A simple embedded system for solar tracking

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Abstract— **This paper presents a low-cost hardware-software alternative for tracking the sun position, for purposes of improving the performances of solar voltaic modules. The system ensures the optimal coordinate position of the photo voltaic modules to achieve the reception of maximum solar radiation. As a result, the solar panel can produce more electricity. The system is based on ATmega328P microcontroller, which control the movement of two servo motors along two axes. The rotation position and related actions are performed by off-the-shelf microcontroller, taking in account the inputs from the four light-dependent resistors (LDRs). The prototype is developed and tested in real conditions. Some of the results are presented and discussed. The main advantage of the system is its low-cost, reliability and logical scalable design.**

Keywords: Dual Axis Solar Tracker, Solar Power, Photovoltaic Solar Panel, Arduino Uno Development Board, ATMEGA 328 AVR Micro Controller, LDR.

I. Introduction

With the inevitable shortage of fossil fuel sources in the future, renewable energy sources have become a topic of interest for researchers, technicians, investors and decision makers worldwide. Solar energy, wind energy, geothermal energy, tidal energy, hydropower and bioenergy, due to their renewable nature, are considered a favorable substitute for fossil fuels.

In 2015, when the Paris Climate Agreement was signed, 5% of the world's electricity was produced from solar and wind energy, growing to 10% in 2021, exceeding the nuclear electricity production for the first time.

By the date 2022, global electricity production is still fossil fuels dominated, 61%. Coal accounted for 36% (10,186TWh), fossil gas 22% (6,336TWh) and other fossil fuels 3% (850TWh) of global production. Hydro remained the largest clean source of electricity with 15% (4,311TWh), and nuclear the second largest clean source with slightly more than 9% (2,611TWh). Wind and solar energy together reached a share of 12% of global electricity (3,444TWh), wind with 7.6% (2,160TWh) and solar energy with 4.5% (1,284TWh).

According to the scenario of net zero CO2 emissions of the International Energy Agency (IEA), to limit global warming to 1.5C, solar electricity production should increase to 7,552 TWh per year by 2030. This requires the growth of solar energy production by 25% per year, and the share of solar in global electricity production would reach 20% in 2030, compared to the current 4.5% achieved in 2022.

To achieve this growth, countries must continually increase their annual solar production targets. For example, in 2023 this would require 318TWh of additional solar electricity generation, while in 2030 the increase would be at least 1,500TWh. IEA Net zero scenario, Figure 1, predicts that by 2040 the energy sector should be at the level of net zero CO2 emissions and the share of solar electricity production will amount to around 40% [1]

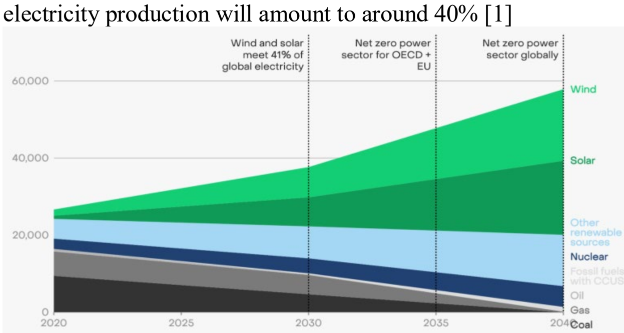

Figure 1. IEA Net zero scenario (EMBER, Global Electricity Review 2023), from [1]

Although there is continuous improvement in photovoltaic materials and current technology provides the cells with an efficiency level of up to 23.5%. Some projects have reached efficiencies higher than 40%, but they are not yet commercially available. Therefore, in order to reduce the price per produced KWh of energy, the efforts rely on the dimensions of the panels and/or the radiation intensity. Increasing the area of solar panels is not a sustainable solution. This increases investment costs and requires larger areas of land. However, the alternative is to maximize the energy extraction from the panels by using the array of cells to their full potential. Of course, all under the condition that it is profitable to invest in an automatic tracking system, bearing in mind that these systems are more expensive to build and maintain. In this case, the exposing the panel surface perpendicular to the sun's rays should be enabled. It is sun tracker strategy, based on Lambert's law, and one or dual axes movement/tracking. There are a number of systems for these purposes, with different features and prices as well as publications presenting related research [2],[3],[4],[5].

This paper proposes a solution that is suitable for companies that base their business on mixed system integration. Individual components are developed and installed as needed, normally if this does not exceed the cost of supply and training.

II. HARDWARE DESIGN

A. General description

The working principle of the system is as follows: the solar panel is positioned temporally and spatially so that its surface is maximally exposed to solar radiation. As a result, it becomes more efficient and produces more electricity.

The system architecture is given in Figure 2. The position of the panel in X-Y plane is achieved by two servo motors, which rotate the solar panel over two axes, based on the inputs received from the four photo sensors located in plane of panel, one in each quadrant of the coordinate system Each LDR sends an equivalent signal of its corresponding resistance value to the microcontroller. The difference between the LDR voltages is used to drive the servo motor, by implementing adequate control algorithm.

One of the two DC servo motors is mechanically connected to the drive shaft of the other so that the first will move with the rotation of the other's shaft. In controlling DC servo motors numerous strategies can be done as example PWM, generated by microcontroller or FPGA [6], [7].

Servo motor shafts are used to drive the solar panel mounted on the solar tracking set [8]. The servo motors are arranged in such a way that the solar panel can move along the X-axis (east-west, left-right) as well as the Y-axis (north-south, up and down).

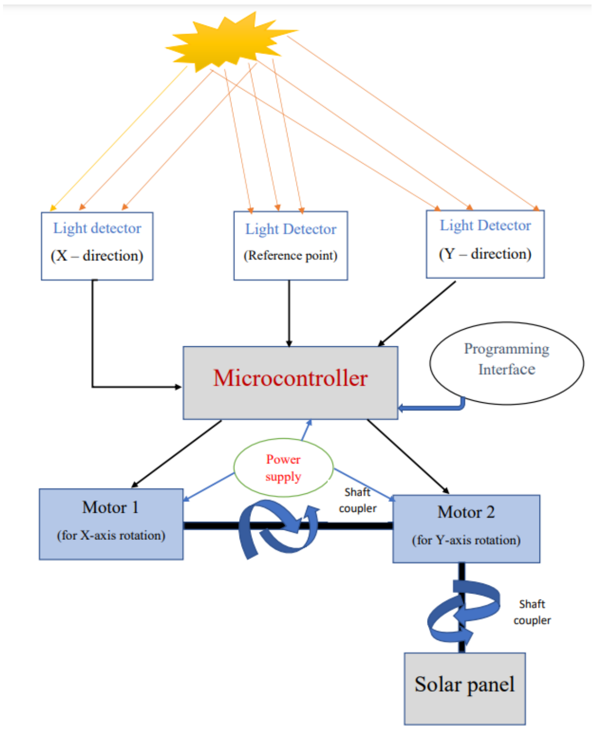

Figure 2. Hardware model block diagram

B. Sensing

The sensitivity curve of LDR is not linear, more exponentials. Figure 3.

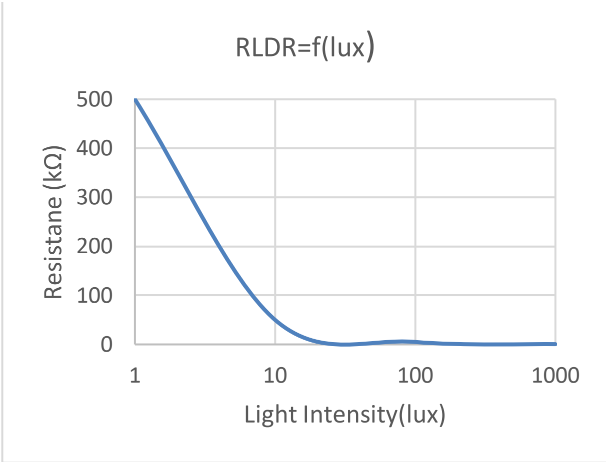

Figure 3. LDR resistance dependence of the illumination

When exposed to the light, the resistance ranges from 5-10 KΩ. For the dark its resistance is of MΩ value. In the simplest applications the LDR is connected in voltage follower circuit, Figure 4, and Vo is changes, increases or decreases, depending on how the LDR is connected. For case on Figure 4, Vo=VCC(5V)*LDR1/(R1+LDR1) that means for maximum illumination, Vo will weigh above 5V and for minimum above 0V, i.e. in digital equivalent, 1024 and 0, encoded as 10-bits.

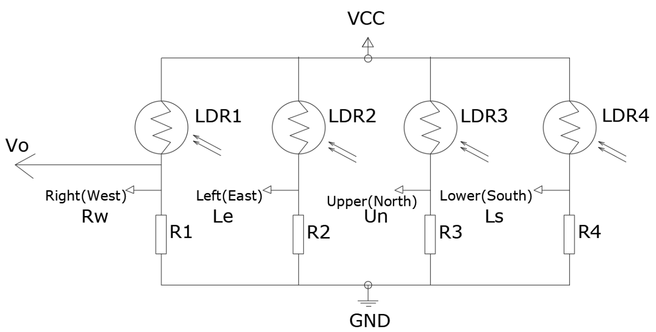

Figure 4. Quadrant of LDR photo sensors.

Rw, Le, Un and Ls are equivalent radiation information from Right(West), Left(East), Upper(North) and Lower(South) sensors.

Other sensors are also used in the system such as temperature sensor, humidity sensor, and light intensity sensor. They provide additional information, the values of which are displayed on LCD or used as needed.

C. System integration diagram

Figure 5 shows basic system diagram for proposed a two-axis solar tracker by using Arduino UNO development board powered by 5V, and connected to the LDR photo sensors. Servo X, rotates the solar panel round X axis. Servo Y: rotates the solar panel round Y axis.

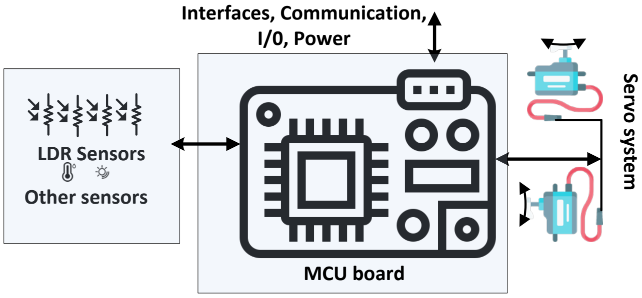

Figure 5. Basic circuit diagram

III. SOFTWARE DESIGN

The software implementation consists of coding the tracking system algorithm in the Arduino IDE environment and loading the code into the microcontroller. A software flowchart is given in Figure 6. The algorithm is based on comparing analog voltage values provided by photo sensors (left, right, upper and lower LDR). For azimuth tracking, the voltage values from the left and right LDR are compared. If the left (east) LDR receives more light, the voltage on the left LDR will be greater than the voltage on the right LDR and the horizontal motor will rotate to the left (east). If the right (west) LDR receives more light, the voltage on the right LDR will be higher than on the left and the horizontal servo motor will move in that direction, i.e. to the right (towards the west). To monitor the tilt angle, the voltage value from the upper and lower LDR is compared. If the upper (north) LDR receives more light, the voltage on the upper LDR will be greater than the voltage on the lower LDR and the vertical motor will rotate upwards (north). If the lower (south) LDR receives more light, the voltage on the lower LDR will be higher than on the upper LDR and the vertical servo motor will move down (south). In order to avoid the constant movement or vibration of the motor, a minimum voltage difference ("error") was introduced, which should be smaller than the voltage difference between the two sensors in order for the motor to start.

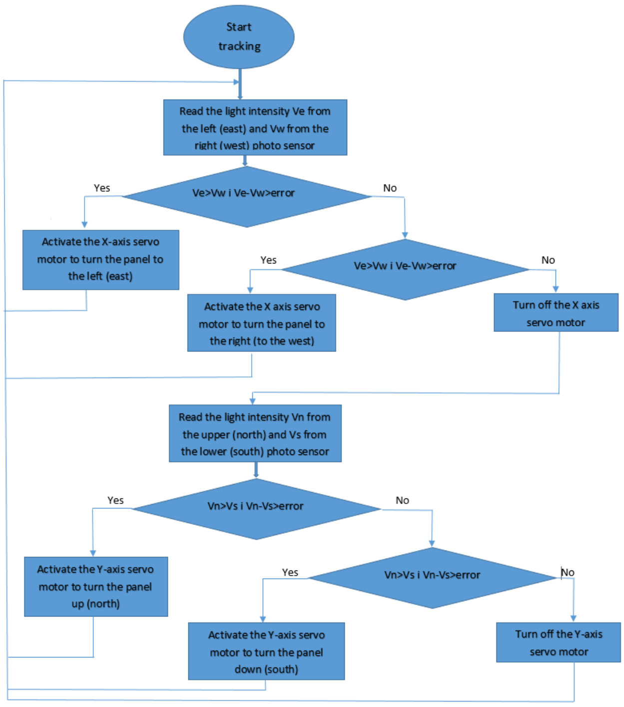

Figure 6. Software algorithm

IV. SYSTEM INTEGRATION

A. Testing the components

The components are connected to prototype, which back and front view are given in Figure 7 and Figure 8. which are connected to the development board, and the board to the computer for purpose of system initialization and testing. After testing all the components, assembly of the solar tracking was started by mounting the components on perforated acrylic plates. Keyestudio solar tracking kit is a good platform for time and performance efficient design.

The development board, LDR photo sensors (East, West, North), temperature and humidity sensor, energy module, servo motor Y, servo motor X, and Solar panel (rear view) are presented on the figure 7.

LCD screen, power module, Light intensity sensor, LDR photo sensors (South), and Solar panel (front view) are presented on the figure 8.

The motors are mounted on a moving mechanism on which a mini solar photovoltaic panel is mounted to enable the movement of the panel along two axes, X along azimuth (east-west, i.e. left-right) and Y along the angle of inclination of the sun's path (north-south, i.e. up- below), to allow the panel to always be at right angles to the sun's rays, to ensure greater efficiency in electricity production.

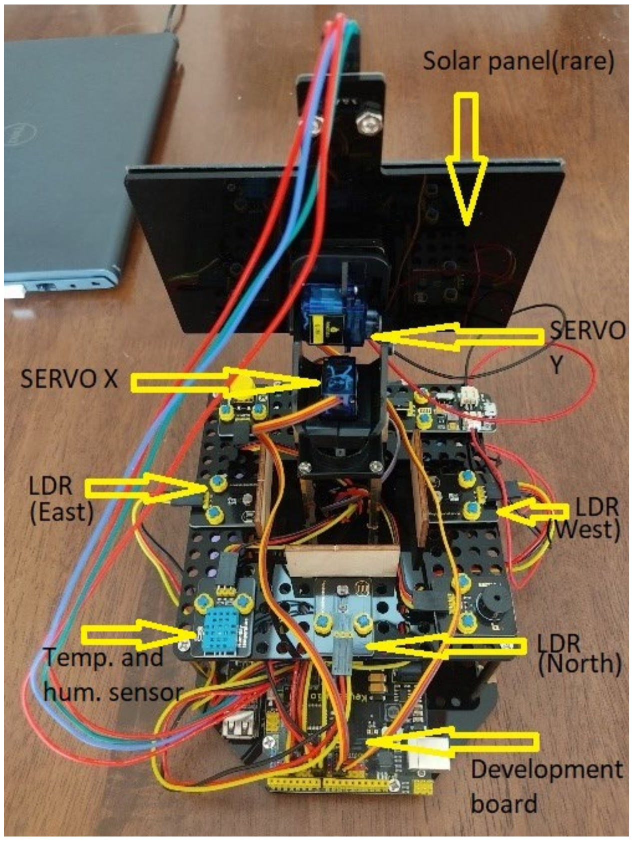

Figure 7. Prototype-back view

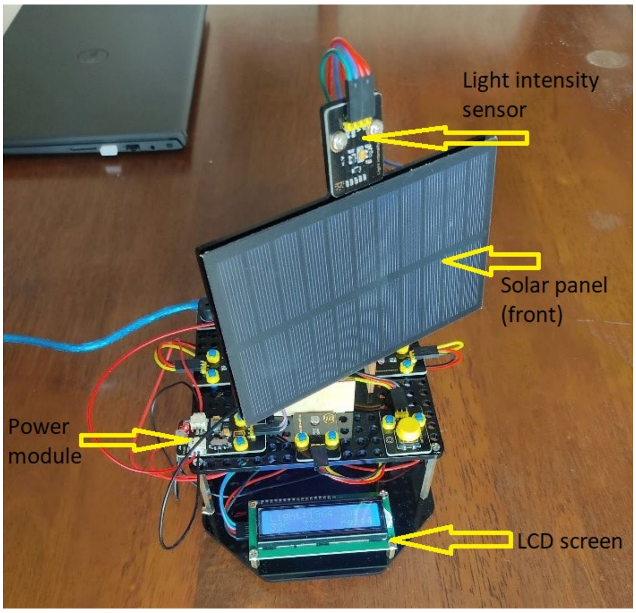

Figure 8. Prototype: front view

V. TESTING AND PRELIMINARY RESULTS

A. *Testing against functionality*

B. In order to verify the functionality of the system, the preliminary testing has been done in laboratory and real environments. In laboratory, a lamp test was successfully performed to determine whether the panel rotates towards the light source, Figure 9. A short video showing the panel tracing the lamp illumination,

https://youtube.com/shorts/wTpoHE-4QKo

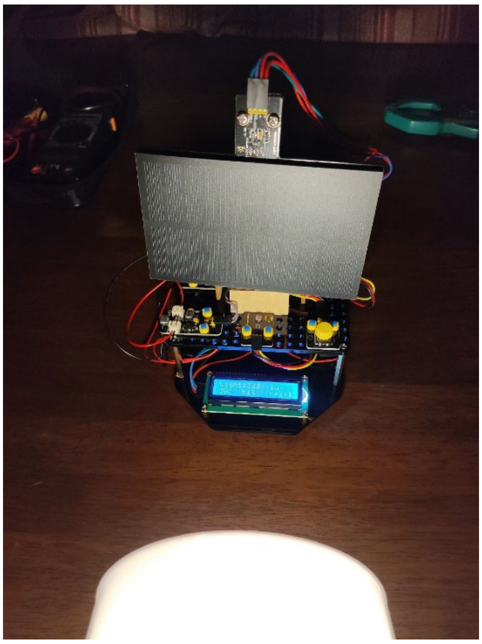

Figure 9. Testing with artificial light

In order to check the practical functionality of the system, testing was successfully carried out in a natural environment, in order to determine whether the panel turns towards the sun, Figure 10. The video shows the panel automatically pointing towards an artificial light source, https://www.youtube.com/shorts/Qpte4JErmA8

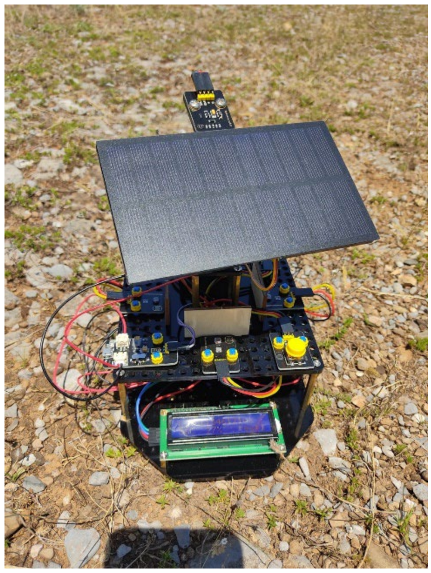

Figure 10. Testing with sunlight

C. *Testing to increased energy generation*

The measurement of the charge current (energy) produced by the solar panel system has been performed in a natural environment near Podgorica, on Ćemovsko Polje, on 07/08/2023. The generated current is measured with digital clamp meter, "ProsKit, MT-3109". The measurement was performed in the period from 06:00 to 20:15, in intervals of 15 minutes. The produced energy is calculated by using the equation: E= I*U*0.25h, as a product of the measured charging current produced by panel I, the voltage U provided by the panel (3.7V) and the measurement time interval (0.25h=15min). The measurement results are given in the graphic, Figure 11.

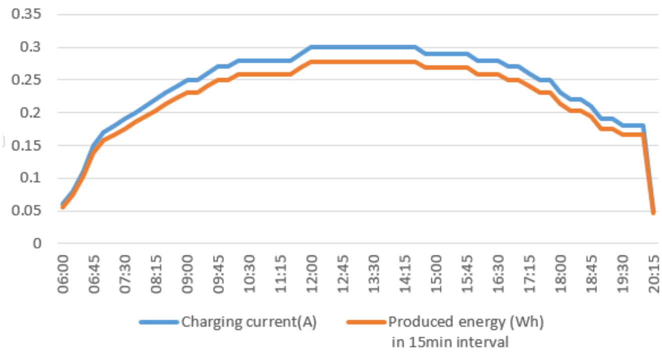

Figure 11 – measurement results with active tracking

Result of the measurement with inactive tracking function are given in Figure 11.

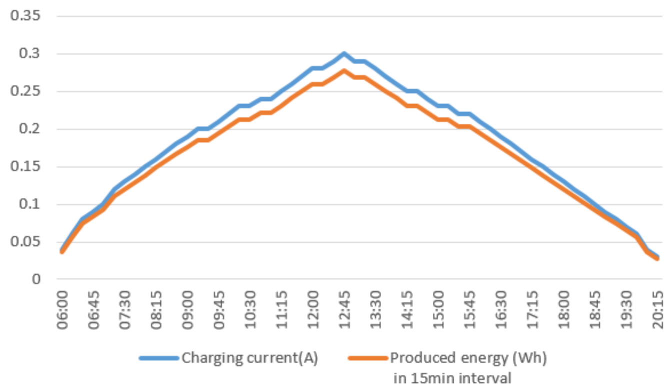

Figure 12 – measurement results with active tracking

The graphic in Figure 13 shows a comparison of the produced electricity with and without tracking.

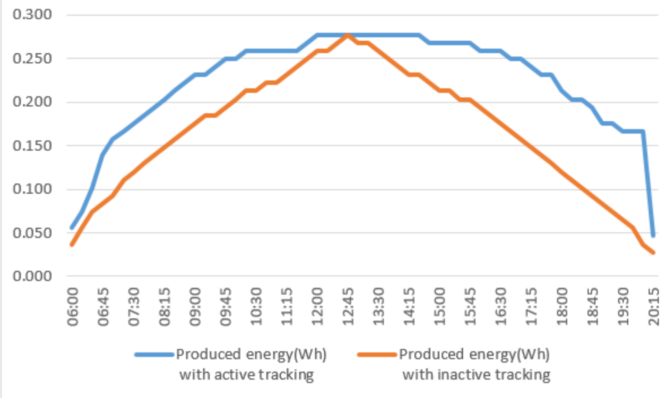

Figure 17 - comparison of the produced electricity with and without tracking

The total energy produced in the case when the tracking is active is 32.9% higher than the energy produced when the regulation was not active, which is a very significant difference that favors the application of such systems in practice.

VI. CONCLUSIONS

In this paper, a system for solar tracking is presented. The key elements of hardware and software are considered. The system is low cost and easy to implement by energy vendors and integrators. The system is able to improve the performance of photovoltaic modules for about 30% that can be of interest and benefit in practical applications.

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