A Solar Tracker Using Commercial Components

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***Abstract*—With a growing global population putting a strain on our energy resources, alongside unpredictable natural and geopolitical factors. Building a stable source of power has been at the forefront of research. Solar trackers are part of the solution. We will take a practical look at solar trackers in general, and we will present a custom-made solar tracker built from commercially available components controlled by dedicated control software.**

***Index Terms*—Robotics, Photovoltaics, Renewable Energy, Potential, Functions**

I. Introduction

Life in the 21st century is unimaginable without electricity, almost everything we interact with on a daily basis depends on it. But for centuries now the lifeblood of our modern existence has been produced by unrenewable and polluting means that have a set eventual total depletion date in the future. Taking into account recent events, now more than ever is the time to decrease our fossil fuel dependency in the energy sector. Not only are we faced with severe fuel shortages, but the fuels that we so desperately need are the same fuels that cause massive air, water, and land pollution, essentially a lose-lose situation, the seriousness of which cannot be understated. Solutions exist, photovoltaics being the most promising potential candidate. However their potential was not explored until recently. Utilizing only a small fraction of the solar radiation that the Earth's surface is exposed to on a daily basis, not only can we meet the energy requirements for all of humanity, but we can also be completely energy independent in a manner that does not pollute or degrade our surroundings. The energy from our Sun is practically limitless, at least it will be for the estimated lifespan of our star, which still has around 5 Billion years to go.

II. Photovoltaics

The purpose of solar panels is to produce electricity using sunlight, lets take a closer look at how exactly this process happens. One solar panel is made up of a large number of individual solar cells, which intern are constructed using silicon, a semiconductor and the second most abundant element on Earth [1]. The key to their function is that they are made up of two layers, an N layer that has excess electrons, and a P layer that has voids where electrons can enter, the place where these two layers meet is called the P/N junction and here electrons can freely pass from one layer into another creating a positive side and a negative side. Sunlight contains tiny particles called photons, when one of these photons hits a solar cell it will dislodge an electron, that electron is now free to travel wherever it wants, but due to the the junction between the silicon layers it has to go in one particular direction, from the N layer to the P layer.

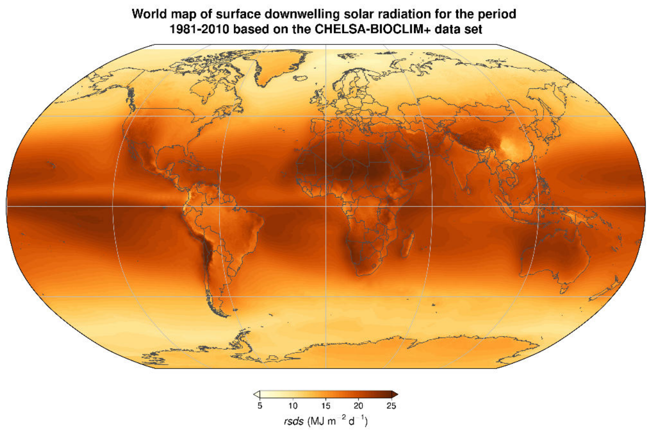

Fig. 1. Global distribution of incoming shortwave solar radiation averaged over the years 1981-2010 from the CHELSA-BIOCLIM+ data set, Credit: Attribution-ShareAlike 4.0, Greenmind1980, CC BY-SA 4.0 https://creativecommons.org/licenses/by-sa/4.0

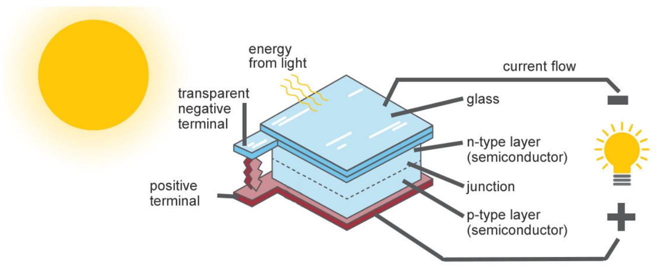

Fig. 2. A diagram showing the basic function of one solar cell via the photovoltaic effect, sourced from a US EID diagram, credit: public domain fair use, U.S. Energy Information Administration (Oct 2008): Photovoltaics and electricity: https://www.eia.gov/energyexplained/solar/photovoltaics-and-electricity.php

A. Solar Trackers

The earth receives ten-thousand times more electricity potential daily from the sun than the whole population consumes

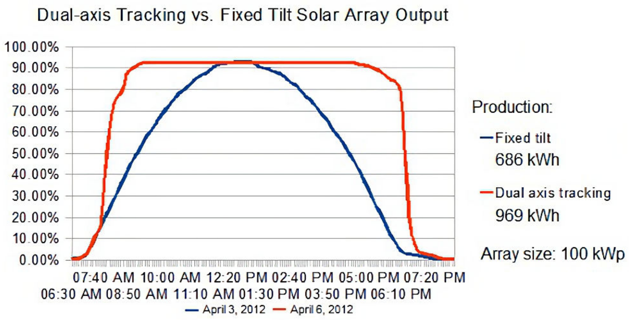

Fig. 3. A comparison between the production outputs of a fixed solar panel and a dual axis solar tracker, credit: Creative Commons public domain, Delphi234, CC0

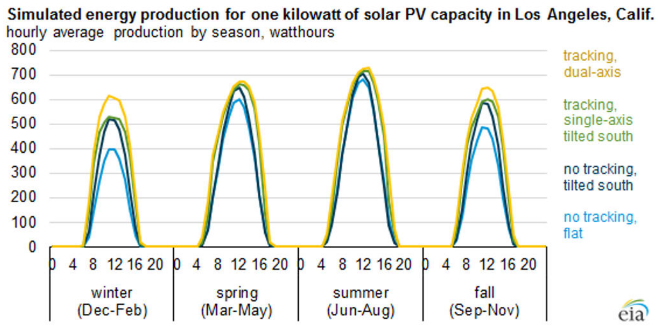

Fig. 4. A simulated comparison of hourly average produced output power for one kilowatt of solar PV capacity, between a dual-axis solar tracker, a single-axis solar tracker, and a fixed solar panel array, by individual season in Los Angeles California, credit: public domain fair use, U.S. Energy Information Administration (Oct 2008).

annually. The main issue in using solar energy is how to maximize the exposure of solar panels to the sun in order to increase the generated electricity. Fixed solar panels miss a significant part of the total energy, from 10% lost potential at an angle of 25° of the sun to the panel, up to over 75% lost potential at an angle of 70°. Because the solar panels are static this means that they're in an ideal parallel relationship with the sun for only a small fraction of the day. It's important to increase the exposure of solar panels to direct sunlight because it contains 90% of the energy. Solar trackers exist solely to fix this issue [2].

A solar trackers main purpose is to follow the movement of the sun and keep the devices payload parallel to the sunshine throughout the entirety of the day [3]. Using solar trackers we substantially increase the produced output of our solar panels because we no longer have wasted hours during the day where the panels are not in direct sunlight, thus improving productivity. All of this is usually accomplished using three essential parts, these parts are: a motor for movement, a sensor of some type for data input, and a circuit for processing the information received from the sensor and data output to the motor.

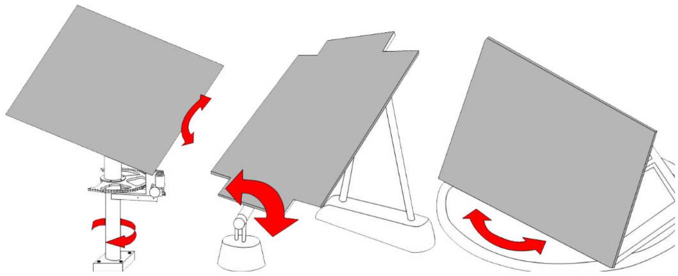

Fig. 5. Types of solar trackers, credit: Sebastijan Seme, Bojan Štumberger, Miralem Hadžiselimović., CC BY-SA 4.0 https://creativecommons.org/licenses/by-sa/4.0

B. Types of Solar Trackers

There are two basic types of solar trackers, and they are divided based on their axis of movement. These are solar trackers with one axis of movement or two axis of movement. Single axis solar trackers are the most common type because they offer a fair compromise between trackers with two axis of movement and fixed solar panels [4].

Types of single axis solar trackers:

- Horizontal trackers, with these solar trackers the axis of movement is placed horizontally to the ground, the best location for such trackers is as close to the equator as possible, due to the angle of the sunlight that the equator receives. These trackers move in a north-south motion.
- Vertical trackers, mostly used in regions closer to the earth's poles due to the angle of the sun's rays, these trackers move from east to west and as the name applies are placed vertically to the ground.

Types of solar trackers with two axis of movement:

- Tip-tilt trackers, are mounted on a pole which gives them not only horizontal and vertical axis of movement but also tilt capabilities, as the name suggests, these trackers allow great flexibility for where they can be placed due to their wide range of motion.
- Azimuth-altitude, here Instead of rotating the array around the top of a pole we use a large ring mounted on the ground itself, on top of which are mounted rollers for movement. The advantage of this type of system is that it can support drastically higher weight compared to others, however it reduces the density of how many solar trackers can be placed at a given location.

There are many different types of solar trackers, which can be used in a plethora of different locations with many different needs. The size of the installation, local weather, physical geography and production requirements are key factors that influence the type of solar tracker used. Solar trackers generate more electricity than fixed panels, due to increased exposure to direct sunlight, in the same amount of space required, making them ideal for optimizing land use. However they are indeed more expensive compared to stationary panels, due to the moving parts necessary for their operation, and require some ongoing maintenance. Overall, solar trackers are highly

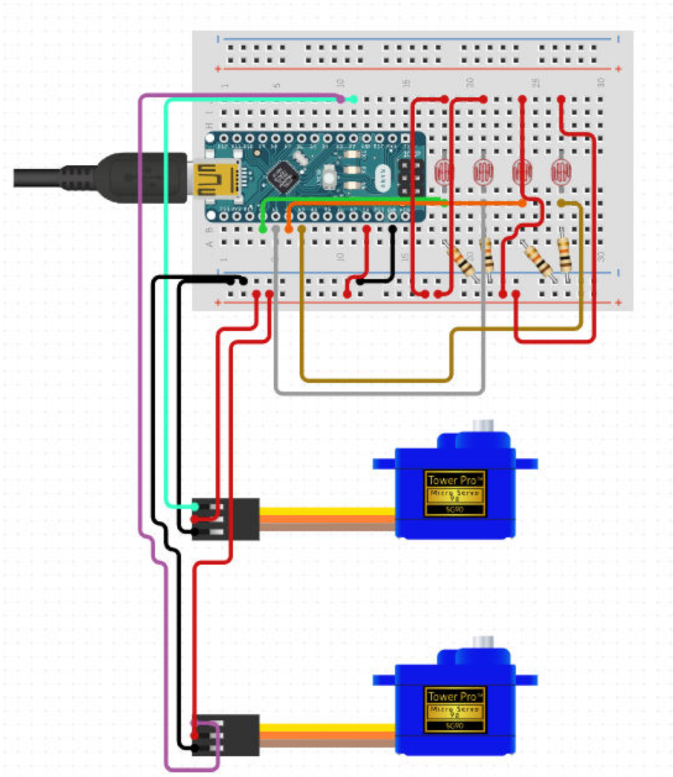

Fig. 6. Scheme for how each individual part of the project is connected

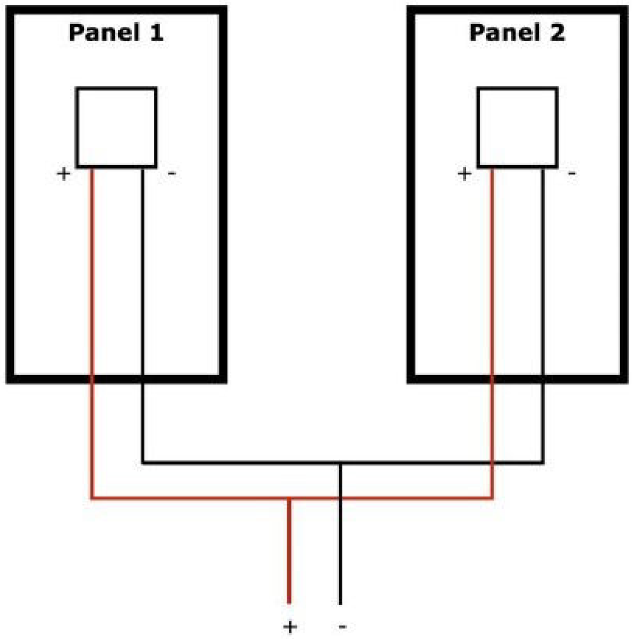

Fig. 7. Scheme for how the two solar panels are connected in parallel

efficient systems that offer a wide range of versatility in many different circumstances [5].

III. Building a Solar Tracker

Firstly, let's start with a short overview of the parts used for this project, which are:

- 1 x Arduino nano: The arduino nano is the brains of the entire project, based off of the ATmega 328 IC, it manages all input data and output movement to our drivers.
- 2 x Servo motors sg90: These servos are the brawn of the project. Light, compact and barely uses any power, these drivers allow us to do precise movements that are vital for accurate tracking of the source of light.
- 4 x Photoresistors: The sensors, or eyes, of our project, they allow us to to "see" the outside world via a varied resistance output that is tied to the brightness of light in their immediate surroundings
- 1 x Dual axis servo gimbal: This is what holds the entire project together, light yet sturdy it allows us two axis of movement with our servos without adding additional unneeded bulk.
- 2 x Mini solar cells 6V - 200mA: Combined in parallel these solar cells provide us with a placeholder payload to prove the effectiveness of such solar tracking devices.

This project is based around the Arduino Nano micro-controller. On our micro-controller we connect four separate photoresistors, these photoresistors will serve as the sensors in our project, sensing the presence/intensity , or lack there of, of light in the robots vicinity, this is achieved by averaging their resistance. Additionally to our Arduino we have connected two servo motors, these servo motors serve to direct our payload, in this case solar panels, in the desired direction based off of the data that our sensors provide, essentially always following, and holding our payload parallel to the direct sunlight. The two solar cells in our payload are connected in parallel to each other, this is done to further increase their output power, our two 6-Volt 200-milli Amp cells provide us with up to 5-Volt 1-Amp, 5-Watts, through the used step down converter.

The sensors provide information about light in the near vicinity, that information is then read by the Arduino and processed by it using the microcontroller's written source code. Once the information has been read and processed it is then analyzed based on a few key context criteria, the software then decides which context the device is currently in and sends an adequate response output via the Arduino to our servo motors, these servo motors then move in the commanded direction precisely, putting out payload parallel to the sunlight at all times. Our device uses its sensors to detect how much light there is nearby, this is done by measuring the resistance of the photoresistors. For accurate measurements, and redundant information avoidance, we separate our four photoresistors into 4 quadrants using a wall in the shape of a plus symbol with one photoresistor in each section, this way there will always be a shadow cast on at least one photoresistor.

After the resistance is measured it is then read by our Arduino microcontroller through its analog pins, for each photoresistor we have one dedicated analog pin on our Arduino , the read data from the Arduino is then processed by the microcontrollers source code, this software takes each read resistance from the photoresistors and takes their average from our four quadrants. This average is then sent further down our software where it is read by conditional clauses. Based on which of these conditions our data meets, that's the context that we are currently inside of, in context to the sunlight on our payload. Once we are in one of these conditions the software sends an output to the servo motors, connected on our Arduino on their own separate analog pins, to move in a designated direction based on the context that we are in. After the device moves in that direction the resistance from the sensors is read again and the process is repeated until the payload is parallel to the sun.

The project was built using a bare prototype printed circuit board, initially tested on a typical breadboard, with all the components soldered to this board.

Figure III shows the source code, whereas figures III and III present the final project look.

IV. Future improvements

Generally the issues faced on such a small scale example project will be easily avoidable on a much larger implementation of these technologies. Lets put some minor hardware problems of the device we've built into perspective. For example the total produced output power of our two small photovoltaics is enough to charge a cellphone or power a small speaker but not much more, proportionally our small solar tracker can indeed hold more weight, however to get actual useful household power outputs here this device will need to be scaled up significantly. Aside all of the obvious issues that arise from building a small prototype proof of concept like this, that are easily remedied of course, solar trackers in general have some systemic issues that are typical to their use. These issues can, and will be, remedied in the near future as solar tracker technologies continue to evolve with the increased global investment into photovoltaics and renewable energy. Trackers like this can benefit significantly from AI, or at the very least an increase in the workable dataset available to devices like this. For example, if we have a network of large scale solar trackers at solar farm located in a geographic region that is prone to fast and unpredictable weather changes, we can use artificial intelligence, alongside a large dataset that has been collected in regards to meteorological events, to predict the estimated power output for our solar farm and the power draw for our solar trackers. Using a system like this we are granted an extended and more accurate foresight into the near future as to when our solar farm will run optimally and produce the most power. This information can be used to decrease unproductive uptime for such devices, decrease latency, increase tracking accuracy, increase power production, and give us detailed service window times thus decreasing down time. With a change like this these solar tracking systems would be able to essentially run themselves without human intervention indefinitely, requiring outside assistance only for regular service to be maintained, which they could schedule themselves.

```
#include <Servo.h> // initializing the use of the servo library
Servo horizontal;  // declaring variable for horizontal servo
int servoh = 45;   // initial value for our varaiable
Servo vertical;    // declaring variable for vertical servo
int servov = 45;   // initial value for our varaiable
int ldrlt = 2;     // declaring and setting variables for each of our
//Light Detecting Resistors based on their location.
int ldrrt = 1;
int ldrld = 3;
int ldrrd = 0;
void setup()
{
    Serial.begin(9600);
    horizontal.attach(9); // declaring analog pins for our servos
    vertical.attach(10);
}
void loop()
{
    int lt = analogRead(ldrlt); // reading values from our ldrs
    int rt = analogRead(ldrrt);
    int ld = analogRead(ldrld);
    int rd = analogRead(ldrrd);
    int dtime = 9;            // declaring value for time
    int tol = 100;            // declaring value for tolerance
    int avt = (lt + rt) / 2; // calculating values for average resistance for top,down,left,right…
    int avd = (ld + rd) / 2;
    int avl = (lt + ld) / 2;
    int avr = (rt + rd) / 2;
    int dvert = avt - avd; // calculating difference between horizontal and vertical axis
    int dhoriz = avl - avr;
    if (-1 * tol > dvert || dvert > tol)
    { // start of conditions for context for our vertical servo
        if (avt > avd)
        {
            servov = ++servov; // moving our vertical servo appropriately
            if (servov > 180)
            {
                servov = 180;
            }
        }
        else if (avt < avd)
        {
            servov = --servov;
            if (servov < 0)
            {
                servov = 0;
            }
        }
        vertical.write(servov);
    } // writing info for movement to the servo
    if (-1 * tol > dhoriz || dhoriz > tol)
    { }
        { // start of conditions for context for our horizontal servo
            if (avl > avr)
            {
                servoh = --servoh; // moving our horizontal servo appropriately
                if (servoh = 0)
                {
                    servoh = 0;
                }
            }
            else if (avl < avr)
            {
                servoh = ++servoh;
                if (servoh > 180)
                {
                    servoh == 180;
                }
            }
            else if (avl == avr)
            {
            }
            horizontal.write(servoh);
        } // writing info for movement to the servo
        delay(dtime);
    } // delay for how long to wait before the program repeats again // end of program.
```

Fig. 8. Source code of the project

V. Closing thoughts

The future of electricity is in renewable, green, methods of power generation. Their implementation, although slow, contributes to a significant improvement to the decrease of environmental pollution and its future prevention. According to research conducted in 2017, about 1.1 billion people, or 14% of the total world population, do not have access to electricity. Most of these people live in India, Indonesia and Africa, regions with some of the most favorable conditions for solar energy production. Solar energy is becoming more and more the ideal option for generating electricity, especially in regions that are still in development. A large number of

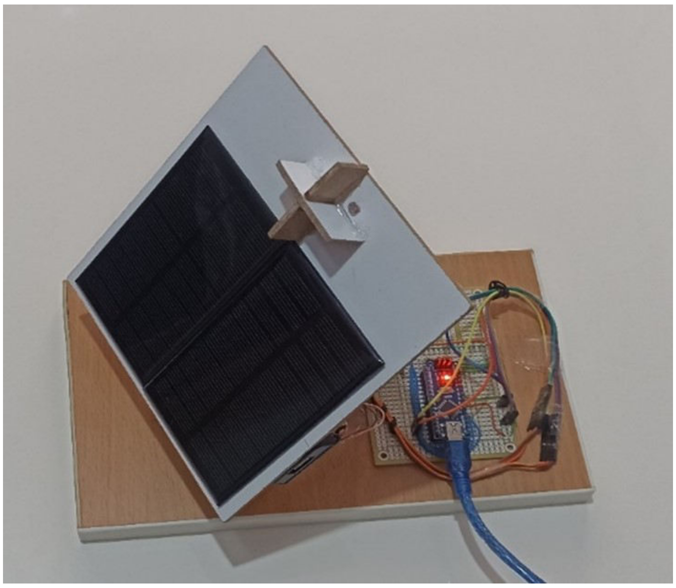

Fig. 9. The final project look

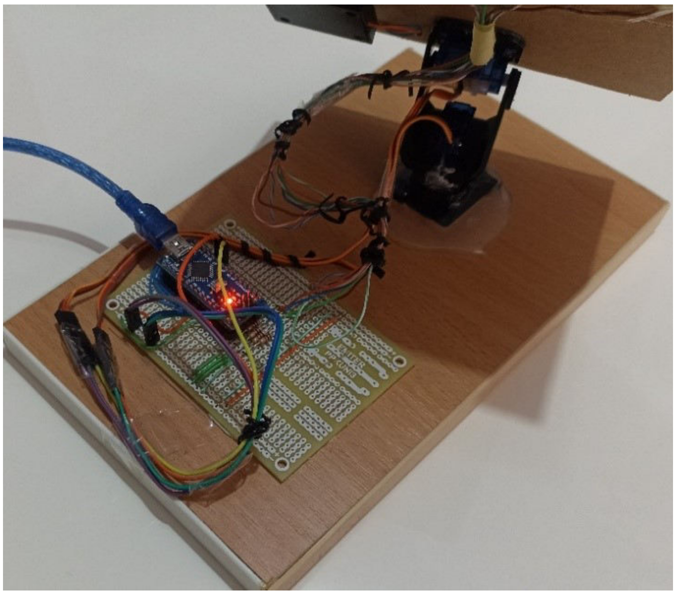

Fig. 10. Wiring and electronic part

African countries are located in areas with ideal conditions for solar energy production, the potential is massive. These countries are near the equator, the length of days in these countries is above-average, they contain favorable geographical conditions with a relatively flat physical geography, and they have favorable climate conditions. For these countries, solar energy production is easily the best option, not only based on production potential, but also because solar is cheap to maintain and generates a significant amount of electricity, proportionally greater than fossil fuels. If we cover an area of 335Km by 335Km with solar panels, even with regularly available panels with moderate efficiencies, we will generate more than 17.4TW of power, which is enough power for the entire Earth's population. Such an area is 112,000 square kilometers. The Sahara Desert in Africa is 9.2 million square kilometers and is excellent for solar energy with more than twelve hours of sunlight per day. This means that 1.2% of the Sahara is enough to cover all the world's energy needs in the form of clean solar energy. Fossil fuels can't compete with this. In a few decades, solar power will replace most current fossil fuels in the energy production sector. There will still be a need for liquid fuels, but it will probably be hydrogen produced by the electrolysis of water, which will be done with power produced by photovoltaics. The potential is vast, all over the world, for clean energy but economic and political factors prevent us from reaching full energy independence for now.

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