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A comparison of fuzzy logic and PID controller for a single-axis solar tracking system

Emre Kiyak* and Gokhan Gol

Abstract
Proportional integral derivative controllers are widely used in industrial processes because of their simplicity and effectiveness for linear and nonlinear systems. The fuzzy controller is the most suitable for the human decision-making mechanism, providing the operation of an electronic system with decisions of experts. In addition, using the fuzzy controller for a nonlinear system allows for a reduction of uncertain effects in the system control. In this study, a proportional integral derivative controller and a fuzzy logic controller are designed and compared for a single-axis solar tracking system using an Atmel microcontroller. According to the angle of solar energy, a solar panel is oriented to the side where light intensity is greatest by being designed for the related supervisory controllers. Thus, the aim is to increase the energy obtained from solar panels by providing the specular reflection of the sun's rays to a solar panel. At the same time, a maximum efficient processing system has been determined by taking account of two controllers for the designed system.

Keywords: Solar tracking system, Fuzzy controller, PID controller, Energy efficiency

Background

Renewable energy is a type of energy that is derived from ongoing natural processes and energy of natural processes converted into available forms. Renewable energy sources can be listed as sunlight, wind, flowing water, biological processes, and geothermal. The use of renewable energy sources is growing rapidly because of the fact that fossil fuels are limited, being rapidly depleted, pollute the environment and cause climate change. In addition, another factor that increases the use of renewable energy sources is that they can be installed everywhere, and can be developed using various technologies.

The most common sources of renewable energy are solar and wind energy. The siting of wind turbines must ensure maximum exposure to wind in order to achieve wind energy, but not every province in Turkey can provide such conditions. Also, wind turbines must be built far from residential areas, due to the fact that the sound of wind turbines greatly inconveniences people. In addition to this, the rural setting of wind turbines is generally on the migration route of birds. Research shows that birds often change their migration routes or that birds die by hitting operational turbines due to the siting of such turbines (Akkaya et al. 2002). Accordingly, it is observed that solar farms, as a source of renewable energy, are more widespread than wind turbines.

Due to the fact this method of obtaining electrical energy using solar energy is easier, more practical, less harmful, and at lower cost than other renewable energy sources, it is rapidly becoming widespread. However, the efficiency of solar cells is only around 20 %, so it prevents the conversion of solar energy into electrical energy at full efficiency (Green et al. 2000). Therefore, solar tracking systems have emerged, in order to obtain the greatest efficiency from sunlight.

A solar tracking system is a monitoring system which aims for solar panels to operate by tracking the sun at full efficiency during the day to allow for the sun rays arrive perpendicular to the panels. It can be seen that the efficiency achieved from the solar panels increases from between 25 and 55 % (Irina and Cătălin 2010).

In recent years, there have been many studies concerning the development of solar tracking systems. Studies are currently being conducted to get sun rays perpendicular

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to panels using a variety of control techniques (Shugar et al. 1996; Roth et al. 2004; Colak et al. 2005). According to the study, applications on solar energy have increased rapidly in recent years, and new materials and methods are being developed for this energy source.

In another study, a SCADA system is developed in order to allow for optimal sun tracking and real-time control using a programmable logic controller (PLC) and step motor in a two degrees of freedom (DOF) tracking system. In this study, power generation increases, compared to other PV systems, and non-tracking systems because real-time control and monitoring is provided (Figueiredo and Costa 2008).

It can be seen that the tracking system is made very stable by the development of a microprocessor-based solar tracking system. A microprocessor-based solar tracking controller was designed and manufactured in 1990, in New Delhi, India. The controller has several features which makes it versatile for tracking and system control/monitoring applications (Saxena and Dutta 1990).

Environmental conditions effect power production in solar energy, but our devices work on a constant voltage. If light intensity and temperature do not change, a maximum power point (MPP) will occur at a constant voltage. However, if the environmental conditions change over time, the voltage in the MPP will also change. In this case, for better performance, a more complicated controller is required with parameter changes according to atmospheric conditional changes (Nopporn et al. 2005). The output power of a solar panel depends on the amount of light on the panel (Li et al. 2005). The designed Fuzzy logic controller technique can find peak power by doing wide range of illumination and temperature variations (Ghassami et al. 2013).

A fuzzy logic-based two-axis solar tracking system increases efficiency by 33.416 % compared to a non-tracking system. In this study, a stepper motor is used for the direction control and an Arduino Uno is used for the microcontroller. In addition, the proposed fuzzy logic controller has been implemented and tested using MATLAB for this study (Bawa and Patil 2013).

Fuzzy logic is used in many engineering applications, because it is considered by designers to be the simplest solution available for a specific problem, for instance, in household electrical appliances, auto electronics applications, and industrial automation systems (Peri and Simon 2005). With complicated processes where control is hard, it becomes necessary to use a fuzzy logic controller (Takagi and Sugeno 1985). Fuzzy logic controller is adaptive and nonlinear nature, which provides it robust enactment under load, supply voltage disturbances, and parameter variation (Punithaa et al. 2013).

So far Fuzzy logic control-based solar trackers of different configurations have been implemented on FPGA and PIC microcontrollers, but the control logic for this research was implemented on a simple microcontroller board Arduino Uno (Hamed and Mohammed 2012; Khaehintung et al. 2007).

In the solution there is a dual-axis solar tracking system, based on solar maps, which can predict the exact apparent position of the sun, by latitude location, thereby avoiding the need to use sensors or guidance systems (Abdallah and Nijmeh 2004).

In another study, a solar tracking algorithm is designed and implemented on a solar tracking experimental platform, using a tri-positional control strategy. It makes use of measured values for radiation from appropriate sensors and assures command of the platform's two positioning motors. The implementation technique reduces the cost of the tracking method and makes it cost-effective technology (Arghira and Iliescu 2013).

A solar cooling system is important for improving of energy efficiency. This study's aim is to improve energy efficiency of a solar cooling system by an innovative combination of optimized solar cooling, storage techniques, and an absorption chiller, with highly developed techniques for control using known tool; TRNSYS and MATLAB with Simulink (Visek et al. 2014).

A single-axis sun tracking system with two sensors was designed. The data acquisition, control, and monitoring of the mechanical movement of the photovoltaic module were implemented based on a programmable logic-controlling unit (Al-Mohamad 2004).

In this study, the design and application for a single-axis solar tracking system is developed based on both fuzzy logic and PID controller in a real system. The necessary control circuits are designed. The control circuit is built on an Atmega 328 microcontroller and necessary software is installed into the control unit according to MATLAB simulations. In this study, it has been shown that fuzzy controllers are more efficient than PID controllers in single-axis solar tracking system. This result is reached using real-time measurement data obtained in the scope of the study.

Solar tracking system

The purpose of the solar tracking system is to allow sun rays to reverberate to a solar panel with full angle in the solar system which has low efficiency and to generate energy at full efficiency. Therefore, sun rays placed at different points on the system are controlled using an intensity sensor, and the solar panel is thereby moved toward the point gathering most sun rays by a DC motor. The materials used for the solar tracking application are as follows:

- Atmega 328 microcontroller
- DC motor
- DC motor drive circuit
- Solar panel
- Mechanical systems for single-axis control
- Feed circuit
- Sensors

Atmega 328 microcontroller

An Atmega 328 on an Arduino UNO is a microcontroller, with 14 digital input/output, and 6 analog inputs. Six of the digital pins can be used for pulse width modulation (PWM). Input/output pins can provide up to a maximum 40 mA of current. There are 32 GB flash memories for storing written code, a 2 kB static random access memory (SRAM) used for creating a work area, and a 1 kB erasable programmable read only memory (EEPROM) for users on the microcontroller.

Certain additional elements, such as an external crystal and capacitors are necessary in order that the Atmega 328 microcontroller can be used as a control unit in a circuit. A 16 MHz crystal, and a two 22 pF capacitor for operation of the microcontroller are also required (Fig. 1).

DC motor

An electrical device which can direct current electric energy and convert it to mechanical energy is called a DC motor. In this study, a low speed, high torque direct current motor is used for moving the solar panels. The motor used (titan motor) operates at a low speed of 5 revolutions per minute (rpm) and can produce 32 kg torque per cm. It uses a low amount of current with 400 mA at maximum load capacity and 24 mA at idle.

DC motor drive circuit

DC motors are motors which start to rotate when provided with energy from a battery directly. The motor rotation direction changes when the positive and the negative terminals of the battery are applied to a motor intake interchange. Due the fact that motor direction cannot be changed during use, it is necessary to create driver circuits. There are numerous direct current motor driver circuits. However, in this study, direction and speed control of the motor is performed using the popular H-bridge method. The operating principles of the H-bridge, as illustrated in Fig. 2, are based on the change of logic signal which is applied to the base of the transistors used. As shown in the circuit, if the base terminals of 1 and 4 transistors are given logic 1, and the base terminals of 2 and 3 transistors are given logic 0, the motor rotates to the left. Therefore, a related truth table is drawn according to this principle.

The H-bridge is made using BC237 transistors. However, when this circuit is designed, it can be seen that the transistors overheat and that the motor cannot be controlled properly. This circuit, designed in order to understand how driver circuits work, is not used for motor control in this study. In this study, as shown in Fig. 3, the motor speed and the direction control circuit are mounted on a pcb board.

As can be seen from the circuit, there are two inputs to enter the control signal coming from the microcontroller to the driver circuit. According to Table 1, the motor direction control can be performed by sending a logic signal sent from this input.

DC motor speed control is performed using the PWM method. In this method, the voltage applied to the motor signal cable is a fixed frequency and square wave. That is, the speed of the motor is set by changing the pulse width of logic 0 and 1 sent to the driver. Due to the fact that the motor used in this study runs at a 600 Hz frequency, the period is 1666 µs. The speed of the motor is adjusted depending on pulse width modulation. If the motor is desired to be rotated at full speed, a 255 value is sent to the motor with the help of the microcontroller using an analog Write (255) command. The 255 value is due to the 8-bit output ADC of the microcontroller. In Fig. 4, pulse width modulation is seen according to a duty cycle.

Solar panel

A solar panel is an energy source containing many solar cells enabling the absorption of solar energy. Solar cell/photovoltaic cells convert solar energy into electrical energy using the photovoltaic effect characteristic of semiconductor devices. In this study, 1 solar panel of 15 V 20 W capacity is used.

Feed circuit

Two different voltage levels were required for this study. 5 V is required for the control circuit and 12 V is required for the motor drive circuit. Voltage from the

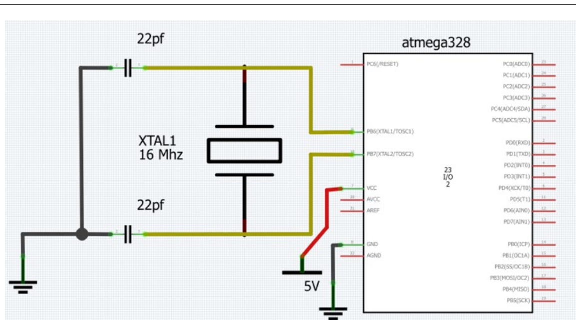

Fig. 1 Atmega 328 circuit connection diagram

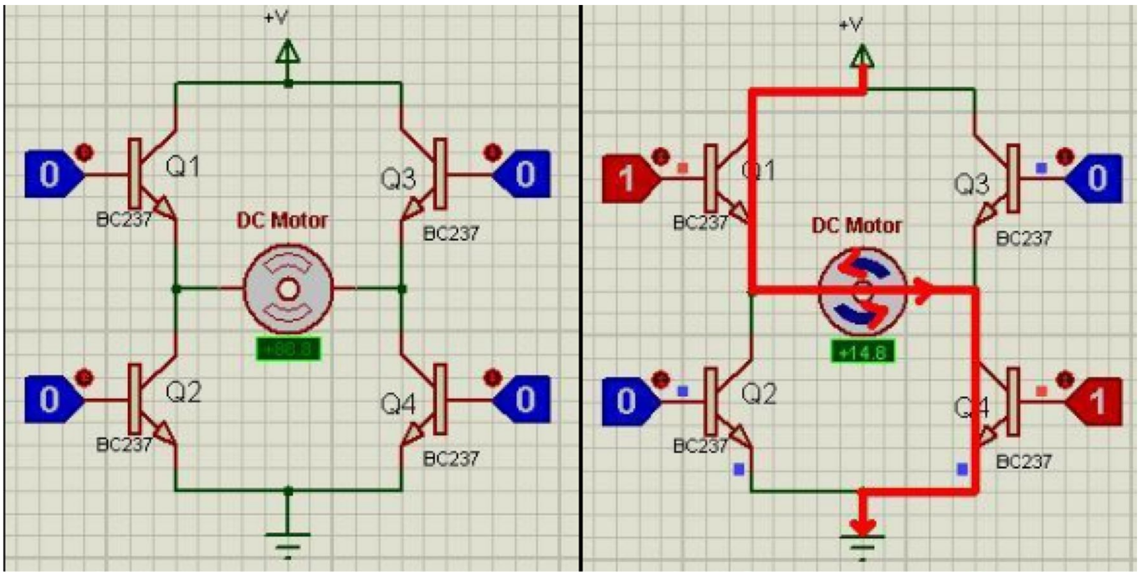

Fig. 2 H-bridge operation diagram

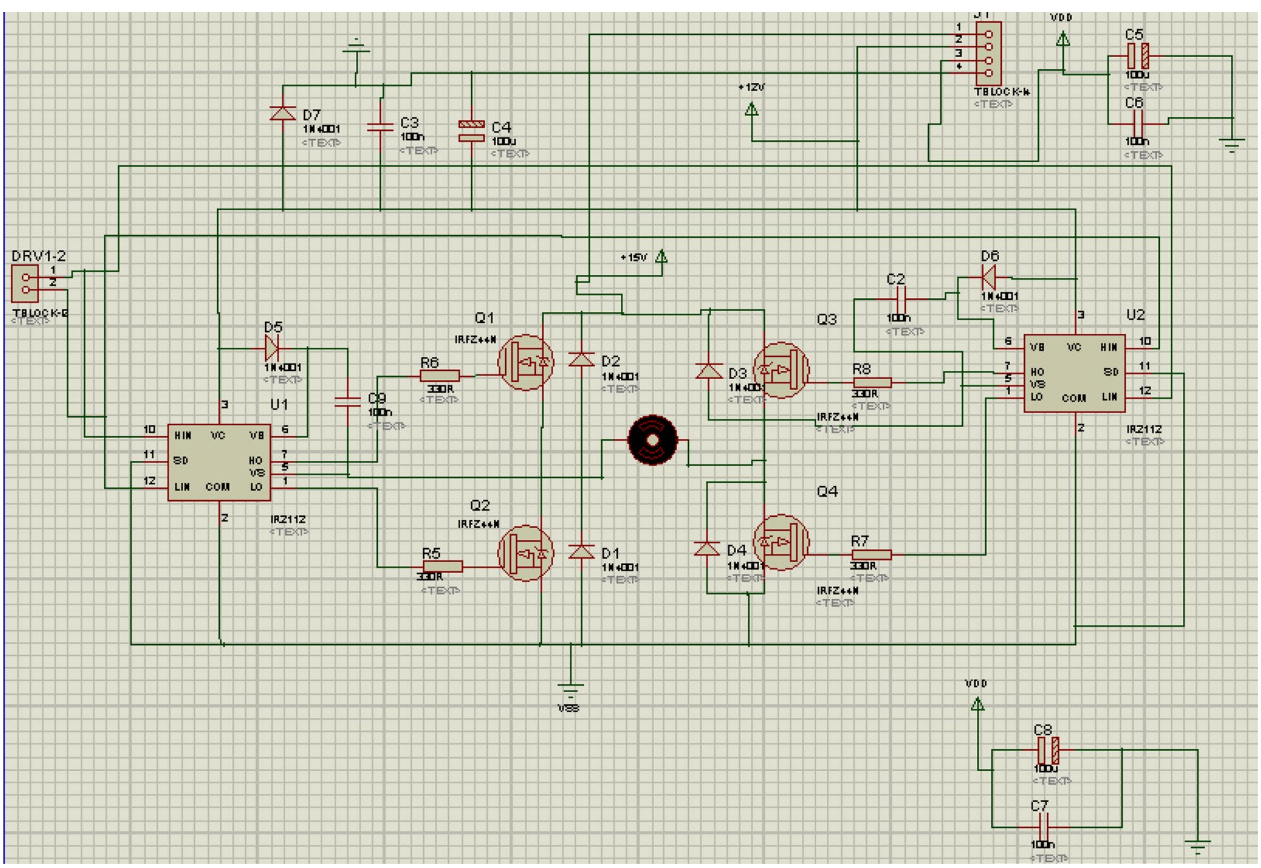

Fig. 3 DC motor driver circuit

Table 1 Driver circuit truth table

Input 1	Input 2	Motor direction
ON	OFF	Right
OFF	ON	Left
OFF	OFF	Stop
ON	ON	Un-solicited status

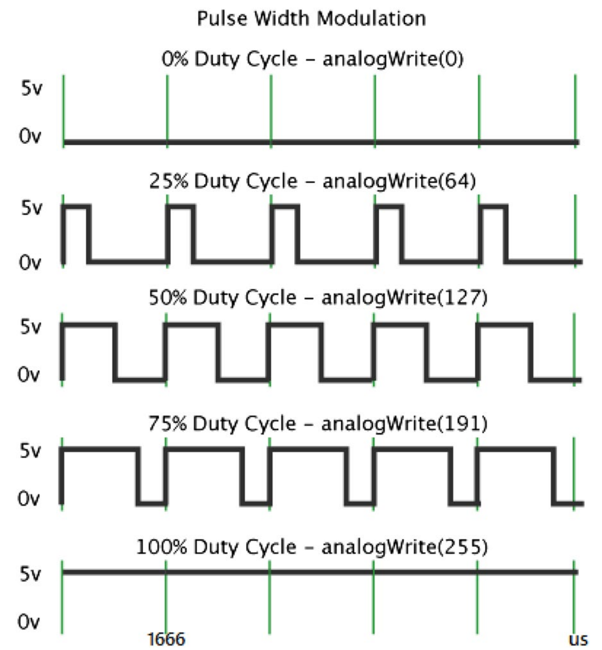

Fig. 4 DC motor speed control

solar panel is not applied to the circuits directly, and the battery is charged by the battery charging circuit. The charging circuit arranged for a 12 V battery is shown in Fig. 5.

The 5 V required for the control unit was made by designing a buck converter circuit. A buck converter is a voltage step-down and current step-up converter. The converter circuit was made using an integrated lm517 as shown in Fig. 6.

Sensors

Sensors are used to interconnect the electronic circuits in a physical environment and are referred to as sense organs of the control systems. There are many sensors used for measuring different values, such as pressure, temperature, humidity, and sun intensity. The values are generally measured in terms of voltage by changing the resistance on the sensor. Therefore, measurements are made by taking into consideration the relationship between resistance and voltage.

In this study, two photo resistances placed in an east–west direction on the solar tracking systems measuring sun intensity are used. A photo resistance sensor or light-dependent sensor (LDR) is a sensor which changes resistance depending on light and is inversely proportional. The voltage values measured from the sensor output located on the east and west parts of the solar panel are compared. Accordingly, the panel is moved in an east–west direction. Thus, the panel is moved into a position receiving the sun rays perpendicularly providing that the values measured from the sensors are within the tolerance value range.

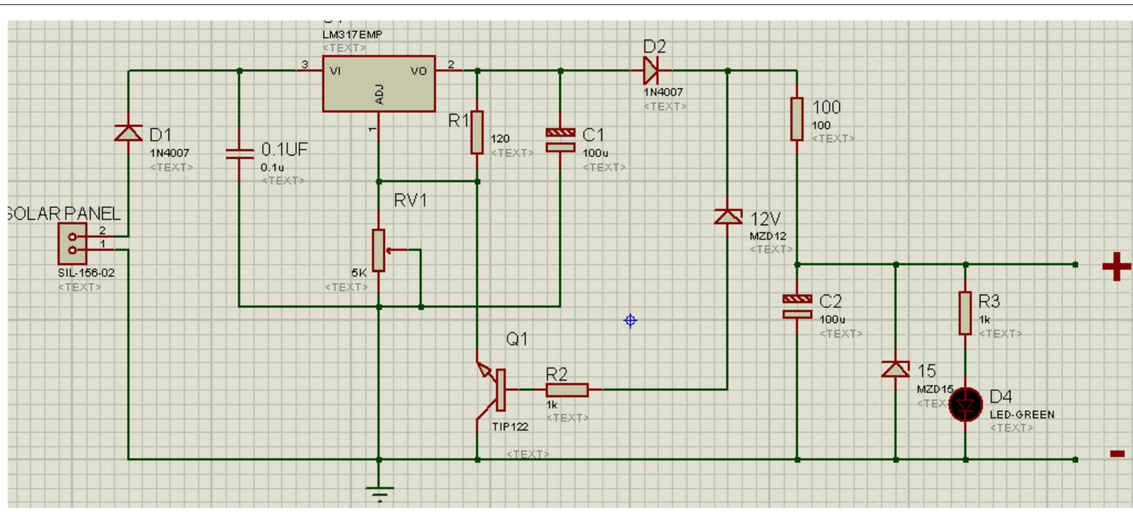

Fig. 5 Battery charging circuit

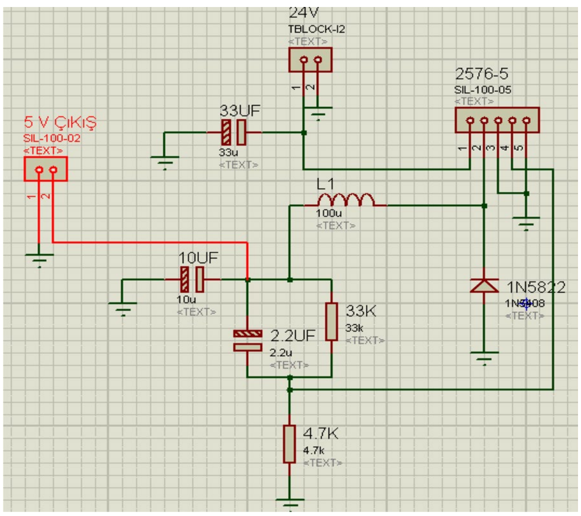

Fig. 6 15–5 V converter circuit

Photo resistance sensors provide voltage data according to changes in resistance. Values are read from the sensor connected to an analog input pins of an Atmega 328 microcontroller with the aid of correct resistance change between 0 and 1023 due the fact that the input ADC value of the controller is 10 bit. In fact, the equivalent value between 0 and 1023 is 0–5 V. The controller–sensor connection is shown in Fig. 7.

PID control system and fuzzy logic controller

PID controllers are commonly used to regulate the time-domain behavior of many different types of dynamic plants (Ahmad et al. 2013). PID is a control technique which aims to reduce errors of a system by undergoing three different mathematical operations and racking the results up producing a control output. PID, an acronym for proportional, integral, and derivative words, constitutes control output from the effect of these three mathematical expressions. The formula for PID is described by (Ozerdem and Zhahin 2014):

$$P + I \times \frac{1}{s} + D \times \frac{N}{1 + N \times \frac{1}{s}}, \tag{1}$$

where: P proportional, I integral, D derivative, N filter coefficient.

Proportional effect has an impact on controller output as errors multiply with a specific gain value. Proportional effect increases the accuracy of static and dynamic response of a system. That is, it has an impact on a system in the way of fast reaction time and a reduction of errors. While the proportional gain factor K increases, the steady-state error of the system decreases. However, despite the reduction, P control can never manage to eliminate the steady-state error of the system. In this study, gain value is found using various automatic tuning methods or by trial and error. In this study, an automatic tuning code is embedded in the microcontroller thanks to feedback obtained from the system. The integral effect has an impact on controller output proportionally to the sum of the errors from the effective operation of the system. While the integral effect increases static accuracy and eliminates error, its dynamic response time reduces. This study focuses on integral effect and the integral coefficient is determined by an automatic tuning system and by the trial and error method.

A derivative effect has an impact on controller output in direct proportion to the change in error. The derivative effect does not contribute to error recovery, while increasing dynamic response.

PID controller has the optimum control dynamics including zero steady-state error, fast response (short rise time), no oscillations, and higher stability. The necessity of using a derivative gain component in addition to the PI controller is to eliminate the overshoot and the oscillations occurring in the output response of the system. One of the main advantages of the PID controller is that it can be used with higher-order processes including more than single energy storage.

In this study, Ziegler–Nicholas method is used for tuning process. Ziegler–Nichols method is one of the most effective methods that increase the usage of PID controllers. The first step in this method is setting the I and D gains (K_I and K_D) to zero, increasing the P gain (K_P) until a sustained and stable oscillation (as close as possible) is obtained on the output. Then the critical gain K_C and the oscillation period P_0 is recorded and the P, I, and D values

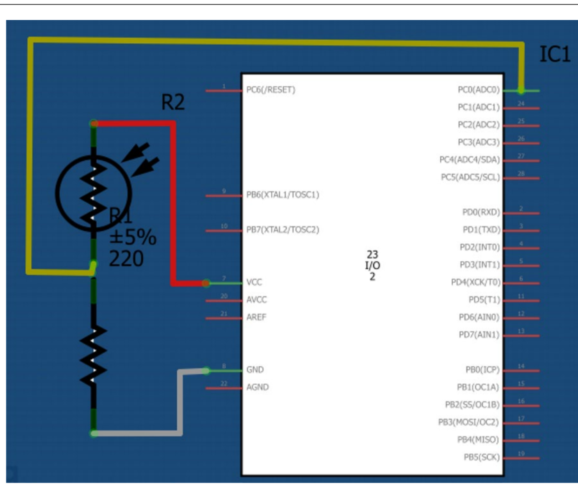

Fig. 7 Atmega 328 LDR connection

are adjusted accordingly. Critical gain K_C and oscillation period P_0 are used to set the gains as shown:

$$K_P = 0.6K_C, \quad K_I = \frac{2K_P}{P_0}, \quad K_D = \frac{K_P P_0}{8} \tag{2}$$

These steps which written software code embedded into microcontroller.

The transfer function of PID control is given by:

$$G_{\text{PID}}(s) = K_P + \frac{K_I}{s} + K_D(s) \tag{3}$$

The term 'fuzzy logic' was introduced with the 1965 proposal of fuzzy set theory by Lotfi A. Zadeh. It is expressed as a mathematical order which is established for the expression of uncertainties and for working with uncertainties (Calvo and Cartwright 1998). The word 'fuzzy' is defined as indefinite, complicated, and imperceptible. As is evident from its name, in this control system, it is intended to obtain approximate values through evolution with reasoned logic in an atmosphere of uncertainty. This control system, which is suitable for many dynamic systems that cannot be modeled in the world, provides an opportunity to view all the states of a system by dealing with, not only 0 and 1, but also all intermediate values contrary to the classical logic of Aristotle.

One-axis solar tracking system generally uses two sensors. LDR sensors measuring light density are placed on solar tracking system by indicating in east and west. The main idea is to read the value from LDR1 and compare it with the value of light density from LDR2. Then, depending on the difference between the two values, the controllers will decide and send commands to the motor and change its angle in order to make the difference equal the tolerance value (LDR1 − LDR2 = tolerance). The tolerance value is determined according to the sensitivity of sensor. Thanks to this it provides that solar rays reflect to solar panels perpendicularly. Control algorithm of the solar tracking system is shown in Fig. 8.

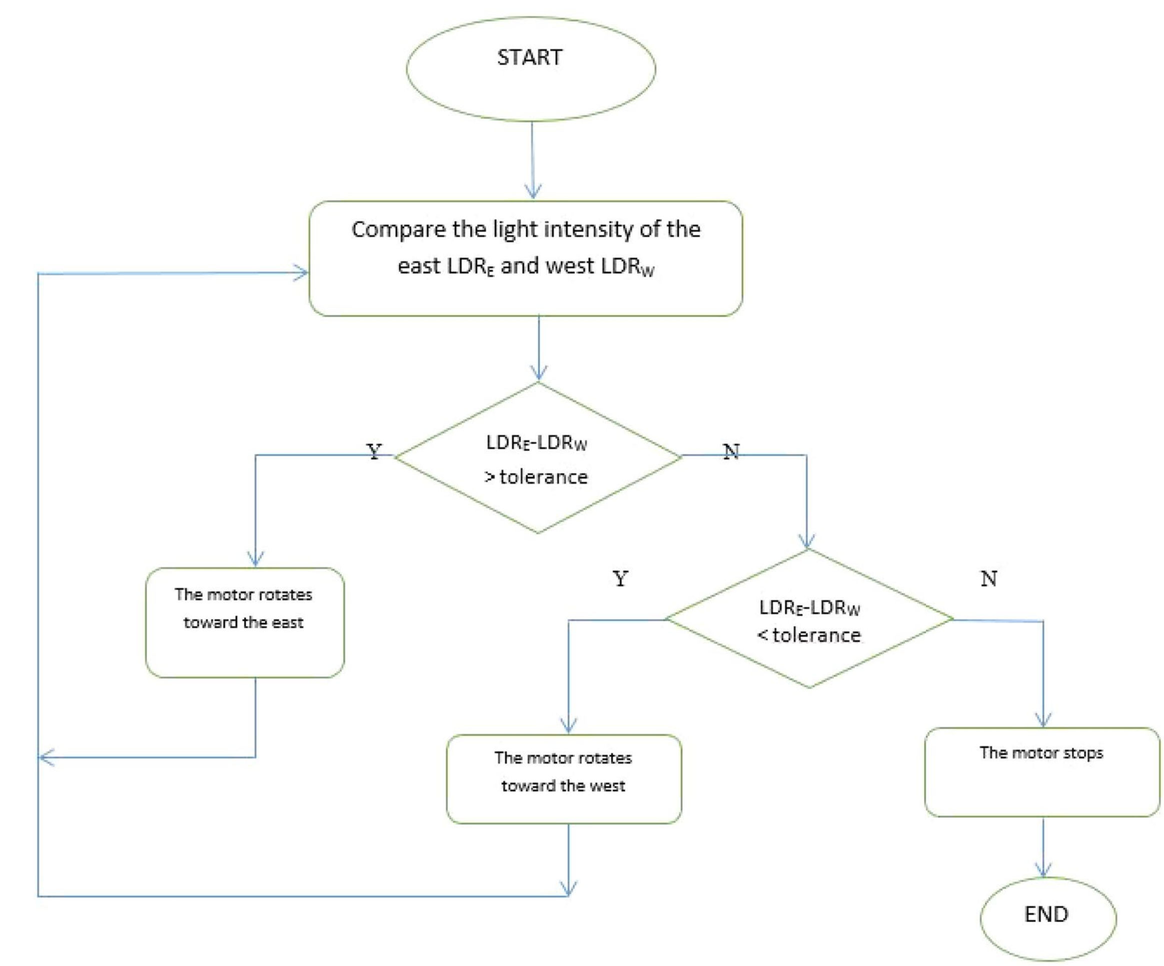

Fig. 8 Control algorithm of solar tracking system

In this study, the maximum revolution of motor used is 4 rpm. Response of the controllers is shown in Fig. 9 according to 4 rpm input signal.

A simplified block diagram representation of the solar tracking system is shown in Fig. 10.

Here, $u(t)$ is the control signal, $y(t)$ is the output signal, $r(t)$ is the reference signal, and $e(t)$ is the error signal in block diagram. According to block diagram, PID output $u(t)$ is calculated as Eqs. 4 and 5.

$$u(t) = K_P e(t) + K_I \int e(t)\mathrm{d}t + K_D \frac{\mathrm{d}e(t)}{\mathrm{d}t} \quad (4)$$

$$e(t) = r(t) - y(t) \quad (5)$$

Results and discussion

Voltage and current data of the solar tracking system using a PID controller, are monitored in real time. The difference between systems remaining at a constant angle and systems with changing angle constantly is shown in Fig. 11.

The flowchart in Fig. 12 explains the algorithm used for fuzzy-based control of the solar tracking system. Block diagram of the fuzzy controller is shown in Fig. 13.

In this study, the solar tracking system is controlled using fuzzy logic. Data obtained from two different photo resistance sensors on the system are applied to the control system as input. Applied inputs are fuzzificated by entering in a fuzzification unit that is the first unit of the fuzzy control. In other words, a membership value is assigned to each item of data, and is transformed into a linguistic structure and then sent to the rule processing unit. Data obtained from the rule processing unit are governed by rules which can be modeled in accordance with rule processing information, like 'if……and……then….

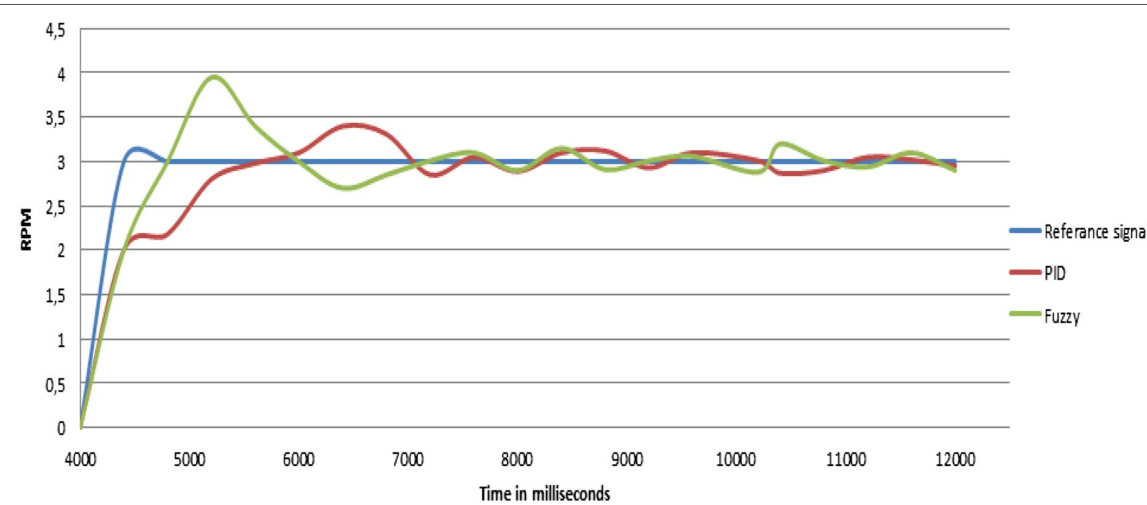

Fig. 9 Response of controller for 4 rpm speed

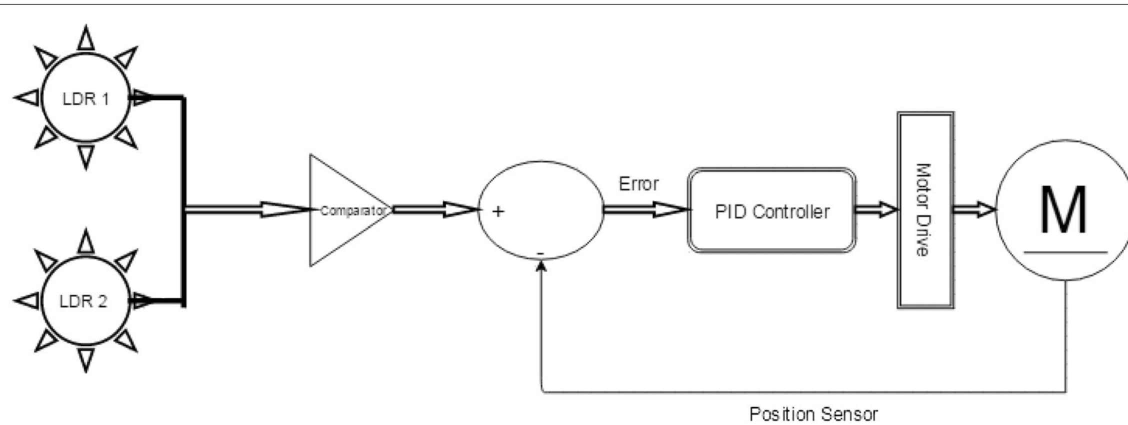

Fig. 10 Simplified block diagram representation of solar tracking system

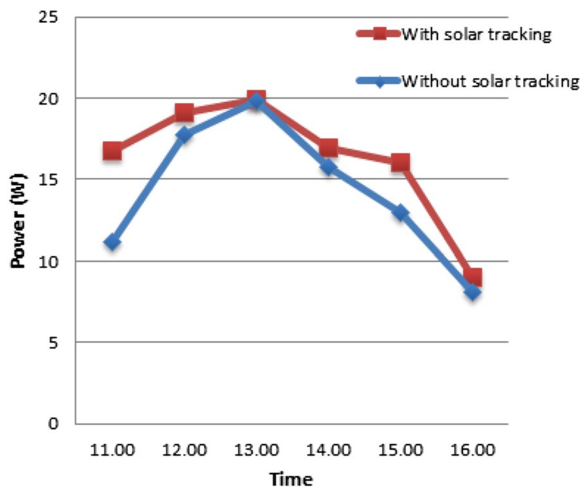

Fig. 11 The graphic of constant and moving angle systems

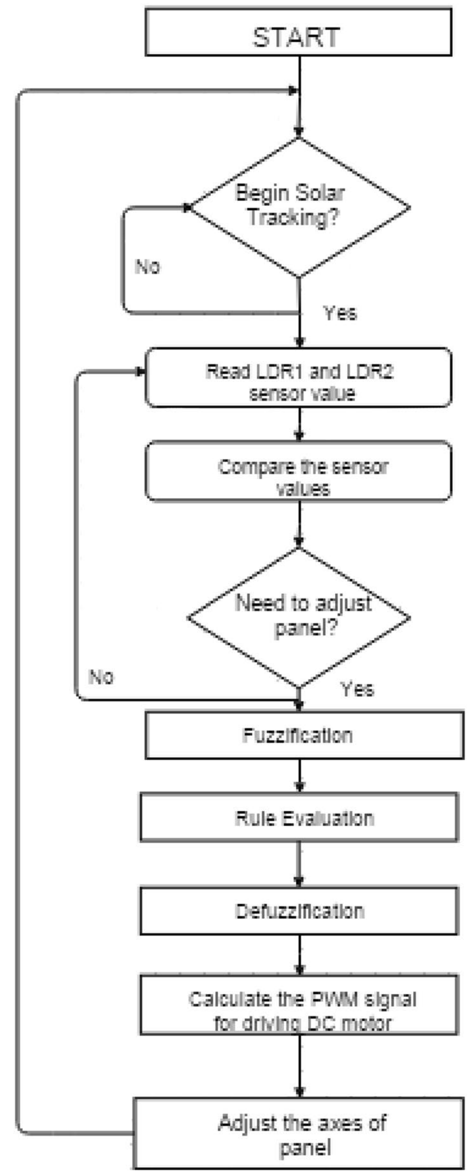

Fig. 12 Flowchart for fuzzy-based control of solar tracking

else', created in this unit. Input consisting of entries and these rules are sent to the inference unit and the result is obtained. In the next step, the results obtained as a result of the rules are sent to the defuzzification unit and then converted into real numbers according to a scale.

In this study, a triangle type is seen to be appropriate as a membership function. Thus, working load of microcontroller decreases as compared with using of other functions (trapezoidal, gauss etc.). The fact that working load in microcontroller decreases it, takes an important place. Membership functions and fuzzy control system are created via a MATLAB program. The created input and output membership are shown in Fig. 14.

Membership labels defined for the membership function mean that:

- NB = negative big
- NK = negative small
- Z = zero
- PK = positive small
- PB = positive big

Input membership set values are obtained by converting solar intensity data between 0–962 from the photo-resistor sensors to the 0–240 value linearly. The photo-resistor sensors are tested in daylight, and set bound values are obtained from the results of these tests. For example, NB set limits are chosen between 0 and 80 (0–341) because the photo-resistor sensor receives maximum sunlight between these values. The maximum 240 (LDR analog value = 962) is the value read from the photo-resistor sensor at sunset.

Output membership set values are determined as positive and negative in order to adjust the rotational direction of the DC motor. Values represent the PWM duty cycle rate.

Data received from the first and second photo resistance sensor are applied to the input. The duty cycle and direction control of the PWM signal of the DC motor which controls speed and direction as output are adjusted. Values beginning with N allow the motor to rotate counter clockwise, while values beginning with P allow the motor to rotate clockwise. The duty cycle is adjusted by selecting appropriate membership values in order that the motor rotates fast and slowly. There is a rule table of the system in Table 2.

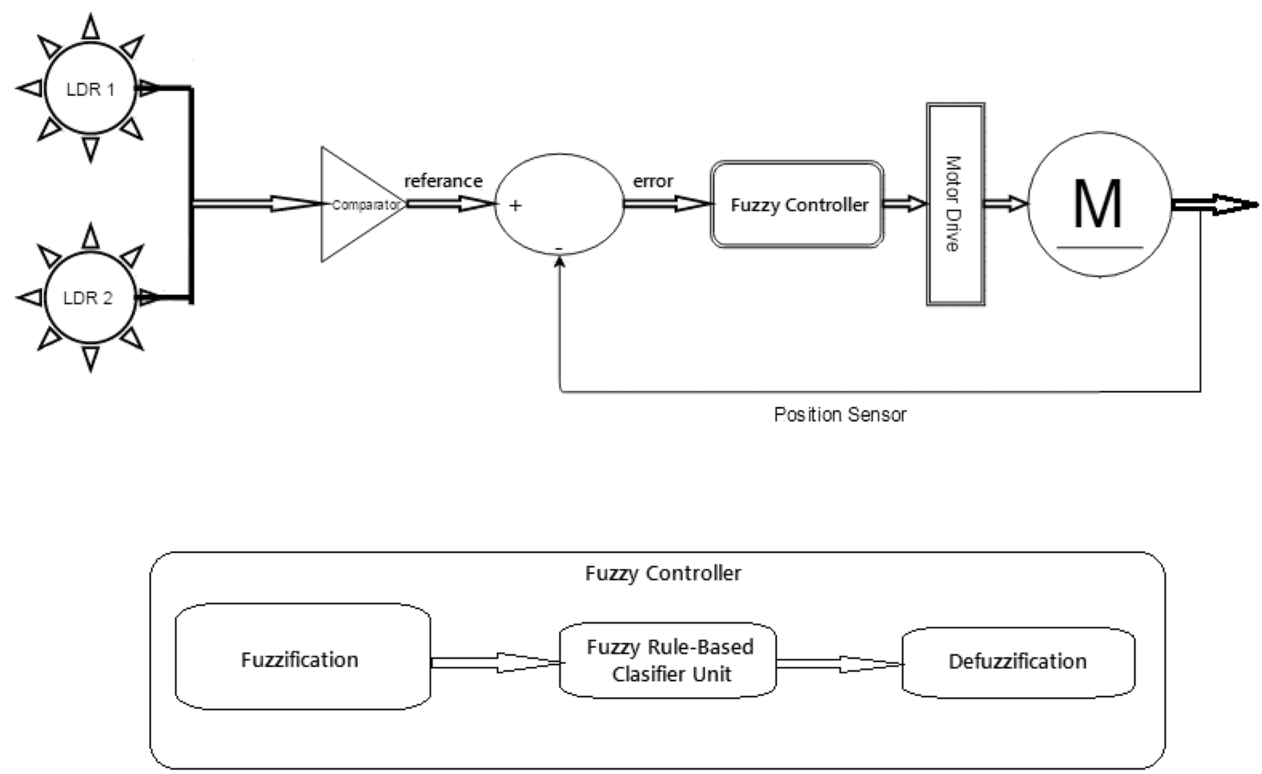

Fig. 13 Block diagram of fuzzy control

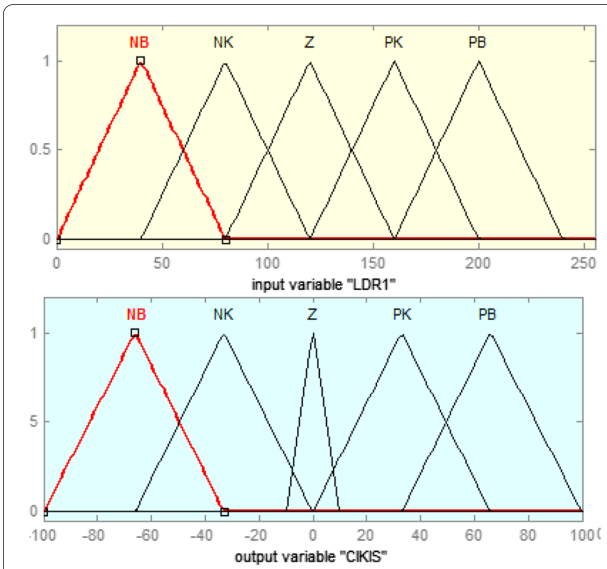

Fig. 14 The first LDR and output membership function

Table 2 Fuzzy control system rule table

LDR2	LDR1				
	NB	**NK**	**Z**	**PK**	**PB**
NB	Z	PK	PB	PB	PB
NK	NK	Z	PK	PB	PB
Z	NB	NK	Z	PB	PB
PK	NB	NB	NK	Z	PK
PB	NB	NB	NB	NK	Z

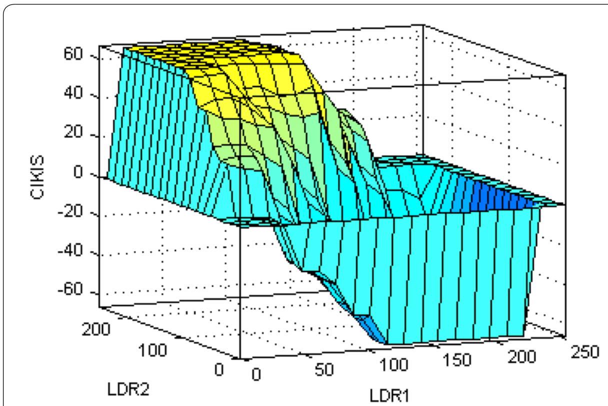

Fig. 15 Matlab rule surface image

The rule table is created as a result of testing. The system is tested over 15 days in different weather conditions. The surface table showing the output of the rules created in the MATLAB program is shown in Fig. 15.

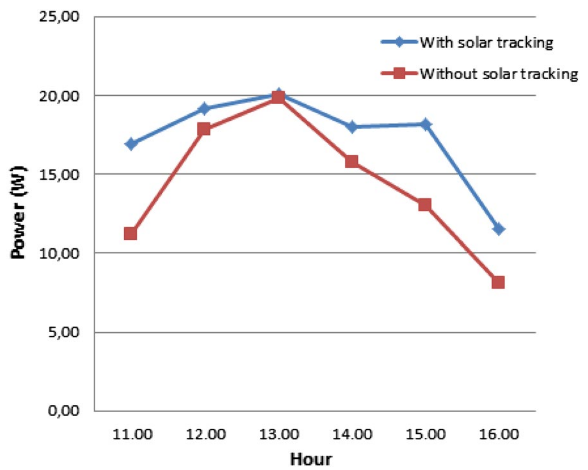

Fig. 16 The graphic of constant and moving angle systems

The voltage and current information of the solar energy system are monitored in real time. The difference between the systems remaining at a constant angle and systems with changing angle constantly is shown in Fig. 16.

Voltage, current, and power information measured for the system with a tracking system, and the system without a tracking system, is given in Table 3. As can be seen from these results, the energy derived from the system using the tracking system increases.

When taking into consideration the power value obtained for cases where the tracking system is utilized or is not utilized in Table 3, it can be seen that efficiency increases by 21.2 %.

$$\text{Efficiency} = \frac{(103.8 - 85.6) \times 100}{85.6} = 21.2\,\% \tag{6}$$

At the same time, the produced and consumed power information for the solar tracking system, based on fuzzy logic and the PID-based solar tracking system, are calculated. Related graphs are shown in Figs. 17, 18, and 19.

Voltage data measured at the top 20 s at the beginning for PID and fuzzy controller are shown in Fig. 20. As is seen, at the beginning PID controller steadied the late to settling time compared to fuzzy controller and the energy at full efficiency is not generated.

Voltage, current, and power information of the solar tracking systems developed with fuzzy logic-based and PID-based controllers is shown in Table 4. As can be seen from these results, the obtained energy increases in system utilized the fuzzy logic-based solar tracking system.

When the total power and power consumption obtained from the fuzzy logic and PID-based tracking system in Table 4 is considered, the efficiency of the fuzzy logic-based system increased by 2.39 %.

$$\text{Efficiency} = \frac{(100.2 - 97.86) \times 100}{97.86} = 2.39\,\% \tag{7}$$

Conclusion

In this study, a solar tracking system is designed in order to the increase efficiency of solar energy, which is a most important energy source for the future. Fuzzy logic and PID-based controllers are used to control the solar tracking system. The mechanics of the control, motor driver, feed circuit, and a single-axis tracking system are prepared.

As a result, it is observed that the energy obtained from the system using fuzzy logic for a solar tracking system increases by 21.2 %, compared to systems not using fuzzy logic for a solar tracking system. It can be seen that the efficiency can be increased when systems designed for the production of electricity from solar energy are combined with solar tracking systems. Also, according to results of tests conducted on the fuzzy logic-based controller and PID-based controller, the fuzzy logic-based tracking system is found to be 2.39 % more efficient than fixed systems. At the same time, fuzzy controller is steadied to settling time according to PID controller.

Table 3 Voltage, current, and power graphic of constant angle and moving angle

Time	Solar tracking with fuzzy			Without solar tracking		
	V (V)	*I* (A)	*P* (W)	*V* (V)	*I* (A)	*P* (W)
11.00	13	1.3	16.9	11.2	1	11.2
12.00	14.5	1.32	19.14	13.9	1.28	17.79
13.00	15	1.34	20.1	15	1.32	19.8
14.00	14.9	1.21	18.03	14.3	1.1	15.73
15.00	15.1	1.2	18.12	13	1	13
16.00	12.8	0.9	11.52	10	0.81	8.1
Total			103.8			85.6

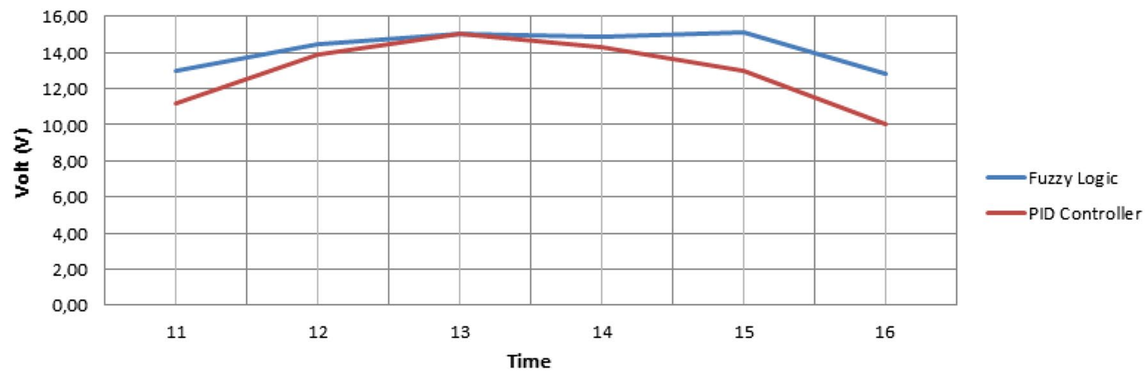

Fig. 17 Voltage–time graph of fuzzy logic-based and PID controller systems

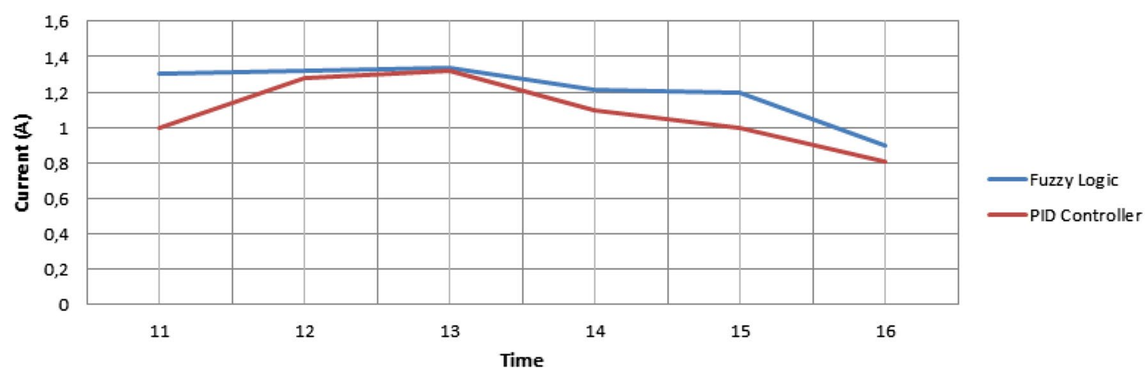

Fig. 18 Current–time graph of fuzzy logic-based and PID controller systems

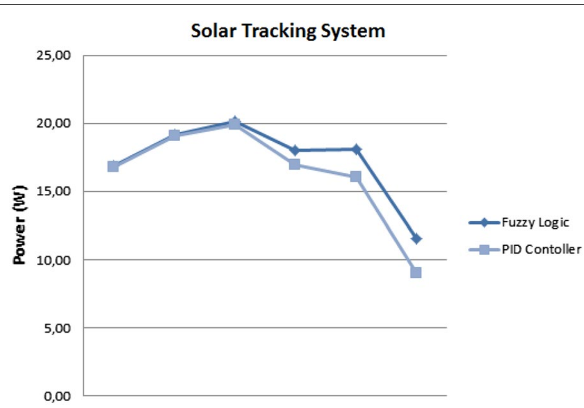

Fig. 19 Power–time graph of fuzzy logic-based and PID controller systems

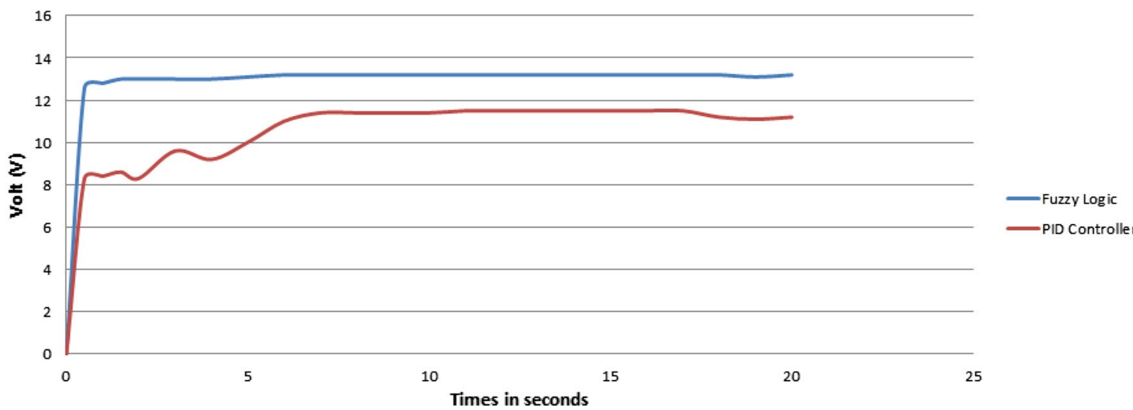

Fig. 20 Voltage–time graph of fuzzy logic-based and PID controller systems

Table 4 Voltage, current, and power values of the fuzzy logic-based and PID-based solar tracking system

Time	Fuzzy logic controller			PID controller		
	V (V)	*I* (A)	*P* (W)	*V* (V)	*I* (A)	*P* (W)
11.00	13	1.3	16.9	11.2	1	16.8
12.00	14.5	1.32	19.14	13.9	1.28	19.1
13.00	15	1.34	20.1	15	1.32	19.95
14.00	14.9	1.21	18.03	14.3	1.1	18
15.00	15.1	1.2	18.12	13	1	17.01
16.00	12.8	0.9	11.52	10	0.81	11.5
Total consumption			3.6			4.5
Net			100.2			97.86

It is planned to apply the solar tracking system in two axes. An interface will be designed considering real-time data transmission and the system will be continuously monitored. Additional sensors are added to the available sensor, as an input to the fuzzy logic control system, with sensitivity being optimized.

Authors' contributions

EK participated in the design of the study and performed the PID controller and fuzzy controller for a single-axis solar tracking system. GG conceived of the study, and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

Competing interests

The author declare that they have no competing interests.

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