ZANCO Journal of Pure and Applied Sciences
The official scientific journal of Salahaddin University-Erbil
https://zancojournals.su.edu.krd/index.php/JPAS

ISSN (print):2218-0230**, ISSN (online):** 2412-3986**, DOI: http://dx.doi.org/10.21271/zjpas**

RESEARCH PAPER

Design and Analysis of the Dual Axis Tracking System for Solar Thermal Concentrator in Erbil City using Arduino Controller

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A B S T R A C T:
Solar thermal is a kind of renewable energy that converts solar radiation to heat using a concentrator that concentrates the heat in the focal point. The receiver is located in the focal and transfers heat to the flowed water, rising the water temperature beyond boiling. To harvest the most solar efficiency, a dual tracking system is used that tracks the sun during the daytime. This paper proposes implementing Arduino Uno dual axis tracking system for the solar parabolic concentrator dish. The tracking system is controlled and managed by using an Arduino microcontroller and light sensors. The proposed system has been installed in the city of Erbil and the testing results showed the success of the proposed system in which the dual tracking system tracked the sun precisely and the concentrator with the help of the receiver raised the flowed water to the desired temperature.

KEY WORDS: renewable energy, solar thermal energy, concentrating solar power, parabolic dish, dual axis tracking system, Arduino microcontroller.
DOI: http://dx.doi.org/10.21271/ZJPAS.35.3.5
ZJPAS (2023) , 35(3);47-58

1. INTRODUCTION:

So far, developed countries' demand for producing energy faced enormous energy challenges to reach promised goals. Continuous energy growth and consumption in many parts of the world, growing levels of affluence, and economic opportunity have been strongly correlated with the continuous rise in energy consumption. However, a major energy concern currently facing civilization is the global warming issues which are coming from using fossil fuels such as oil, coal, and natural gas in producing energy such as producing electricity, industries, transportation, building heating and cooling, etc. One of the dominant solutions is using renewable energies instead of fossil fuels(D'Amico et al., 2019). Renewable energies such as solar, wind, geothermal, and hydropower are good alternatives to fossil fuels (Esen and Yuksel, 2013).

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Article History:
Received: 18/10/2022
Accepted: 04/12/2022
Published: 15/06/2023

Among renewable energies, solar resource is considered the best choice for its cleanest, emission-free, and availability (Prinsloo, 2014). Electricity from solar comes in two types, solar photovoltaic and concentrated thermal technology (Ahmed et al., 2020). The solar thermal concentrator is a technology that produces heat from solar radiation by collecting sunlight in a single focused point. There are different types of concentrators: flat dish mirror, parabolic trough concentrator, etc. Among these, the parabolic dish mirror acts the best in the solar thermal concentrator. (Pavlovic et al., 2015).

Solar concentrators convert solar irradiance to thermal energy, they often use parabolic satellite dishes for minimizing development costs (Ruelas et al., 2018). A parabolic dish can concentrate the sunlight either in a fixed position or by tracking the sun throughout the day, its efficiency is increased by 40% when following the sun by using tracking systems (Hashim, 2020). These tracking systems need controllers to operate and manage them. The controller can be PLC, computer, manual controlling, Raspberry PI, Arduino, etc. Arduino microcontroller was a good choice for its simple installation and maintenance, Arduino, also, can control the tracking system with the help of light-dependent resistors, motors, limit switches, and sensors (Mishra et al., 2017).

Solar thermal technology faces many engineering obstacles, researchers have proposed many technologies to improve the solar thermal efficiency of parabolic dish concentrators using different tracking technologies. (Tami et al., 2018) has proposed a two-axis tracking system to increase the efficiency of parabolic trough solar concentrators to heat water up to 89C° and showed that the dual axis tracking efficiency was increased by 23% in comparison to the fixed system. (Mahmood and Al-Salih, 2018) has compared two solar dish concentrators, the first was covered with small pieces of mirror and the other one was covered with miller paper, results showed that the mirror-covered dish efficiency is improved due to having a better reflecting surface. (Ahmed et al., 2020) shows a solar parabolic dish prototype designed to build up the PV cell efficiency for rural areas and low-income people, output power efficiency has been improved by 3.43% in comparison to a PV panel without a parabolic dish. (Bellos et al., 2019) compared different cavity receiver shapes efficiency to achieve the best thermal efficiency. Among them presented that the cylindrical-conical shape has a better thermal efficiency compared to other cavity receiver shapes due to its absorption through its inner surface.

(Mishra et al., 2017, Gaeid et al., 2020) have proposed a low-cost Arduino-based Photovoltaic dual axis tracking system with help of four light-dependent resistors (LDR). (Hashim, 2020) has proposed the same study by using five LDRs to track the sun and improve the proposed control system's efficiency. (Affandi et al., 2014) (Affandi et al., 2014) investigated a low-cost (1KW)parabolic dish reflected by aluminum-based solar concentered power in Malaysia's environment using MATLAB simulation.

This paper deals with implementing the Arduino Uno controller of a solar thermal concentrator tracking system. The system includes a dual-axis tracking module and a parabolic dish with covering by glass fragments, and a water tank attached to the focal. In addition, an Arduino microcontroller is used to control the dual-axis tracking system. The system has been tested in real-time in the city of Erbil and at different times of the day. Results have been compared with and without a tracker, and with other similar modules in the literature, in this paper, the proposed controller improves the result compared to a fixed concentrator.

The organization of this paper is as follows: literature review and goals are presented in the introduction section. Material and methods have shown in the solar thermal concentrator prototype and tracking section with a tracking flow chart. Implementation and results present achieved graphs and results. In the final section, the conclusion is drawn.

2. Solar Thermal Concentrator Design

Figure 1 shows the prototype of the solar thermal concentrator that was designed for this work. The prototype consists of a dish, light-dependent resistor, photosensor, receiver, water tank, actuator, DC motor, gearbox, limit switches, microcontroller, DC power supply, circuit barker, relay, digital thermometer, and mechanical base.

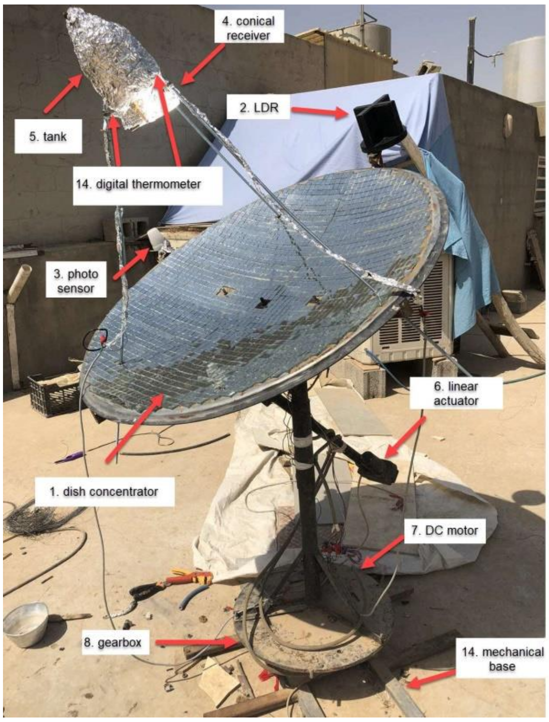

Figure 1: Solar thermal concentrator prototype

2.1 Dish

The dish concentrator is a parabolic shape collector as shown in Figure 2. The dish is 100 centimeters square in width and 9.5 centimeters in depth. The parabolic dish reflector is covered with 1900 pieces of mirror segments each (2cm x 2cm), each mirror connected to the dish surface by using heat and water resistance silicone to protect mirrors from high heat and water or humidity. The dish collects solar radiations in a single point called focal point (f) as shown in Figure 3. Solar parabolic dish concentrator(SPDC) is the most efficient reflector among all collector types, they can achieve temperatures up to 1500 °C (Kalogirou, 2004).

Figure 3 shows the focal length of the parabolic dish in which most of the solar radiation is reflected and collected at the focal point in the distance of focal length which can be found using the following equation(Chaurasiya, 2015).

$$f = \frac{d^2}{16h} \quad (1)$$

where f is the focal length, d is the diameter (opening) of the aperture and h is the depth from the vertex to the aperture opening edge.

The rim angle (ψ_{rim}) can define the shape of the parabola, its angle is between (10°-90°) using the following relation (Pavlovic et al., 2015).

$$Tan(\psi_{rim}) = \frac{1}{\left(\frac{d}{8h}\right)-\left(\frac{2h}{d}\right)} \quad (2)$$

Concertation ratio (CR) is the ratio of solar radiation amount that is concentrated by a certain concentrator, to the solar radiation that is received by the receiver. it can be found in terms of parabolic dimension , is the ratio of the Aperture area to the receiver area using the following relation (Barbosa et al., 2016).

$$CR = \frac{Aa}{Ar} \quad (3)$$

where Aa is the aperture area, Ar is the conical receiver area, and by using the circus area, the aperture area can be found by using the following relation (Chaurasiya, 2015).

$$Aa = \pi \frac{d^2}{4} \quad (4)$$

And the area of the conical cavity receiver can be found by using the following relation(Wikipedia, 2022).

$$Ar = \pi r l + \pi r^2 \quad (5)$$

where r is the radius and l is the slant height.

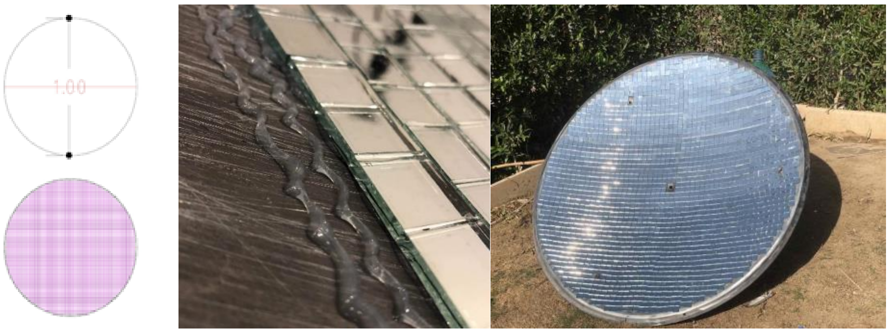

Figure 2: Design and install mirrors on the dish surface

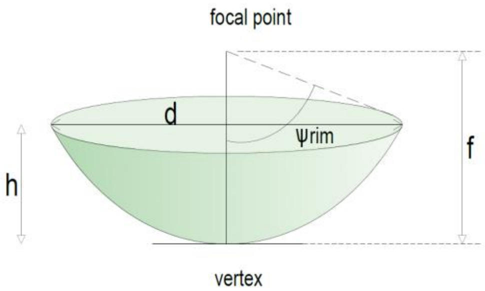

Figure 3: dish overview

2.2 Receiver

The receiver is the essential part of the concentrator which absorbs the reflection of the solar illumination from the concentrator and changes the absorbed radiation to heat. The receiver is the collector of the sun's irradiance and is located at the focal point of the dish at the distance of the focal length *f* (Pavlovic et al., 2015). In this study, the cavity receiver type has been used due to its high heat absorption through its inner surface. The receiver is designed in the shape of conical form as shown in Figure 4. The coil is made of copper tube material that absorbs heat from the focal point of the concentrator and transfers this heat to fluid water in the tube. To minimize heat losses, the outside of the receiver is covered with Rockwool (Barbosa et al., 2016).

Figure 4: conical cavity receiver

2.3. Tracking System

Usually, concentrators are installed in a fixed position, that is, the concentrator does not follow the sun's position movement. Instead, these concentrators are installed in a position that receives maximum solar illuminations specifically at noon. The efficiency of the concentrator is increased by designing it to follow the sun's direction all day. The sun's movement from sunrise to sunset is in two directions: altitude and azimuth, hence, a dual axis tracking system is required (Patil et al., 2016). Figure 5 shows the tracking system block diagram and figure 6 clarifies the proposed dual axis tracking system electrical wiring diagram between Arduino microcontroller and the sensors.

2.4 Light Dependent Resistor (LDR) and photocell

Light dependent resistors are components that change their resistance value when light falls upon them. The calibration for LDR requires testing many of them to get the optimum results, in this research up to 50 LDRs are tested but only five of them succeed in well detecting the sun's brightening and shading. Each LDR is connected with a 10kΩ resistor in series as a voltage divider to give data for the Arduino input during tracking and decrease drawing to a few milliamperes to the Arduino input/output terminals, also, one photocell-based LDR is used to detect day and night for start tracking or stoping it. Figure 7 depicts the structure of the proposed 5 LDR.

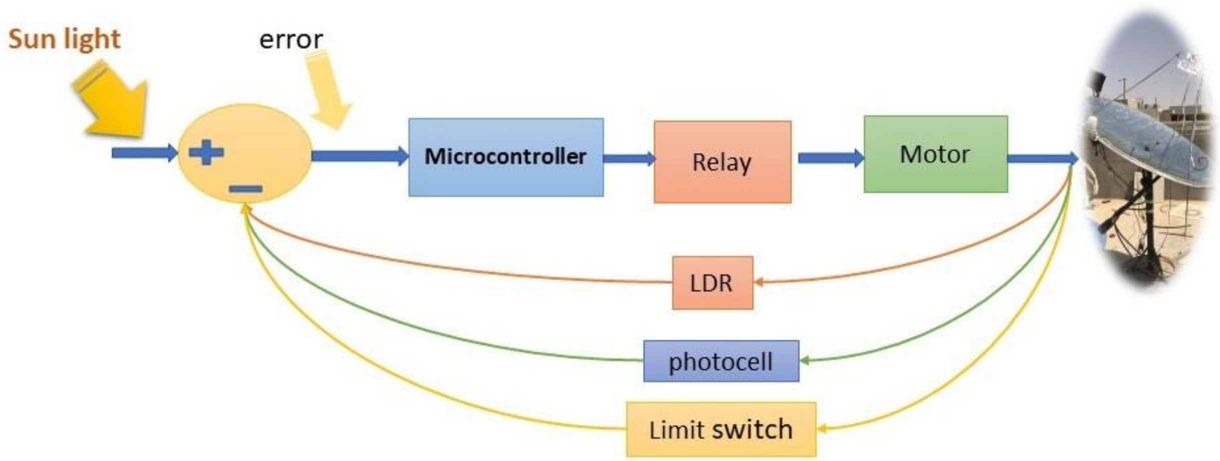

Figure 5: Block diagram of dual axis tracking system

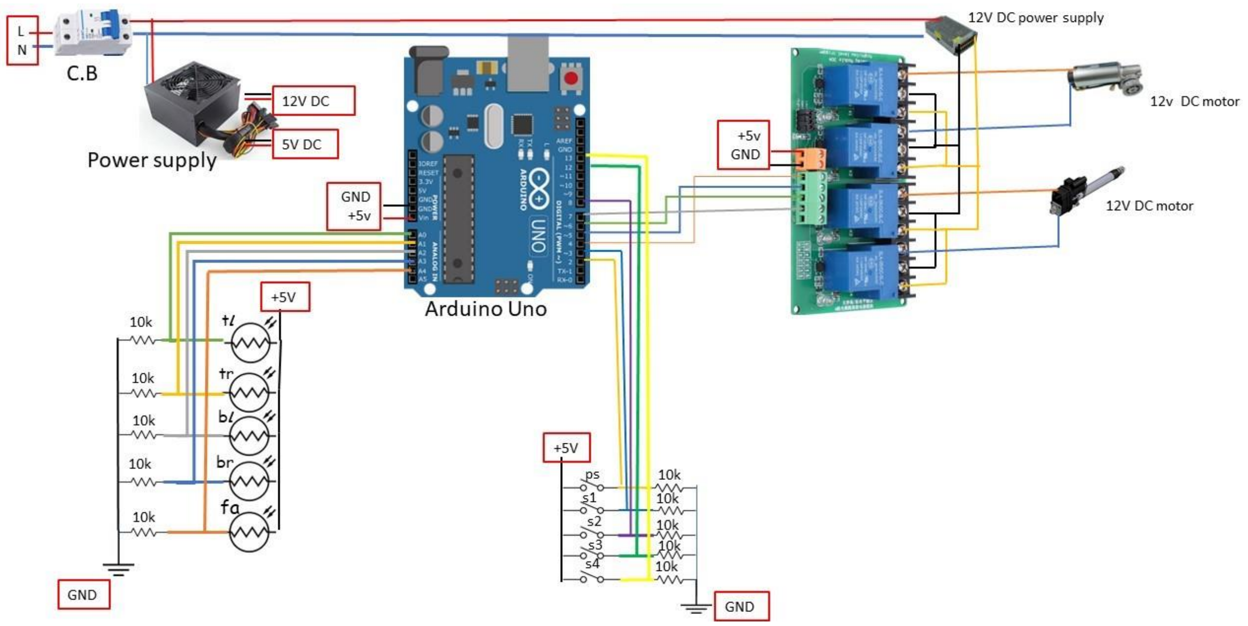

Figure 6: Dual axis tracking wiring diagram

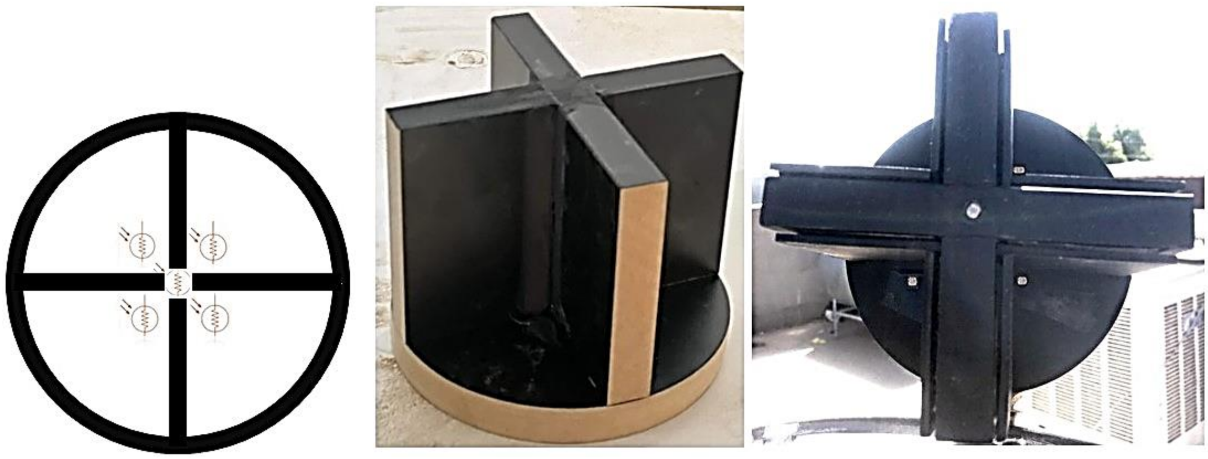

Figure 7: Light dependent resistor (LDR)

2.5 Motors and Gearboxes

For a dual-axis system, two motors are needed. Their types and sizes are selected according to system requirements. Here, two bidirectional motors are used, 24V DC Dunkermotoren with the specification of (GR53x58, gearhead, 53.4 watt power,2.9A,100Ncm torque, 3000rpm). And 36V DC linear actuator with the specification of(18”-inch length, 30 watt, 30-40mA when supplied with 12V DC). To reduce the load of the motors and smoothly rotate the concentrator, gearboxes are attached to the motors. The dual-axis tracker requires rotations along East-West altitude and North-South Azimuth both clockwise and counterclockwise movements. To achieve precise tracking angles, the speed of the motors is decreased by using gearboxes and reducing the supply voltage. The try and error procedure is tested to setting motors to supply proper voltages that give a smooth movement of the parabolic concentrator dish in all directions.

2.6 Limit Switches

Four limit switches are used to restrict the dual-axis movement beyond the designated points where the sun is not there or detected at the lower sunset point. Also, there are two limit switches left (s1) and down (s3) for indicating the start point. And LDR's data calculation will indicate the end of tracking in the evening. The right safety limit switch (s2) is for right movement, and the safety limit switch (s4) is for up movement.

2.7 Relays

Arduino output terminals are oversensitive and work with milliamperes, its terminals can draw no more than 40mA. therefore, four electronic relays are used to protect the Arduino. Also, they are used to safely work with a higher voltage such as a 12V to 36V DC motors.

2.8 Digital Thermometer

Two digital thermometers of DS1820 type have been used and installed in the tank and receiver to read the real-time temperatures and they are connected to Arduino throw 4.7 kΩ resistors as shown in figure 8.

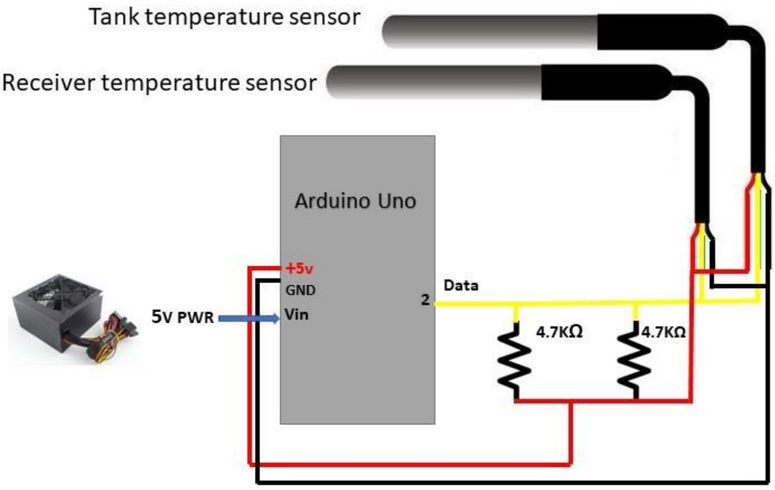

Figure 8: Temperature sensor (DS1820) wiring diagram

2.9 Microcontroller

For controlling the dual-axis process a controller is needed. Among different types of available controllers, the Arduino Uno microcontroller is used due to its cheap, easy programming, maintenance, and handling input/output interfacing selected to be implemented in this controlling method. Arduino Uno uses a series of Atmega328 chipsets which are powered by a 5 Vdc supply and it has 6 analog inputs and 14 digital inputs/outputs (Ahmed et al., 2020). In our system, there are 4 LDRs data readings for comparing the sun's light, and the fifth LDR is located in the center for activating the motor direction through a relay, part of the Arduino Uno tracking code shown in figure 9.

```
void loop()
{
  tl=analogRead(v1);
  tr=analogRead(v2);
  bl=analogRead(v3);
  br=analogRead(v4);
  fa=analogRead(v5);

  ps=digitalRead(v6);
  s1=digitalRead(v7);
  s2=digitalRead(v8);
  s3=digitalRead(v9);
  s4=digitalRead(v10);

  tl=map(tl,0,1023,0,fa);
  tr=map(tr,0,1023,0,fa);
  bl=map(bl,0,1023,0,fa);
  br=map(br,0,1023,0,fa);

Serial.println("top left");
Serial.println(tl);
Serial.println("top right");
Serial.println(tr);

Serial.println("bot left");
Serial.println(bl);
Serial.println("bot right");
Serial.println(br);

Serial.println("center");
Serial.println(fa);
Serial.println("ps");
Serial.println(ps);
fa=0.9*fa;
delay(1000);
```

Figure 9: Part of Arduino Uno microcontroller dual axis tracking system code.

3. Principle of Operation

The principle operation of the dual axis tracking system of the solar thermal concentrator controller is based on five LDRs: top left (t*l*), top right(tr), bottom left(bl), bottom right(br), and center (fa), a photo sensor (ps), left and right limit switches s1 and s2, and up and down limit switches s3 and s4. The central LDR, fa, is always in a brighter area and reads higher than other LDRs. While the tracking system checks the position of the sun, the value of fa is updated according to the following expression.

fa (new)= 0.95fa(old) (6)

Hence, the new value of fa is compared with the other four LDRs to find the correct new location of the sun.

At the steady state, the dish must install in the initial position towards sunrise (left and down limit switches are activated), when the sun rises and the photo sensor (ps) senses sufficient light, the tracking will start. Arduino microcontroller will rotate motors to the right and up and reading of all LDRs are compared to find the exact location of the sun instantly. This process will be continued till the ps is activated which means that the dish reached the endpoint where the sun is close to sunset. At this location, the solar thermal concentrator no longer heats the water in the receiver. The microcontroller is programmed to detect the endpoint and brings the system to the start position in order to be ready for operation in next day. Figure 10 shows the simplification flowchart of the solar thermal concentrator tracking system operation and control.

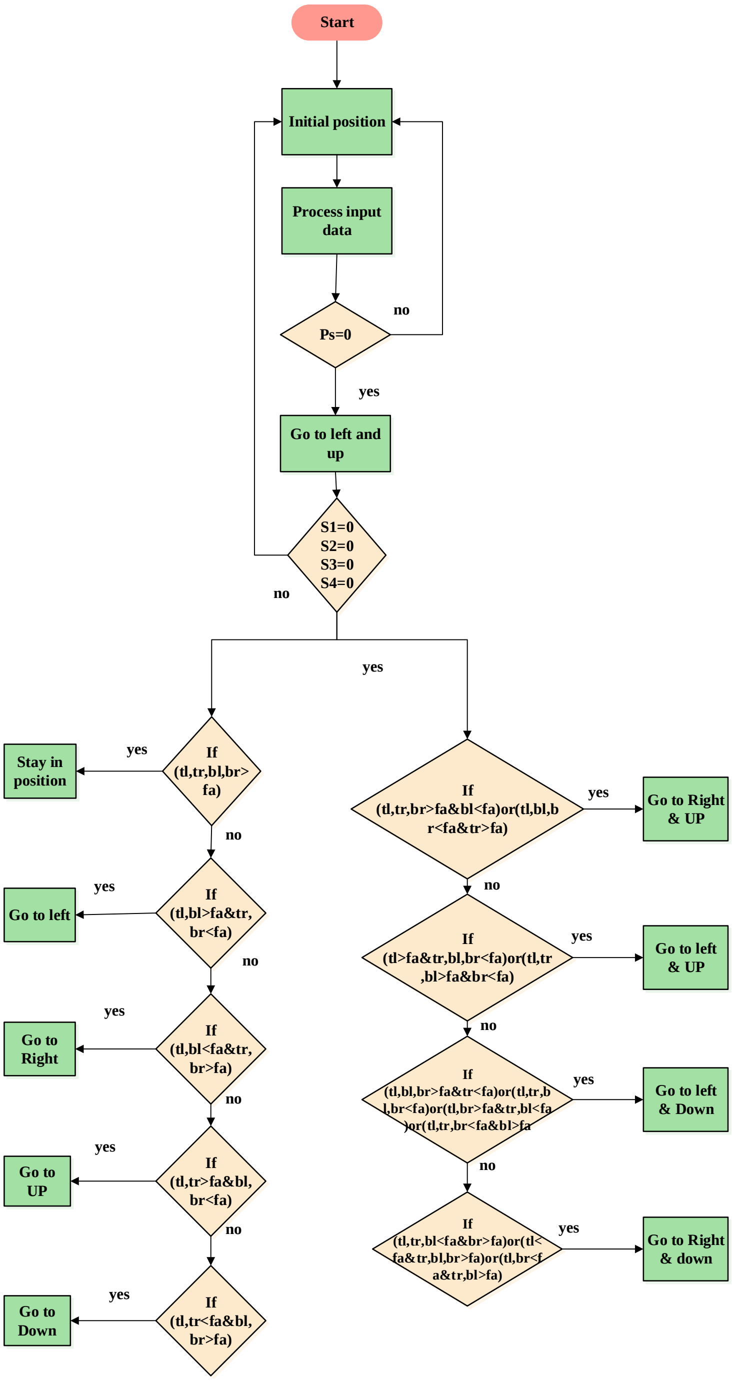

Figure 10: Flowchart of the dual axis tracking system controller

4. Implementation and Results

A complete solar thermal concentrator with its dual-axis controller has been assembled and tested in the city of Erbil. The site of the test in the city of Erbil is located at a longitude 36.19^{o} N and a latitude of 44.00 ^{o} E(Geodatos, 2022). The main goal of the system was to reach the tank water temperature up to 100^{o} Celsius degree in a clear sky with and without operating the tracker. Table 1 includes the parameters of the designed solar thermal concentrator with the dual axis tracking system.

At the first experimental test, the receiver was filled with 80 milliliter water and without tracking, that is, the concentrator was set at a fixed position toward the sun at 1:00 pm and 237 ^{o} solar azimuth and 68^{o} solar elevation. The receiver water temperature was recorded at different times of the day, 09:00 am, 11 am, 1:00 pm, and 3:00 pm. After each test, the water inside the receiver and tank is cooled. Figure 11 shows the water temperature in the receiver when the dish is in a fixed position. As shown, the temperature of the water goes beyond 100C^{o} degrees only at 1:00 pm while it was not just far from boiling temperature but it was close to an ambient temperature at other times of the day.

In the second experiment, the solar thermal concentrator was tested with a dual tracking system that is controlled by Arduino. Again, the receiver was filled with water and cooled after each test. With the operation of dual axis tracking system, tests have been repeated at four different times of the day. The results are shown in Figure 12. As shown in this figure, the water temperature has been raised up to 100^{o}C degrees for all four tests and they took around 90 to 180 seconds only. It should be noted that the water temperature raised up to 127^{o}C when the system was tested at noon (Figure 13).

In the third experiment, a water tank was attached to the receiver and filled with 500 milliliters of water, and the test was carried out without using the tracking system. The dish was set at a fixed position at 219.77^{o} solar azimuth and 59.73^{o} solar elevation so that to get the maximum possibility of solar radiation. Figure 14 shows the tank water temperatures as recorded at 9:00 am, 11:00 am, 1:00 pm, and 3:00 pm. As shown, the water temperature reached boiling temperature only at noon while at other times was far from boiling temperature even waiting for a long time.

In the last experiment, the third experiment was repeated but with the tracking system. In this case, the water temperature in the tank reached the boiling temperature almost in all tests and in shorter times as shown in Figure 15.

The above tests show that the proposed controller solar thermal concentrator successfully raised the water temperature in the receiver as well as in the tank. The performance of the concentrator was very much improved by adopting the dual axis tracking system. On the other hand, the Arduino microcontroller handles the operation of the entire system without any problems or difficulties.

5. Conclusion

In this paper, a complete solar thermal concentrator with a dual axis tracking system is designed and tested. The Arduino microcontroller with different types of sensors is programmed to control the operation of the entire system. To validate the success of the proposed system, different experiments were carried out. The results show the effectiveness and success of the concentrator. The system was assembled from components that can be easily and cheaply founded in the market and also easily constructed. Overall, the following can be concluded:

1- The dish that was used in this study was totally designed from cheap glass segments which are different from other types in literature. Where they used different materials. And the methods have been used to be compatible with Arduino. And other components are all new that has not been used in other studies.
2- Proposed concentrator was capable to harvest more solar radiation from morning to evening and gaining higher temperature results while tracking the sun from morning to evening.
3- The conical receiver can absorb more temperature and becomes hotter and this yields into transfer of more heat to flowing water which boiled water in less time. and covering with a Rockwool insulator has a better result compared to others in the literature.
4- Using Arduino was very helpful for controlling parameters, changing conditions in real-time, and observing output data and had a good relation with sensors and other components.
5- 80 milliliter water of proposed conical receiver heat heated up to 127^{o} in less than 180 seconds and about 500 milliliters in 450 seconds, which is a good result in comparison to others in the literature.
6- Using a gearhead dunker motor type with a warm speed reducer was more compact , flexible , stronger, had a better performance and softer bidirectional movement in windy conditions in compare to the motors and gearboxes that has been used by other works in literature.

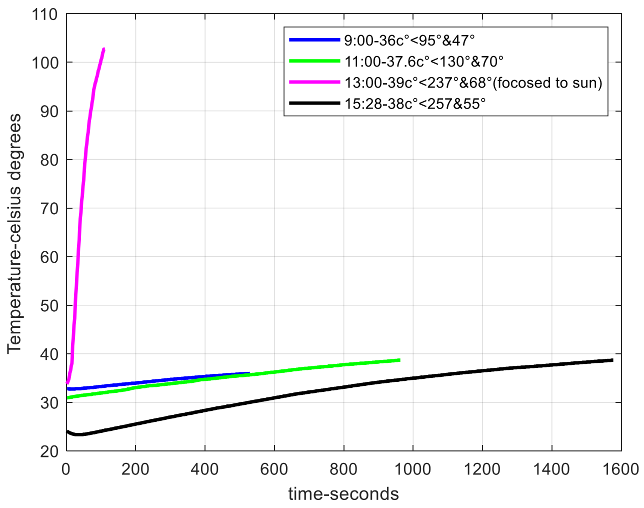

Figure 11: Receiver rising temperature without a tracking system.

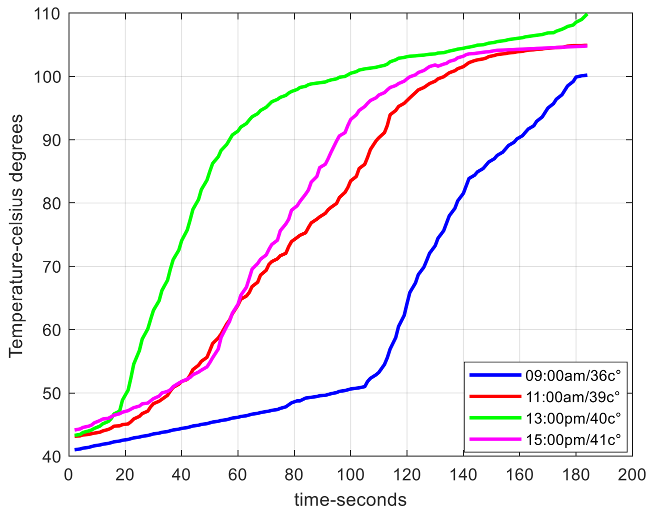

Figure 12: Receiver temperatures with the tracking system

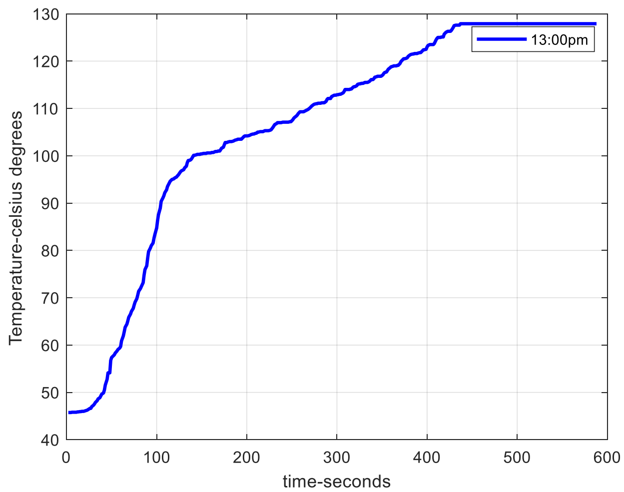

Figure 13: Water temperature inside conical cavity receiver

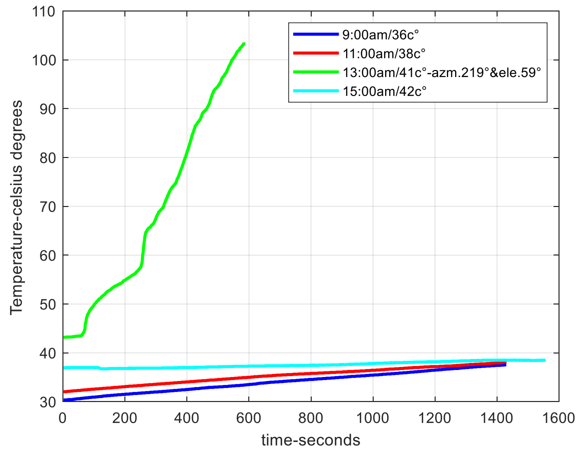

Figure 14: Tank temperature rising without a tracking system.

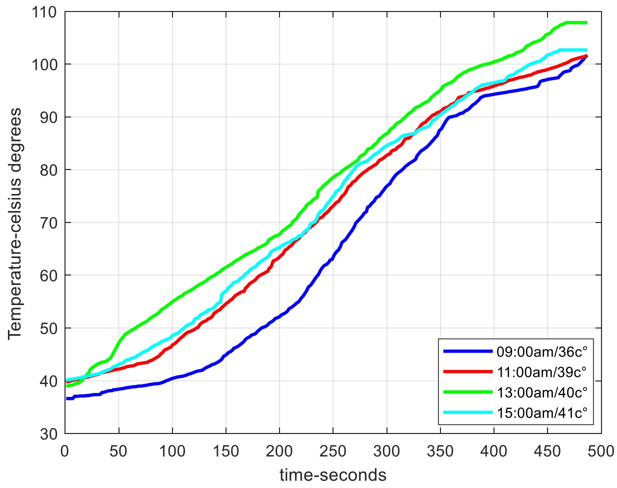

Figure 15: Tank rising temperature using the dual axis tracking system

Table 1: Parameters of concentrator dish and receiver

Parameter	Value	Unit
Diameter of parabolic Dish concentrator	100	cm²
Depth of the parabolic dish	9.5	cm
Reflect surface of the parabolic dish	Mirror	-
Frame of the parabolic dish	metal	-
Tank water capacity	700	milliliter
Receiver water capacity	100	milliliter
Receiver tube made of	copper	-
Receiver tube diameter	3/16	0.47625 cm²
Receiver dimension	12 x 5.5 x 8	cm
Aperture area of the parabolic dish (Ap)	78.54	cm²
Aperture area of the Receiver (Ar)	26	cm²
Focal length of the dish from vertex (F)	65.7	cm
Rim angle of the dish (Φ)	41.35	°
Concentration ratio (CR)	30.2	-
Number of Mirror	1900(2cmx2cm)	pieces

Table 2: List of Abbreviations

Abbreviation	Definition
SPDC	Solar Parabolic Dish Collector
°C	Celsius degree
f	Focal point
d	Aperture diameter (opening) of parabolic dish
h	vertex to the distance across the aperture
ψ_{rim}	rim angle
LDR	light dependent resistor
tℓ	top left LDR
tr	top right LDR
bℓ	bottom left LDR
br	bottom right LDR
fa	Central LDR
PS	Photocell sensor
s1	left limit switch
s2	right limit switch
s3	up limit switch
s4	down limit switch
V	voltage
DC	Direct current
R	Resistor
Ω	ohm
kΩ	kilo ohm
MΩ	mega ohm
A	ampere
mA	milliampere
Vin	input voltage
PWR	power supply
i/o	input/output

Ncm	newton centimeter
N	North
E	East
π	3.14

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