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Construction and Performance Test of Smartflower Solar Tracking System

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ABSTRACT

The exploitation of solar energy is a viable solution not only to the energy crisis but also to environmental disasters of the present world, as it is a clean and abundant source. Among many modern technologies, solar photovoltaic panels are a prominent technology that can capture both direct and diffuse solar radiation and directly produce electrical energy from it. As the sun changes its position throughout the day, solar trackers are essential for ensuring maximum panel efficiency, by enabling the panels to consistently orient towards the sun such that the sun rays always incident perpendicularly on the panels. However, traditional sun trackers suffer from a few limitations including poor performance under bad weather conditions, lower response rate of the sensors, lack of self-cleaning ability etc. A smartflower solar tracker can thus be a convenient upgrade of the tracking technology that addresses and effectively resolves these issues. In this work, a prototype of the smartflower solar tracker was constructed and its performance evaluation was carried out under different illumination conditions such as well lit, low light, partial shading etc. The results revealed that well-lit environments were ideal for the system's performance, but low light levels caused some difficulties. However, the capability of this responsive mechanism to safeguard the PV panels in adverse environmental conditions sets it apart from conventional solar tracking systems.

Keywords: Solar Tracking, Smartflower Design, Renewable Energy, Photovoltaic Technology, Environmental Impact.

1. Introduction

Rapid growth in population, industrialisation and urbanisation are the key factors contributing to the surge in world energy demand. Continuous use of non-renewable energy sources, particularly fossil fuels with limited reserves, is bringing about climate change and heavy natural disasters damaging ecosystems and the health of the living species of the planet [1, 2]. It is therefore important to opt for reliable, cost-effective, everlasting and eco-friendly renewable energy sources for meeting energy demand and also the betterment of the future world [3]. Solar radiation is the most abundant source of renewable energy and it is available in both direct and indirect forms. The Sun emits energy at a rate of 3.8×10^{23} kW, of which, approximately 1.8×10^{14} kW is intercepted by the earth [4, 5]. Nevertheless, this boundless resource of energy is still challenging to harness due to the low conversion efficiency of solar photovoltaic (PV) panels. [6, 7]. PV panels convert sunlight directly into electricity based on the photovoltaic effect [8]. Commercial PV panels possess low energy conversion efficiencies ranging from 14% to 22% [9], which is further compounded by environmental factors, primarily solar radiation [9-11]. The extent of incident solar radiation on the PV panel varies with its relative position with respect to the sun. According to [12], maximum solar radiation is captured by the panel when it is perpendicular to the direct beam radiation. Under this condition, maximum power is generated by the PV panels [9, 13-16]. Any deviation from the perpendicular position results in reduction of power generation [17]. Systems with fixed panels can facilitate exposure to direct radiation only at specific times of the day [18]. Therefore, solar tracking systems are necessary in order to utilise most of the available solar radiation. Solar trackers follow the path of the sun throughout the day and maintain the PV panels perpendicular to the direct radiation in order to generate maximum power. Traditional solar trackers available in the market commonly use sun-pointing sensors having high level of precision [19]. However, this strategy is not reliable [20] due to the limitation of sun-pointing sensors as they are ineffective without the sun and also under high intensity of reflected light [21]. These sensors are also prone to tracking errors resulting from improper installation and varying weather conditions and thus result in poor tracking performance [22, 23] which in turn negatively affects the power generation by the PV panels. A Smartflower Solar Tracker addresses these issues. It is an innovative and sophisticated combination of biomimicry and advanced technology, distinguishing it from other technologies. It is designed to optimise the performance of PV panels by dynamically orienting itself towards the sun [24, 25]. It features foldable solar cells within a foundational solar petal structure for tracking the panels along the sun's path [26] as shown in Fig. 1. It replicates the natural heliotropic movement of sunflowers in order to effectively maximise sunlight exposure throughout the day and assures continuous alignment of solar panels with the sun's position, resulting in a significant rise in overall efficiency. In addition, the smartflower solar tracker has an extraordinary feature of protecting itself not only from dust but also from hostile weather conditions (like heavy rain or storms), since solar radiation is not sufficient for efficient performance under such conditions, the panel remains closed. It is thus also capable of self-cleaning. As the petals rub against each other while folding and unfolding, they eliminate dirt, dust and debris. These outstanding features make the system more reliable, and robust along with a

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prolonged lifetime, allowing it to stand out from traditional solar tracking systems.

Fig. 1 Smart flower Solar panel [27]

Various researchers across the globe have contributed to the development and technological advancements regarding smart flower solar trackers. Research is still ongoing in this area in order to overcome the limitations of the present systems.

Guo and Wang [28] constructed an improved system for tracking the sun that consistently adjusts the orientation of the PV panels with respect to the sun in order to ensure perpendicular incidence of direct radiation on the panels. Their technique improves tracking accuracy, anti-interference capabilities, and motor control precision by combining a current amplification module with a closed-loop architecture. Their method provides a reliable solution for better solar energy consumption and adapts well to different latitudes and terrains.

Sabran and Fajardo [17] modified the conventional tracking system to employ variable stepping and directed reorientation within a predetermined range of altitude angles. The systems' potential for residential PV systems was demonstrated by the results, which showed an 84% reduction in tracking error, a 15% increase in power generation, and a 53% drop in motor current consumption.

Alnaieli et al. [26] designed a Smart flower PV panel and evaluated its performance under varying sunlight and temperature conditions. Results showed that higher solar radiation considerably enhances power output— a 104% increase in radiation led to a 115% increase in peak power and a 100% rise in output current. However, elevated temperatures negatively impacted performance, with a 400% temperature rise causing an 11.11% reduction in power. These findings, validated by MATLAB simulations, support the model's accuracy and potential for real-world application, advancing the Smart flower's manufacturing and control capabilities.

Mulayna et al. [25] examined the feasibility of implementing the Smart flower technology particularly in Indonesia. They used SolidWorks to design and simulate the Smart flower model. This study focused on the Smart flower model's structural soundness by conducting static and battery drop tests while designing and simulating it using SolidWorks. Because the design can sustain both static loads and drop impacts without deforming, the simulations show that it is strong enough for production.

The smart flower solar tracker is a promising solution that addresses the growing global demand for renewable energy by efficiently maximising the capture of solar energy. This study therefore approaches a to construct a prototype for the proposed smart flower solar tracker and conduct comprehensive examination of the design, functionality, and transformative potential of the Sunflower Solar Tracker in the field of solar power generation.

2. Methodology

2.1 Experimental setup and working procedure

The proposed smart air purification system consists of two key units as shown in figure 2.1: the tracking unit and the control unit.

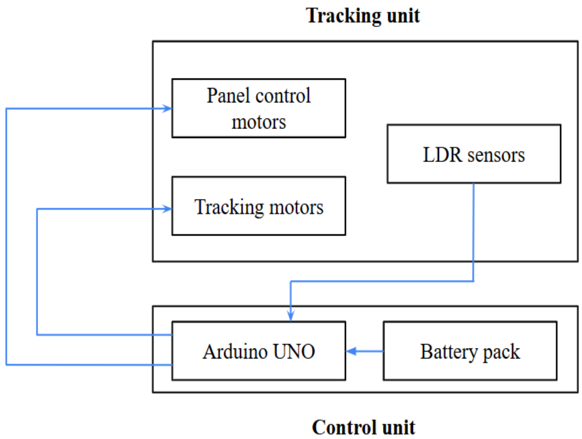

Fig. 2 Block diagram of the proposed smartflower solar tracking system**.**

The tracking unit consists of four LDR (Light Dependent Resistor) sensors, tracking motor assembly and a panel control motor assembly. Arduino UNO microcontroller is used in the control unit which renders the system as a smart solar tracker and interfaces the sensors. Since it cannot directly power motors, a motor driver unit is used as an interface between arduino & the motors. The battery pack powers the whole tracking system.

The LDRs detect light intensity from different directions and send signals to the microcontroller, which processes those signals and decides the motor movement based on which LDR detects more light. Two sets of servo motors are used as tracking motors in order to enable the PV panels follow the sun throughout the day. One set controls the up-down movement of the PV panels and the side-by-side movement is controlled by the other set of servo motor. Opening and closing of the flower-like panel holder structured is controlled by the N20 gear motor.

In this study, a prototype of the proposed smart flower solar tracker system was constructed as shown in Fig. 3 and Fig. 4. Its performance was evaluated under varying lighting conditions. When sunlight hits one side of the flower more than the other, the LDRs detect this imbalance. The Arduino then signals the motor driver to activate the N20 motor and/or servo motor, adjusting the flower's position to follow the sunlight. This continuous adjustment optimizes the sunlight exposure on the solar panel, enhancing energy capture.

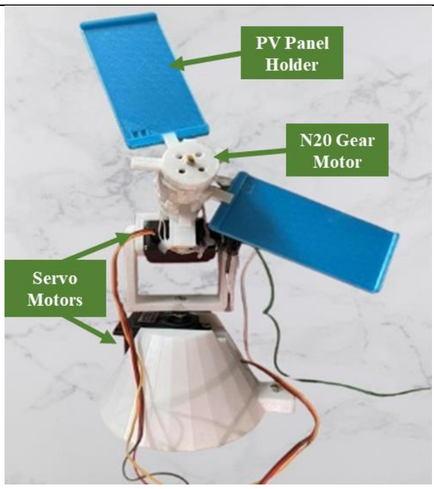

Fig. 3 Developed structure of the proposed smart flower solar tracker prototype.

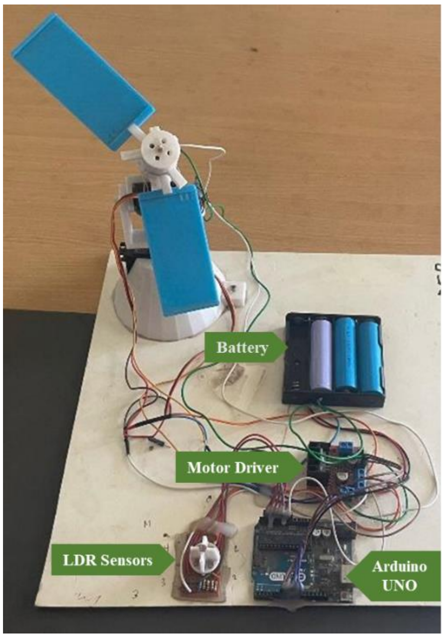

Fig. 4 The overall developed prototype of the proposed smartflower solar tracking system

2.2 Major Components

Table 1 lists the major components of the proposed smart flower solar tracker, along with their required quantities and specifications.

Table 1 List of components used in the proposed system.

Component	Specification	Quantity
Servo motor	4.8~7.2V	2 pcs
N20 low RPM gear motor	3~12V	1 pcs
Arduino UNO	5V	1 pcs
Motor driver	5~35V	1 pcs
LDR sensor	-	4 pcs
Resistor	10 k	4 pcs
Battery	3.7V	4 pcs
Battery case	-	1 pcs
Vero board	-	1 pcs
3D printed mechanisms	-	100gm
Wires	-	As required

A servo motor converts electrical power into mechanical power and facilitates fast movements in dynamic systems. It's commonly used in dynamic systems where fast movements are required. The N20 gear motor is a kind of DC motor which utilises a gearbox to reduce the motor speed and increase the torque. The gearbox comprises a set of gears which operate concurrently so as to attain the desired output torque and speed.

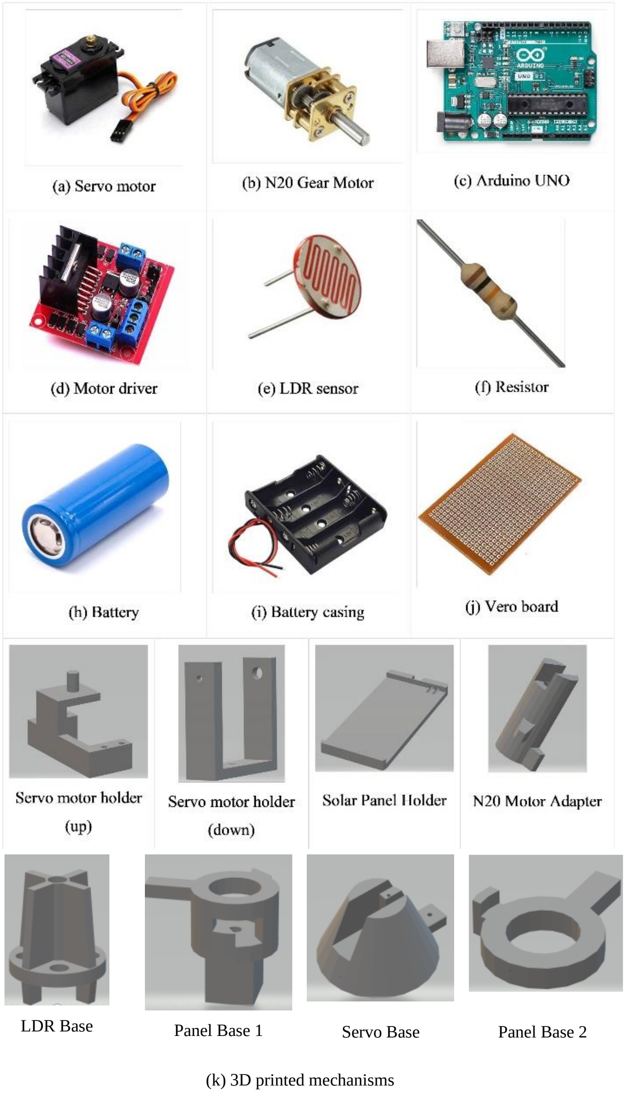

Fig. 5 Major components used in the smart flower solar tracking system

Arduino UNO is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (6 can be used as PWM outputs), 6 analogue inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button. It is programmable with the Arduino IDE (Integrated Development Environment). A motor driver is an integrated circuit chip that controls the operation of electric motors. It acts as an interface between the motor and the control system, allowing accurate control on the speed, direction, and other parameters of the motor. LDR sensors are passive electronic components that work based on the principle of photoconductivity i.e., their resistance changes in accordance with the incident light's intensity. Semiconductor materials are use to make these sensors that manifest a reduction in resistance as the light intensity increases and vice versa. This alteration in resistance can be measured and rendered as a signal. The battery pack is used to supply the necessary power for all the components to operate.

3. Results and discussion

Before the performance assessment of the developed system prototype, the functionality of the individual LDRs was tested separately. In each case, only one LDR was allowed to be exposed to light and the rest of the LDRs were completely shaded by placing pieces of paper over them. The threshold value for both the aperture actuation and the tracking operation was set at 250. As demonstrated in Fig. 7, all the LDRs were fully functioning as they responded accordingly to the variation of the incident light. When the intensity on an LDR exceeded the threshold, the solar petal array fully deployed resembling a flower and oriented itself towards the sun in order to allow the absorption of maximum solar radiation. Here, tracking was achieved even though only one LDR was illuminated and the other three LDRs were shaded and therefore incident light on them did not surpass the threshold. This implies that this system can manage to perform tracking operations even if one or more LDRs get damaged.

The performance assessment of the proposed system prototype was analysed in 3 cases. Firstly, evaluation was done when none of the LDRs recieved any illumination. The second scenario was such that all the LDRs were exposed to sufficient lighting. The third case involved inspection under low light conditions.

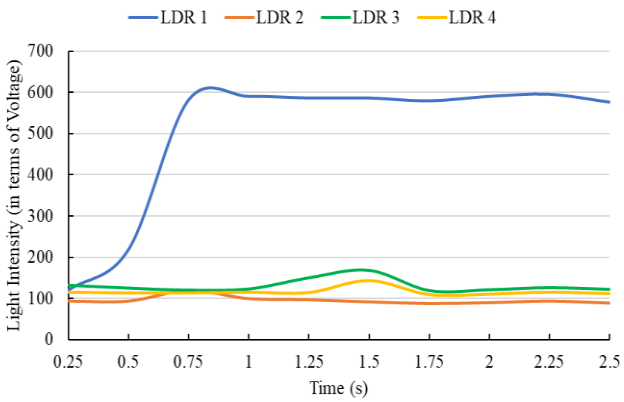

Fig. 6 Functionality test of LDR 1

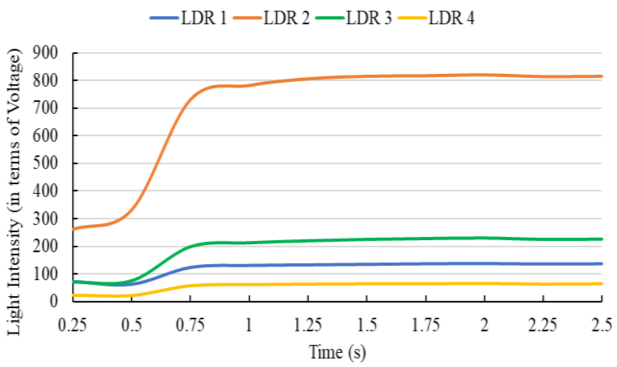

Fig. 7 Functionality test of LDR 2

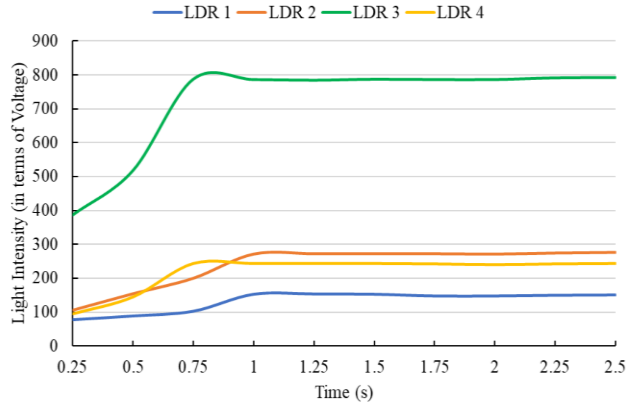

Fig. 8 Functionality test of LDR 3

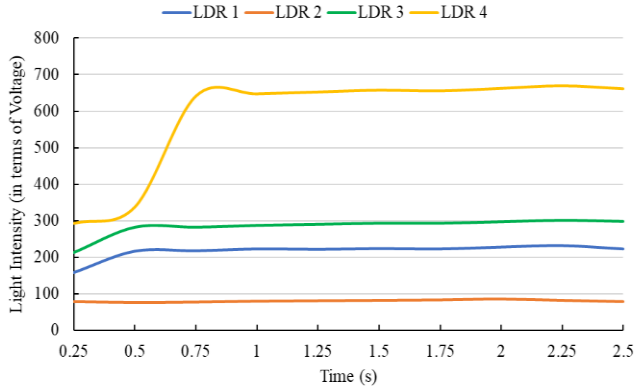

Fig. 9 Functionality test of LDR 4

In the first case, no light condition was artificially created by fully covering up all the LDRs. As a result, light intensity on none of the LDRs exceeded the threshold value. Therefore, as depicted in Fig. 10, no aperture action or tracking operation was performed and the LDR sensors displayed somewhat constant outputs.

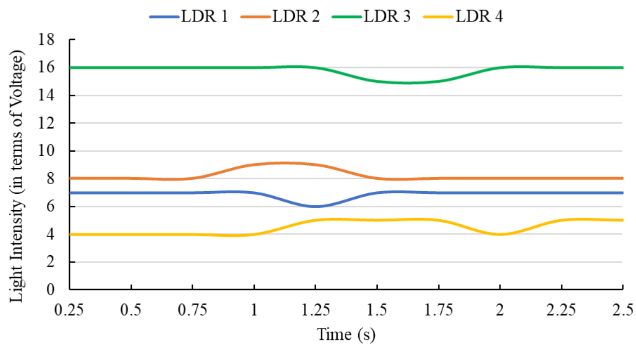

Fig. 10 Variation of intensity in LDR when there is no light.

The second case implies a scenario where all the LDRs are exposed to light, however, not at the same intensity. On account of exceeding the threshold limit, the PV panels will deploy and the tracker will orient them towards the direction of the LDR receiving the highest radiation intensity in a manner that, all the LDRs will eventually capture maximum radiation.

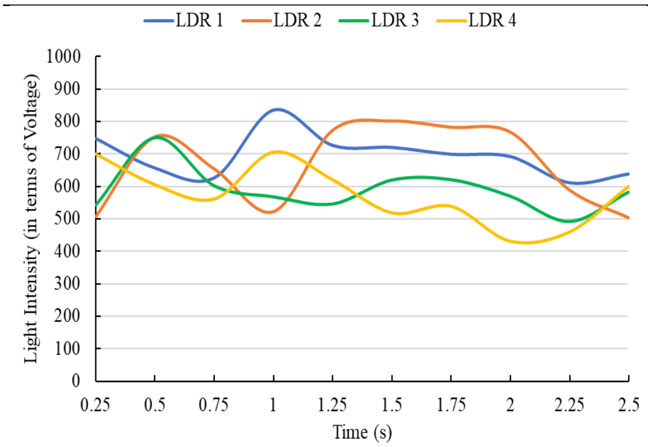

Fig. 11 Variation of intensity when all LDRs receive light.

As manifested in Fig. 11, initially the LDRs received light at various intensities (all beyond the threshold), hence the aperture action took place followed by the tracking action within about 2.5 seconds. It can be seen from the figure that the light intensities on each LDR are almost equal after the tracking action has been achieved. This outcome justifies the theory and meets the expectations.

In the third case, low light conditions were imitated by using a candle as the light source. Here all the LDRs received light at various intensities like in the second case, but deviations were more prominent. The two LDRs on the same side as the candle received significantly larger intensities of light as compared to the two on the other side. As a result, only the first set of LDRs exceeded the threshold and the other two did not. However, as the system was designed such that even if only one LDR exceeds the threshold, the system will be activated, hence the petal array deployed and oriented itself towards the candle in such a manner that all of the LDRs received an almost equal amount of light, which can be seen in Fig. 12.

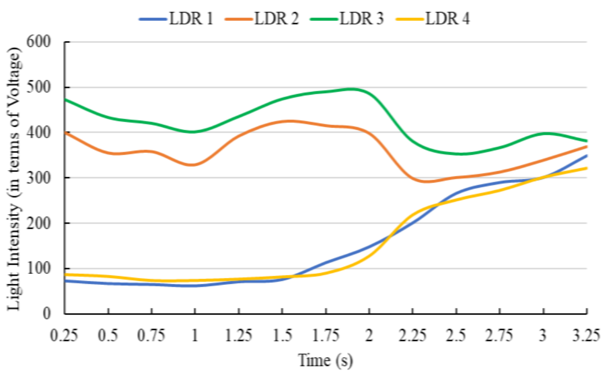

Fig. 12 Variation of intensity in response to candle light.

But in this case, the time taken to accomplish the tracking operation is higher than that in case two. This can be due to a number of reasons. Firstly, LDRs have higher resistance under low light, thus it takes longer to reach the threshold value. Moreover, signal noise or perturbations such as shadowing or fluctuations in ambient light levels become more significant under low light conditions. These issues influence and delay the system's decision-making regarding movements towards the light source. This indicates slightly lower tracking efficiency at low light conditions.

The experimental outcomes of this study make it evident that the system in question operates only when it is convenient and energy efficient i.e., when the threshold limit is exceeded. Otherwise, the array remains closed, protecting it from adverse weather conditions such as heavy rain or storms since solar radiation is not sufficient for efficient performance under such conditions along with enabling self-cleaning from dust and other debris. As a result, minimal maintenance is required for this system. These extraordinary features make the smartflower solar tracker system more reliable, robust and provide a prolonged lifetime, allowing it to stand out from traditional solar tracking systems. However, the installation of this system is much more complex than the traditional ones due to its bulky structure. Nevertheless, the above-mentioned benefits of this tracking system outweigh the difficulties regarding installation. Therefore, it can be said that this comprehensive system facilitates the global transition toward renewable energy by enabling the efficient exploitation of solar energy.

4. Conclusion

In this study, in order to maximise the efficiency of solar PV panels, a prototype for a smart flower solar tracker was constructed. Its performance evaluation under various lighting conditions revealed valuable insights. The system performed best under well-illuminated conditions and struggled slightly under low-light conditions. However, this responsive mechanism distinguishes itself from traditional solar tracking systems by its unique capabilities of protecting the PV panels under unfavourable environmental conditions, self-cleaning from dust and debris and therefore minimsing maintenance requirements. The installation difficulties of such a bulky system can be offset by the advantages it offers over traditional systems. Further research in this area can help mitigate the existing limitations of this innovative system.

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