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IJIE

http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

An Innovative Approach for Environmental Monitoring by Solar Powered Kite

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DOI: https://doi.org/10.30880/ijie.2020.12.05.031
Received 28 May 2020; Accepted 30 June 2020; Available online 30 June 2020

Abstract: This study investigates the design of a solar powered kite equipped with sensors for any environmental data monitoring, such as, temperature, pressure and so on towards the elevated environment. The developed prototype transforms a traditional kite with a unique design approach that involves the upward height measurement, energy harvesting by solar cells as well as data transmission via wireless network. However, the results from initial monitoring show only the vertical mapping of ambient temperature as the test case. The developed system can successfully sense and display the temperature data from various heights within a certain range as found in the initial investigation. Therefore, upon monitoring various environmental parameters at any cases or during emergency situations using the solar-kite as the simple tool, decision can be made to take appropriate measures against any detrimental changes of the environment by other means.

Keywords: Kite, solar energy, environmental monitoring, temperature mapping, GPS

1. Introduction

The growth of renewable energy technology has become quite competitive to fulfill the challenge of the sustainable energy future. There are various types of renewable energy resources, such as biomass, geothermal, hydropower, marine energy, solar energy and wind energy (Ellaban O. et al. 2014). Solar energy is the direct energy conversion from sunlight into electricity, either by using photovoltaic (PV) or using concentrated solar power (CSP). Solar energy has become a popular subject in research and development due to its versatility in usage. Many researchers have come out with different designs and associated prototypes in solar energy usages from small to very large scale for energy generation.

A kite-flying is a traditional game where it reacts with air to create lift and drag. In Malaysia, kite is also known as Wau. It is widely used for entertainment, competition and handicraft. There are various types of Wau such as, Wau Bulan,

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Wau Barat, Wau Burung, Wau Pari, etc. The kite manufacturing requires quite a long time and certain expertise to produce beautiful and perfect kites. There are five basics components to produce a traditional kite, such as the head of kite, arc, kite's wing, kite's hip and kite's tail. However, in aerospace, kite is used as a concept to propel a spacecraft (Jack, C. et al. 2005; Johnson, L. et al. 2014). A simple analogy shows that kite, with large mirrors driven by radiation pressure as imposed by sunlight, will sail like being blown by the wind (Fu, B. et al. 2016; Liu, J. et al. 2014). However, in China, kites equipped with air sensor allowed people to get concerned in monitoring their local air quality. This project was carried out to express anger to the authorities about environmental pollution and lack of integrity for their own safety.

Solar energy equipped appliances are getting popular around the globe due its advantages of utilization at generation feature and customization according to needs (Hassanpour, S. and Damaren, C.J., 2018; Shen, F. et al. 2016). However, solar cell or smaller panels are now equipped in unmanned aerial vehicle (UAV) or drones to be used for various purposes in order to prolong the hauling duration, starting from environmental monitoring (Roseline, R.A. and Sumathi, P., 2014; Gallacher, D., 2016; Malaver, A. et al. 2015; Rojas, A.J. et al. 2015; Vacca, A. and Onishi, H., 2017). However, utilization of green technology such as photovoltaic (PV) system on a kite for any monitoring purposes is quite unexplored (Kabalci, E. and Kabalci, Y., 2018). There are some designs or prototypes such as solar balloon and solar-powered UAV/drone but not yet in kite shape to carry the circuit boards, for environmental monitoring purposes (Eskelinen, T. et al. 2017). After years of research and development in Malaysia, kite has been widely used for handicraft, competition and recreational activities purposes (Md. Noor R. et al. 2011; Alcântara, E. et al. 2013). However, the possible problem with this kite design is the load of the solar panel and remote sensing module that considerably heavy to make any normal kite fly. Many research works have been studied on the kites, mostly was focusing on the design of the kite and kite's aerodynamics. The key issue in developing the solar-kite lies on the fact that the photovoltaic (PV) and environmental monitoring part as placed on the kite should ensure the kite fly in good condition. As it is possible to construct solar-powered drone for environmental monitoring, hypothetically it is also possible to design solar-powered kite for environmental monitoring purpose as a low cost alternative. There exist limitations like the situations of pay-load changes for other sensors, however it could be solved by changing the kite design for best aerodynamic designs.

Furthermore, environmental monitoring system can be used to monitor temperature, humidity, soil moisture and weather monitoring, etc. (Giannopoulos N et al. 2009). Thus, to implement environmental monitoring system on the kite, there are challenges in hardware and software parts as well as integration of the system that needs to be considered before building Solar-KITE. For instance, the system integrates temperature sensor, monitoring system to transmit and receive the data and Global Positioning System (GPS) to measure the altitude of kite apart from positioning, date and time inputs. Again, there are many ways to design the kite and monitoring system, as the monitoring system is usually controlled by a microcontroller. Therefore, many customized circuit board designs are possible to make the lightest or smallest on-board system to ensure the kite's smooth flight. This method can indirectly improve the stability of kite while flying.

2. Methodology

Kite for environmental monitoring is a new thing that needs to be explored. The early solar kite system is designed to propel a spacecraft (Lappas V. et al. 2015). Nowadays, the use of kite for environmental monitoring has become quite popular to researchers and related community. There are three parts involved in designing solar kite for environmental monitoring, which are kite design or selection, hardware and software design. As for the first part, a suitable kite is either to be designed from scratch or choose among most suited existing designs to equip with solar power and electronic devices. Then, hardware development part includes the process of designing temperature sensor devices, i.e. DHT22, GPS, X-Bee module, solar charge controller and microcontroller. Finally, as the software development part, C programming language for Arduino is used to integrate the hardware design to enable its function and perform the desired task. Lastly, the modification and adjustment is performed to make sure the software programming is correct and the selected kite can fly with solar power modules with electronic devices on board. Fig. 1 shows the flowchart of overall process of solar-kite development for environmental monitoring.

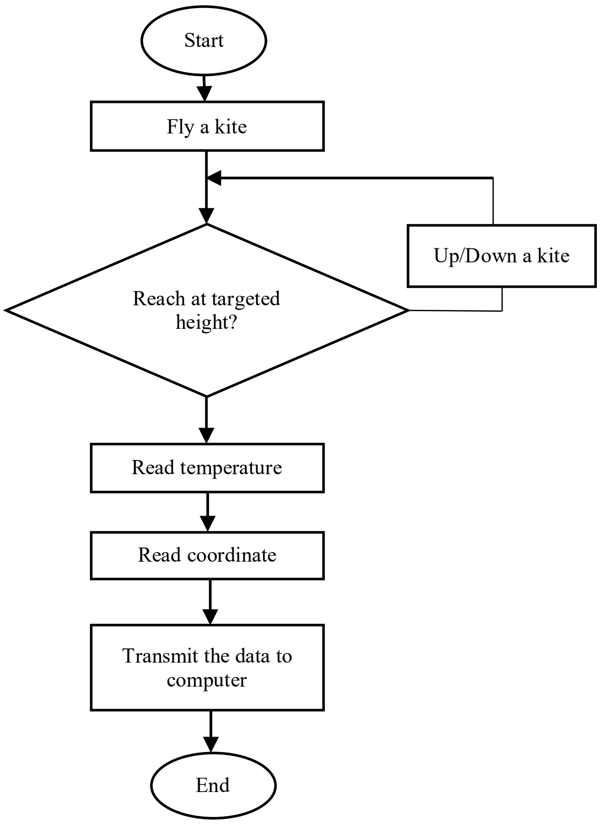

Fig. 1 - The overall process flow of a solar-kite for environmental monitoring

2.1 Selection of Kite for Modification

A Malaysian traditional kite known as *Wau* has been selected initially as the carrier kite to develop the prototype. The process of designing or choosing a kite has also been referred from some other literatures with some research outcomes. Usually, the main components to construct a *Wau* (kite) are bamboo, paper, thread, glue and a blade. Normally, Wau has four main parts, which are head, wings, waist and tail. To make a framework of a kite, a bamboo will be smoothened thoroughly and fine to get a good shape of kite. The blue shape on the top of a kite is a thin solar cell module sized as per need in the on-board electronic circuits. The placement of the solar cell module is located at the best position to ensure kite's smooth haul. Thereafter, the red box represents the temperature monitoring device or sensor as located at the center of a kite to get the best position without disturbing the aerodynamic design. When designing the structure of a kite with some additional load from thin solar panels or smaller electronic board, the size of kite and weight of load must be considered to make sure kite's unrestricted flying. The initial sketch of the proposed design of the solar-kite equipped with thin solar cell modules and electronic devices is shown in Fig. 2.

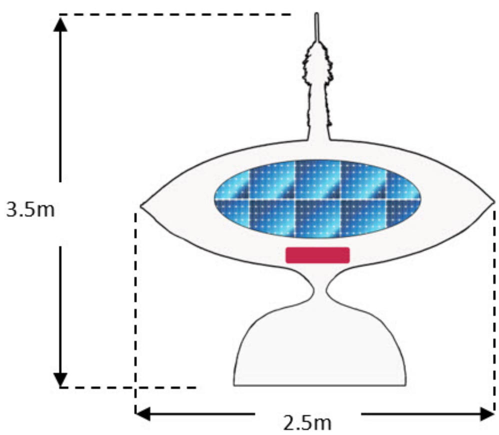

Fig. 2 - Schematic of the design of the proposed Solar-kite equipped with thin solar cells and electronics

2.2 Hardware Development and Integration

The next step after the design or selection of the kite is to design a suitable temperature-sensing device as a part of environmental monitoring. The hardware part uses some sets of design approach that include the measurement of distance, height, energy harvesting system optimization and data transmission. There are four individual devices involved in transmitter part, which are temperature sensor, XBee module, GPS module and solar charge controller as shown in Fig. 3. The GPS module is used to measure the altitude of kite, to detect the location of kite and to give the date and time of experiments. Next, the DHT 22 sensor module is always triggering the signal of surrounding temperature. Once the kite is reached at targeted height, the XBee module will transmit the data of temperature and GPS to the receiver part. In addition, the solar panel is used to charge the battery and to turn on the electronic devices.

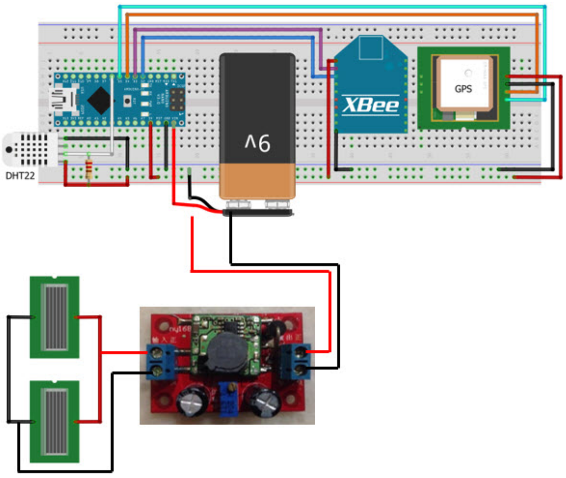

Fig. 3 - Schematic of the environmental monitoring part

2.2.1 Energy Harvesting Module

Customized flexible and thin solar module has been constructed with an array of tiny crystalline silicon solar cells. The crystalline silicon solar cells are used as they are more stable and have good efficiencies in the range of 18% to 25%. In addition, the thin film is incredibly light and can be adaptable to any different surfaces. Nowadays, crystalline silicon thin module is very common in power harvesting systems but not likely to be used in any flying object like kites. Here, two similar optimized modules are attached on two wings to charge the battery and turn on electronic circuits on-board. Table 1 shows the specifications of two different flexible solar modules.

Table 1 - Specification of two different flexible solar modules

Name	Specifications	
	Flexible Panel (L)	Flexible Panel (R)
Power, W	2.634 ±5%	2.602±5%
Open-circuit-voltage (V_{oc}), V	15.768	15.866
Short-Circuit-Current (I_{sc}), A	0.254	0.218
Maximum Voltage (V_{pm}), V	13.484	13.236
Maximum current (I_{pm}), A	0.196	0.197

2.3 Measurement of Height/Distance

The proposed system is also designed to measure the altitude of a kite by using an on-board GPS module. GPS is a navigation device that includes location and time information in any weather. In addition, the on-board electronics has EEprom to store the setting and the rechargeable battery to back up all the data. Here, GPS NEO 6M series is used that allows any data logger or computer to read the coordinate of the solar-kite. Table 2 below shows the specification of GPS NEO 6M.

Table 2 - Specification of GPS NEO 6M

Specification	Description
Supply voltage	2.8V to 3.4V
Sensitivity (Tracking)	-161 dBm
Range	Up to 90m
Size	1.2cm x 1.6cm
Weight	12g

2.4 Data Transmission

The next step is transmitting the data by using wireless communication device. It is needed to send the information between two different locations, which are not connected by any wire. In this project, size and distance are the requirement for the selection of short-range communication device. Based on survey from several wireless network devices, it is decided to use XBee series 1. XBee is a low cost device with minimal power requirement and provides reliable transmission data between devices. Table 3 below shows the specification of XBee series 1.

Table 3 - The specification of XBee module series 1

Specification	Description
Transmit power output	1mW
Supply voltage	2.8V to 3.4V
Range	Up to 90m
Size	2.438cm x 2.761cm
Data rate	250Kbits/s

2.5 Temperature Sensor

The temperature sensor DHT22 is chosen in this project to measure the temperature at different height. Basically, it uses a thermistor to measure the surrounding ambient temperature. In addition, this sensor is more accurate, that can measure in a wider range of temperature with precision. Fig. 4 shows the circuit of a temperature sensor that has been used.

Table 4 - The specifications of DHT22 sensor

Type	Description
Model	DHT22
Input Voltage	3.3V to 6V
Output signal	Digital signal
Sensing element	Polymer capacitor
Sensing period	2s (average)
Size	14mm x 18mm x 5.5mm

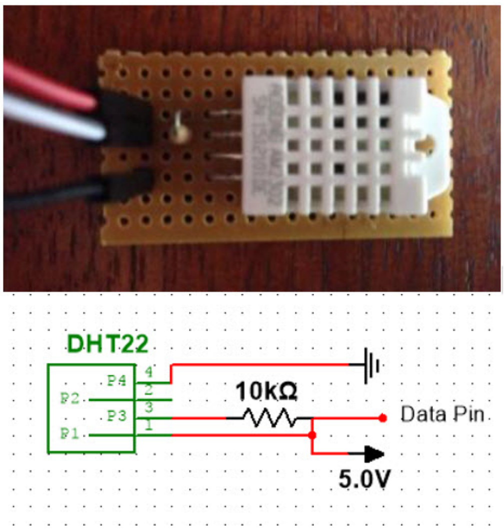

Fig. 4 - Schematic and actual circuit of DHT22 sensor module

3. Results and Discussion

This study initially investigated three individual entities or categories of the integrated system, such as kite test, temperature sensor test and height/distance measurement test. The tests involved both of hardware and software part to make sure the system is well functional as desired.

3.1 Kite Design

There have been changes in kite design compared to initial designs due to the supply limitation. This is because of the difficulty to get and process the bamboo trees to produce a big kite or Wau. Therefore, the similar design is used to carry out this study as the alternative. Fig. 5 shows a kite prototype with solar power and electronic devices. The placement of the solar cell modules and temperature monitoring device are located at the best position to make sure that kite flies well

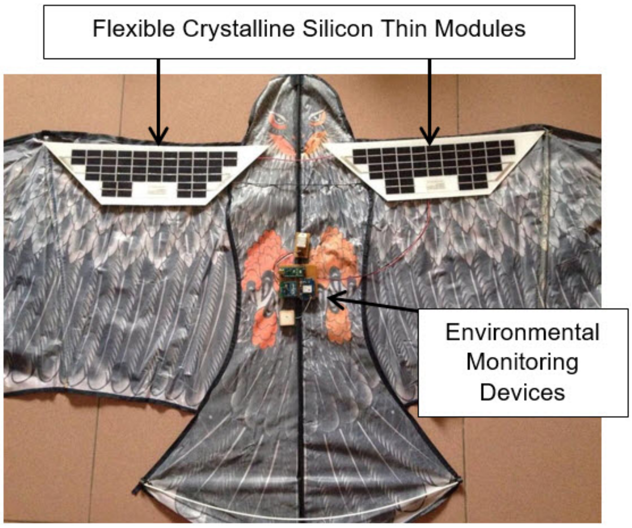

Fig. 5 - A kite prototype (similar) with solar power module and electronic devices

Table 5 shows the results of initial flight test of a similar kite in terms of size under four conditions. For the first condition, the kite can fly freely without any components on-board. Next, custom made thinner solar cell modules are placed on top of both wings of the kite and it still can fly with the weight of the thinner solar modules as found. However, the kite faces difficulties upon putting the electronic circuit module with temperature monitoring devices, as the total weight of rechargeable battery and GPS module is quite heavy to make this kind (replacement/substitutional) of kite to fly. Other factors that may restrict the kite's lift-off include the size of this kind of kite with required weight to carry additional weight. However, Wau or the proposed Malaysian traditional kite may solve the lift off problem as these are usually big in size with ample weight to carry certain amount of load on it, which needs to be verified as the future prospects of this study.

Table 5 - Results of Initial flight-test

Type of test	Observation
A kite without any component	Flies well
A kite with two solar panels only	Flies well
A kite with temperature monitoring devices only	Confronts lift-off problem
A kite with solar cell and temperature monitoring devices	Confronts lift-off problem

On an outdoor test, the output voltage and output current of the solar cell are found to keep increasing till 2PM and then all decrease as shown in Fig. 6. The output voltage and current are not constant because they depend on sunlight condition. The other factors that affect solar panel efficiency are sky condition, position of the solar panel and temperature. The highest output voltage and current reading are at 2PM, where on that day there was bright sun but mostly covered by cloud as usual in a tropical region like Malaysia.

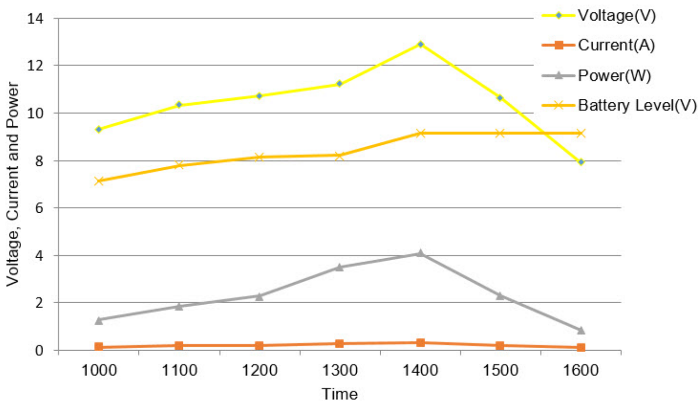

Fig. 6 - Output Voltage, Current and Power at different times of a typical day

3.2 Altitude Measurement

To measure the altitude of the flying kite, a GPS module is used. Since, the pay-off load is heavier in the current design, the electronic device is tested at each floor of a multi-story in-campus building, to understand the actual reading of GPS module. Fig. 7 shows the actual data reading panel of GPS module that is used to obtain the height of each floor, apart from other data like latitude, longitude and date with time.

```
Sizeof(gpsobject) = 115

Sats HDOP Latitude Longitude Fix  Date       Time       Date Alt
          (deg)    (deg)     Age                        Age  (m)
-----------------------------------------------------------------
9    89   2.92703  101.77726 457  05/28/2016 19:25:15   474  72.50
9    106  2.92702  101.77726 534  05/28/2016 19:25:16   551  73.00
9    89   2.92702  101.77726 609  05/28/2016 19:25:17   627  73.10
9    89   2.92702  101.77726 682  05/28/2016 19:25:18   700  73.20
9    86   2.92702  101.77726 754  05/28/2016 19:25:19   772  73.30
9    86   2.92702  101.77726 830  05/28/2016 19:25:20   848  73.50
9    86   2.92702  101.77726 73   05/28/2016 19:25:22   151  74.10
9    80   2.92702  101.77726 194  05/28/2016 19:25:23   254  74.30
9    86   2.92702  101.77726 405  05/28/2016 19:25:24   424  74.40
9    86   2.92702  101.77726 473  05/28/2016 19:25:25   491  74.50
9    86   2.92702  101.77726 548  05/28/2016 19:25:26   565  74.40
9    86   2.92702  101.77726 620  05/28/2016 19:25:27   637  74.30
9    86   2.92702  101.77726 702  05/28/2016 19:25:28   721  74.20
9    86   2.92702  101.77726 769  05/28/2016 19:25:29   787  73.80
9    86   2.92702  101.77726 847  05/28/2016 19:25:30   865  73.80
8    86   2.92701  101.77726 115  05/28/2016 19:25:32   77   73.90
9    84   2.92701  101.77726 235  05/28/2016 19:25:33   292  74.10
9    84   2.92701  101.77726 410  05/28/2016 19:25:34   428  74.30
9    84   2.92701  101.77726 486  05/28/2016 19:25:35   504  74.50
8    96   2.92701  101.77726 561  05/28/2016 19:25:36   578  74.80
```

Fig. 7 - Measurement of height and location of GPS module in case of standard multi-story building

3.3 Temperature Measurement

Further to the investigation, the temperature sensor is continuously moved upward to each level of the building as the alternative way to measure the upward changes of ambient temperature. To get the best reading, the experiment is carried out at 12.00 p.m. in the premise. Fig. 8 shows the measured temperature at a conventional height of third floor of any standard building, which is tabulated in Table 5 for better mapping. At ground floor level or relative zero meter of height, the temperature is found to be 34.6°C. Then, the temperature kept increasing until 43.41°C, when it reached to the height of 15.311 meters as shown in Table 6. However, the temperature reading is not constant since it depends on the instant fluctuation of the weather. The other factors that affect the temperature reading are shade, sky condition and air pockets at vertical position.

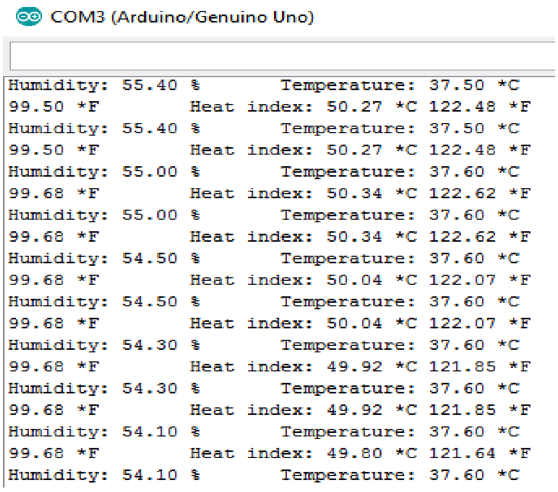

Fig. 8 - Temperature data as obtained on serial monitor

Table 6 - Measured temperature versus height

Height (m)	Temperature (°C)
0	34.6
4.103	36.2
8.301	36.9
12.64	37.8
15.311	43.41

4. Summary

The proposed prototype successfully accomplished the use of solar powered flying kite to observe vertical mapping of temperature or any other atmospheric parameters for environmental monitoring purposes. The results find that this method is able to sense the temperature changes, measured height and transmit the data from temperature monitoring devices to computer. Furthermore, the temperature sensor device can be integrated with other sensors to monitor the environment continuously to let user take measure in case of unusual occurrence. This approach is the alternative to other UAV or weather balloons as the low cost solution in any emergency situations.

Acknowledgement

Authors would like to thank the Department of Electrical, Electronic and Systems of Universiti Kebangsaan Malaysia (@The National University of Malaysia) to accomplish the project. Gratitude is also indebted to the Institute of Sustainable Energy of the Universiti Tenaga Nasional (@The National Energy University) for overall encouragement through its BOLD2025 Program.

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