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Design, 3D Printed packaging, fabrication and testing of a Technology Assisted Smart Solar-system (TASS)

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***Abstract*—This paper focuses on the design, fabrications and testing of a Technology Assisted Smart Solar-System (TASS) that uses a solar panel both as an energy source and a sensor for tracking. A microcontroller, interfaced to a mini solar-cell array, was used to control and test the systems efficacy to track the light source employing (a) a motorized solar panel and (b) a robotic platform. The TASS packaging and printed circuit boards were designed and fabricated using 3-D inkjet printing. A roof-top TASS was built to demonstrate an in-expensive application. The TASS developed in this work is also applicable to a light-tracking flowerpot for a smart home.**

Index Terms*—*Solar tracking system, light dependent resistor, microcontroller, 3-D inkjet printer, stepper and dc motors.

I. INTRODUCTION

The Technology Assisted Smart System (TASS) research, benefiting directly from the latest developments in micro and nano technologies, can help integrate emerging technology components into a Microsystem useful for many applications. A particularly interesting aspect of an inexpensive TASS is the integration of control circuits, wireless interfaces, microsys- tems components (sensors and actuators), software and power sources into a single mass producible unit using 3D inkjet printing and microfabrication. Examples of TASS applications are energy scavenging/harvesting, solar tracking systems, night light systems, mind-controlled robots and microdrones for surveillance and harsh weather monitoring, and optoelectronic systems.

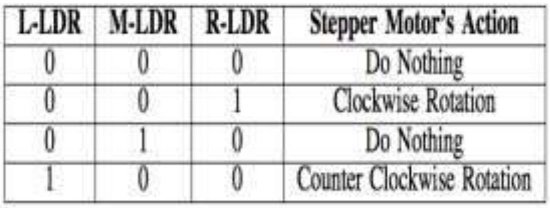
Recently, extensive research has focused on solar tracking systems [1]–[13]. Shape memory alloy based actuators have been implemented in some solar tracking systems [1]–[3] but they have low actuation frequency, controllability, accuracy and energy efficiency [14]. A design of two axes solar tracking using a micro-optic solar concentrator is presented in [4] which is suitable for some applications. In [10], [11], [13], light dependent resistors (LDR) or (photo-resistor) were utilized as sensors to read the voltage changes according to the amount of sunlight intensity. Design and construction of a system for sun- tracking was implemented to measure the direct beam solar irradiance by a pyrheliometer [15], in which four-quadrant photo detectors used to sense the position of the sun and a computer program calculates the position of the sun when it cannot be detected by sensors. A Commercial webcam has also been used as a sensor element to provide high-precision solar tracking system [16]. The webcam was connected to a personal computer and MATLAB was used to implement a simple image processing algorithm for the incoming frames. In [17], a neural network was applied to a tracking system for solar concentrators to reduce tracking errors. A Two-axis sun tracking system was used to investigate its effect on the thermal performance of compound parabolic concentrators [18]. This system was equipped with two photo transistors and it was designed to follow sun light every three to four minutes in the horizontal axis and every four to five minutes in the vertical axis. Sun-Tracking system designed to improve the efficiency of photo-voltaic panels using a programmable logic controller was also reported [19]. It was proved that the solar tracking system increases the power output of the solar panel by 20% in comparison with a fixed module.

The unique features of this paper are (a) the use tracking at the solar panel and robotic platform levels, (b) 3D inkjet printed circuit board and TASS packaging and (c) a solar tracking flowerpot for a smart home and d) the use of solar cells as sensors in replacement of LDRs and investigating the differences between them in terms of accuracy.

II. SOLAR TRACKING AT THE PANEL AND ROBOTIC PLATFORM LEVELS

A. *Solar tracking panel*

1) Tracking with LDR sensors: The solar tracking panel is accomplished to maximize light intensity by aligning the solar panel toward sun radiation. Photo resistors were utilized to detect the sun position and movement status. As illustrated in Figure 8, the base holder of the solar cell is attached to a rod, which is placed on 5v stepper motors shaft. Three LDRs were placed on the left (L), middle (M) and right (R) side of the solar panel with about 45-degree angle to measure the light intensity by reading their signal that changes based on the amount of light intensity and then this information is fed to the microcontroller that makes the decision in which direction the stepper motor should rotate. The middle sensor is the OFF sensor, i.e., when it receives maximum sunlight, the motor will shut down. The left sensor is installed on the east side of the panel and the third sensor is installed on the west side of the panel. The movement of the sun will cause a shadow on the middle and one of the side sensors and that turns on the motor. The motor will move toward the highest light intensity that is measured between the left and right sensors. Motor rotation continues until the middle sensor receives maximum light intensity or all sensors receive low light intensity (night time). The operation conditions are illustrated in Table I. The microcontroller used in this system is ATmega328, which is used in the Arduino board. As can be seen in figure 1,the reading of LDR1, 2 and 3 sent to the micro-controller to control the movement of the stepper motor.



L-LDR	M-LDR	R-LDR	Stepper Motor's Action
0	0	0	Do Nothing
0	0	1	Clockwise Rotation
0	1	0	Do Nothing
1	0	0	Counter Clockwise Rotation

TABLE I: Operation conditions of the stepper motor; where 0 means dark or low light intensity and 1 means light or high light intensity.

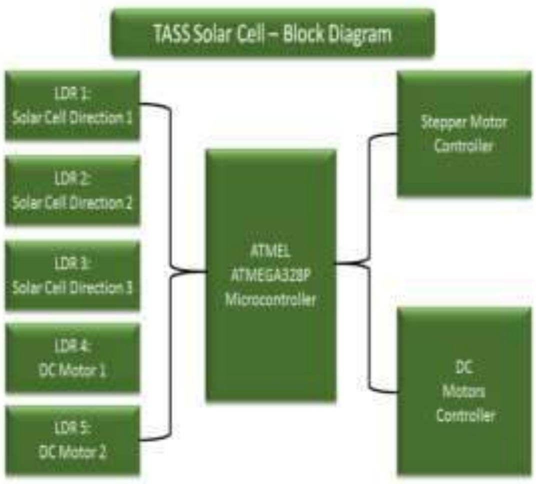


Fig. 1. Block Diagram of a TASS application.

2) Tracking with solar cells used as sensors: In the pre- vious subsection, photo-resistors were utilized to read the voltage variation that is caused by the change of the sun light intensity. A combination of mini-solar cells are used to replace the LDRs role and used as a sun light detector. The main principle of this technique is that the change of sun directions has a high effect on the solar cell, which gives a reasonable amount of variation of output voltage and that allows reading the sun position. Figure 2 shows a diagram of the proposed system. The four-quadrant mini-solar cells have been tested to find the output voltage under a high spectrum light source that mimics the sun spectrum. Figure 3 shows the circuit schematic of the implemented experiment. It contains four mini solar cells with 3v and 70mA each. Schottky diode was used due to its very low forward-voltage drop and very fast switching speed. It prevents discharging battery voltage at nighttime. Because of the low sensitivity, that will be explored in the coming section, of the solar cells, a calibration method used to determine the maximum and the minimum output voltage at the highest and the lowest light intensities. In addition, a boost converter with 0.52 duty cycle used to get 5v out of 2.4v from the rechargeable battery. In order to have dual axis tracking with precise movement toward highest light intensities, two stepper motors are used in the vertical and horizontal axes as can be seen in figure 2.

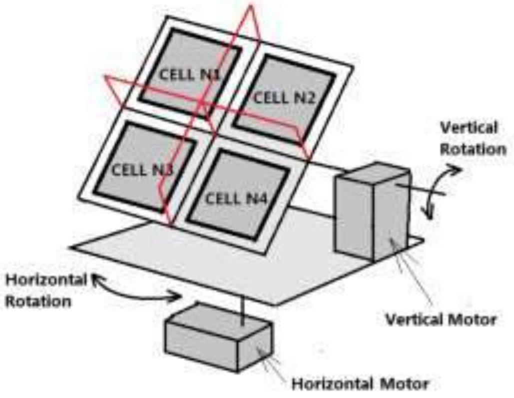


Fig 2. Concept diagram of dual axis solar tracking system with solar cell sensors.

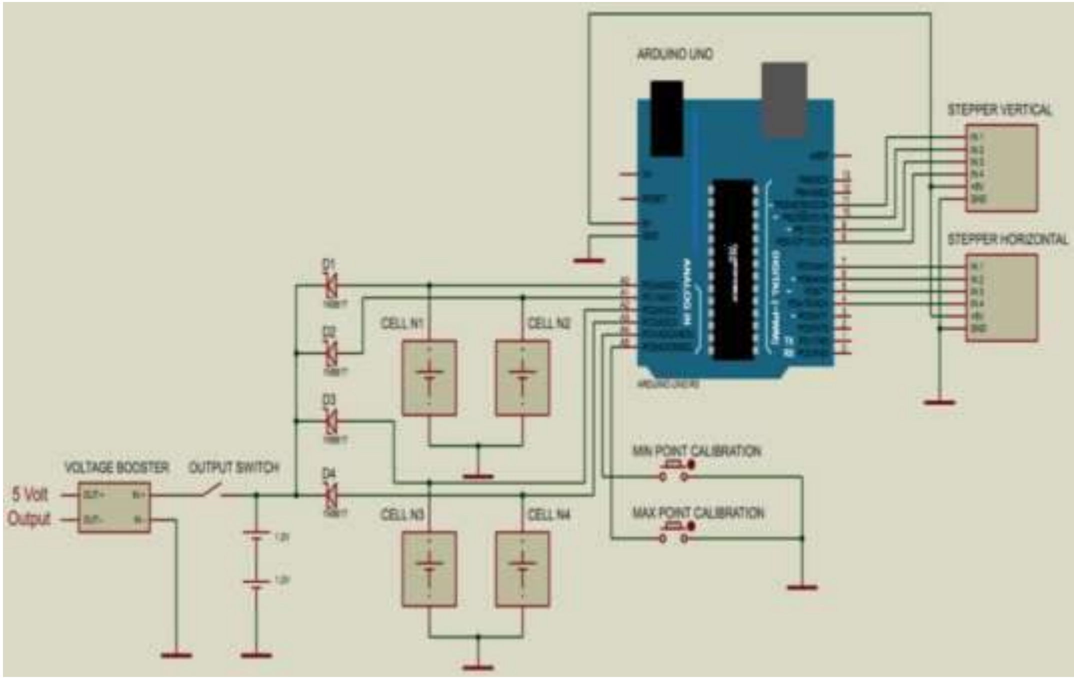


Fig. 3. Circuit Schematic of dual axis solar tracking system.

The voltage difference between solar cells plays major role in deciding the position of sunlight. As the sun moves, the reading of solar cells changes and the rotation of the motors also change accordingly. When the solar cells N1 and N3 receive higher or lower sunlight than N2 and N4, then the horizontal motor turns ON and rotates clockwise or counterclockwise, respectively. The vertical motor will be turned ON when the solar cells N1 and N2 receive higher or lower sunlight than the solar cells N3 and N4. A flow chart of the system is shown in figure 4.

3) Comparison between LDR and solar cell sensors: LDRs and mini-solar cells were both successfully used as sensors in the solar tracking system. However, their sensitivity needed to be explored in order to make a full accurate comparison between them. Although, the use of the solar cell sensor has an advantage in reducing the number of components of the system by using it as a power supply, the LDR was found to be more sensitive to the light variation.

In the test, a high spectrum light source which mimics sun light irradiance was used. Figure 5 shows a diagram of the experiment along with the circuit schematic. Figure 6 shows clearly that the difference between LDR 1 and 2 is higher as compared to solar cells 1 and 2. The angle of incident goes from zero to 180 degree to mimic the movement of the sun from east to west. The output of the solar cells is almost identical and that makes it less sensitive to light variation than LDRs. However, this variation could affect the precision of the reading that was fed to the microcontroller. An isolation frame enclosing around the solar cell sensor would make it work better as it was implemented in the test of the dual axis solar tracking using solar cells sensors. Solar cells can be used as a power supply as well as sensors for sunlight tracking.

B. *Solar Tracking Robotic Platform*

The idea of the Solar Tracking Robotic-Platform (STR) is to make the solar tracking system mobile and portable. This has tremendous advantages to enhance the efficiency of the STR in some applications that will be discussed in this paper. The STR system consists of two LDR's (4& 5 in figure 1), two DC motors, and one swivel caster. Figure 7 shows the combined circuit schematic of the solar tracking panel using LDRs and the solar tracking robotic platform. The stepper motor used for the single axis tracking that controlled by LDR 1,2 and 3. Two DC motors used to move the whole solar panel and LDR 4 and 5 are used to direct the panel toward higher light intensity.

III. 3D INKJET PRINTED TASS PACKAGING

A. *3D printed solar tracking panel*

A 3D Inkjet printer was used to print the TASS system packaging. All parts were designed using SolidWorks software based on the system requirements. The solar tracking panel was first designed as shown in figure 8. The mechanical structure was precisely designed to fit the components that are used in the system. The stand pillar of the solar cell can be used on any type of motors. The only part that needs to be changed is the small nut that goes on the bottom side of the stand pillar. It was specially designed to fit the stepper motors shaft used in the system. LDRs sensors were placed around the mini-solar panel with a tilted surface structure to detect the direction of the highest light intensity.

B. *3D printed solar tracking robotic platform*

The solar tracking robotic platform was also designed and printed using a 3D printer. Figure 9 shows the plate where the solar cell is placed, a rod that holds the solar cell plate attached to the motors shaft, two open holders for LDR 4 and 5, a solar car base where all electronics parts are placed, and a swivel caster that allows the car to move in multiple directions. The DC motors are attached to the back end of the car and they rotate based on the LDRs output. The solar cell panel is equipped with LDR 1, 2 and 3 to control its direction in the same way as in the previous section. This design can be disassembled and used in different applications.

C. *PCB/Breadboard with shadow mask 3D printed packaging*

3D printers are capable of metal interconnect printing have been reported recently [20], but they are not yet available commercially. An integration of 3D printing and metallizationwas explored and partially used in some parts of the TASS project. See figure 10.

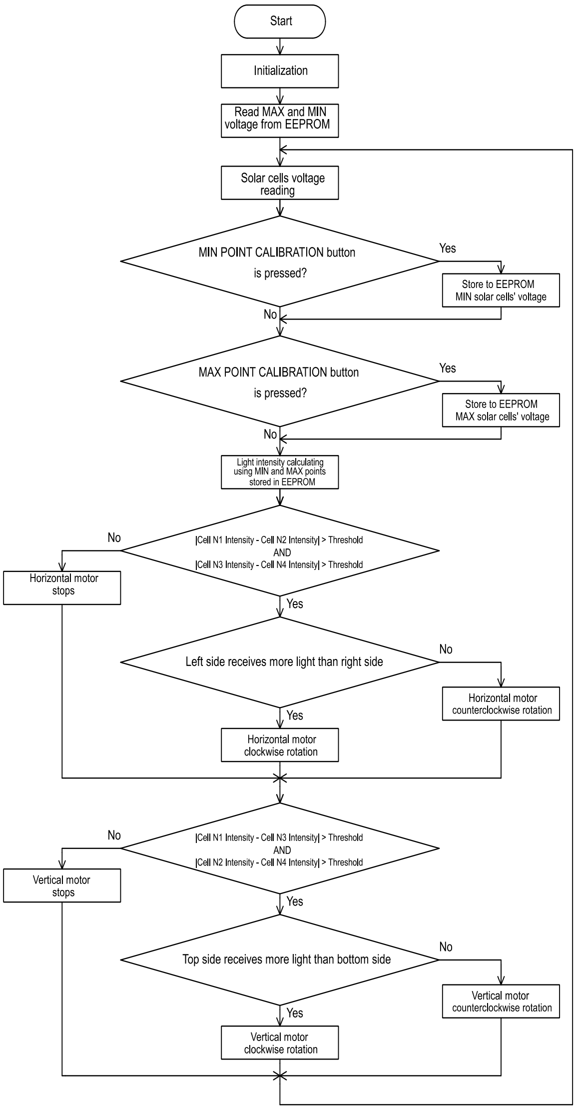


Fig. 4. Flow chart of the dual axis solar tracking system using solar cells sensors.

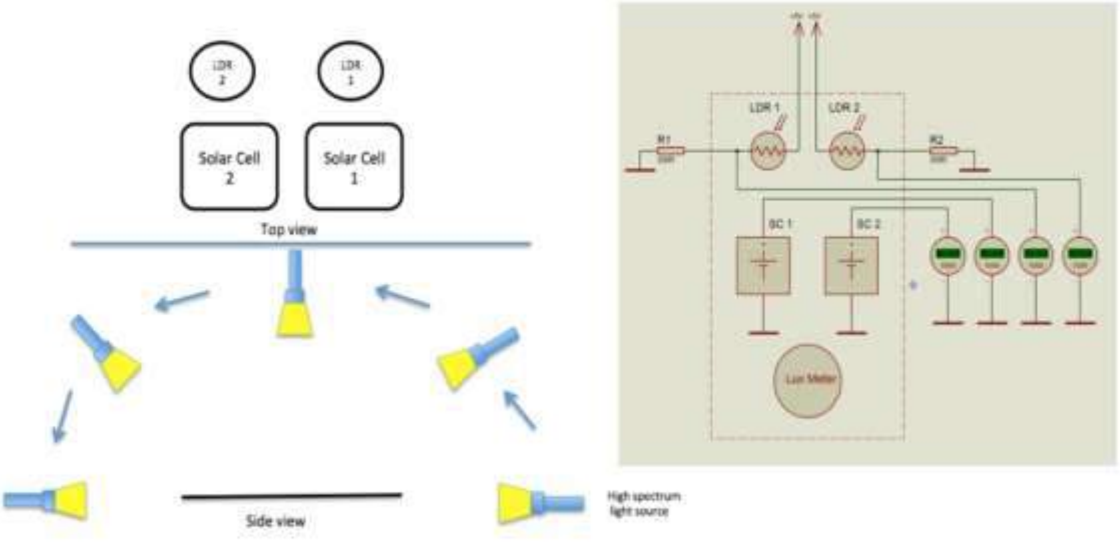


Fig. 5. Sensitivity comparison test between solar cells and LDR's.

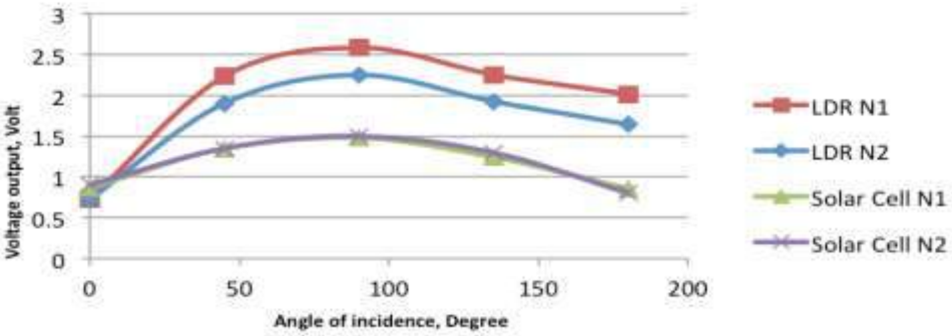


Fig. 6. Output voltage of LDR's and solar cells as a result of different angles of incidents

Parameter	Solar Tracking Panel			Two Fixed Solar Panels		
	Position 1	Position 2	Position 3	Position 1	Position 2	Position 3
Voltage (v)	1.890	1.705	1.840	2.370	2.230	1.970
Current (mA)	0.89	0.86	0.70	0.600	0.10	0.410
Power (mW)	1.682	1.466	1.280	1.422	0.223	0.80
Avg. Power	1.478 mW			0.815 mW		

TABLE II: Comparison between fixed and movable mini-solar cell.

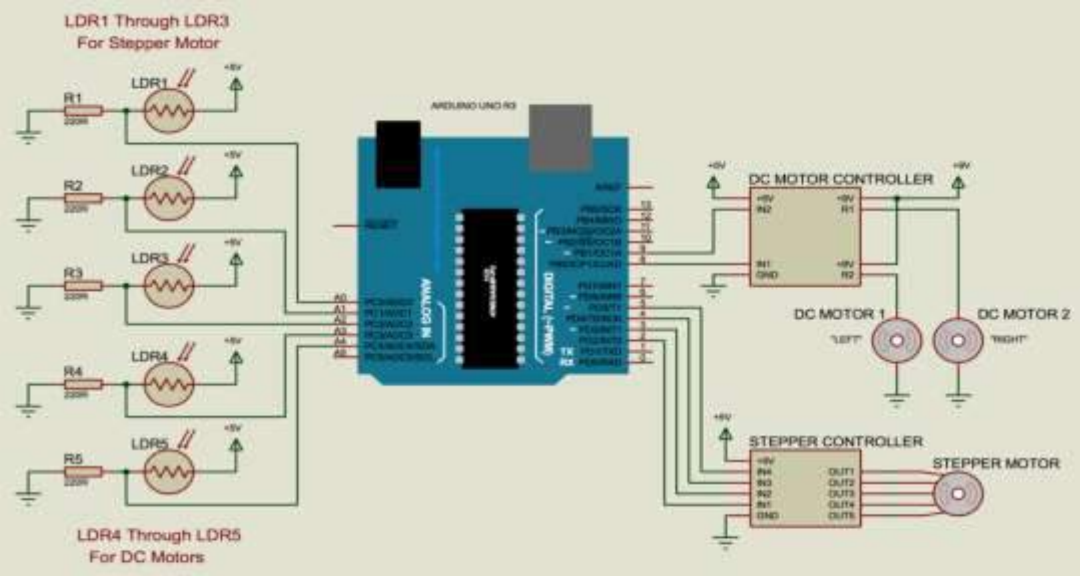


Fig. 7. Circuit schematic of the solar tracking panel and robotic platform.

IV. TASS APPLICATIONS

A. Rooftop solar tracking panel

Most of the solar panels that can be seen in some buildings are placed in a fixed position on the top of the buildings reducing the efficiency and wasting valuable sunlight during the morning or the afternoon because of the movement of the sun. This means that a single solar panel placed with this arrangement may harness most of the energy during the mornings but be almost useless in the afternoons. There is another option which takes this into account, put solar panels on both sides, increasing the initial costs of the project and the future maintenance cost while trying to join the two sources of energy and placing them into one device. What has been done in this project, assuming a rooftop with triangular shape (or a surface where the panel can be placed easily), is to place a single solar panel that is able to change its position based on the amount of energy available to be harnessed.

An experiment has been setup to calculate the variation of the efficiency and power output of the rooftop tracker. It is composed of three LDRs, one stepper motor for single axis tracking, one mini- solar cell and some LEGO parts to build the structure. In addition, a high light intensity source is used to mimic the sunlight. The experiment was conducted in a dark lab room where no other light sources existed. The output power of the solar panel was calculated in three different angles (45, 90 and 135 degree) between the flat floor and the light source. The solar panel was successfully following the light source. Table 2 shows the output parameters of one mini solar panel tracking light and two-fixed mini solar panel.

From the results shown in the table, the solar tracking panel on the rooftop is more efficient than the fixed solar panel in terms of power and cost. The average power is increased. One mini-solar panel was used in the tracking system whereas two solar panels were used in the fixed one on both sides of the rooftop. The whole design of the experiment is shown in Figure 11.

B. Flower base solar tracking robot for smart home.

The TASS shown in Figure 9 was also used to build and test a proof of concept for a possible smart home application. A flower pot was mounted on the rear side of the TASS system as shown in Figure 12. Although it shows how this system followed the light coming from a window in the kitchen area, it was tested in different areas of a contemporary home in the Ann Arbor area. The use of ultrasonic sensors to avoid objects in the tested areas would enhance the functioning work in this type of projects.

Fig. 8. Packaging design of the solar tracking panel system.

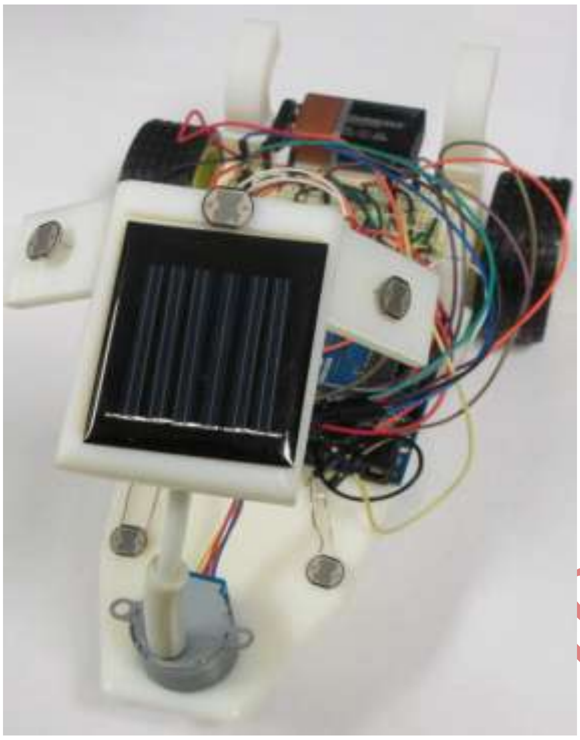


Fig. 9. TASS system with 3D printed components.

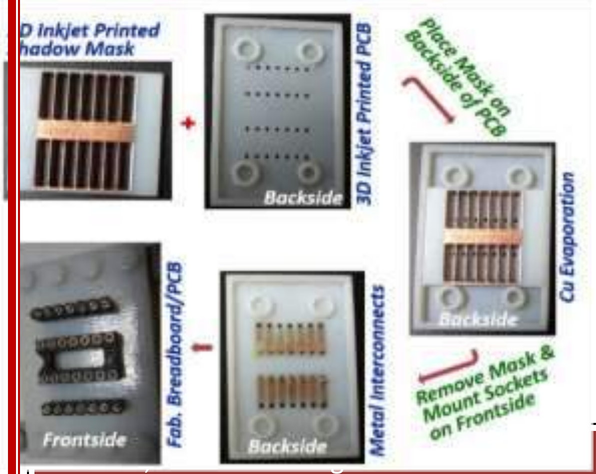


Fig. 10. PCB/Breadboard fabrication using evaporated Cu and a 3D printed shadow mask

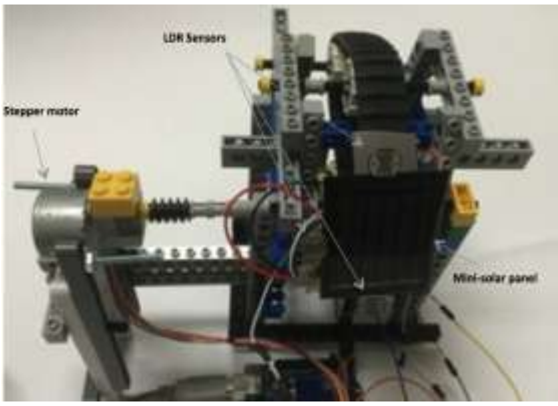


Fig. 11. Prototype experiment of rooftop solar tracking system.

Fig. 12. TASS flowerpot system for smart home.

V. CONCLUSION

This paper describes the technology assisted smart solar- system(TASS) project. It has the following unique aspects; 1) TASS project has been developed to enhance and better use of the output energy of a solar panel, 2) the use of solar tracking system at the panel and robotic platform levels has tremendous advantage toTASS project, 3) two types of sensors, LDR and PV sensors, were used to achieve the goal solar tracking systems, 4) comparison between the two sensors was investigated and its been found that the LDR is more sensitive to light variation but also that PV sensors can be used to achieve the same goal of LDR , 5) the use of 3D inkjet printed circuit board and TASS packaging, 6) different applications of TASS were implemented and discussed in this paper. Two approaches were made for the fixed and trackingpanels, where the LDR sensors play the most important role, in which only one solar panel were needed. In the rooftop prototype experiment, the tracking panel was much better than the fixed module. There are several applications of the solar tracking car that include its use in smart houses and offices, mobile self-powered robots and micro drones. The expected future work of TASS is implementing MEMS Actuated Solar-cell Array (MASA).

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