Chapter 7
Design and Fabrication of Solar Powered Unmanned Aerial Vehicle for Border Surveillance

R. Vijayanandh, J. Darshan Kumar, M. Senthil Kumar, L. Ahilla Bharathy and G. Raj Kumar

Abstract Unmanned Aerial Vehicles (UAVs) are one of the important types of aircraft, which are controlled by a remote controller or pre-programmed method. Nowadays UAV is being proposed for many critical applications including surveillance, mapping, etc. In general, the surveillance around the international border has been carried out by soldiers. Monitoring the border through soldiers is not perfect surveillance, due to the natural factors of human beings may be the error will occur in the border surveillance. To avoid this problem, the monitoring of the border region is to be covered by UAV. Enemy's activities around the dangerous and large border coverage area are difficult task to handle in border monitoring, so a normal UAV is not suitable for this process. Hence advanced solar UAV is a better solution for this monitoring because it's having unique characters like high operational speed, more stability, long life, etc. This paper proposed to motivate research on aerospace renewable energy sources and primary aims are to make calculations and respective designs to create an e-aircraft model, capable of powering its flight using solar energy, overcoming the challenges by increasing the speed, range, and endurance of the UAV using the solar power in order to provide

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full-time border surveillance. The overall 3D solar UAV is modeled by CATIA V5 with the inclusion of theoretical design values. The intruders detection in borders through image processing has been completed using MATLAB.

Keywords Border surveillance · Image processing · Renewable energy
Solar cells · UAV

1 Introduction

The modern world needs an innovative solution in the non-renewable energy field, because of its excessive usage. Solar power thus is an interesting option also it is the best alternative, which has needed to be investigating for usage of all aircraft. A solar powered UAV is an aircraft that turns on electric motors rather than internal combustion engines, with electrically coming from solar cells, and batteries. In recent years, the level of interest in the development of fixed-wing UAVs for various missions has risen significantly. A crucial issue concerning these aircraft is their high power consumption compared to their limited energy storage capability. The ability for an aircraft to fly during a much extended period of time has become a key issue and a target of research, both in the domain of civilian aviation and UAVs. The required endurance is in the range of a couple of hours in the case of law enforcement, border surveillance, forest fire fighting or power line inspection. One possibility to increase the up-time is through the use of solar cells [1].

In order to reach the target endurance, the design of the aircraft has to be thought very carefully, as a system composed of many subsystems that are continuously exchanging energy. One of the milestones of this paper is the selection of the general configuration for an UAV and primary objectives are that the design should make efficient use of solar cell converge on the wing with aerodynamic design consideration. The first component considered is the wing, whose basic configuration is determined by area limitations and solar-cell coverage optimization, thereby final consideration in configuration selection is the conventional wing. Note that the rectangular shape of the wing is not very efficient aerodynamically, but allows for maximum coverage of solar cells over the wing area, which is an important parameter to maximizing speed. The shape of the fuselage is keep as small as possible to reduce its contribution to parasite drag also realized that UAV would want a fairly long fuselage to move the airplane's centre of gravity (e.g.) as far forward as required for stability reasons. Figure 1 shows the overall concept of proposed solar flight.

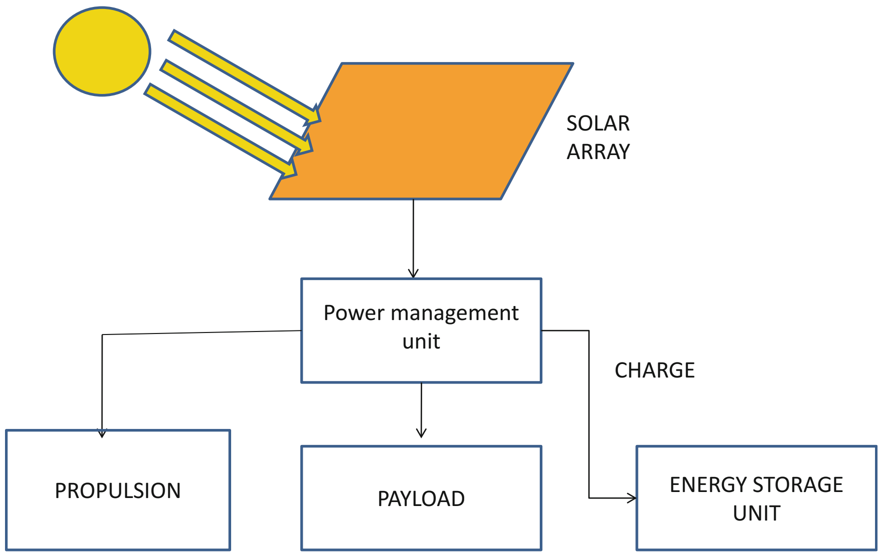

Fig. 1 Concept of proposed solar flight

2 Theoretical Design Approach of a Solar UAV

Theoretical analysis of a solar UAV comprises of Aerodynamics, Structures, Propulsion, Systems and Instrumentations. In general, initial step of theoretical analysis is need to estimate or fix the speed of an UAV before estimating its weight.

The aerodynamics part of a solar UAV is responsible for external configuration layout, component sizing, airfoil selection, stability calculations and control surface sizing, flight testing to resolve to handle quality issues and modifying the test bed to arrive at a final design. For fixed wing UAV, the ratio between span and chord in average model aircraft is between 1:7 and 1:8; thereby the chord is 137/7 = 19.5 cm and the wing surface area determined as 2671.5 cm^2. Aspect ratio as 7.02, Altitude as 0.5–1 km, flight speed as 8–12 m/s. The speed range, at which the airflow will be smooth and laminar, can be estimated using the value of Reynolds number is 170×10^3. The airfoil has been selected for fixed wing of Solar UAV is NACA4418. Optimized speed of the solar UAV is 30 km/hr, which based on account the limited capacity of solar cells and its safety. The mass and life of a solar UAV either determine by top-down approach or bottom-up approach. Choose the top-down approach, since it is easier to make a plane lighter than to increase its lift. The lift and mass have been calculated as 10.3173 N and 1.05 kg respectively through aviation's lift formula. The lift produced by a semi-span of the wing should be proportional to the half of the UAV's weight. From then on each structural member is designed for its specification. The spar design is optimized to withstand the maximum load on the wing while minimizing the overall structural weight. The front spar is placed 20% of the chord leaving space for slat actuators and the rear spar at 70% of the chord is allowing space for flaps and actuators. Both the front spar and the rear spar can carry bending loads, which are the function of the movement of the centre of pressure. It also becomes necessary to consider the wing thickness (height) available at the spar location i.e. usually rear spars have lower spar height thus requiring a larger spar cap area to provide the required moment of inertia which would take the bending. But in the case of laminar flow airfoil, the maximum thickness occurs at the rear. Hence the rear spar height will be more than the front spar [2].

The propulsion group is assigned two major tasks for this paper, which are selection of the motor and selection of the propeller. Selection of motor for solar UAV concern several parameters. i.e., launching system of solar UAV, types of propellers configuration, solar panels configuration on the aircraft. After surveying the motors available, finally GT2213-09KV1180 motor has been selected for solar UAV. Selection of motor is based on ability to custom the wind power thereby it would operate at the desired current and voltage, the cost of the custom wound motor and the electronic speed controller, the brushless motor controller combination is almost efficient after figuring in losses [3]. For propeller selection, a recommendation has been given to the maximal propeller size, in which the propeller's maximal diameter plays vital role than maximal lead. A propeller with its lead being similar to its diameter is best suited for fast-flying airplanes, whereas a propeller with a small lead and larger diameter is excellent at providing the maximal force. Here the selected specification of the propellers are lead is 17.78 cm, diameter is 25.40 cm and speed of propeller is 34.3 m/s.

2.1 Solar Panel Test

A solar cell is a solid state device, which converts the energy of sunlight directly into electricity by the photovoltaic effect. For critical application, the requirement of the electricity is more so cells are often linked together in groups known as solar modules. Number of solar cells is depends upon the output power requirement [4]. A typical solar cell on the FR 4 sheet has been shown in the Fig. 2.

The placement of solar cells on non-lifting surfaces is ruled out to minimize drag and decrease the sensitivity to side winds. However, if required it is decided to put

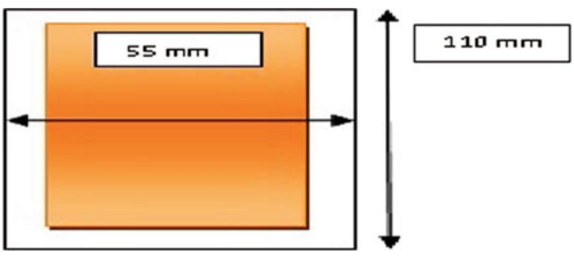

Fig. 2 Fabrication of solar cells on the Fr 4 sheet

solar cells on the rudder and elevator as they would be more effective during dusk and dawn. To integrate the stiff solar cells the following designs are considered (a) the first consists of distorting the airfoil shape by placing the cells on the top cut into pieces (b) the second solution consists of extending the trailing surface of the wing (c) the third involves placing Solar cells inside the wing, enclosed by an anti-reflective coating on top [5]. With the help of solar arrangement possibilities and calculation of wing surface area, we can finalize the arrangement of solar cells in our UAV.

Short circuit current and open circuit voltage of each cell array has been initiated the solar panel test. In which, the arrays are then individually numbered and their electrical characteristics are recorded for health confirmation. Solar testing of a UAV revealed that some cells did not provide the minimum rated short circuit current to be within specification. Several subsequent tests of the solar cells are performed using all 12 cells, which are soldered together and mounted on a sheet of cardboard for overall voltage measurement. Panel test occurred at several different times during the day, but usually, results are taken between 11 AM and 3 PM on relatively sunny days with constant voltage. This variance in testing times gave us an idea how the output from the cells would change in relation to the sun's position in the sky. The current is highly sensitive to the attitude of the cardboard w.r.t the sun so it is shifted from perpendicular to the sun to about 0°, 30° and 45° away from the sun, which demonstrates the cell require direct sunlight throughout the flight and high light intensity. Table 1 shows the solar cells testing output at various angles of incidence.

Solar UAV for forest surveillance is must want a battery as light as possible, yet powerful enough to supply sufficient energy so Ni-Mh Battery is the best option. The renewable energy source is the only way to reduce the weight of an UAV by decrease the components which involves in their propulsion unit [6]. Weight reduction and high-speed achievement is the prime techniques of this solar UAV thereby dimensions of the one solar cell are given here: Length is 25 mm; Breadth is 60 mm; Output voltage is 0.5 V; Output current is 1.5 A; Length of one solar panel as 150 mm; breadth is 135 mm; number of solar cells on wing as 24, which are connected in the series manner. Overall weight estimation and its comparison have been listed in Table 2.

Table 1 Solar cell testing at various angle of incidence

Degree of orientation to the sunlight	Time (hrs)	Voltage (V)
0	12	14.02
	12.5	13.19
	13	12.59
30	12	12.59
	12.5	13.02
	13	12.38
45	12	12.01
	12.5	11.66
	13	11.68

Table 2 Weight estimation

Element	First plan mass (g)	Actual mass (g)
Engine	135	70
Battery	120	50
Servo motors	10	38
ECU	10	35
Receiver	15	12
Propeller	15	10
Solar panels	500	200
Frame	500	500
Payload	50	50
Total weight	1290	965

2.2 Design and Fabrication of Solar UAV

Figure 3 shows the different views of a solar UAV, which has been modelled by CATIA. The solar UAV dimensions are has been derived from the standard analytical approaches. The individual components of a solar UAV have been designed with the help of literature survey, existing UAVs design and finally with the inclusion of aerodynamics consideration. Figure 4 shows the final prototype of solar UAV with estimated dimensions.

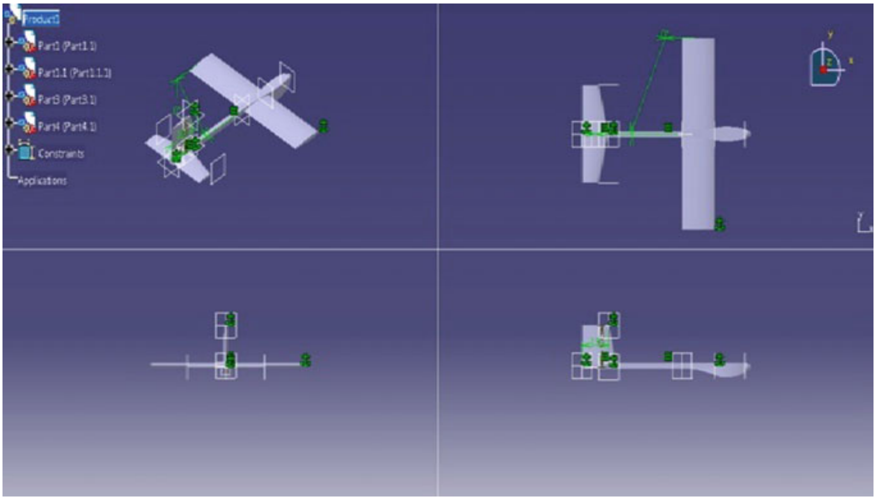

Fig. 3 Different views of solar UAV

Fig. 4 Solar UAV

3 Result and Discussions

The military use of UAVs has emerged because of their ability to operate in dangerous locations while keeping their human operators at a safe distance. Nowadays smaller UAVs are more comfortable than larger UAVs for critical applications. The handling of dangerous applications with smaller UAVs is a challenging task, but this task can be efficiently deals with the help of advanced avionics techniques such as intelligent video surveillance system, moving object detection techniques, feature extraction and template matching. After long survey the most appropriate method is selected and suggested for this paper, in order to recognize the intruder's image and efficiency is measured, which is nothing but the intruder's images are recognized by vision based navigation system. Important component for vision based navigation is localization of perfect intruder's detection algorithms, sensing the intruder's by camera, and finally representations of the border environment. In this work consist of two major steps; first one is creation of the solar UAV prototype and the next one is creation of moving intruder's detection matlab algorithm and its verification. Finally the integration of these two works practically will be carried out in future for the purpose of recognize the intruder's entering in the border region by autonomous solar UAV. Theoretically to know the intruders status in the border region, image processing and signal processing approaches are the methods available in MATLAB. For this work the image processing approach is selected to capture the intruder's images in the border with the help of smaller UAV [7].

3.1 Image Processing

In this paper there is survey of different object detection techniques and for object identification as intruders techniques such as enemy matching, edge based matching, skeleton extraction are studied. In image-processing applications, the brightness of the image and template can vary due to lighting and exposure conditions, so the images can be first normalized. Higher level image processing algorithms have been implemented as finite state machines the high-level control loop cycles through states representing goals. A classification algorithm typically performs better using the statistics extracted using the features instead of using the original data. The intruder's detection algorithms developed for this paper followed the same overall step-by-step with exchangeable sub-components. In this paper, standard vision features such as different intruder's identification, enemies shape, and weapons identification have been used. In addition the analyser also explored the different intruder's features and shapes learning techniques to obtain features that outperformed the standard feature set. The main work of this algorithm is to differentiate the intruder's image from the own country people's image and takes the needful action when an aerial images capture in the camera [8, 9]. In this paper, image processing has been simulated by MATLAB with the help of reference images and aerial images are taken from the internet. The verification of image detection algorithm is vital part in this paper, which may give confidence about intruder's prediction. Figures 5 and 6 show the reference image and UAV captured image, which are taken from the internet. All the images are taken from the internet for the purpose of verify the derived algorithm.

The matching percentage of images are simulated by MATLAB, the result file show in the Fig. 7 is the matching percentage of same images. The matching region in captured image compare with reference image is 100, because both the images are same for the purpose of verification.

Fig. 5 Reference image

Fig. 6 Solar UAV captured image

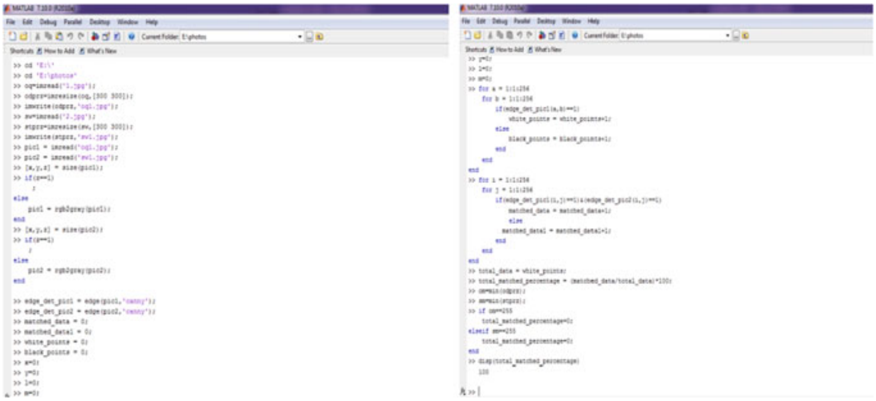

Fig. 7 Enemy detection result

3.2 Vision Based Navigation for Future Surveillance by Autonomous Solar UAV

In future this paper suggest the intruder image capturing techniques to be captured by vision based navigation by video surveillance in order to increase the enemies detection accuracy level in the monitoring area as a reference background for image subtraction. Real time videos will be captured in the border region with the help of rotating camera, which is attached in the autonomous solar UAV. These videos are splits in the form of frames to compare it with reference. Ground control station is the major part of the system, which is used to collect the video captured by the camera. After collecting the images from video, processing of that video in real time is done by the laptop using MATLAB. The error matching percentage of border images will be evaluated with the help of modern techniques and typical kind of intruder's inputs. If the error matching percentage is more than 50% then the alert system will be activate by ground controller and the output will be delivered in the

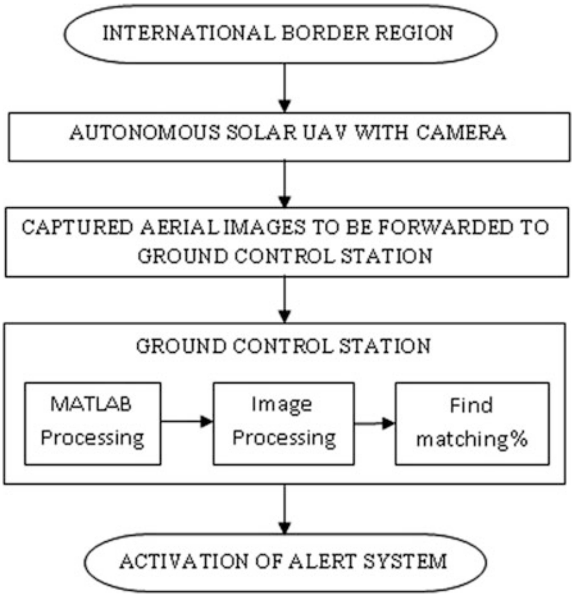

Fig. 8 Working flow chart of autonomous solar UAV

solar UAV. This solar UAV can be used in surveillance, monitoring of border regions that are large distances from the base station and also takes the necessary action with the help of warning system such as create the sound and send the intruder's position images to the ground controllers [9]. The step-by-step procedure of image processing of border region by autonomous solar UAV explained in Fig. 8.

4 Conclusions

Each and every component's specification of a solar UAV has been derived from theoretical calculation. The overall design of a solar UAV has been modelled by CATIA V5. The numerical progression of image processing and matching percentage of an enemy has been completed by MATLAB. Extensive test, numerical progression and respective calculations showed solar UAV is capable of flying, with solar power. Solar UAV has unique characters such as more comfortable flight, high lifespan with low power consume so it can able to reliable and capable to withstand any critical environment for a practical application such as intruders detection, activation of warning system. With the help of solar panels, the UAV can able to track any intruders as well as cover the whole predefined border region with long duration. Hence the proposed solar UAV is a better solution for border surveillance. In future the autonomous solar UAV for border surveillance will be added.

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