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RESEARCH ARTICLE
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Designing and programming a microcontroller based on a solar tracking system

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Abstract. This paper is regarding the designing and programming of a microcontroller Arduino Uno board using Arduino software to work as a photo-sensor (Active) Single Axis Solar Tracker System (SASTS). A solar panel, two photo-resistors which are also known as Light-Dependent Resistors (LDRs) on two sides (north/south) of the photovoltaic (PV), and a servo motor are connected to the Uno board, which is previously running a code that is prepared by Arduino Integrated Development Environment (IDE) then it works as a tracking system. Here, the LDRs send the signal of the presence or absence of the light to the board, and based on that signal the Uno reflects a new signal to the servo motor to rotate and find the light source, lastly, the photo sensor single-axis tracker is made. While the system tries to move the panel face to the sun and change the irradiance intensity, in the meantime it starts a search to find the angle of the highest irradiance. Based on the results that are extracted from the data, the tracker system significantly boosts the output power ratio of the solar panel. Through using the Micro-controller Uno board, LDRs, servo motor, and specially designed mechanical base, the tracking system is constructed, determined from acquired data the influence of the Solar Tracker System (STS) on increasing the solar panel power ratio is tremendously obvious. Significantly, the tracker system rises the power ratio of the PV system. Significantly, the tracker system raises the power ratio of the PV. As a result, the tracker system remarkably boosts the output power ratio of the solar panel and increases by up to 32.18%.

Keywords: Solar Tracking System, Arduino Uno Board, Solar Cell Efficiency, Maximum Power Point.

1. Introduction

The high consumption of energy and the industrial revolution led to concerns about the environment and energy sources, raising the temperature of the earth and limiting the usage of fossil sources. Fossil fuels are the primary source of energy globally, which is considered more than 80 % of global energy consumption. Overconsumption of these kinds of non-renewable energies could contribute to global warming due to the massive emissions. The problems related to fossil fuels and serious environmental concerns have motivated scholars and engineers to seek alternative eco-friendly resources. Consequently, the researchers have tried to utilize solar as renewable energy to minimize those issues. Edmond Becquerel discovered the principle of the PV system in 1839, and since PV is not introducing any pollution to the environment, it can be called sustainable energy [7]. Nowadays, due to the above-mentioned facts, solar panel is mainly used as a major source to produce electrical energy in most countries throughout the world. The solar panel does not negatively impact the environment, such as air pollution (carbon dioxide) and global warming. Also, solar panels' source of energy is the sun, which is an infinite source of energy. [1, 2]. While the produced energy is directly changing with the intensity of the radiation, also the intensity of the sun radiation changes due to the deflection angle of irradiance. Thus, the output power ratio of the PV depends on the irradiance angle and irradiance intensity. The best and most effective angle is a normal angle, which means the sunlight normally radiates on the PV. Due to the continuous movement of the sun throughout the day, the amount of emitted radiation is not always the same on the panel face. Therefore, the Solar Tracker System (STS) is needed to solve that problem [1]. The STS is costly because it requires a mechanical base and proper installation as well as requires electrical energy to work. The majority cost of the tracker's structure (Mechanical base and the installation) is the mass and type of material that has been used. Furthermore, the geometry of the structure also affects the cost [4]. Mainly, STS has been divided into different types based on the tracking approach [1]. STS types are tracking based on optical sensors and microprocessors (Active), tracking based on date and time (Active), and fixed or manually change tracker. The Active STS is classified into single-axis and dual-axis trackers. Single-axis STS can track the solar in the azimuth path but cannot track it in the altitude path [3]. This paper seeks to investigate the effect of the STS on the output power ratio of the solar panel.

2. Materials and methods

2.1 Solar Radiation

Solar radiation is the main key to achieving the output power ratio from the PV. The irradiance has two-part, the first is the direct beam that reaches the PV surface, and the second is reflected irradiance, which is reflected from the PV surface. It is worth mentioning that the irradiance does not provide energy to PV to produce electricity [5]. Equation (1) gives the direct irradiance received on the PV surface. where I_D is the direct irradiance, θ is the irradiance angle, and I_{DN} is the normal direct irradiance.

Two angles can determine the sun's position: Altitude angle and Azimuth angle (see figure 1). These Two angles are given by equation 2 and equation 3, respectively.

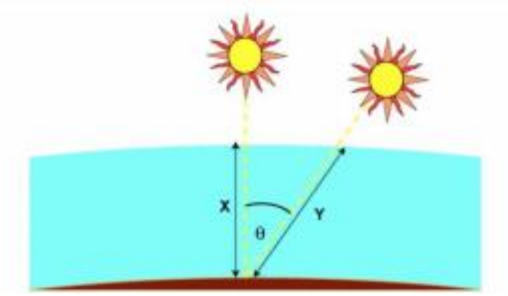

Figure 1: Sun Radiation Angle [6]

Both angles of altitude and azimuth can be calculated by using the information on local attitude(ϕ), Solar declination angle, (δ), and hour angle (ω) [6].

2.2 Design and Equipment

The mechanical structure of the tracker system is made of aluminum, and it has lightweight with a servo motor altogether weighted about 200g. The overall volume of the structure is 30 cm, 25 cm, and 25 cm. The structure consists of a structure holder, gear shaft, panel holder, and servo motor holder, as shown in figure 2. It could be a move-in altitude path (west to east) and easily can work as a Single Axis Solar Tracking System (SASTS). The servo motor controls the gear shaft's motion, and it rotates with low torque, which can be handled by the High-Torque Metal Gear Servo Motor for Robotics (MG-996R). The essential point is that the Uno board can supply the required voltage for the servo motor to rotate at a specified speed and angle. The rigidness and low air resistance are good points of the mechanical structure of the SASTS.

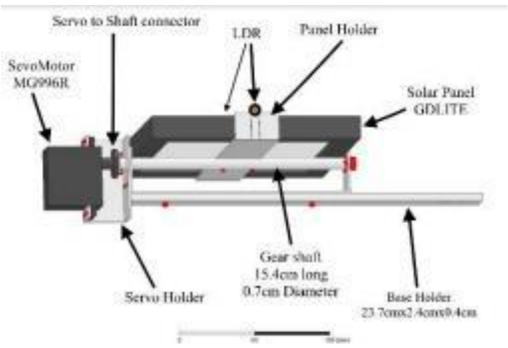

Figure 2: Mechanical Structure of SASTS

2.3 Uno Board

The Arduino Uno board is an open-source microcontroller [12]. It holds sets of digital and analog Input/Output (I/O) pins. The digital pins of 2,3,4,5, which work as output pins, send the signals to switch on/off the Metal Oxide Silicon Field Effect Transistors (MOSFETs) one by one and in pairs and triples and all together, as shown in figure 3. The analog pins such as A0, and A1 get the signal from the LDRs. A3, A4, A5, and A6 get the output voltages from the switching circuit, and these pins work as input pins. The microcontroller also has USB type B, connecting to the computer and loading with Arduino Integrated Development Environment (IDE). A voltage between 9-20V can power it, and all digital and analog pins support 5V voltage [13].

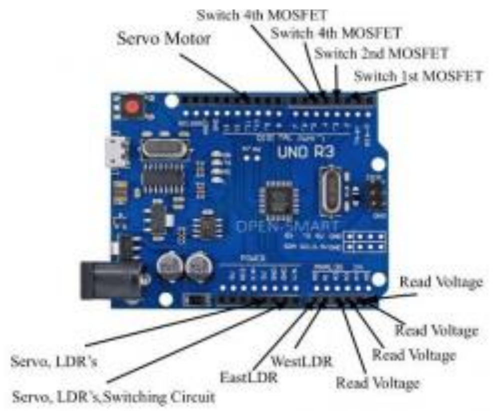

Figure 3: Micro-controller Uno Board

2.4 LDR

LDR is an abbreviation of Light Dependent Resistance; it is made from semiconductor materials. The resistance of LDR depends on the light's intensity, while the light intensity increases in turn the resistance of LDR decreases and vice versa [5]. The LDR works as a photo-sensor, in this study two LDRs are used, and when the light intensity is different on them, their resistances cannot be equal, two LDRs are shown in the circuit diagram of figure 4. The difference in the resistance causes unbalancing in the circuit. As a consequence, the LDRs send a signal to the Uno board. Finally, based on the programmed code in the microcontroller, a signal is sent to the servo motor to rotate until the LDR's circuit will be balanced again [14].

$$R(LDR1) = \frac{R1}{\frac{Vs}{V(LDR1)} - 1} \quad (4)$$

$$R(LDR2) = \frac{R2}{\frac{Vs}{V(LDR2)} - 1} \quad (5)$$

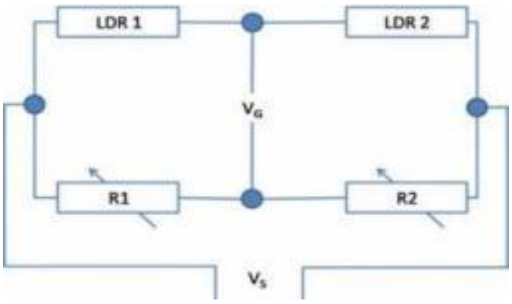

Figure 4: Balanced Circuit [5]

From equation 4 and equation 5, if $R_1 = R_2$, $V_{LDR1} = V_{LDR2} = V_g$, and then $R_{LDR1} = R_{LDR2}$, during the balanced mode, as mentioned before, the resistance value of each LDR depends on the intensity of the light, therefore, this will produce unbalanced system even if the intensity of the light changes too. This phenomenon helps to make a photo-sensor system that continuously searches for maximum intensity to balance both east-LDR and west-LDR.

2.5 Servo Motor

This High-Torque Metal Gear Servo Motor for Robotics (MG996R) Digital Servo can rotate approximately 120 degrees (60 degrees in each direction) and can support about 10Kg loads. Meanwhile, any servo code, hardware, or library to control these servos can be used [15]. A servomotor is a rotary or linear actuator that allows for precise control of angular or linear position, velocity, and acceleration [8]. Therefore, based on the output signal, which comes from the Uno board to the servo motor and then the motor starts to rotate, bearing in mind the weight of the solar panel is about 200g, and simply the servo can withstand that amount of load. The main benefits of the servo motor are to supply voltage which is from 4.8V to 7.2V, and hopefully, the Uno board can withstand this amount of voltage. Details of this duty cycle appear in figure 5.

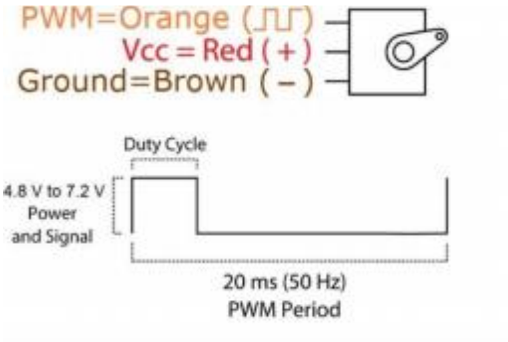

Figure 5: PWM Period, Duty cycle, and Power [15].

2.6 Switching Interface Circuit (Voltage regulator circuit)

The switching interface circuit as shown in figure 6 is used for controlling and regulation purposes, the input voltage from the solar panel is around 12V, and this amount of voltage is high for the microcomputer to read. As it has been mentioned before, digital and analog pins can support a maximum of 5V. Accordingly, the voltage divider board is designed by R_5 to $R1_0$, moreover, the regulated voltage would be directed toward the Uno board through the outgoing signal from the digital pins. The aim of using R_1, R_2, R_3, and R_4 is just for the protection of MOSFET. The MOSFET working principle is based on the digital pins of the Uno board, while the microcontroller would respond based on the signal from the written code on the board.

The additional purpose of the designed circuit is to have several different voltages. Each of the switches (MOSFETs) can be turned on by the digital microcontroller, and each time Uno receives one voltage data once the first switching mode has been finished. The new switching mode will emerge, such as double transistors, triple and quadruple based on the aforementioned modes. The Uno board can receive about 14 different voltage measurements. Based on Kirchhoff's Voltage Law (KVL), the input voltage (Vpv) and the voltage on R_5 and R_{10} can be calculated using equation 6.

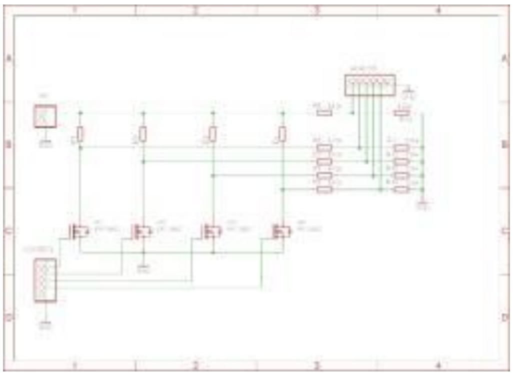

Figure 6: Switching Interface Circuit

$$VPV = VR5 + VR10 \qquad (6)$$

Both resistors (R_5 and R_{10}) are connected in series, thus based on Kirchhoff's Current Law (KCL), the amount of current which

passes through each resistor is the same, thus equation 6 can be rearranged as shown in equation 7.

$$VPV = ,R5 + ,R10 \qquad (7)$$

The output voltage is a part of the total resistance and can be determined as equation 8.

$$Vo = \frac{R10}{R5 + R10} xVpv \qquad (8)$$

The output voltage of the solar panel is 11.25V and R5=147KΩ and R10=100KΩ, while the output voltage of the Uno board can be determined by substituting the values into equation 8 as depicted in equation 9.

$$Vo = \frac{100}{100 + 147} x11 = 4.45V \qquad (9)$$

The measured output voltage (4.45V) is a satisfactory value for the input to the microcontroller. Determining the output voltage of the switching interface board is repeated for all other resistors.

2.7 Solar Panel

The mechanical base and servo motor can easily manage the amount of the solar panel's weight due to the specification of the panel since it has lightweight, the panel specifications are listed in Table 1. While figure 7 illustrates the solar panel with the servo motor.

Table 1: Specification of GD-020WP Solar Panel

Parameters	Current/ A	Voltage/ V	Power/ W
Peak Power			2
Open Circuit Voltage	0.267		
Short Circuit Current		11.25	
Maximum Power Voltage		9	
Maximum Power Current	0.23		

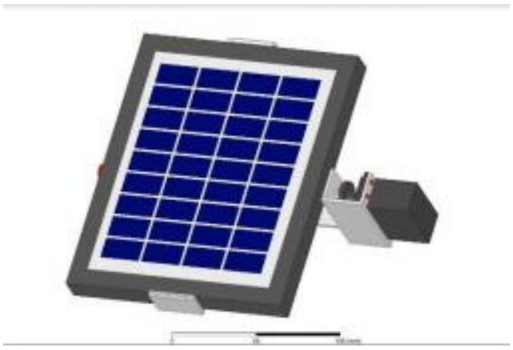

Figure 7: Solar panel GD-020WP

3 Integrated System

The SASTS came from combining the microcontroller Uno board, LDRs, servo motor, switching interface circuit, and a solar panel. The system would be weighted around 1 Kg and can be installed on the roof, wall, and ground, in addition to that, could be fastened by two screws. The switching circuit board, the Uno board, and the portable battery are attached to the mechanical base body, as shown in figure 8.

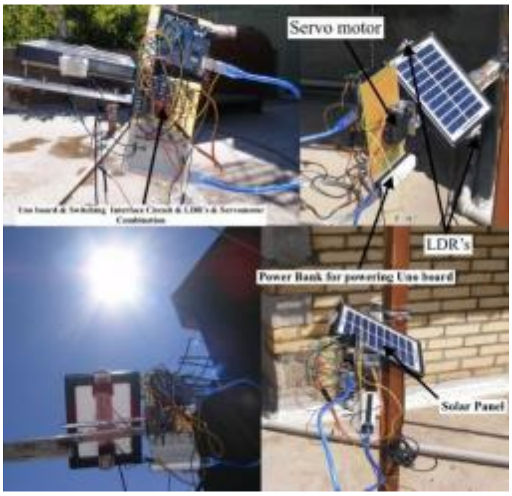

Figure 8: The tracker system from a different angle of view.

4 Flow chart

The code in the Arduino Uno board can be represented as the flow chart displayed in figure 9. The tracker system mainly depends on the LDRs signals, and the amount of error can be calculated by subtracting the value of west-LDR from east-LDR. If the intensity of light on one side of the solar panel is greater than the other side; thus, an error amount will be produced, and the Uno board would sense it. Therefore, the Uno board sends a signal to the servo for rotating in the direction of higher intensity LDR, which finally makes the panel adjust accordingly. The Uno board rechecks the LDR intensities if still sensed an amount of the error, in which if it is greater than the absolute value of 5 Lux, then the panel will rotate accordingly again. However, if the error is smaller than the absolute value of 5 Lux, the system would receive the voltage data as explained in subsection 2.6.

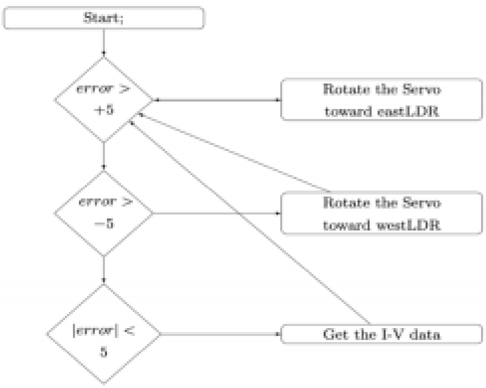

Figure 9: Arduino Uno board flow chart

5 Operation of SASTS

LDRs can be considered the eyes of the system. The LDRs try to find the sun in the sky and prepare the solar panel to be fixed while incoming normal radiation as proved in equations 4 and 5. The most effective irradiance is when the rays normally faced the PV panels based on equation 1. The LDRs located on both sides of the PV, which was shown in figure 2. The incoming signal from LDR transfers to the Uno board, and the board sends a signal to the servo motor to rotate at the angle based on the new information and toward the highlighted LDR. As a result, the new signal will come to the Uno board again from the LDRs, and the Uno board specifies the value of the error, if the error value is smaller than the value which has been assumed, then the Uno sends a new signal again to the servo motor to stop the rotation. However, if the error is larger than the specified value, the new signal is ordered to continue the rotation. The Uno board will get the voltage measurements from the switching interface circuit when the error is small.

Therefore, only voltage data is measured, but based on the code uploaded to the Uno bard, the current and power for each data are determined by the known resistors shown in the circuit.

6. Results

6.1 Experimental detail

The Single Axis Solar Tracker System (SASTS) can determine the Maximum Power Point Tracking (MPPT) based on the measured data. The designed system has been tested at the end of April 2020 for two days, from 8:00 am to 16:00, in Halabja city in the Kurdistan region/Iraq. On the first day, the SASTS worked properly, and the data has been collected while the photo-sensor tracker was used, moreover, the data have been taken for each hour. On the second day, the system was used without the tracker system as a fixed solar panel. These two different situations aim to prove and determine the influence of the tracker on boosting the power ratio of the solar panel.

6.2 Experimental results

As discussed before, the Uno board can be considered the core of the system. Based on the Arduino IDE's code syntaxes in this study, the Uno Board takes responsibility for any upcoming situation. The data have been achieved from the experiments and listed in table 2 and table 3 for both situations, using with SASTS and without SASTS (fixed solar panel), respectively. Figures 10, and 11 show the solar panel characterization.

For the fixed solar panel case, data have been collected in the different deflection angles of sun radiation (0^{o} to 90^{o}) degrees, and the average value is chosen (neither the best normal irradiance nor the worst 90^{o} deflections). The maximum power point has been derived from the voltage-power curve based on equation 10 for both experiments.

Table 2: I-V-P Data for the fixed solar panel.

Voltage /V	Data for the fixed solar panel	
	Current/mA	Power/mW
0	4.1	0
2	4	8
4	3.9	15.6
6	3.8	22.8
8	3.6	28.8
9	3.5	31.5
9.5	3.1	29.45
9.8	2.5	24.5
10	1.8	18
10.1	1	10.1
10.2	0.3	3.03

Table 3: I-V-P Data by using the solar tracking system

Voltage/V	Data by using the solar tracking system	
	Current/mA	Power/mW
0	90	0
2	87	174
4	85	340
6	80	480
8	78	624
9	75	675
9.5	67	636
9.8	60	588
10	40	400
10.1	30	303
10.2	10	102

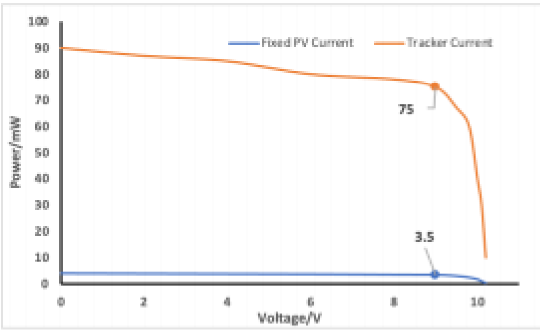

Figure 10: The I-V Curve characterization for both fixed and solar tracking system solar panels (low power range).

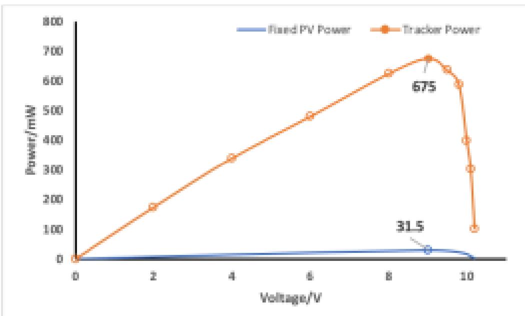

Figure 11: The P-V Curve characterization for both fixed and solar tracking system solar panels (high power range).

6.3 Power Ratio

In this section, the effectiveness of the SASTS can be figured out. The boosted power ratio is obtained during the MPP point, through the usage of SASTS to achieve the MPP point for the fixed solar panel. The MPP2 is obtained through the utilizing of STS and MPP1 for the fixed case, in addition to that, the power ratio can be calculated based on the formula mentioned in equation 10.

$$\eta = \frac{\text{MPP2 Experimental}}{\text{MPP of Real}} * 100\% \qquad (10)$$

where η is the power ratio

The achieved MPP2= 675 mW with solar tracker system indicated in figure 11. For a fixed case, as shown in figure 10, there are 12 MPP points. It is clear that there are no points for these 12 MPPs which is related to the specific deflection angle, as a result, the maximum and minimum of the MPP can be considered as the biggest and smallest angle of deflection, respectively. Therefore, the MPP of the real system = 2000 mW, equations 11, and 12 can be derived by substituting the MPP1 values in equation 10.

$$\eta = \frac{(675)}{2000} * 100\% = 33.75\% \qquad (11)$$

$$\eta = \frac{31.5}{2000} * 100\% = 1.57\% \qquad (12)$$

referring back to both ratios, it can be concluded the usage of the tracking system improved the output efficiency by 32.18%.

7 Conclusions

It is very clear, that the usage of SASTS for the solar panel would increase the output power ratio significantly. It is reasonable to use the tracker for large solar projects, due to the fact of increment in the power ratio when SASTS is utilized, improvement in the power ratio has been achieved by up to 32.18%.

The advantages of the solar tracker can be summarized below.

1. The SASTS is a system that needs low energy to work and is supported by the Uno board. Nevertheless, two-axis STS always need more electrical energy to handle.
2. Advancements in technology and reliability in electronics and mechanics are gradually declining the long-term maintenance concerns about STS.
3. It is highly recommended for those geographical locations where the intensity of the solar radiation is poor, in another word, the sun is radiated by the high deflected angle (usually the north part of the earth and far locations from the equator line).

4. STS is caused to speed up the charging of the batteries, the batteries charging usually depend on the power and power ratio of the PV. Therefore, when the power ratio of the PV increases, the battery charging is faster. Thus, the batteries are not going to drain sooner than their actual lifetime.

There are some drawbacks of the SASTS which are discussed below:

a. The SASTS may not cover or track all sun's motion paths; thus, some of the radiation energy is wasted, thus the output power ratio is always less than the peak value.
b. SASTS needs energy to operate, therefore for a large project, a large amount of energy is required for the operation of the SASTS.
c. For its installation, wide and flat ground is essential. This means a suitable place is required to put the system on it. Meanwhile, the place must be wide and sufficiently far from the trees and shadows.
d. The construction of the mechanical base of the tracker needs budget, tools, and time. The tracker also requires observation and maintenance.

8 Nomenclature

The following abbreviations are used in this manuscript:

SASTS	Single Axis Solar Tracker System
MPP	Maximum Power Point
PWM	Pulse-width modulation
PV	Photo-Voltaic
LDR	Light Depending Resistor
IDE	Integrated Development Environment

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