Final Report
Spring 2022 EN.520.453
Advanced Undergraduate ECE Design Team

Solar-Powered Mosquito Trap

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Contents

Abstract

The purpose of this project is to design an electronic control circuit for a solar/battery powered mosquito trap. Working with Dr. Conor McMeniman from the Johns Hopkins Bloomberg School of Public Health, we aim to control a heatable fabric using a microprocessor.

According to data from Dr. McMeniman, the heating pad shall be turned on from about 2 hours before sunset to about 3 o'clock in the morning, local time. The desired temperature for the heating pad is about 2 degrees celcius higher than ambient temperature, which, combined with insecticides, can lure and kill mosquitoes.

This device is intended to be deployed in underdeveloped regions in Africa in an effort to control various mosquito-borne diseases such as malaria. Thus, it should be as durable, affordable, and simple as possible.

The control challenge comes when combining the traps two energy sources: a battery, and a solar panel. The goal for the trap is to create energy from the solar panels during the day to charge the battery during the night. The battery can then power the device while the sun is down. This means that our circuit will have a power circuit and control circuit, as seen in the wiring diagram.

Keywords: Solar energy; Circuit design; Mosquito control method

Chapter 1

Introduction

This is our final report for the Spring 2022 Advanced Undergraduate ECE Design Team project. We designed, constructed, and tested prototypes of a new solar-powered mosquito trap, which charges itself with sunlight during the day and heats up a heating pad covered with insecticide during the night. This design process builds on the progress made in the Fall 2021 semester. In order to work effectively in low-income regions in Africa for mosquito control, the device must be cost-effective, durable, and low-maintenance.

1.1 Motivation

"Malaria afflicts 229 million people globally and kills approximately 409,000" (World Health Organization, World Malaria Report 2020). A team of four undergraduate ECE students at Johns Hopkins University collaborate with the Johns Hopkins Malaria Research Institute at Bloomberg School of Public Health to provide an innovative solution for mosquito control.

1.2 Objectives

The objective of this project is to design, test, and build a mosquito trap that is: - Easy to assemble and deploy: Minimize the need of extra wiring and complicated circuits;

- Affordable: Cost to be under 10 dollars each and be as low as possible;
- Durable: Able to trap and kill mosquitoes about 8 to 10 hours each night and works consistently for at least 3 months per year; - Effective: Able to attract, trap, and kill the majority of mosquitoes around the device (precise percentage trapped to be determined); - Low-maintenance: Minimizes battery swaps, solar panel replacements, cleaning, etc.

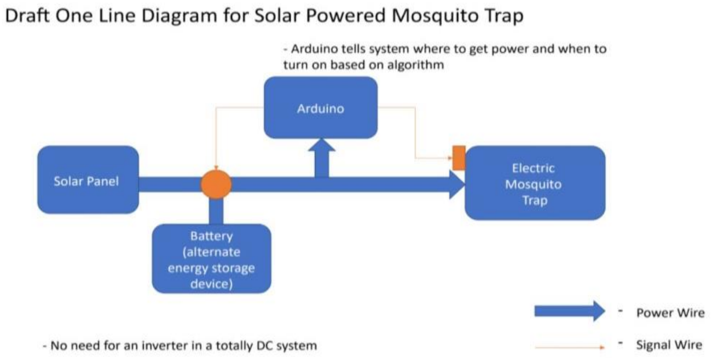
1.3 Structure of the Report

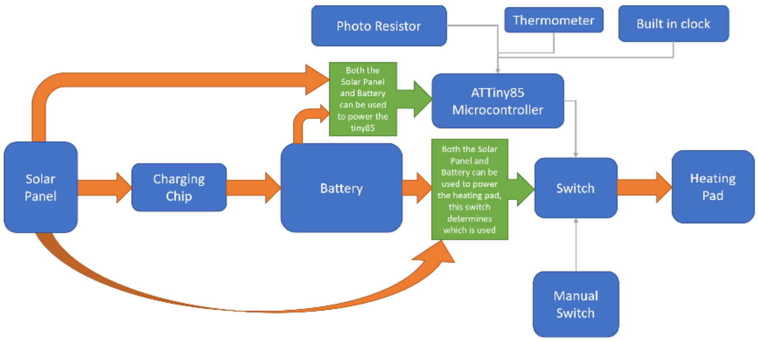
This report goes over the preliminary data, brain-stormed ideas, and prototypes of the project.

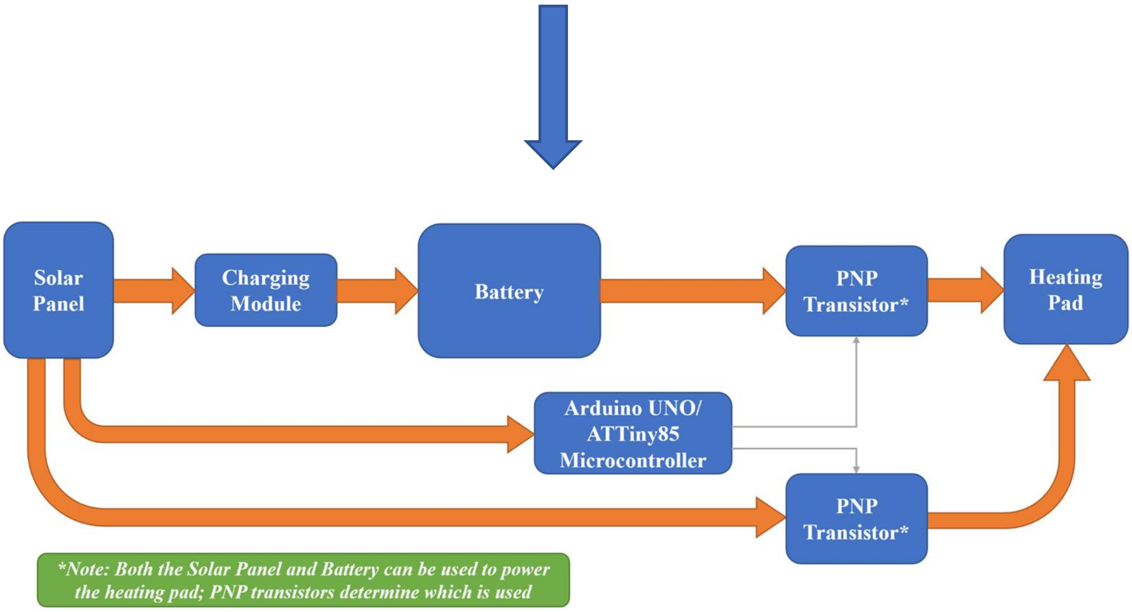
The following components' selection and design are discussed:

- Battery
- Solar Panel
- Control circuit and switch
- Box and stake

Below are the one-line diagrams we began with, versus the simplified version we finalized:







Chapter 2

Methods

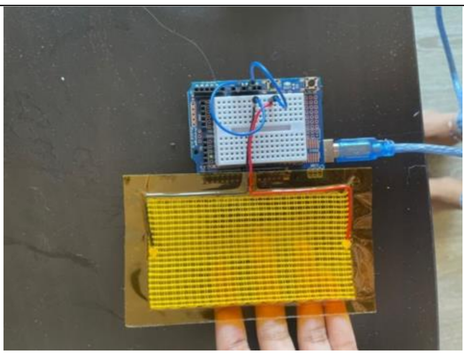
2.1 Heating Pad

2.1.1 Materials

SparkFun Heating Pad (Datasheet)

Information
Digi-Key Part Number: 1568-1797-ND
Manufacturer: SparkFun Electronics
Manufacturer Product Number: COM-11288
Operating Voltage: 5V DC
Operating Current: 600 mA (8.3 Ω)
Dimensions: 100.00mm x 50.00 cm Cost:
$3.75/ea.

Usage
Originally for providing heating as a hand-warmer, which is several degrees Celsius above human body temperature. In our project, the heating pad is powered by the solar-powered battery during the night, which provides a heat source to attract mosquitoes.



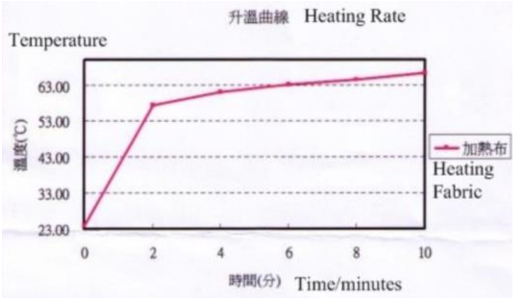


Figure 1: SparkFun 5V DC Heating   Figure 2: Sample Heating Curve Pad

2.1.2 Testing Methods

Connected the heating pad to 5V DC source and measured operating current experimentally. Actual current measurement is 0.54 A (540 mA).

The temperature can go above human body temperature (typically ranging from 97 F (36.1 C) to 99 F (37.2 C)). We tested the heating pad at two different voltages: 3.7V (common battery voltage) and 5V (operating voltage). At 3.7V, the pad reaches 96.8 F (36 C). At 5V, the pad reaches 104 F (40 C). According to Dr. McMeniman, the heating pad should be 2 degrees about ambient. The efficacy of the mosquito trap will depend on the average temperature of its environment.

2.2 Battery

2.2.1 Materials

Information

Likely using a rechargeable Li-Ion battery pack.

Ideal battery power duration depending on what kind of battery we use:

1. If we use 2 1.5V Duracell batteries (2.85 Ah/2850 mAh):
   a. (2*2850 mAh) / (600 mA) = 9.5 hours
   b. (2*2850 mAh) / (540 mA) = 10.5 hours

2.2. Battery

2. If we use 9V battery (400 mAh):
    a. 400 mAh / 600 mAh = 0.6 hours
    b. 400 mAh / 540 mAh = 0.75 hours

Battery Requirements and Analysis

In order for the heating pad to heat up continuously for at least 8 hours, the ideal battery capacity should be greater than 2850 mAh. The operating voltage could range from 3.7V to 5.0V.

The following battery could work (3000 mAh, 3.7V):

3.7V 3000mAh 105151 Lipo Battery Rechargeable Lithium Polymer ion

Battery Pack with JST Connector (Amazon Link)

Information

Item model number: YDL2018032931

Manufacturer: YDL

Operating Voltage: 3.7V DC

Capacity: 3000mAh

Material: Lithium Polymer

Net Weight: 53g

Operating Current: 600 mA (8.3 Ω)

Dimensions: 51 x 51 x 10mm / 2.01" x 2.01" x 0.39" (L*W*T)

Connector Type: 2P PH2.0mm Pitch; Cable Length: 5cm / 2" Package Content: 1 x Lithium Polymer Battery Cost: $14.00/ea.

Usage

The battery can be charged by the solar panels during the day and power the heating pad during the night, controlled by the controller switch. Lithium polymer batteries can charge and discharge simultaneously and can handle lots of charging cycles

Figure 3: 3000mAh, 3.7V Battery Sample

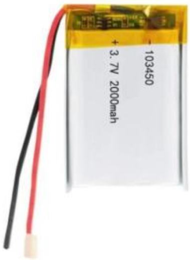


Figure 4: 2000mAh, 3.7V Battery Sample

throughout its lifetime.

However, this battery is relatively expensive. A more affordable option is this one:

(103450 2000mAh 3.7V Lipo Polymer Lithium Rechargeable Battery) which cost $5.50/ea.

List of Possible Types of Batteries

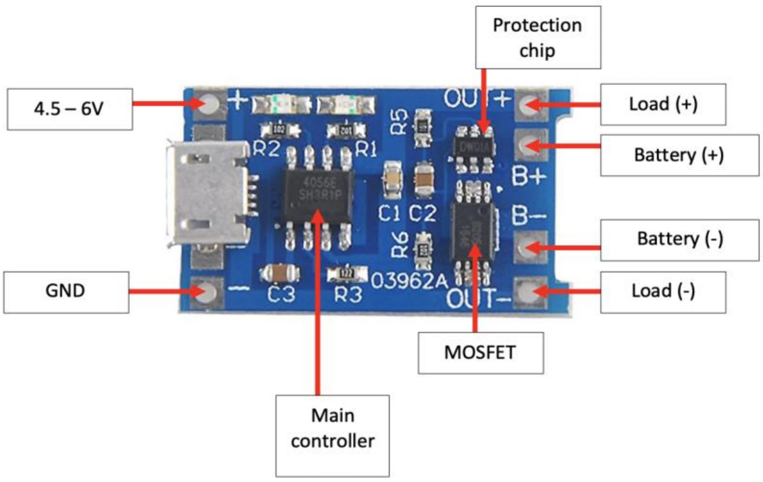
- Li-ion (lithium ion): More expensive, take less time to charge, voltage output unaffected by amount of charge that is left, lightweight, degrades, or may even explode when exposed to high temperatures greater than 130$^{\circ}C$.
- NiCd (nickel-cadmium): Heavier, cheaper, suffers from the memory effect (can charge up to 1000 cycles).
- NiMH (Nickel–metal hydride): Much larger capacity than NiCd, voltage output unaffected by amount of charge that is left, lightweight)
- LiFePO4 (lithium iron phosphate): Safe, tolerates extreme outdoor temperatures, lightweight, quick charge/discharge)

2.2. Battery

In order to meet the project requirements, the best battery options are NiMH, Li-ion, and LiFePO4 batteries. Review (this chart) for more battery ordering options.

Solar Charging Module to aid battery:

In order to charge the lithium-ion batteries, a circuit that acts as a charging module and battery protection unit is needed. A charging circuit must be incorporated to prevent the Li-ion battery from discharging below 2.4V, safely charge the battery to 4.2V, and limit the output of the battery if the discharge rate exceeds 3A.



Charging Module Photo Source: MakerFocus Website https://www.makerfocus.com/products/10pcs-tp4056-charging-module-5v-micro-usb-1a-18650-lithium-battery-charging-board

2.2.2 Testing

As of December 2021, we haven't tested batteries with solar panel charging and heating pad powering.

Next steps includes 1) purchase various batteries and compare the performances; 2) Take apart a few solar chargers and study their functions; 3) Look for affordable battery options.

2.2.3 Diagram

A diagram for our prototype is the following:

The Arduino will sense the temperature of the heating pad and switch the battery on and off to save energy. A photoresistor will detect low illumination levels and determine the time of sunset. Note that this system is entirely DC and should be self-sufficient for long periods of time.

2.3 Solar Panel

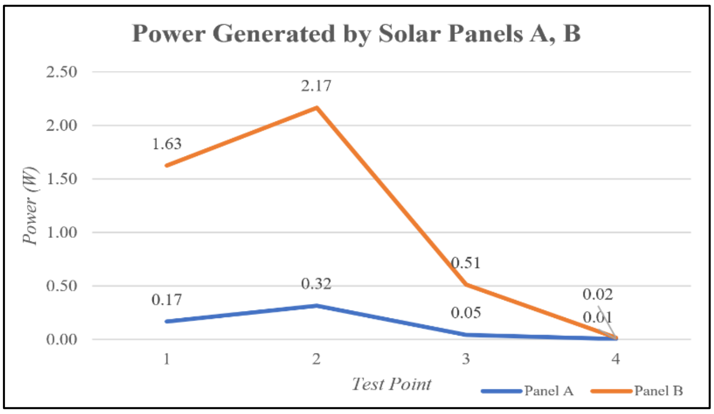
2.3.1 Materials

- Battery
- Solar Panel
- Charging Module
- Multimeter (for determining power production of panels)

2.3.2 Testing Methods

- Charge solar cells with sunlight or lamps and measure battery charging
- Compare multiple solar panels

Two sizes of solar panel (4.05 x 4.05 cm - panel A and 10.64 x 12.07 cm - panel B) and their resulting powers were compared, with results shown below:



Based on its only slightly larger size but substantially higher power production, solar panel B was chosen to continue in our designs.

2.4 Control Circuit

2.4.1 Materials

- Photoresistor Arduino Circuit: When the illumination level drops below a certain level, the switch (LED) turns on and the heating pad begins heating.
    - PNP transistor (x2)
    - LED (x2)
    - Diode (x2)
    - Resistors of various values (at least 4)
- 10.64 x 12.07 cm Solar panel
- 3.7 V Li-Ion Battery
- Arduino UNO
- ATtiny85 (singular chip instead of Arduino UNO/ATmega328 microcontroller): will still offer needed EEPROM and I2C capability for thermometer and luxe sensor, but will be more compact and cost-effective.

Parametrics

Click on a property to perform a parametric search for other products with that property.

Max ADC Resolution (bits)	10
Program Memory Size (KB)	8
Number of Comparators	1
CPU Speed (MIPS/DMIPS)	20
Data EEPROM (bytes)	512
Max 8 Bit Digital Timers	2
Ethernet	None
I2C	1
Program Memory Type	Flash
ADC Channels	4
Low Power	No
Operating Voltage	1.8 - 5.5
outputcomparatorPWM	5
Pin Count	8
SPI	1
Temp Range (°C)	-40 - 85

Figure 6: Specifications of ATtiny85 Microcontroller

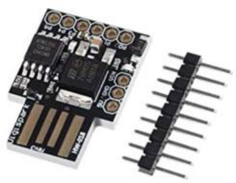


Figure 7: Currently working with micro USB development board using ATtiny85

- We also need a temperature measuring unit (ie. DHT11 thermistor) to monitor the temperature.

2.4.2 Testing Methods

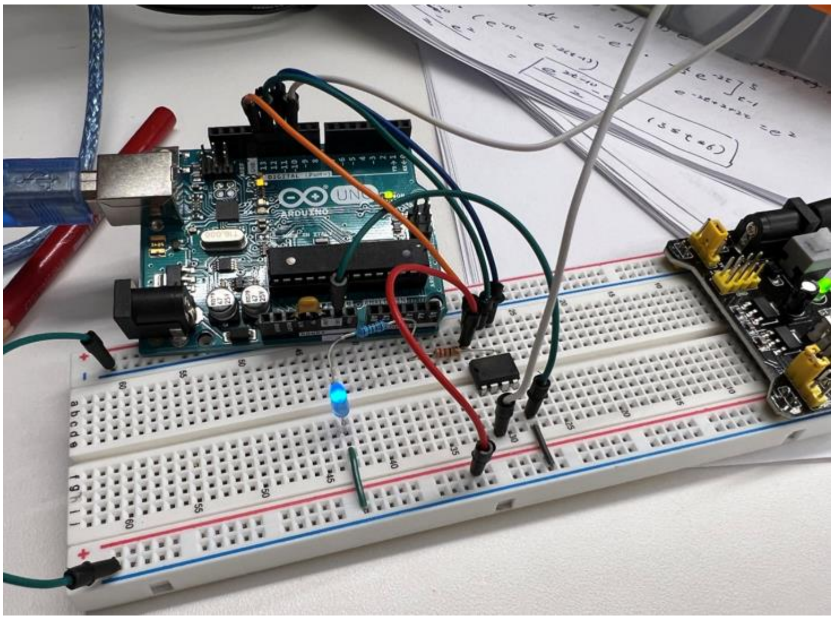
I. Configuring ATtiny85

In the Spring semester, the ATtiny85 was incorporated into the design. It has the functionalities of an Arduino UNO required, but without the extra capabilities and power usage. After a few periods of troubleshooting, the process for uploading programs to the ATtiny85 was solidified, and these steps are included below. Note that this chip is being discontinued, so a similar one should be selected for future continuation of this project.

A. Arduino IDE Configuration Settings to Upload to ATtiny85:
   1. tools > board > ATtiny25/45/85
   2. tools > processor > ATtiny85 w 1MHz clock
   3. tools > programmer > Arduino as ISP

B. Uploading Programs to ATtiny85

1. Ensure that the board is switched back to Arduino Uno under “Arduino Mkll” rather than the Arduino as ISP
2. Upload the ISP script to enter ATtiny programming mode
3. After confirming that the wiring is correct, upload a different program to ensure uploading is happening successfully.



After uploading the “blink” and “fade” programs to the AtTiny, the LED blinks and fades as intended, even without the arduino.

C. Burning the Bootloader

To avoid previous memory/confusions on the ATtiny chip, the bootloader should be burned once for each chip. The steps are as follows:

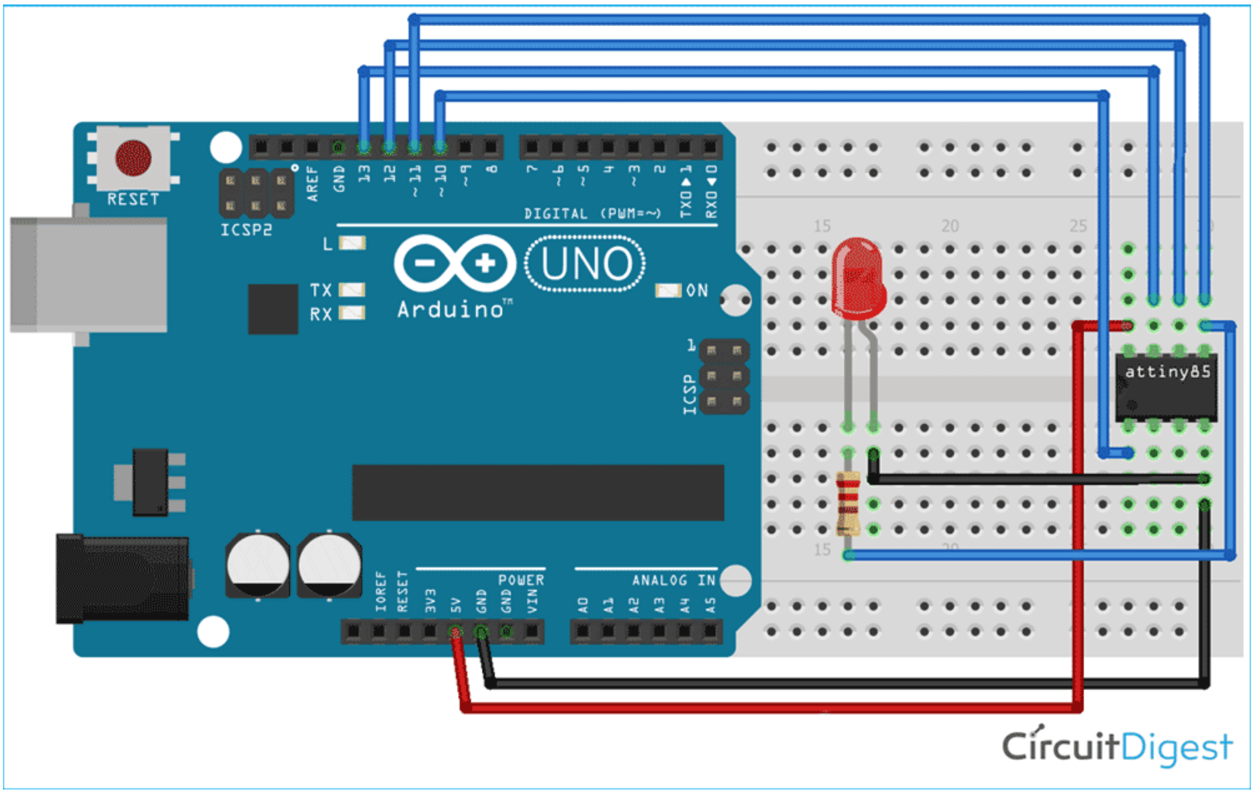
1. Go to Tools -> Board. Scroll to the bottom select ATtiny25/45/85
2. Under Tools -> Processor--> 8 MHz (internal)
3. Under Tools-->Programmer-->Arduino as ISP
4. Check that all wiring, capacitor, and board selections are correct
5. Finally select ***Burn Bootloader***
6. Leave the wires connected

A message will appear saying "Done Burning Bootloader"

Then, repeat the steps to upload the next set of code.

D. Links for reference:

1) Tutorial on Programming the Attiny: https://circuitdigest.com/microcontroller-projects/programming-attiny85-microcontroller-ic-using-arduino
2) Another tutorial with Bootloader instructions: https://www.instructables.com/How-to-Program-an-Attiny85-From-an-Arduino-Uno/



II. Power Source Switching Circuits

Based on the sunlight available, the mosquito trap should switch between solar power and battery power. For example, the heating pad will primarily draw power from the battery during the dark nighttime hours. But in the hours just before sunset when the heating pad should be on, there may be ample sunlight to bypass the battery and draw power directly from the solar panel.

A. Version 1 - LED Control Based on Sunlight Available

Preliminary attempts at this circuit consisted of using the reading from a solar panel to power an LED on or off. When the solar panel was receiving light, the LED turned off, and when it was not receiving over a certain threshold of light, the LED powered on. The LED represented the heating pad, simulating how the heating pad should be on during the nighttime and generally off during the day.

The Arduino code, which we also adapted and uploaded successfully to the ATtiny85, for this circuit is shown below:

solarSwitching | Arduino 1.8.19 (Windows Store 1.8.57.0)

File Edit Sketch Tools Help

solarSwitching

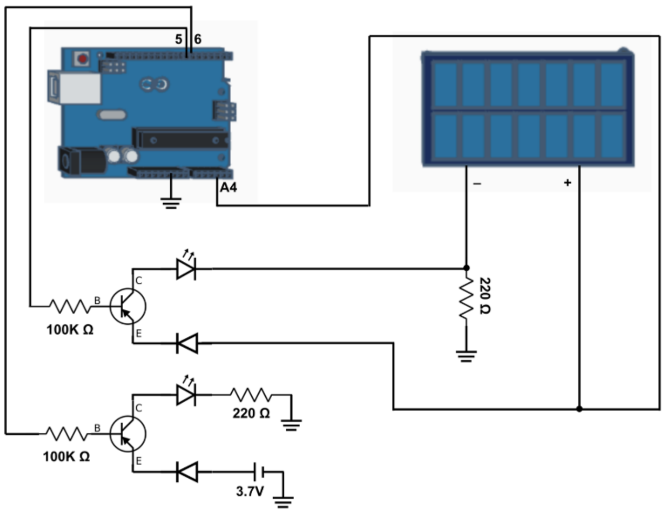
```
/*
 * Madeline Chabab, Amanda Fernandes, Carl Urbanik, Joy Yeh
  This code is an adapted version of Arduino's example "Blink.ino" code.
  In this code, when a solar panel's reading is over a certain threshold voltage,
  (simulating daylight), the LED representing the trap's heating pad will turn off.
  When the panel is not detecting over the threshold voltage,
  this triggers "nighttime mode", turning on the LED.
*/
int analogPin = A2;
int LEDpin = 0;
void setup() {
  // initialize digital pin LED_BUILTIN as an output.
  pinMode(LEDpin, OUTPUT);
  //Serial.begin(9600);
}

int val = 0;
// the loop function runs over and over again forever
void loop() {
  val = analogRead(analogPin);
//  Serial.println(val);// read the input pin
  while (val > 300) {
 //   Serial.println(val);
    digitalWrite(LEDpin, LOW);   // turn the LED on (HIGH is the voltage level)
    val = analogRead(analogPin);
  }
  digitalWrite(LEDpin, HIGH);    // turn the LED off by making the voltage LOW
}
```

B. Version 2 - Full Power Source Switching Utilizing Solar Panel and Battery

Once the preliminary circuit was functioning with only the solar panel, we incorporated a battery for full switching capabilities depending on sunlight levels. For this circuit, both MOSFET chips and basic PNP transistors were tested, and PNP transistors were selected due to familiarity and ease of use.

The circuit we finalized to control this power switching is shown below, as well as the controlling Arduino sketch.



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powerSourceSelector_4-12

```
// when uncovered inside at 6:19, analogRead is 940 or 950
// when covered inside at 6:21, analogRead is generally less than 300

// PNP transistors used, close switch when base is low

int solarPin = A4;
int batteryGate = 6; //switch for battery power
int solarGate = 5; //switch for solar panel. Inverse of batteryGate.

void setup() {
  pinMode(batteryGate, OUTPUT);
  pinMode(solarGate, OUTPUT);
  Serial.begin(9600);
}

int solarVolts = 0;
void loop() {

  solarVolts = analogRead(solarPin);
  Serial.println(solarVolts);// read the input pin
  if (solarVolts < 230) {
    // if less than 230 solar is available, power heating pad (LED) using battery power
    Serial.println("battery");
    digitalWrite(batteryGate, LOW); //close the battery switch, powering LED
    digitalWrite(solarGate, HIGH);
  }
  else {
    // if ample solar is available, power heating pad (LED) using solar panel
    // this would be the case during evening when mosquitos are out but little sunlight is
    //     still available
    Serial.println("panel");// read the input pin
    digitalWrite(batteryGate, HIGH); //open the battery switch, turning off LED
    digitalWrite(solarGate, LOW);
  }
  delay(50);

}
```

Figure 8: Preliminary Arduino sketches and circuit to control power source selection

2.5 Box and Stake

2.5.1 Materials

- We currently have a cardboard box without glue. The dimensions are about 20 * 15 cm.
- The advantages are the low cost, ease of assembly (doesn’t require adhesives), and ease of creating alternate designs.
- However, the box might not be versatile enough in extreme weather. Circuit components might also fall off.
- Design Sketches on next page.

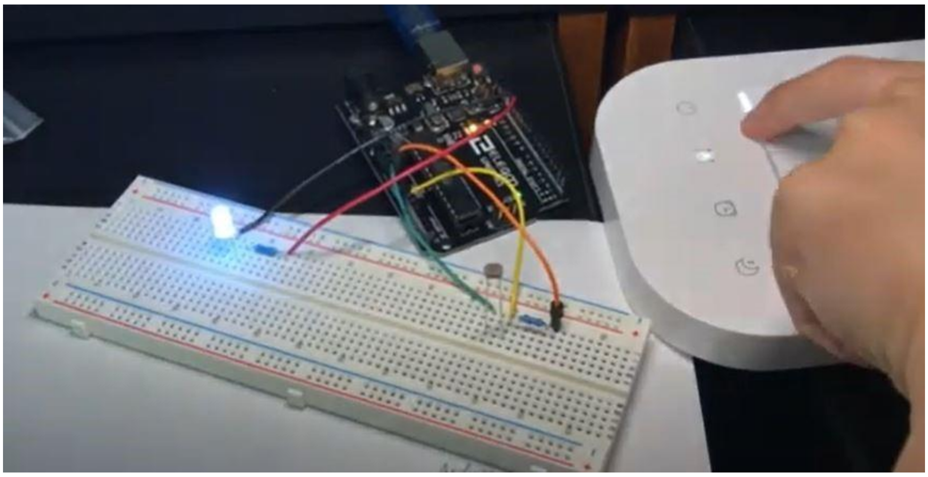


Figure 9: Illumination-Controlled Switch with Photoresistor

2.5.2 Challenges

- Cost, ease of transportation, durability
- Should provide more advantages compared to current consumer-use mosquito traps

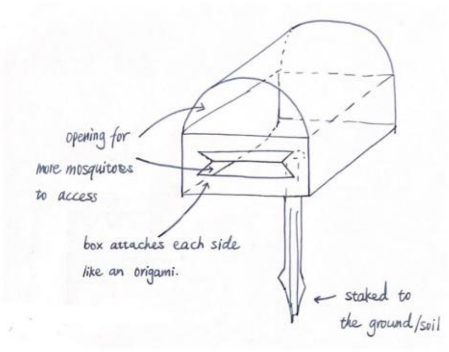
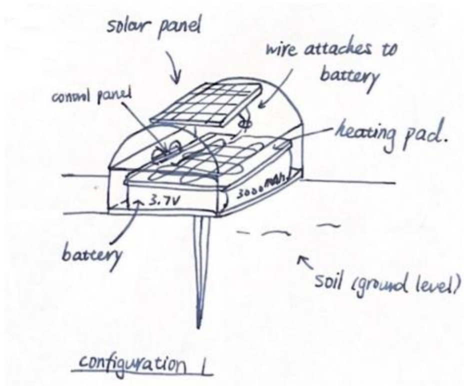


Figure 10: Current Box and Stake Design



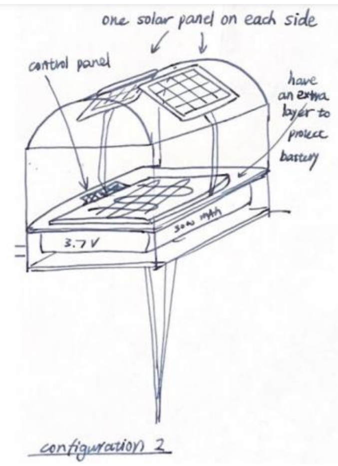


Figure 11: Component Configuration 1 Figure 12: Component Configuration 2

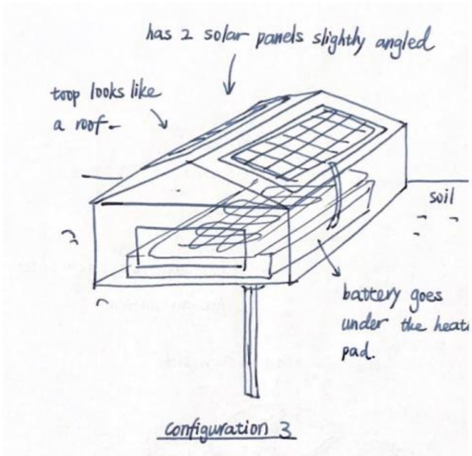


Figure 13: Component Configuration 3

Chapter 3

Results & Discussion

Objectives Achieved

During our two semesters working on this mosquito trap, we achieved the following objectives:

- Identified the main design challenge and project objectives
- Visited the Malaria Research Institute and explored the facilities and research at the lab
- Obtained preliminary experimental data on the heating pad, batteries, solar panels
- Experimented with Arduino code and related light and temperature sensors
- Brainstormed possible device configurations through hand sketches
- Identified suitable battery types and capacities
- Tried to capture mosquitoes with adhesives next to the heating pad overnight in the lab (trials conducted by Dr. Rankin-Turner), which captured 95% of mosquitoes in the chamber
- Conducted power tests to determine most suitable solar panel options
- Designed and constructed power source switching circuit to transition from solar power to battery power and vice versa

Next Steps

A future group continuing this project should consider focusing on the following items:

- Equip the device to run for extended periods of time. A higher storage capacity may be needed for the timing mechanism to function properly alongside the other controller processes.
- A custom charging module will need to be sourced or manufactured to support battery charging with the solar panels this device employs. The power levels currently being produced by the onboard solar panel are too low for compatibility with most commercial charging modules.

- Incorporate a robust timing mechanism. For this switching circuit to be useful to the mosquito trap, it will need to operate autonomously for a period of at least a few months, if not longer.
- Experiment with new box design with plastic, plywood, different types of cardboard, etc.
- Once the electronic system nears completion, it should be fitted to mount compactly onto the foldable box and stake structure shown to the right.
- If possible, conduct lab trials at the MRI and measure the efficiency of capturing mosquitoes.
- Solder components together to make a functional prototype (as opposed to breadboarding)
- Attempt to reduce the complexity of the circuit and achieve the same functions with ICs