Solar Oven with Sun Tracking.

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2. Abstract

The objective of this project will be developing the system modeling and simulation of a solar cooker of our own design.

The cooker will focus the suns solar radiation, called isolation, onto a cooking pot via a reflective parabolic dish, cooking the food within the pot. The system can also measure the temperature of the cooking object and adjust the angle of the dish relative to the sun in order to raise or lower the temperature accordingly while constantly monitoring the temperature in order to create more adjustments as necessary. Power for motion and monitoring will come from solar panels fixed to also track the sun, so the solar cooker is self-sustained.

(Samanta Chan, James Alexander)

3. Introduction

3.1 System Configuration

Due to their simplicity and ease of use solar cookers of some type have been around for centuries, and as is the case with most technologies that have existed for centuries there are a vast array of methods and types of solar cookers. Of these types the fastest cooking per solar area is a parabolic dish, or paraboloid. However, the parabola is so efficient only when pointing directly at the sun, which has a well known tendency to move across the sky at a constant rate. For this reason the design is solar tracking, meaning it will follow the suns trajectory across the sky. Tracking the sun will allow the cooker to cook as hot as possible for as long as possible.

In order to move of its own volition the cooker must have a source of power, and since it will already be tracking the sun the addition of a solar panel to generate DC is obvious. If the system is well balanced the power demand will be minimal and not constant, only needed to move the dish, not hold its place.

The sun will be tracked east to west by two light sensors placed next to each other, one east and one west, bisected with a single blade raised toward the sun. As the sun moves across the sky the blades shadow will fall on one of the sensors. This difference between the sensors shall cause the motor to rotate the dish until the two sensors are signaling equal sunlight. Similarly if the pot becomes too hot the dish can rotate until a sensor is in the blades shadow. With this method the blades height can be altered to adjust the systems sensitivity. The taller the blade the more the sun’s movement will be exaggerated and the the quicker the shadow will move to cover/uncover a sensor.

(James Alexander)

3.2 Background and Technical Trend

There are many types of solar cookers, but the vast majority currently being use ared relatively cheap, low-technology devices, such as:

Box Cooker: A box cooker consist of a transparent glass or plastic top, which may have additional reflectors to concentrate sunlight into the box. The top is usually removable to allow dark pots containing food to be placed inside. One or more reflectors of shiny metal or foil-lined material may be positioned to bounce extra light into the interior of the oven chamber. Cooking containers and the inside bottom of the cooker should be dark-colored or black, while the inside walls should be reflective to reduce radiative heat loss and bounce the light towards the pots and the dark bottom, which is in contact with the pots. The box should have insulated sides.

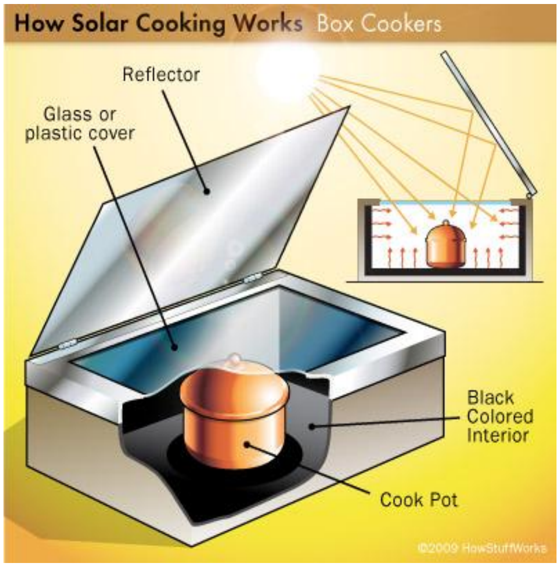

Fig 1. Box Cooker

Panel Cooker: Panel solar cookers use reflective panels to direct sunlight to a cooking pot that is enclosed in a clear plastic bag. It can be produced by pasting a reflective material, such as aluminum foil, onto a cut and folded backing, usually corrugated cardboard. It is lightweight and folds for storage.

The HotPot is an advanced panel cooker design that includes a glass bowl with an inner black steel liner and a glass top. The panel has polished aluminium sections that fold flat. The HotPot has high thermal gain due to the greenhouse effect.

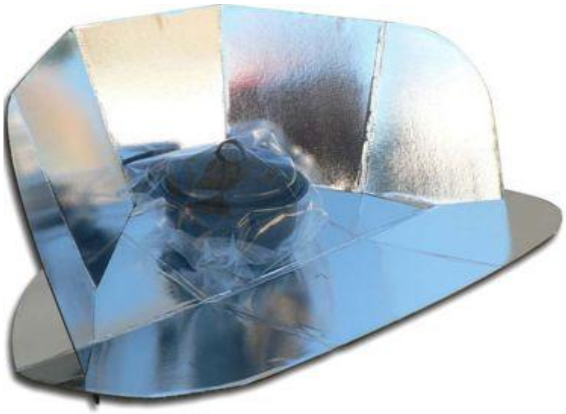
Fig 2. Panel Solar Cooker

Solar Kettles: The solar kettle-thermos flask is a solar thermal design that uses an evacuated solar glass tube (solar vacuum glass tube) constructed from borosilicate glass to capture and store energy from the sun. The tube consists of an inner glass layer characterized by a dark exterior that heats up in sunlight, whereas the outer glass layer is transparent allowing sunshine to penetrate. This sunshine transports the solar infra-red energy and penetrates through this outer layer and subsequently through the vacuum layer onto the inner layer where it is absorbed. The air is evacuated between these two layers with a consequent insulating vacuum.

The difference between a classic solar cooker and a solar kettle is the latter runs off the principle of accumulated rather than concentrated solar thermal energy. In essence these kettles only need diffused sunlight to work and needs no sun tracking at all.

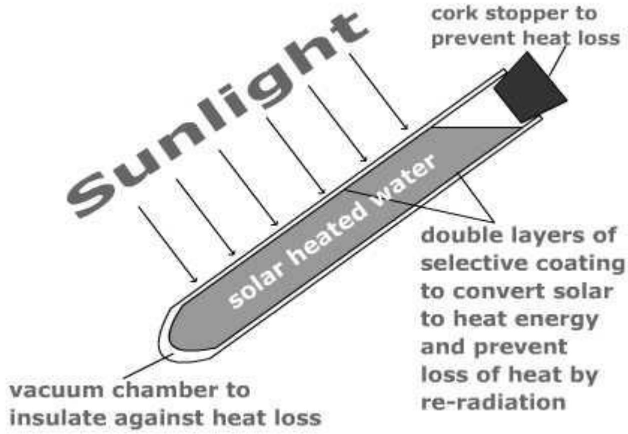

Fig 3. Solar Kettle

Scheffler Cooker: uses a large ideally paraboloidal reflector which is rotated around an axis that parallel with the earth's by a mechanical system, turning at 15 degrees per hour to compensate for the earth's rotation. The axis passes through the reflector's centre of mass, allowing the reflector to be turned easily. The cooking vessel is located at the focus which is on the axis of rotation, so the mirror concentrates sunlight onto it all day. The mirror has to be occasionally tilted about a perpendicular axis to compensate for the seasonal variation in the sun's declination. This perpendicular axis does not pass through the cooking vessel. Therefore, if the reflector were a rigid paraboloid, its focus would not remain stationary at the cooking vessel as the reflector tilts. To keep the focus stationary, the reflector's shape has to vary. It remains paraboloidal, but its focal length and other parameters change as it tilts. The Scheffler reflector is therefore flexible, and can be bent to adjust its shape. It is often made up of a large number of small plane sections, such as glass mirrors, joined together by flexible plastic. A framework that supports the reflector includes a mechanism that can be used to tilt it and also bend it appropriately.

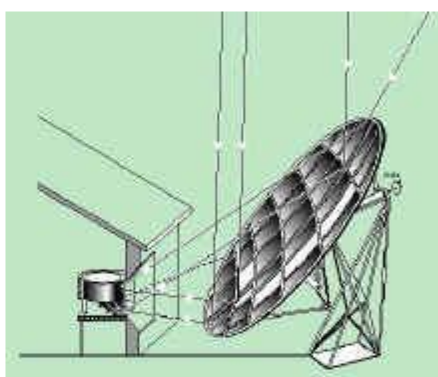

Fig 4. Scheffler Cooker

Hybrid Cooker: A hybrid solar oven is a solar box cooker equipped with a conventional electrical heating element for cloudy days or nighttime cooking. It consists of an adjustable paraboloidal reflector suspended in a tripod with a movable grill surface. When solar energy is not available, the design uses any conventional fuel as a heat source, including gas, electricity, or wood. However, a hybrid cooker ends up being very expensive compared to other types of solar cookers.

Fig 5. Hybrid Cooker

Although various ideas for high-tech solar cookers have been proposed, such as the electric oven powered by solar cells, very few of them have progressed past the experimental stage to the point where they are used in practice, because they are generally much more expensive than low-tech cookers.

(Samanta Chan)

4. Analysis and Simulation

4.1 Math Model and Analysis

The main idea for the control system is that it would take temperature, and light as input and output rotation according to the sensors. The two light sensors will be compared so that a “high” signal goes through only if the sensors report differing results indicating a position change is needed. The Temperature sensor signal will then be subtracted from this, preventing movement if the temperature is already at desired result. This will keep the temperature of the food within a short range of the desired temperature. From this description we can create the following state machine diagram and truth table**.**

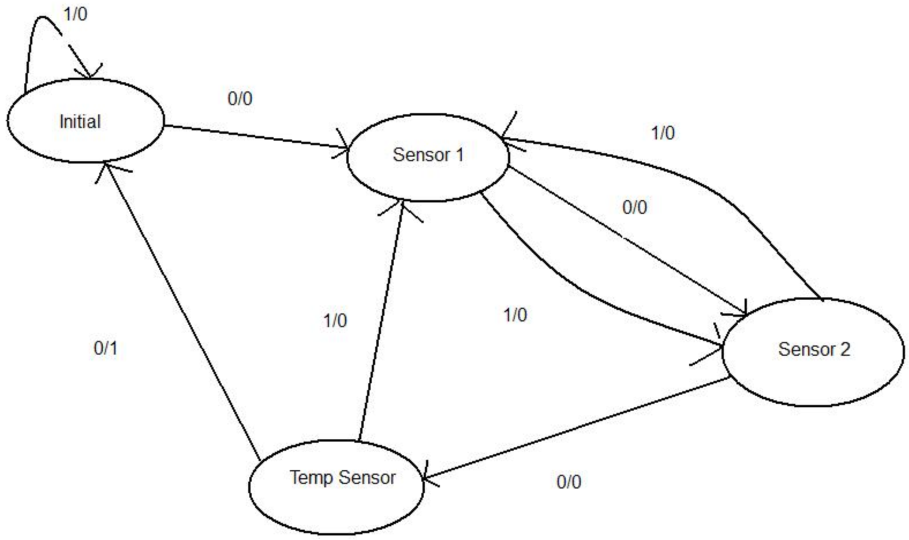

Fig 6. State Machine Diagram

Table 1. Truth Table

Using the truth table, we can compute the necessary equations to design a circuit to accomplish our task on a basic level using flip-flop chips and logic gates.

$A1(k+1) = \overline{A1}\ A0 + A1\ \overline{A0}\ \overline{In}$

$A0(k+1) = A0\ In + \overline{A1}\ \overline{In}$

$Output = A1\ A0\ \overline{X}$

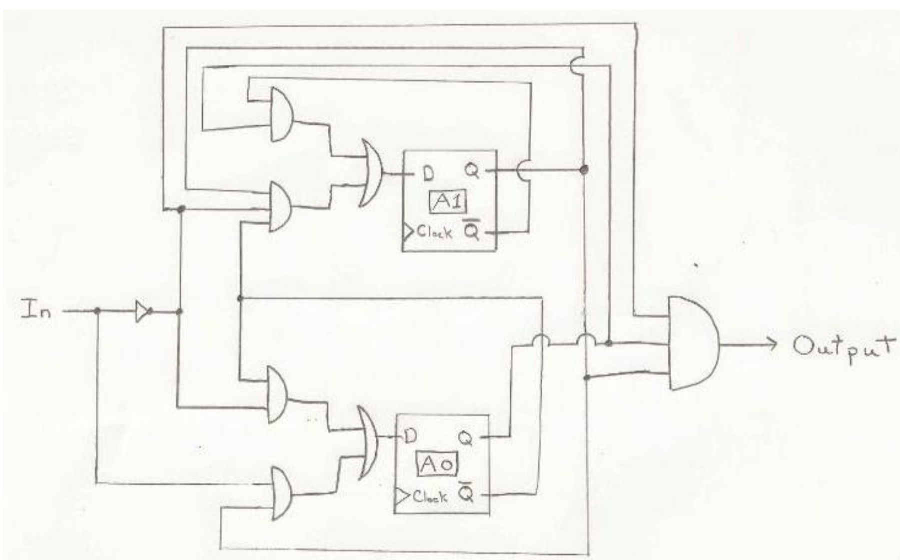

Fig 7. Circuit Diagram.

Using the following equations we can create a state space model for the control system of the solar cooker.

$$\tau = F \times r = M \cdot A \cdot r = M \cdot r^2 \cdot \alpha$$

$$T(s) = \frac{\theta}{\tau} = \frac{1}{(M \cdot r^2 \cdot s^s)} = \frac{1}{9.5} \cdot s^2$$

$X1 = \theta$

$\dot{X1} = X2$

$\dot{X2} = \alpha$

Resulting in the following Matrices:
A = [0 1; 9.5 0]
B = [1; 0]
C = [1 0]

(Jeffrey Kornder)

4.2 Simulation

In order to design a controller we gave the system some requirements based on expected results:
Settling Time = .01s
% Overshoot = 10%

Since the machine will be moving in small increments, it should reach settling time quickly and have a relatively low overshoot. From these requirements we can derive the damping ratio and angular velocity using known relationships.
Damping ratio (ζ) = .6
ω_m = 666.67

We can then transform our original Characteristic equation
Q = 9.5 s^2

Into the desired equation with control:
$Q_d = 9.5s^2 + 800s + 44{,}444$
K = [44,444 800]

Using the new transfer function, we can design a control system and plot the output response of our design.

$$G(s) = \frac{1}{(9.5s^2 + 800s + 44{,}444)}$$ With control

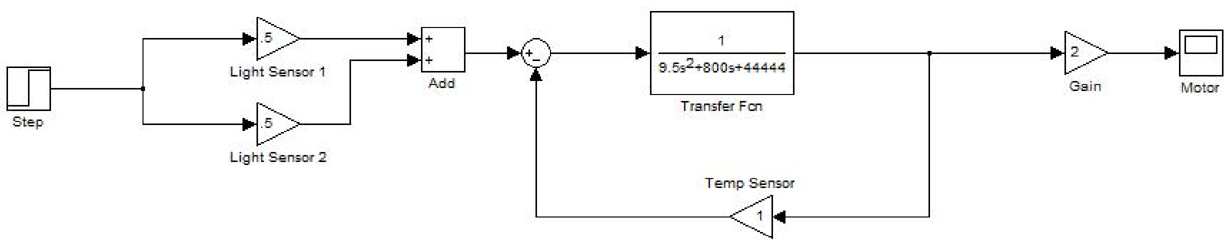

Fig 8. Matlab/Simulink Model

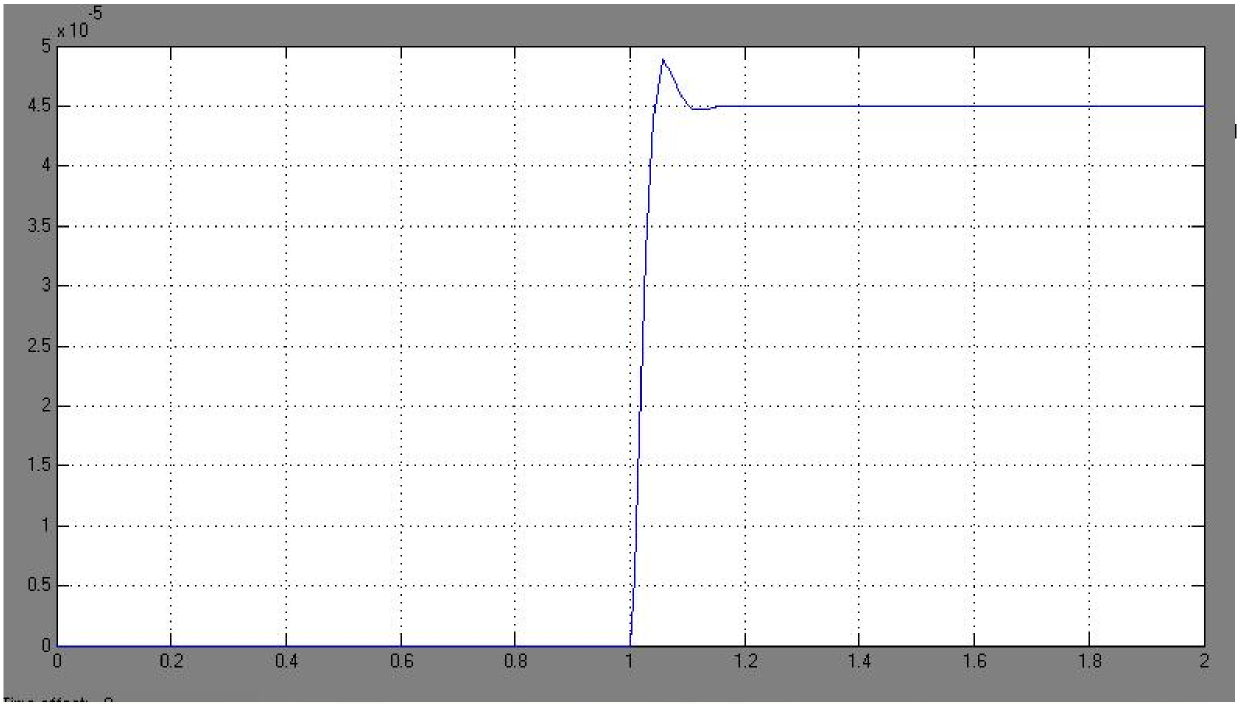

Fig 9. Output Response

(Jeffrey Kornder)

4.3 CAD Modeling

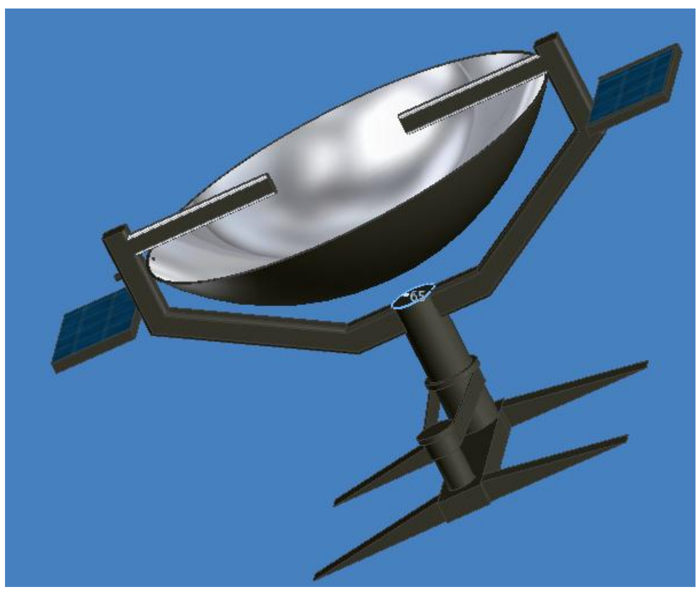

Fig 6. Original Discarded Model

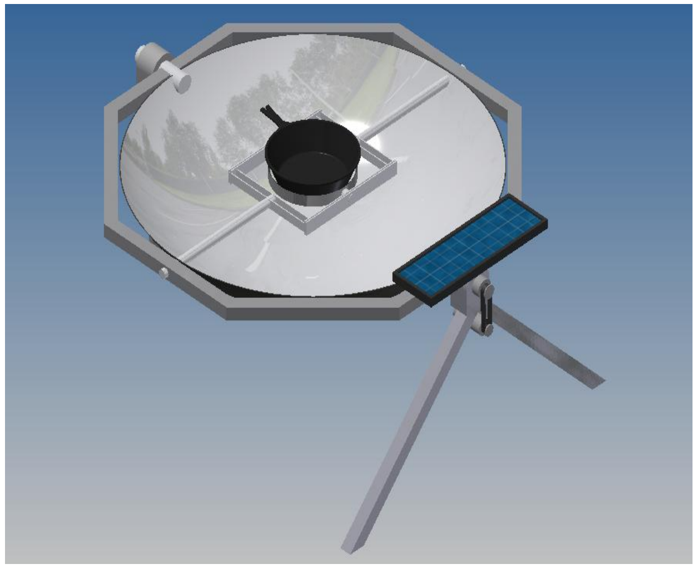

Fig 7. Solar Cooker – Isometric View

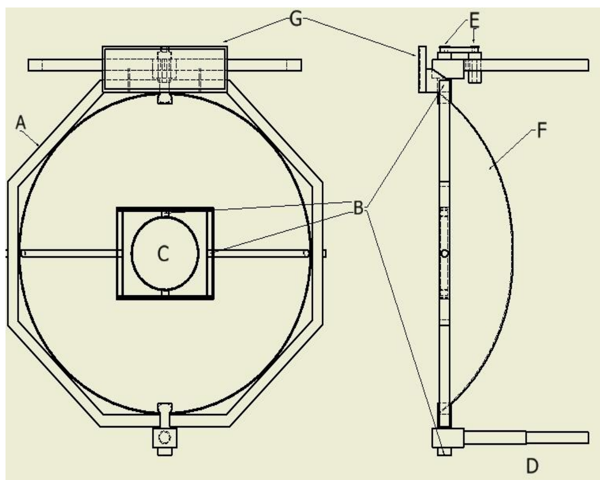

Fig 8. Solar Cooker – Orthographic View

A: Primary frame. Will rotate and support dish, pot, and solar panel.

B: Bearings to track sun and hold the pot level.

C: Pot goes here

D: Adjustable third leg to pitch dish towards suns path.

E: Motor and belt drive train to follow suns path.

F: Reflective parabolic dish.

G. Solar panel to power system. Will also track sun by being on the frame.

(James Alexander)

4.4 Discussions

Our primary focus was to analyze the original concept and improve upon it. As we found out, the software part of the model presents no major problems, conversely, we realized that the hardware design requires drastic modification, would be unable to track the sun during ideal perpendicular sunlight conditions.

(James Alexander, Samanta Chan, Jeffrey Kornder)

5. Conclusions

5.1 Achieve and Learned

Through this project we learned how to apply the knowledge from this class and other courses to a real life situation. We used statics, dynamics, and thermodynamics to model the mechanical system; microcontrols and digital controls to design its circuitry; and finally but not least, control systems to communicate between the electrical and mechanical parts, and to improve their functionalities.

(Samanta Chan)

5.2 Future Study

Solar cookers are an attractive alternative for cooking because they use no fuel and are non-pollutant, but they also present many disadvantages such as a longer cooking time compared to electrical or gas kitchens, and there is always the possibility that the meals won't be fully cook.

The objective for this project was not only to design a clean energy, environmental friendly, and safe cooking device, but to automate its functions so it is a more efficient and less hand-on process. Having done a model, the next step in the project would be to create a prototype based on the model, test it and improve it, so it is affordable, safe, and reliable.

(Samanta Chan)

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7. Appendix

7.2 Sun Tracking Program (using Arduino micro-controller).

```
#include <Servo.h>

Servo myservo;
unsigned long time;
unsigned long timetest;
int val = 0;
int down = 255;
int up = 0;
int pos = 90;

int InL = 0;
int InC = 1;
int InR = 2;

int BaseL = 0;
int BaseC = 0;
int BaseR = 0;

int OutL = 0;
int OutC = 0;
int OutR = 0;

int difL = 0;
int difR = 0;


void setup()
{
```

```
  Serial.begin(9600);
  pinMode(InL, INPUT);
  pinMode(InC, INPUT);
  pinMode(InR, INPUT);

  BaseL = analogRead(InL);
  BaseC = analogRead(InC);
  BaseR = analogRead(InR);

  myservo.attach(9);
  myservo.write(pos);

  //time = millis();
}

void loop()
{

  OutL = analogRead(InL) - BaseL+511;
  Serial.println(OutL);
  OutC = analogRead(InC) - BaseC+511;
  Serial.println(OutC);
  OutR = analogRead(InR) - BaseR+511;
  Serial.println(OutR);

 difL = OutC - OutL;
 difR = OutC - OutR;

  if (OutL < OutC && difL > difR)
  {
   moveL();
  }
  if (OutR < OutC && difR > difL)
  {
   moveR();
  }
  Serial.println(".....");
  delay(25);
  timetest = millis() - time;
```

```
  //if (timetest > 20000)
  //{
   // reset();
  //}
}

void moveL()
{
  difL = OutC - OutL;
  if (difL > 4)
  {
    pos = pos + 1 ;
    myservo.write(pos);
    difL= OutC - OutL;
    if(difL < 4)
    {
      reset();
    }
    if(pos == 0)
    {
      for(pos = 0; pos < 90; pos++)
      {
        myservo.write(pos);
        delay(25);
      }
    }
    Serial.println("Moving Left");
    Serial.println("New position: " + (pos));
    delay(55);
  }
  return;
}

void moveR()
{
  difR = OutC - OutR;
  if (difR > 4)
  {
    pos = pos - 1 ;
```

```
    myservo.write(pos);
    difR = OutC - OutR;
    if(difR < 4)
    {
      reset();
    }
    if(pos == 0)
    {
      for(pos = 180; pos > 90; pos--)
      {
        myservo.write(pos);
        delay(25);
      }
    }
    Serial.println("Moving Right");
    Serial.println("New position: ");
    Serial.println(pos);
    delay(5);
  }
  return;
}


void reset()
{
   BaseL = analogRead(InL);
   BaseC = analogRead(InC);
   BaseR = analogRead(InR);
   time = millis();
}
```

(Samanta Chan)