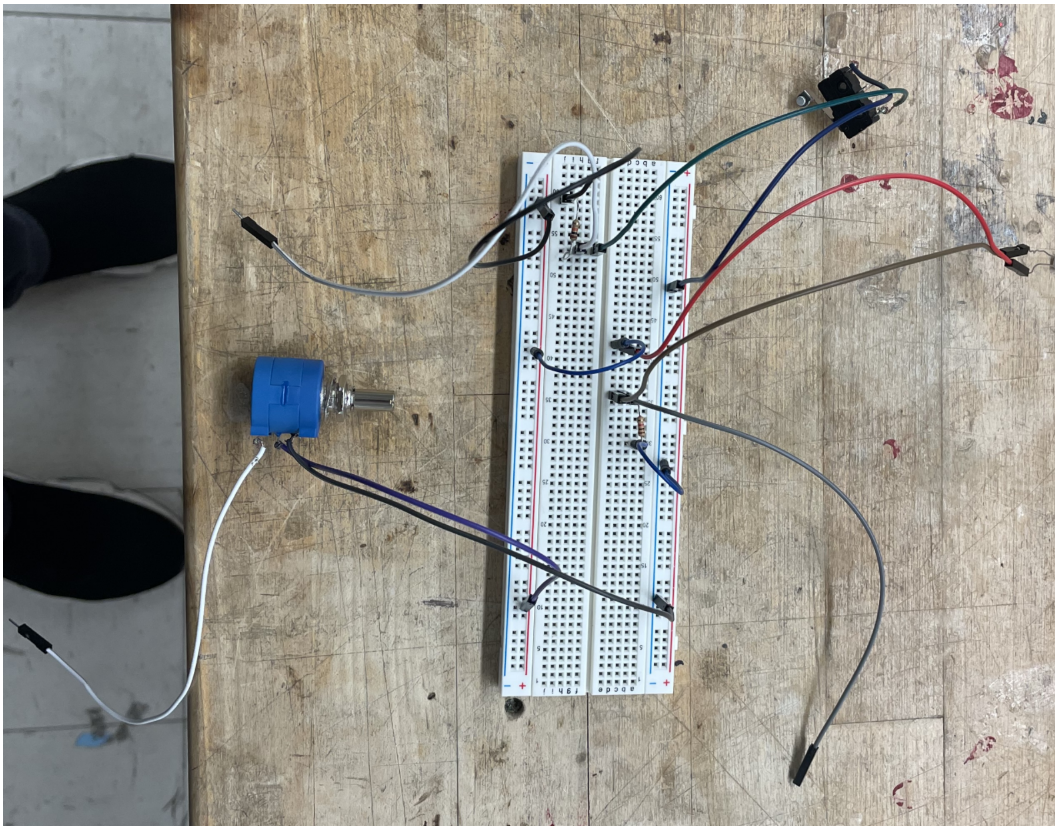


Figure 11: Real electrical wiring on breadboard.

Above are pictures of a hand drawn electrical schematic showing how we connected all of our components to the Arduino. The DC, stepper motor, potentiometer, and photoresistor with a 1k ohm resistor in front of it (in series), are in parallel, with each wire experiencing a 5V drop powered by the Arduino and Motor Shield. The stepper motor, potentiometer, and node between the 1k resistor and photoresistor have wires that connect to the analog pins of the Arduino so they can be read. On the schematic the limit switch is represented on a separate loop since it relays a different set of readings (either HIGH or LOW) to a digital pin on the Arduino. The second picture is of the real electrical circuit connected to the bread board, figure 11.

The potentiometer (i.e. pot) only outputs a voltage which is always known. In this experiment we needed to relate the voltage read from the pot to an angle taken when the photocell takes a max reading. To take that angular position and convert it to a voltage that we want the pot to be at, we created two functions. The two functions being:

```
int deg2step(int deg){
    return deg * 1.425;
}

int step2volts(int steps){
```

```
        return steps * 0.2027;
    }
```

The deg2step function takes a desired degree we the stepper motor to turn. This is done by converting the degree to steps by multiplying it by 1.425. Then the step2volts function takes the number of steps from the angle where the max photocell reading was taken. Converting it to volts for the target voltage, which is what we want to DC motor the drive the pot to be.

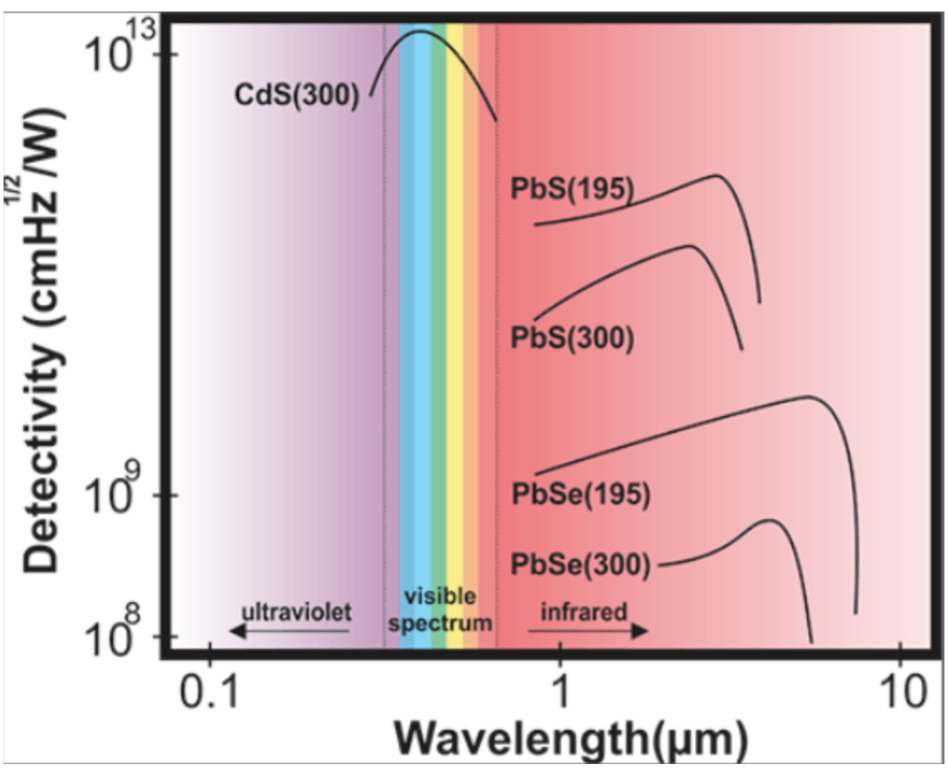


Figure 12: Wavelength detectivity for various photocell materials [2]

As mentioned in the theory section, observed behavior with respect to wavelength is dependent on the material from which the photoresistor surface is made. Our photocell uses

Cadmium Sulfate (CdS), which we confirm operates well within the visible light spectrum (see figure 12). Also mentioned in the theory section, however, is that we designed the experiment so that photoresistor involvement would be purely qualitative. By incorporating the photocell into a voltage divider, we need only to locate a peak among the voltage values measured at each angle, a fact that would hold true for any photoresistor operating within the visible light spectrum.
Some of the shortcomings of this experiment include that our overall build was quite flimsy because cardboard was the main material used. As a result, we had difficulties designing our device so that the limit switch would be push by our rotating cardboard piece. We were able to correct this by carefully positioning and orienting the limit switch in a way that made it easiest for the cardboard to push. Our potentiometer also rotated and wasn't properly fixed in place for a period of time, leading to our solar array angle calculations not being calibrated properly. To fix this, we glued the potentiometer in place.

6 Conclusion

The motivation for this experiment was to introduce and educate ourselves with the open-source platform Arduino, an extremely popular platform for its affordability, availability, ability to work with a variety of systems, and relative ease to use. With an large and helpful online community to help with problems in a multitude of applications, learning Arduino is essential for aspiring engineers. In this experiment we were tasked with designing and manufacturing a solar tracking system from cardboard and mechanical components provided (table 1), and writing code for it to upload and run on the Arduino.

Developing the solar tracker, an extremely useful tool in the sustainable energy business today, serves to teach us the importance of the design process, from intent, planning, executing, and then debugging all as a team. Additionally, we gained experience using some of the individual components we implemented in the overall design of the solar tracker, such as the photocell, potentiometer, and DC, limit switch and Stepper motors.

In conclusion, we would say that the results of our apparatus make sense. Our methodology proved to effective, as our design was able to do everything we set out to achieve. When the solar tracker is turned on it calibrates and starts to move to stepper motor so that it continuously turns, collecting the max photocell value, and in turn the max position. Then upon hitting the limit switch, the code resets the stepper by tuning it back 180 degrees, setting the max position in volts for the potentiometer (converted from max step value). Next, the code takes that target voltage, compares it to the current voltage in the potentiometer, and pulses the DC motor in the correct direction with an accuracy factor that we decide in the code for a given scenario.

A Appendix

Figure showing the top view of our full apparatus.

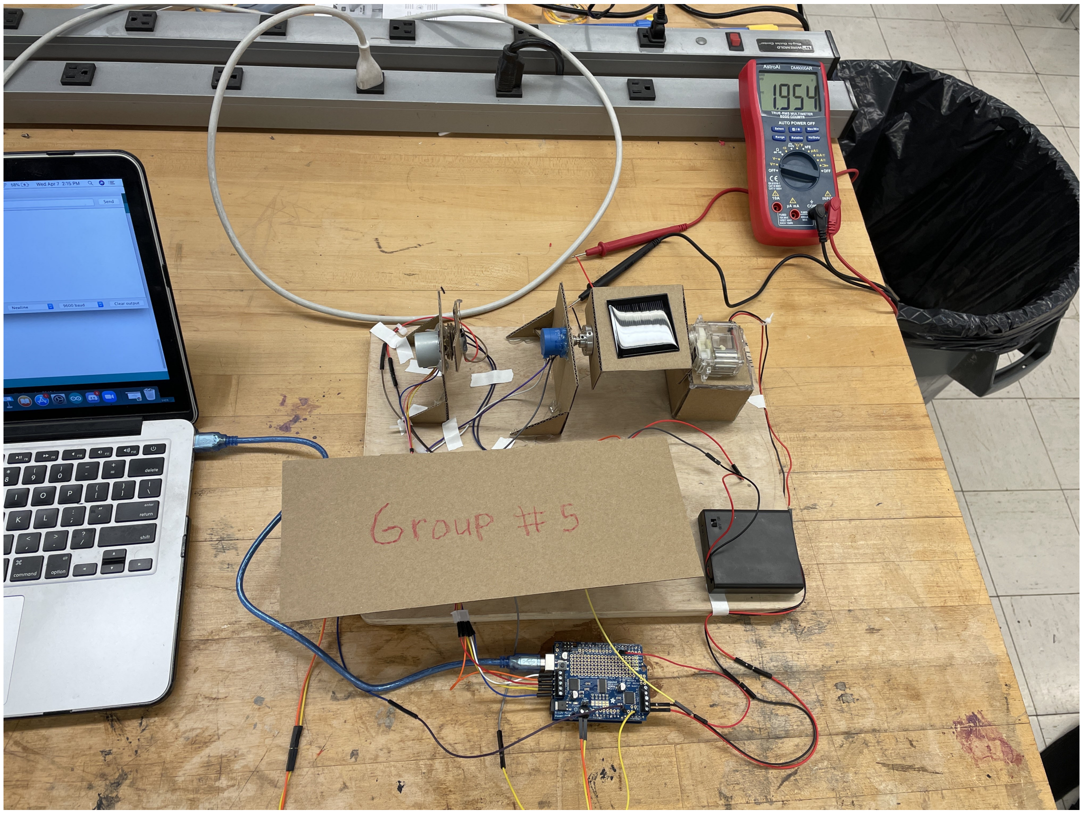


Figure 13: Top view of our completed solar tracking apparatus.

Figure showing the top view of just the portion containing the Solar array, potentiometer, and DC motor.

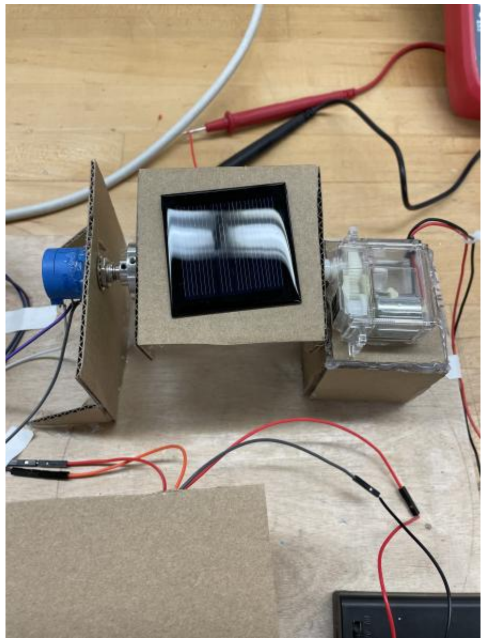


Figure 14: Our Solar array connected to the potentiometer and DC motor.

Figure showing the side of the apparatus that houses the stepper motor, photocell, and limit switch.

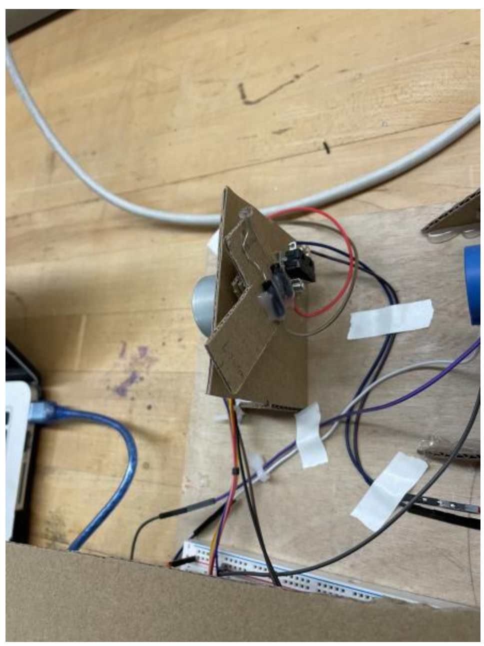


Figure 15: Our photocell connected to the potentiometer via an L shaped cut out, that presses the limit switch.

If you are interested in seeing our full code for this experiment, the code is on pastebin.com, link: https://pastebin.com/kFB28YeL

References

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