

Design and task management of a mobile solar station for charging flying drones

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Abstract. This paper provides design and task management of the first stage of a project entitled “Fall-Army Worm (FAW) insect killer”. The project has three main stages: design and energy management stage, flying control of drone stage and detecting and killing FAW stage. The goal of this project is to detect and kill; without chemical methods; a harmful FAW insect which is rapidly spreading in Africa and Asia. This paper focuses on design of the first stage of the system, getting maximum power and controlling the energy of the system. A Photo Voltaic system with energy storage devices is proposed to be the source of power. A new algorithm to control the time scheduling of the killing and detection mission is proposed and its effects on the system’s energy and mission period are studied. A comparison between different methods for tracking the maximum power from PV panels is performed to choose the best (less time and high accuracy) method. The results of simulation indicate the effectiveness of the proposed maximum power tracking and task management system.

1 Introduction

The food industry relies mainly on agriculture. Agricultural mechanization is predominantly based on fossil fuels that are harmful to the environment and adversely affects climate change as well as being depleted. Fossil fuels can be replaced by renewable energies, especially solar energy. Solar energy has a significant impact on agriculture in general and particularly on agriculture robots. Robots are used in many fields in agriculture such as harvesting, planting or spraying pesticides which can save human efforts, money and time in addition to finishing unreachable tasks in efficient ways. In 2012, Karina Dühring designed a daily use solar powered agriculture robot for navigation, scouting and weeding [1]. The system is built on returning the robot to a separate docking station after discharging its battery. It is ended with using the fixed docking station rather than movable PV panel on robot roof after comparison between them. In 2016, T. Pachal from KIIT university designed and fabricated a safe, high performance, cost-efficient solar powered vehicle [2]. This work is different from work in [1] because a moving solar panel implemented on the vehicle roof is used. Based on the works developed in [3-6], which describe steps of designing a solar-powered grass cutter, Mudda and others [7] designed a solar-powered grass cutter that operates autonomously with no need for skilled person. The system was 10-watt power with no control for Maximum Power Point Tracking (MPPT) or Energy Management System (EMS).

A continuous flying drone is the main concern of many researchers to increase flying time and do more daily tasks. Some of researches aspire to make the drone not only continuous flying but also renewably powered to save money and time especially in remote areas and difficult access to energy. Some scientists used stationary solar power station to feed drones and other used mobile stations. Fujii and others [8] developed an automatic battery replacement system which enables drones to fly continuously without being constrained by battery power limitations. But they used non-renewable power source to charge batteries before replacement with deployed drone’s one. However, it is a continuous flying system but cannot be used in the remote area in case of shortage of power source.

A new approach is proposed in [9] where a fleet of drone consists of a certain number of drones, and an adequate number of charging stations to guarantee that fully charged drones are always available to replace swarm drones whose battery depleted. This work did not use battery replacement system to make continuous flying system, but it has been provided to ensure that a certain number of them will fly. This work is new but costly and more complicated than the pre-mentioned work in [8]. However, both did not propose a renewable source of energy and depended on a stationary charging station. Michini proposed a project to use the drones to search for something and contact with ground vehicles to move towards the detected goals [10]. So, a continuous power supply is a must for these long-term missions. A special

changer with non-renewable energy source is designed to enable fast hot swaps charging of 8 batteries for multiple vehicles to achieve one vehicle system with endless time of working. It reduced the charging time by changing the charging method rather than battery replacement as done in prementioned works.

In 2017, Khonji has proposed a system entirely powered by a solar panel that stores energy into a 50000-watt-hour solar battery [11]. The solar power station was stationary and there is a mobile robot as a movable battery which charge from the fixed solar panels. When the drone sense battery depletion, it sends a signal to the mobile battery (Robot) to move towards it and the drone is equipped with an inductive wireless receiver in order to start charging procedure. This method achieves renewable power sourcing but with larger time, because of charging, and stationary power station. Also, there is power loss in case of mobile battery being away from the PV panels in drone charging mission.

A solar irradiation estimation on a solar-powered UAV is performed in [12]. Estimating the solar radiation and getting the maximum power from Photo Voltaic (PV) systems are critical for the performance and task finishing for solar powered drones. This work focused on solar irradiation calculations and comparison of two different flight paths for solar power collection during a transport or inspection mission.

The new in our proposed system is achieving the three goals: a continuous moving power supply using moving power station, renewable energy source for remote area using solar panels and continuous flying drone using Automatic Battery Replacement system (ABR). Another novelty is using an algorithm to control the time scheduling of the mission where its effects on system energy and mission period are studied. Our project is called 'Eco-friendly Fall Army Worm Insect Killer' which concerns with building an eco-friendly system free of chemicals to kill a very catastrophic insect called Fall Army Worm (FAW). This insect can adapt with chemicals and can mutate in the next generation [13]. The system consists of a mobile solar charging station with battery bank and Automatic Battery Replacement (ABR) system in addition to swarm of drones carrying a thermal camera for detecting the insect and a manipulated laser beam system for killing the insect. To guarantee continuous flying of drones, we solve the problem of drone's battery charging time by using ABR and the absence of electrical source in most of far farms by using solar-powered robot as a movable renewable charging station. FAW habitats in Africa include mainly both the 'corn strain' and the 'rice strain'. In Africa almost all major damage has been recorded on maize. However, FAW has been reported from many other crops in Africa but usually there is little or no damage. So, the insect in maize remains the overriding priority [13].

As a prototype for the project, we used one drone instead of the swarm of drones to represent the concept of the project and a modified SEEKUR robot as a moving solar power station. Because of the short life cycle of this insect which lasts for 6-8 weeks [13] and in order to make the most benefit of this project, the project parts are used for other tasks during the agricultural season. The mobile

robot can be used in killing the insect underneath the soil before planting the crops and that is published in [14] as a part of this project. The drone can be used in spraying fertilizers and seeds, automatic picking and placing objects for forestation; as published in [15]; etc.

The work in this paper consists of three main sections. The first section is to design a PV system based on the required energy for the mobile robot, moving ABR motors and one drone. The second part handles the simulation of the system with Maximum Power Point Tracking (MPPT) method to get maximum power from the PV panels. The MATLAB® Simulink is used to simulate the overall system. In the third section, a task management algorithm is proposed to autonomously start and stop the system to get most energy efficient tasks.

2 The proposed system

The system consists of robot's battery bank (2 batteries), drone's battery bank (4 batteries), docking station motors (2 motors) and robot's motor (2 motors). The mechatronic systems details are shown in table 1.

Table.1 The ratings of each element in the system.

Item	Power rating	number	Total
The motor of solar station	320 (W)	2	640 (W)
Solar station's Battery	10 (Ah)	2	20 Ah
ABR Motor	50 (W)	2	100 (W)
Drone's battery	2.2 (Ah)	4	8.8 (Ah)

2.1 PV system design

To design the PV panels, the daily required energy must be estimated. The drone's Li-Po battery lasts for about 13 minutes and the drone's mission lasts for not less than 5 hours (10am-3pm) to search, detect and kill insects during the day. The mobile station's speed is 6.48 km/h and runs for about 5 min per each hour to follow the drone's location. The ABR system replaces the battery each 15 minutes and finishes its work in about 2 min. According to the previous information, the result of calculations for maximum daily required energy is shown in table 2.

Table 2. The calculated daily required energy.

Item	Daily energy (kWh)
The motors of solar Station	0.26
Drone's Energy	0.62
ABR Energy	0.02
Total	0.9

The solar radiations for some random days (1-May, 1-June, 1-July, 1-August and 1-September) in 2019 are shown in fig. 1. The radiations are shown in two different cities: Aswan (far south of Egypt) and Alexandria (far north of Egypt). The relation between the solar irradiation

and extracted power is not linear, so to design the required PV panel rating, we use the irradiation curve for different months to check the extracted daily energy as will be shown later in results. The radiation data for the 5 months was obtained from the site of SODA for web services [16] and tested on a PV module (1 panel form type Suntech STP275-20/Wfw) as shown in fig. 2. The preference in this panel type, as shown in fig. 3; is that the PV voltage range at different radiations is small and that can make fast response to reach maximum power point.

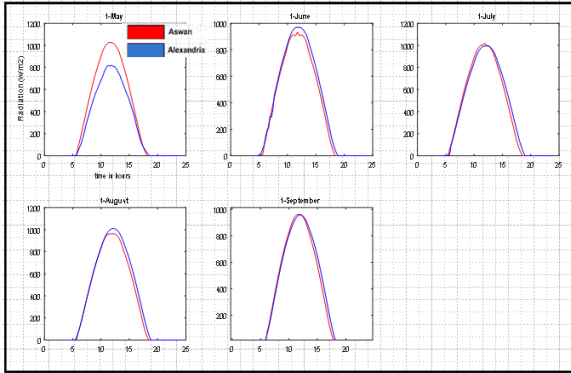


Fig. 1. Solar radiation in Aswan and Alexandria.

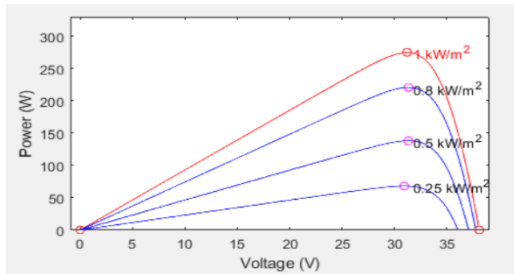


Fig. 2. The power-voltage curve.

Electrical Characteristics			
STC	STP275-20/ Wfw	STP270-20/ Wfw	STP265-20/ Wfw
Maximum Power at STC (Pmax)	275 W	270 W	265 W
Optimum Operating Voltage (Vmp)	31.2 V	31.1 V	31.0 V
Optimum Operating Current (Imp)	8.82 A	8.69 A	8.56 A
Open Circuit Voltage (Voc)	38.1 V	37.9 V	37.8 V
Short Circuit Current (Isc)	9.27 A	9.15 A	9.02 A
Module Efficiency	16.8%	16.5%	16.2%
Operating Module Temperature	-40 °C to +85 °C		
Maximum System Voltage	1000 V DC (IEC)		
Maximum Series Fuse Rating	20 A		
Power Tolerance	0/+5 W		

Fig. 3. The electrical data sheet of the used panel.

2.2 The task management

If we fix the start/stop time for all “FAW detecting and killing” missions in all days, the batteries at the next day may be not fully charged for some days where sunset and sunshine times are different. So, an electricity blackout can occur at the first hours of mission which can results in shortage in mission completion. On one hand, If the start time is early, the batteries may be not fully charged. On the other hand, if the start time was lately, there may be a useless time between the moment the batteries reach fully charged and start of mission where the PV power is forced

to be zero. Fixing the start time of mission can result in loss of power and time during the mission. The proposed algorithm shown in fig. 4 indicates the process of time scheduling for the system mission for each day separately. This is done to make the system more autonomous and energy efficient FAW killer. The expected irradiation data can be fed to the system using weather predictor (we used [16]).

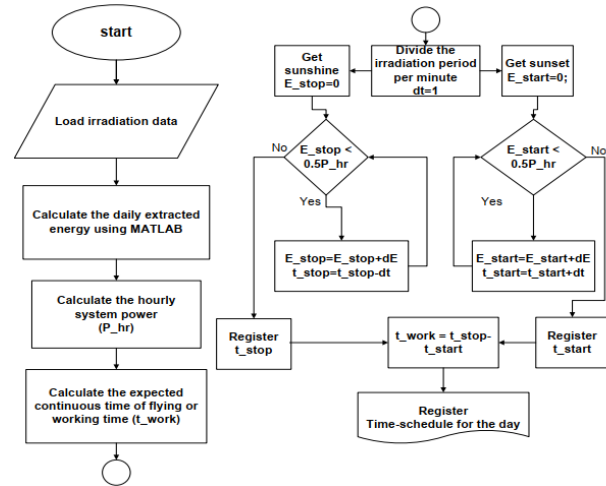


Fig. 4. The proposed algorithm to calculate the start/stop time of the mission to benefit maximum flying time.

3 Results and discussion

In this section, the results of the extracted power from the PV panels all over the day in the far south and far north of Egypt are provided. A new algorithm to control the time scheduling of the mission is proposed and its effects on system energy and mission period. Different methods are tested to select the best one which is more suitable for our mission.

3.1 The extracted power and energy

Fig. 5 shows the extracted power at the two sites (Aswan and Alexandria) for 5 months that cover the maize season (FAW insect feeds mainly on maize in Africa) where figure 5 indicates that during the five selected days, the designed PV system can cover the daily required Energy (dash line value = 0.9 kWh). The conventional method (Perturb and Observation as medium efficiency method among methods of MPPT tracking as will be shown in later comparison) is used for the power estimation.

The energy extracted from PV panel for each day for the five months are shown in figure 4-a. According to the predetermined mission of our project (flying time from 10 am to 3 pm), the PV panel can cover the required energy efficiently which is represented by the dashed line in the fig. 6 below.

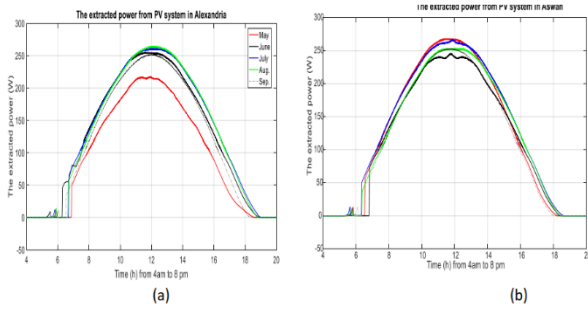


Fig. 5. The extracted power in (a) Aswan (b) Alexandria.

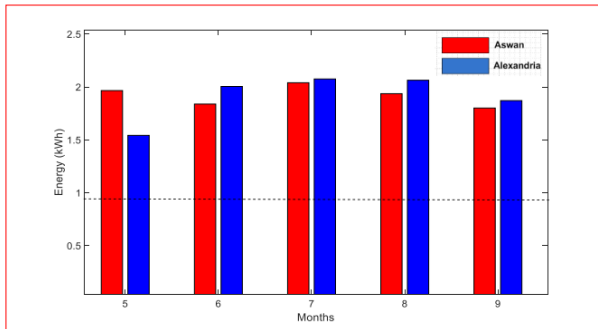


Fig. 6. The daily extracted energy from PV panel in Aswan and Alexandria.

3.2 The start/stop of the mission.

The solar station cannot move if the ABR motor for the docking station is moving and the ABR motor cannot move if the solar station's motor is on as shown from the task scheduling in figure 7. This can decrease the load stress on the PV system also protect the drone from falling if it lands while the robot moves and prevent the docking platform from being broken. During time zone1 in figure 5, the docking station has an action and the robot was off, so the docking motor runs. In zone 2, the robot has a moving action, but the docking station was out of the robot, so the robot's motor cannot move (The station motor= 0 in the figure). In zone 3, the moving action of robot still applied until the docking station comes back to the solar power station (robot). Then the motor of the mobile station begins to run, and the robot moves. In zone 4, the docking station receives a moving signal while the mobile robot is moving, so no action done in docking station until the mobile robot stop (zone 5). There is no overlap between the robot's motor (red signal) and the motor of docking station (green signal).

The task scheduling algorithm guarantees that at the next day the system will start mission with fully-charged batteries (solar station's and drone's) where there will be a time after mission stops (above the blue line in fig. 8) until sunset and from sunshine until the mission starts (under the red line in fig. 8). When the working hours are calculated, the consumed power is multiplied by a factor 1.1 to cover the drone's energy (flying + detection and killing energy). This out-of-work period is calculated for each day separately to guarantee starting the next mission in fully-charged-mode. The lower red curve in the figure

indicates the start time of flying in the five days; solid red curve in Aswan location and dashed red curve in Alexandria. The text arrows in the figure gives the maximum number of hours (mission time) when the drone can fly continuously. The maximum mission time in Aswan was 9 hours in July and in Alexandria was 9.2 hours in June and July.

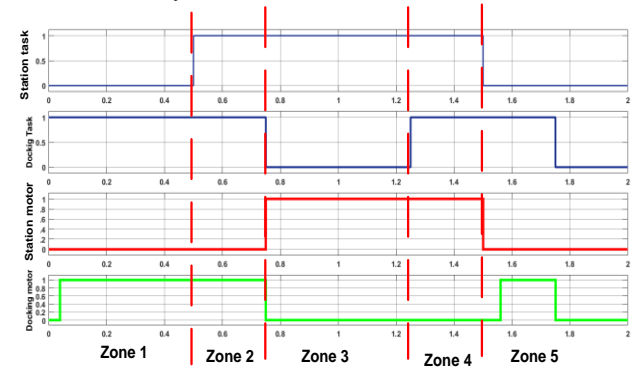


Fig. 7. The commands and actual motion of robot's motors and ABR motors.

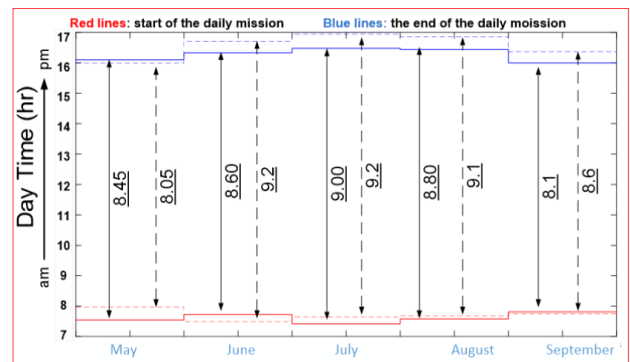


Fig. 8. The start/stop results after using the time scheduling algorithm.

3.3 MPPT methods.

Three different MPPT methods; Incremental conductance (IC), Perturb and Observation (P&O) and Particle Swarm Optimization (PSO) are tested to select the best one for the system. A 1-second test was carried out to compare the method efficiency, behaviour under dynamic load (starting of motor as shown in fig. 9 by the green ellipse). The PV tested under 1000 w/m² radiation and 25o C for the first 0.5 second and 500 w/m² and 25o C for the other 0.5 second. The overall system with batteries and motor was simulated in this 1 second. The fluctuation in both current and voltage was the highest in IC method and the lowest in P&O method but with small difference compared with PSO.

Table 3 shows the comparison between the results of executing the test on the three methods. The most efficient method (which can reach 275watt power for the first 0.5 second and 138 for the next 0.5 second) is PandO with 98.68% and with 200.15 W power extraction from 206 W (275*0.5+138*0.5) desired power. however, the P&O method takes more time for execution (simulating the

power extraction on the overall simulated system) with 163 sec.

Table 3. comparison between different MPPT methods.

MPPT Method	Average efficiency (%)	Extracted energy from 206 W	Execution time(sec)
P&O	98.68	200.15	163
PSO	98.58	200.1	158
IC	97.1	195.9	162

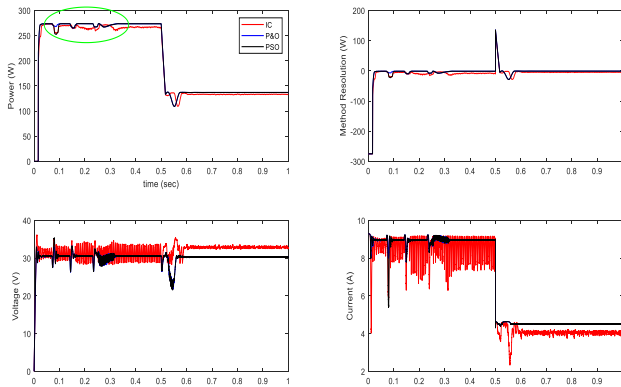


Fig. 9. The response of the three MPPT methods.

4 Conclusions

The goal of this paper is to provide an energy efficient, renewable powered and continuous flying system to be used as detector and killer of FAW insect. A small PV system is designed, and project energy is estimated to check the energy balance between generated PV power. A new start/stop time control algorithm is provided to achieve maximum running time of drone. Between the three used MPPT methods, PSO is recommended to be used because of its fast response and reasonable efficiency. For fast response PSO is preferred, but for good efficiency P&O method is preferred.

In the future, A robust battery management system will be proposed and experimental setup for the all system will be constructed. An automatic battery replacement system will be designed with automatic control system of swarm of drones.

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