The Study of Path Planning for a Perpetual Solar Powered Flight across Regions around the World

by

Tan Chin How

Supervisor: Dr. Parvathy Rajendran

Thesis submitted in fulfilment of the requirements

for the Bachelor Degree of Aerospace Engineering (Honors)

May 2017

ABSTRACT

Perpetual flight of solar power UAV on same location has been achieve in recent researches. If the perpetual flight of solar power UAV is change into worldwide instead on same location, it can be a pseudolite, function as a part of communication satellite. It will be cheaper and easier to launch for those countries still under development. In order to achieve the perpetual flight, the power supply play important role. Since it is solar powered UAV, it able to collect energy from sunlight during day time and store up the excessive energy into battery for the power consumption during night time. The amount of energy available in night time must sustain the flight, which are manipulated by the capacity of battery, total energy collected and energy consumption rate. The total energy collected is highly depend on intensity of solar irradiance. In the recent researches, a lot of study on UAV has been done in order to increase the performance in term of endurance. Researches on path planning of UAV are available but limited to surveillance missions, target tracking and real time autonomous path planning. The data of worldwide solar irradiance intensity for each hour is required in order to plan a delicate flight path and achieve perpetual flight. In this paper, the worldwide solar irradiance intensity and digital elevation will be collected and used in Matlab programming software. Matlab programming software is used to identify the possibility of perpetual flight across region around the world. The battery status along the flight paths will identify and analyse. It also expected the UAV signal coverage will cover every region on earth. The path planning result shown that flight pattern A and B both have the possibility to achieve perpetual flight. But flight pattern A have higher risk and restriction than flight pattern B. The parameters with high impact have discussed in this thesis and recommended range are suggested.

ABSTRAK

Penerbangan UAV jenis berkuasa tenaga solar tanpa berhenti di lokasi yang sama telah dicapai dalam kajian baru-baru ini. Jika kawasan liputan penerbangan UAV berkuasa solar tanpa berhenti bertukar kepada seluruh dunia bukan pada lokasi yang sama, ia boleh menjadi pseudolite, fungsi sebagai satelit komunikasi. Ia akan menjadi lebih murah dan lebih mudah dilancarkan oleh negara-negara masih di bawah pembangunan. Masalah berkalan kuasa merupakan faktor utama untuk mencapaikan pernebangan UAV tanpa berhenti. UAV berkuasa tenaga solar boleh mengumpul tenaga dari cahaya matahari pada waktu siang dan menyimpan tenaga yang berlebihan ke dalam bateri untuk penggunaan kuasa pada waktu malam. UAV boleh mencapai pernerbangan tanpa berhenti pada waktu malan adalah bergantung kepada kapasiti battery, jumlah tenaga berkumpul dan tenaga diguna pada waktu malam. Jumlah tenaga yang boleh dikumpulkan adalah bergantung kepada kekuatan sinaran matahari pada waktu siang. Dalam kajian baru-baru ini, banyak kajian mengenai UAV telah dilakukan untuk meningkatkan prestasi dari segi mempanjangkan masa pernerbangan. Manakala kajian tentang perancangan laluan UAV kebanyakan terhad kepada misi pengawasan, pengesanan sasaran dan perancangan laluan dengan autonomasi. Untuk mencapaikan matlamat pernerbangan tanpa berhenti, kekuatan sinaran matahari sepanjang laluan UAV hendaklah dipertimbangkan. Data kekuatan sinaran matahari, ketinggian permukanan bumi akan dikumpulkan dan masuk ke dalam perisian Matlab. Data data tersebut akan digunakan untiuk mentafsirkan kemungkinan mencapai pernebangan UAV tanpa berhenti. Status bateri akan dicatakkan dari semasa ke semasa sepanjang pernerbangan. Kawasan liputan UAV akan meliputi seluruh permukanan bumi. Keputusan kajian menunjukkan bahawa laluan A dan B menpunyai kemunkingan untuk mencapai pernerbangan UAV tanpa berhenti. Tetapi

laluan A menpunyai risiko yang tinggi dan syarat yang ketat. Faktor faktor utama telah dibentangkan dan bahagian perbincangan dan berberapa cadangan telah dicadangkan.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest appreciation to all those who provided me with the possibility to complete this project. A special gratitude I give to my final year project supervisor, Dr. Parvathy Rajendran for stimulating suggestions, guidance and encouragement throughout the thick and thin of this project and helping me in coordinating this project. Furthermore, I would also like to thank to my coursemates for their advices and help. Special thanks to who motivate me and helping in solving some technical problems during this project. Last but not least, I would like to thank to my family, for their love and support and for being my pillar of strength through the daunting times in completing this project. Thanks to everyone who was directly or indirectly involved in the completion of this project.

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree

____

Dr. Parvathy Rajendran

Date:

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

____

Dr. Parvathy Rajendran

Date:

STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available to outside organizations.

____

Dr. Parvathy Rajendran

Date:

TABLE OF CONTENTS

Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HALE	**: High Altitude Long Endurance**
UAV	**: Unmanned Ariel Vehicle**
SoDa	**: Solar Radiation Data**
DEM	**: Digital Elevation Model**
3D	**: Three Dimension**
GMT	**: Greenwich Mean Time**
SOC	**: State of Charge**

NOMENCLATURE

Ir	: Global solar irradiance
EIr	: Extra-terrestrial solar irradiance
AM	: Air mass coefficient
W	: Wide of region covered by UAV
Alt	: Cruise altitude
$signal\_length$	: Range of Signal UAV can reach
n	: Number of cycle around earth
L	: Distance of prime meridians
θ	: Change of vector from centre of earth
P	: Vector P
Q	: Vector Q
s	: Distance travel
r	: Radius from earth centre
T	; Time taken in flight
v	: Cruise velocity
$Longitude_{change}$	: Angle between each zig zag path
$L_{equator}$	: Length of equator line
$N_{zig\ zag}$	: Number of zig zag path in one section
$N_{section}$	: Number of section earth divided
$D_{zig\ zag}$	: Distance of each zig zag path
$t_{half\ year}$	: Total time represent half year

t_i	: Number of iteration to determine the value of solar irradiance for respective location
t_{fly}	: Cumulative flight time
$zone$	: The time zone for respective location
$Power_{in}$	: Power generated from solar cell
$Power_{out}$	: Power usage
$battery_{charge_i}$	: Battery charge at current location
$battery_{charge_{i-1}}$	: Battery charge at previous location
$t_{fly_{i-(i-1)}}$	: Time taken for changing location
SOC_i	: State of charge of battery

CHAPTER 1

1. INTRODUCTION

1.1 GENERAL OVERVIEW

Satellite are widely used mainly on collect and transfer data which are creating a better and convenient living environment to human. However, advance technology and huge investment is needed to launch a satellite. Here the idea come to launch a perpetual solar powered UAV across regions around the world instead launch a satellite. Definitely launching a UAV is easier and less cost needed compare to satellite. The reason of solar powered management was chosen because it allows UAV perform perpetual flight with sustain solar irradiance along the flight path.[1] Beside, solar powered UAV have zero emission and benefit to environment. Furthermore, UAV has higher efficient with solar power management because additional mission like landing purposely for refill source of energy can be neglected. With a perpetual solar powered UAV fly across regions around the world, it can function as a part of communication satellite, or pseudo-satellite (pseudolite).[2]

In order to maintain perpetual solar powered UAV fly across regions around the world, power management system of UAV is one of the key to success.[3] The UAV had to design with high endurance specification.[4] So that the power consumption is under reasonable range and it still able to work well during dark fall by using power supply from battery.[5] As result, the solar irradiance and height of cruise need take into account along the flight path so that the energy collect during day time is sufficient to the power consumption during dark fall. Besides, there are some sensitive regions on world surface are prohibit from any aerial vehicle pass by. Furthermore, the efficient of collect and transfer data is highly depending on the cruise speed and area coverage of UAV,[6] which are the parameters that associated with energy consumption. Hence, a designed flight path that integrated on these parameters is needed.

Recently, there is numerous research on pseudolite over the year. Various modification had been done, with the intention of improving the power management.[7] These had contributed to lower the limitation of perpetual flight. On the other hand, there are some researchers study on UAV path planning such as surveillance missions[8], target tracking[9] and real time autonomous path planning.[10]

However, these researches still not able to provide a solution on path planning of perpetual solar powered UAV across regions around the world. Because the researches on path planning is not worldwide target and perpetual flight on same coordinate. The designed path may take few months to complete where involving changes of climate and day and night. Some additional study on the real time solar irradiance[11] along the flight path is required. Besides, the climate along the flight path over the year are changing time to time that need take into account.

In this paper, the study on the change of solar irradiance and sea level on earth surface is done in order to achieve the final goal, path planning solar powered UAV across regions around the world.

All the collected parameters of solar irradiance and sea level will include in the matlab program. Integration among these parameters will be done in order to obtain more than one possible flight path. From the determined possible flight path, the time taken, ideal initial flight time and battery status will be study. Time taken is related to the performance of collect and transfer data and ideal initial flight time is highly depending on the starting location. While the battery status is the key to determine the risk and lifespan of battery.

1.2 Problem Statement

In the recent researches, it shown that perpetual flight over an area are possible. Besides, some researches on target tracking path planning or surveillance missions present few ways to control the path of UAV. However, the provided information is insufficient to apply in this case. In this case, UAV is designed to be a perpetual flight fly across region around the world. As mentioned above, solar power management is applied, the power supplied is the key to make sure the UAV keep flying. Hence the solar irradiance intensity should consider along the flight path. There are several factor effect on the solar irradiance intensity. The main factor is the local time. Day and night result the UAV should fully charge the battery during day time so that the power consume at night time is sufficient. Besides, the minimum battery pack for specific flight path can be determined in order to reduce the battery pack, or the weight of whole UAV in other word.

In order to obtain a reasonable solution, the study on the change of solar irradiance and elevation on earth surface are required. By using the data, designed few possible flight path and study on the characteristics and relationships such as region of cover and flight altitude, time taken for one complete cycle, battery status and battery pack, lastly effect on flight performance if varying the initial flight time.

1.3 Objective

The research work in this thesis is performed based on the following objective:

1. To understand the important parameters to sustain perpetual flight across the world.
2. To propose possible flight path of solar powered UAV across the world.
3. To investigate the possible flight paths considering the elevation and intensity of solar irradiance in timely manner.

1.4 Thesis Layout

This thesis is divided into five chapters. Chapter 2 describes the previous work regarding to solar powered UAV. The aerodynamic design, power system configuration and UAV path planning for target tracking or other purpose are discussed. Chapter 3 presents the general algorithm and proposed method in this thesis. The mathematical equations and the approach taken to determine the state of charge of battery are outlined. In this chapter, the way to evaluate the performance of the UAV is presented. Chapter 4 show the path planning result. In this chapter, it is divided into two sections; the requirement to achieve best path planning of perpetual flight across region of world are discussed and the how some of the important parameter alter the result of state of charge of battery and time taken of the mission. Chapter 5 summarizes the conclusion of this thesis and presents an outlook for future work.

CHAPTER 2

2. LITERATURE REVIEW

Endurance is one of the important fundamental element to achieve perpetual flight. There are a lot of research on the endurance of UAV in varies aspect[12-16]. One of the key to increase the endurance of UAV is based on the aerodynamic design[17]. Research shown that with a good aerodynamic design, the endurance of UAV can be improve. Besides, the structural design are important to support UAV to achieve good performance in high endurance achievement[18, 19]. Because some structural issue such as flutter will limit the performance of UAV. Furthermore, the type of power supply in UAV power system also highly related with the endurance characteristic[12, 15, 20-23]. Research shown that with same amount of power supply, electrical power is better than fuel power due to the weight parameter. Solar powered UAV also have a greater advantage because power generated during flight which further increase the flight time. Even though all these researches do not provide a solution on launch a perpetual flight across all region of the world, but them provide us the concept on how to increase the endurance of UAV. Based on these concept and knowledge, there are few more researches successfully launch solar power UAV and the flight more than 24 hours[24-28]. This shown that the possibility of perpetual flight can be achieve and it is not an impossible mission.

Nowadays, human do research on solar powered UAV for few specific purpose[8, 9, 29-33]. These mission include target tracking, navigation and surveillance types missions. These research shown us the variety usage for the function of solar powered UAV and how manipulate the design in power management in order achieve the mission objective.

Besides, a sample of solution or idea how path planning carried out. However, most of these research launches their flight and stay on same region only. Study on performance of solar cell in solar powered UAV had been carried out[23, 31, 34-36]. These research are with the intention to improve the power conversion efficiency. The configuration of solar cell and power management system in UAV are the focus which is important and we should focus on it. Besides, enhancing on the mission profile of solar powered UAV can improve the power management[23] too. Result of study shown with a better mission profile, the power usage will decrease. However, condition of across the longitudinal line are involved in this topic study. Hence, not all the result of study did in previous research able to apply in this paper. As the UAV crossing longitudinal line of earth, solar irradiance will change which is an important parameter for solar cell generate power.

There is some research on the effect of solar irradiance toward UAV in flight especially endurance[5, 7, 37-39]. Research shown with higher solar irradiance, UAV generate more power. Where the solar irradiance highly depends on the local time and location on earth. In this research, I will have based on available technic or idea in path planning, power management, solar irradiance’s study and HALE UAV, applied in the current study which is path planning a perpetual flight across region around the world.

CHAPTER 3

3. METHODOLOGY

3.1 Data Collection

As mentioned above, the change of solar irradiance and elevation on earth surface will be the focus. A trusted website Digital Elevation Data are used to collect the 3 arc second of global elevation data around the world. The global digital elevation data are downloaded in '.htg' format. Matlab software are used to execute the elevation data from '.hgt' file, otherwise, it is not readable. The code used to execute the elevation data are available in website Mathworks. However, some modifications were done in order to suit and fullfill the necessary output. Besides, another trusted website called Solar Radiation Data, SoDa is used to obtain the solar irradiance thought out the year. The SoDa Service is a broker to a list of services and webservices such as it offers a one-stop access to a huge set of data relating to solar radiation. This study deals with about 648000 coordinates to be key in in order to obtain the solar irradiance over the earth surface. These data are obtained from the provided webservice. In the case of unavailable data, interpolation will be used.

Initially, the method I used to collect solar irradiance data are time consuming and website dependent. Therefore, not practical. Then another method was introduced by project supervisor Dr. Parvathy Rajendran based on the Solar Radiation and Daylight Models by T. Muneer. A modelling of solar irradiance and daylight duration can be compute in Matlab software and that makes this approach practical. The elevation data was arranged according to the location on earth. This is because the solar irradiance is depending on the altitude we measured. A set of solar irradiance data for every surface of earth and throughout the year was computed by using equation 3.1 [40, 41].

$$Ir = EIr \times dis \times AM \tag{3.1}$$

Where,

Ir = Global solar irradiance

EIr = Extra-terrestrial solar irradiance

AM = Air mass coefficient

After collected solar irradiance and digital elevation data, two specific flight pattern were used to further study the perpetual flight characteristic especially the effect of the cruise altitude and elevation on the time taken to finish a complete flight, minimum battery pack for perpetual flight and effect of changing the initial fly time on flight performance.

3.2 Flight Pattern

Two flight patterns, spiral pattern and zig-zag pattern were proposed.

3.2.1 Spiral Pattern (Flight Path A)

The spiral pattern starting flight coordinate was located at N90E00 and the sample of flight path are shown in Figure 3.1

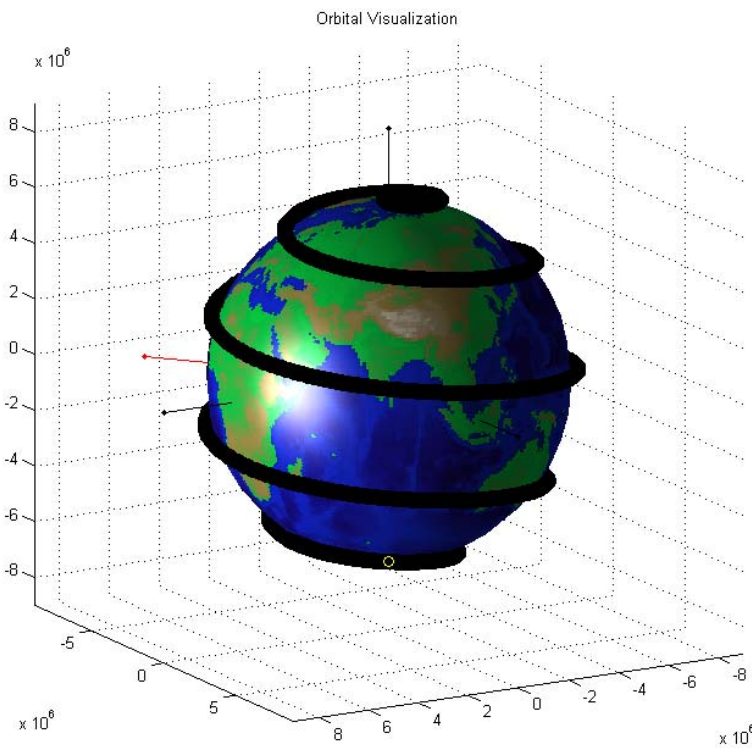

Figure 3. 1: Flight Path A

Some parameters such as flight velocity, battery capacity, solar panel efficiency and UAV specification were fixed to allow us to start modelling such as the signal coverage of uplink and downlink is 100km. By using this uplink and downlink specifications, a number of cycle required to across the prime meridians in order to cover all region around the world can be determined by using equation 3.2 and 3.3.

$$W = \sqrt{(signal\_length^2 + alt^2)} \tag{3.2}$$

Where,

W = Wide of region covered by UAV

Alt = Cruise altitude

$signal\_length$ = Range of Signal UAV can reach

$$n = \frac{L}{W} \tag{3.3}$$

Where,

n = Number of cycle around earth

L = Distance of prime meridians

Prime meridians is a half imaginary circle on earth surface. It is terminated by North and South pole which is set as zero degrees of longitude. The prime meridians is the red line shown in Figure 3.2.

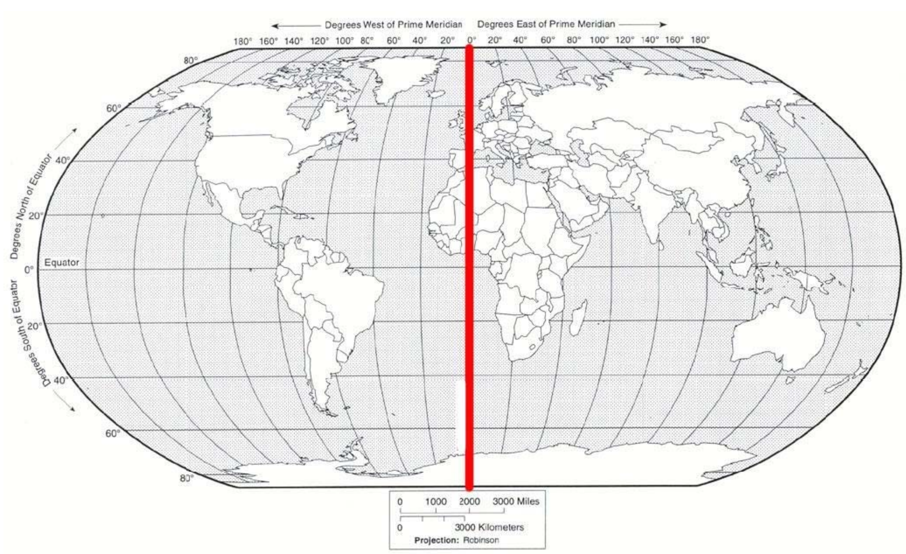

Figure 3. 2: Prime meridians

By using the number of circle, the flight path can be fixed and the changing of latitude respect to 1 degree increment of longitude can be calculated. These longitude and latitude allow us determine the vector of UAV from center of earth. The changing of latitude and longitude result in changing of vector, the angle between two vector can be calculated by using the vector in 3-D space method as shown in Figure 3.3 and equation 3.4.

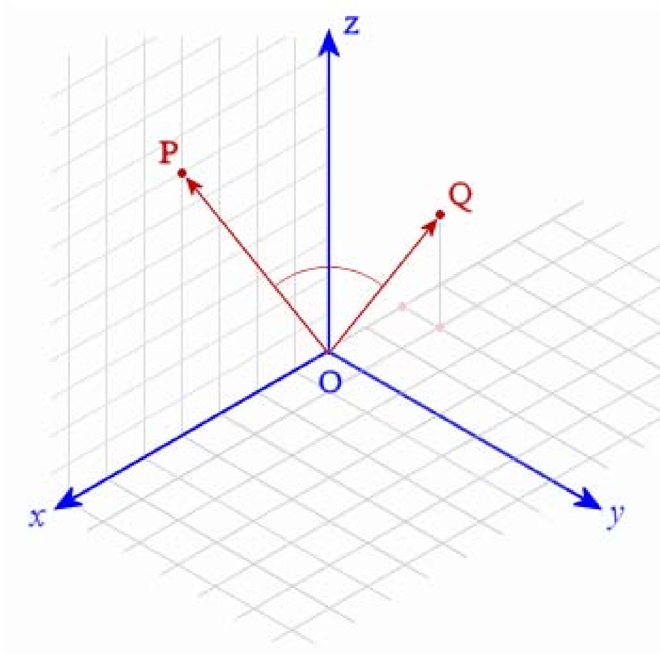

Figure 3. 3 : Vector P and Q in 3D space

$$\theta = cos^{-1}\left(\frac{P \times Q}{|P||Q|}\right) \tag{3.4}$$

Where,

θ = Change of vector from centre of earth

P = Vector P

Q = Vector Q

From the θ of equation 3.4, the actual distance of travel can be estimated by using equation 3.5.

$$s = r \times \theta \qquad (3.5)$$

Where,

s = Distance travel

r = Radius from earth centre

Once the actual travel distance in equation 3.5 had been figure out, the time taken can be calculated by using equation 3.6.

$$T = \frac{s}{v} \qquad (3.6)$$

Where,

T = Time taken in flight

v = cruise velocity

3.2.2 Zig-zag Pattern (Flight Path B)

Initially, the earth surface was separate into few section as shown in Figure 3.4. The UAV is designed fly in zig zag pattern as shown in Figure 3.5.

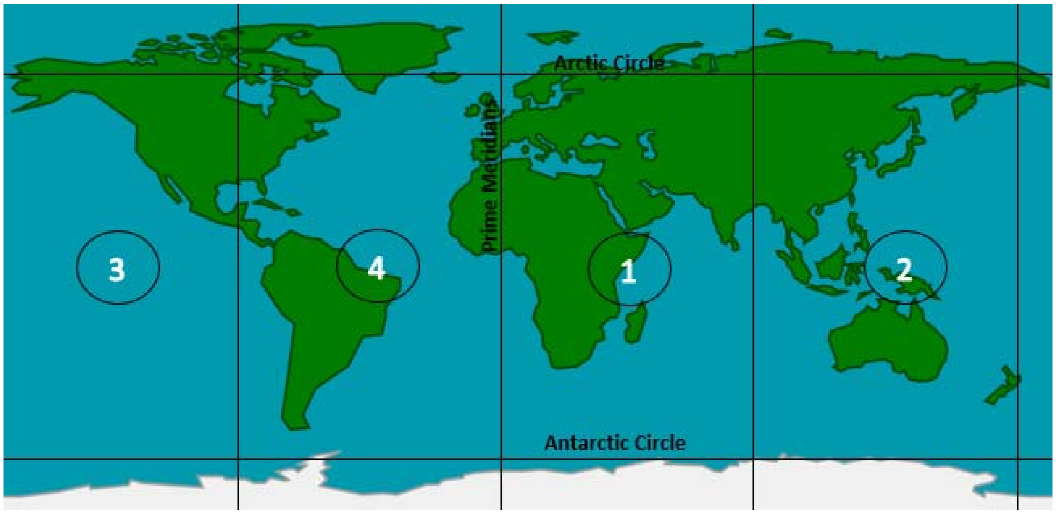

Figure 3. 4 : The example of earth with 4 section divided

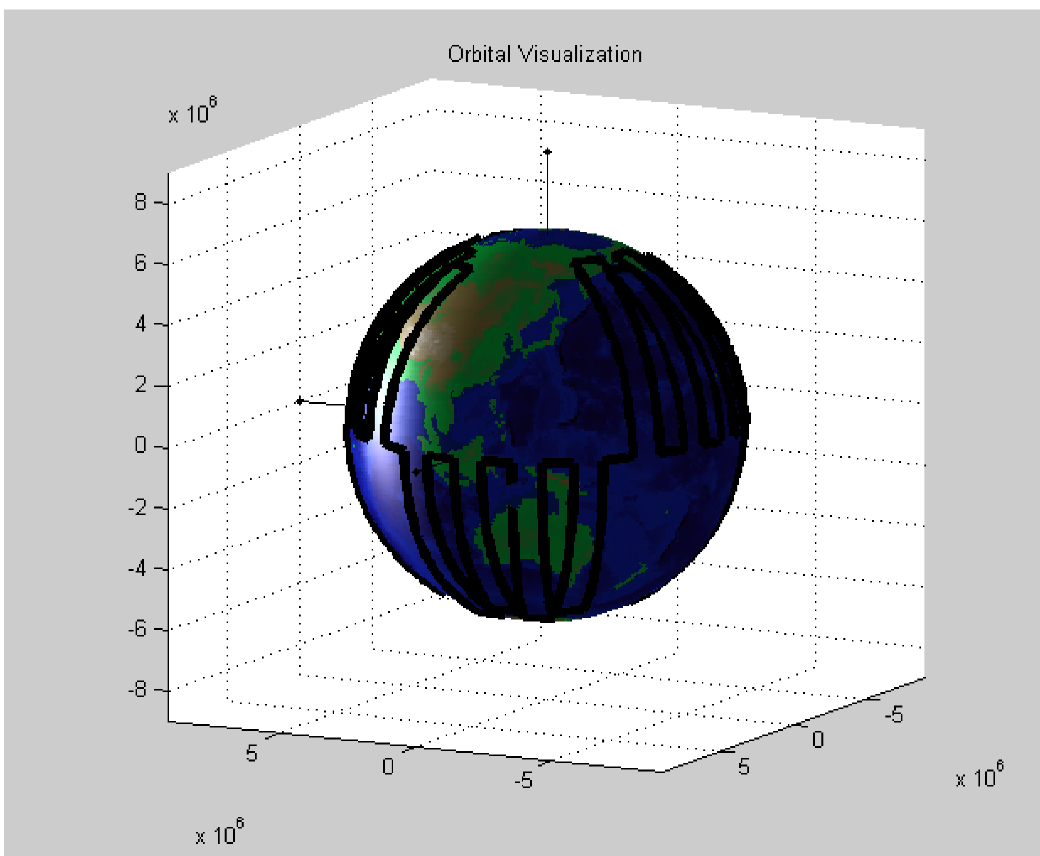

Figure 3. 5 : Flight Path B with zig zag method

Each zig zag path designed shape like ‘M’ but second sharp is shorter to decrease the overlap cover area. Each zig zag path distance depends on the coverage range of UAV signal. Equation 3.7 show how to obtain the angle between zig zag gap.

$$Longitude_{change} = \frac{4 \times \sqrt{(signal\_length^2 + alt^2)}}{L_{equator}} \times 360° \quad (3.7)$$

Where,

$Longitude_{change}$ = Angle between each zig zag path

$L_{equator}$ = Length of equator line

From the angle between each zig zag path, we able to determine how much zig zag path is needed to cover a section of earth hemisphere as shown in Equation 3.8.

$$N_{zig\ zag} = \frac{360°}{N_{section} \times Longitude_{change}} \quad (3.8)$$

Where,

$N_{zig\ zag}$ = Number of zig zag path in one section

$N_{section}$ = Number of section earth divided

By using the number zig zag path in one section, the velocity needed for UAV to finish the section in exactly half year can be calculated using equation 3.9.

$$v = \frac{N_{zig\ zag} \times D_{zig\ zag}}{t_{half\ year}} \quad (3.9)$$

Where,

$D_{zig\ zag}$ = Distance of each zig zag path

$t_{half\ year}$= Total time represent half year

After that, the changing of latitude and longitude result in changing of vector, the angle between two vector can be calculated using the vector in 3-D space method as mentioned in Flight Path A. The actual distance and time taken for each location changes in zig zag flight path were computed and recorded as mentioned in Flight Path A.

3.3 Computing Power and Battery Status

After obtaining time and distance travel for every location changes, configuration of UAV and some required parameters such as air density and time zone were input into the algorithm.

Table 3. 1 : Input Parameter

Input Parameters		
1	Air Density, rho	From sea level until 50km altitude
2	Wingspan, b	3.70m
3	Wing are, S	0.823m^2
4	Parasitic Drag, C_{Do_w}	0.011
5	Weight of UAV, W_{UAV}	29.43N
6	Battery Capacity, $Battery_{cap}$	271.95, 308.70, 388.50, 441.00 Wh
7	Maximum power point tracker, $MPPT$	0.98
8	Solar panel efficiency, $cell_{eff}$	5, 10 ,15, 20, 25, 30, 35, 40, 45, 50 %
9	Starting flight time, t	Depend on date and time selected
10	Solar panel area, A	1m^2
11	Operating Voltage, V_{op}	11.1V

From the calculated time taken required from every positions change, we are able to determine the local time of where the UAV located after take the position of UAV and total flight time of UAV into account. The location of the UAV is important to compute the GMT and include into the local time calculation. This is because, as the UAV moving across the longitude line, the local time where the UAV located will effect the available of solar irradiance. e.g. the local time of Malaysia and United States of America (USA) are different. At the same time, the local time can be converted into the number of iterations to determine the value of solar irradiances for respective location using equation 3.10.

$$\boldsymbol{t_i = t + t_{fly} + zone} \quad (3.10)$$

Where,

t_i = Number of iteration to determine the value of solar irradiance for respective location

t_{fly} = Cumulative flight time

$zone$ = The time zone for respective location

Once the local time and location of UAV are known, the current available of solar irradiance can be obtained. This data will be used in power estimation. The power generated by solar cell can be estimated by using equation 3.11.

$$\boldsymbol{Power_{in} = Ir \times A \times cell_{eff} \times MPPT_{eff}} \quad (3.11)$$

Where,

$Power_{in}$ = Power generated from solar cell

At the same time, the power output by UAV can be estimated by using equation 3.12.

$$\boldsymbol{Power_{out}} = \left(\frac{\mathbf{1}}{\mathbf{2}} \times \boldsymbol{rho} \times \boldsymbol{v}^{\mathbf{2}} \times \boldsymbol{S} \times \boldsymbol{C_{Do_w}} + \frac{\mathbf{2} \times \boldsymbol{K} \times \boldsymbol{W_{UAV}}^{\mathbf{2}}}{\boldsymbol{rho} \times \boldsymbol{v}^{\mathbf{2}} \times \boldsymbol{S}}\right) \times \boldsymbol{v} \quad (3.12)$$

Where,

$Power_{out}$ = Power usage

With the power output and power generated along the flight path, the state of charge of battery can be obtain as show in equation 3.13 and 3.14.

$$\boldsymbol{battery_{charge_i}} = \boldsymbol{battery_{charge_{i-1}}} + (\boldsymbol{Power_{in}} - \boldsymbol{Power_{out}}) \times \boldsymbol{t_{fly_{i-(i-1)}}} \quad (3.13)$$

Where,

$battery_{charge_i}$ = Battery charge at current location

$battery_{charge_{i-1}}$ = Battery charge at previous location

$t_{fly_{i-(i-1)}}$ = Time taken for changing location

$$\boldsymbol{SOC_i} = \frac{(\boldsymbol{battery_{cap}} - \boldsymbol{battery_{charge_i}})}{\boldsymbol{battey_{cap}}} \times \mathbf{100} \quad (3.14)$$

Where,

SOC_i = State of charge of battery

In every iteration, the flight speed, flight altitude and the initial time to fly are changed to obtain SOC of battery.

CHAPTER 4

4. RESULT AND DISCUSSION

4.1 Spiral Pattern (Flight Path A)

Spiral pattern (flight path A) is simple to understand and easier to simulate. However, there are few constraints that limit the performance of UAV. The SOC profile of UAV by using highest battery pack, highest solar panel efficiency, flying with 60km/h and different starting time from 1st day of each month were compute and shown in figures 4.1 and 4.2. The parameters used in simulation shown at Table 4.1.

Table 4. 1 : Parameters used

Cruise Velocity, km/h	Altitude, km	Solar Panel Efficiency, %	Battery Capacity, Whr	Target Output
60.00	1.00	50%	441.00	Figure 4.1 – 4.12

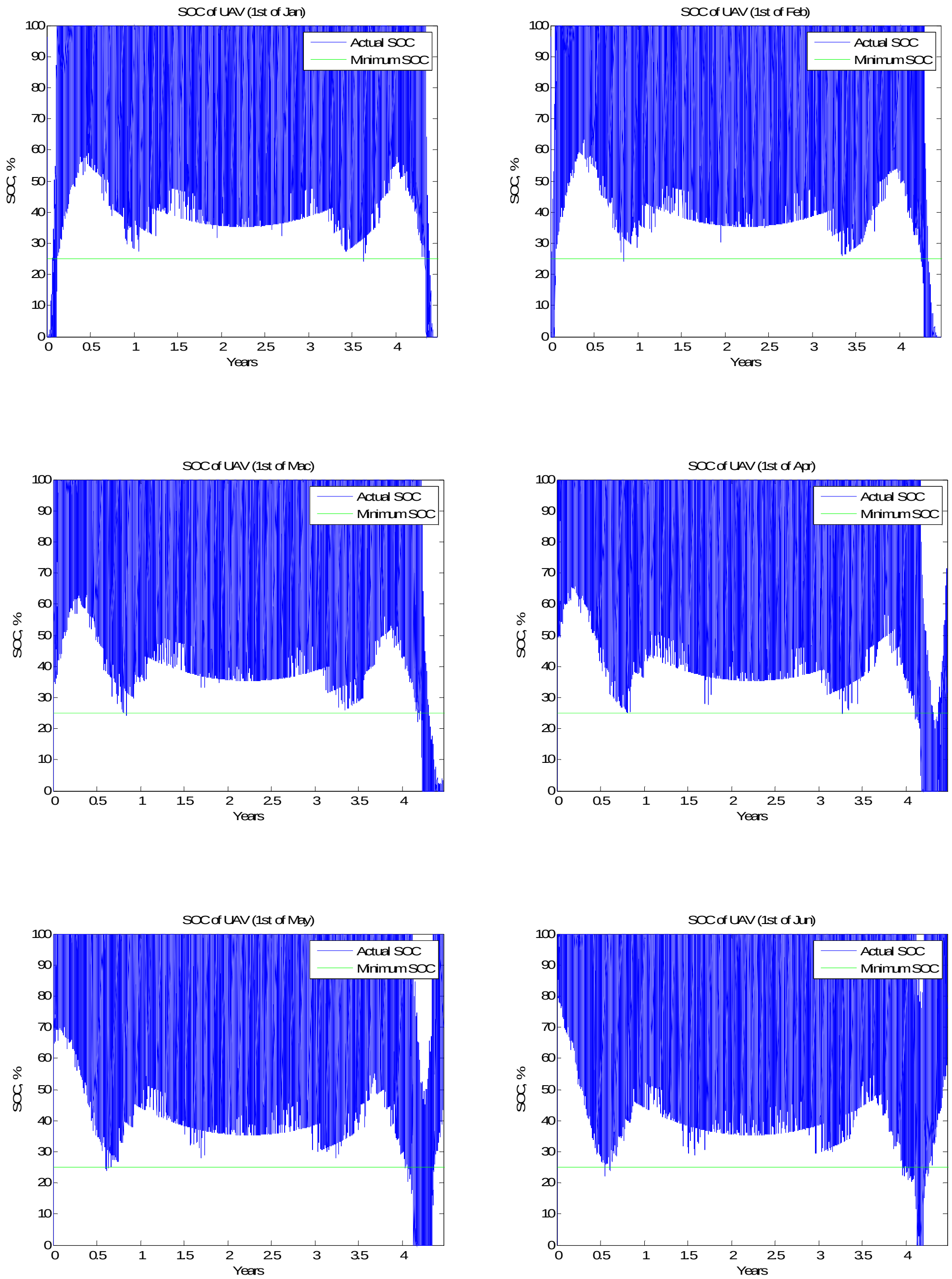

Figure 4. 1 : SOC profile of UAV (1st of each Jan-June)

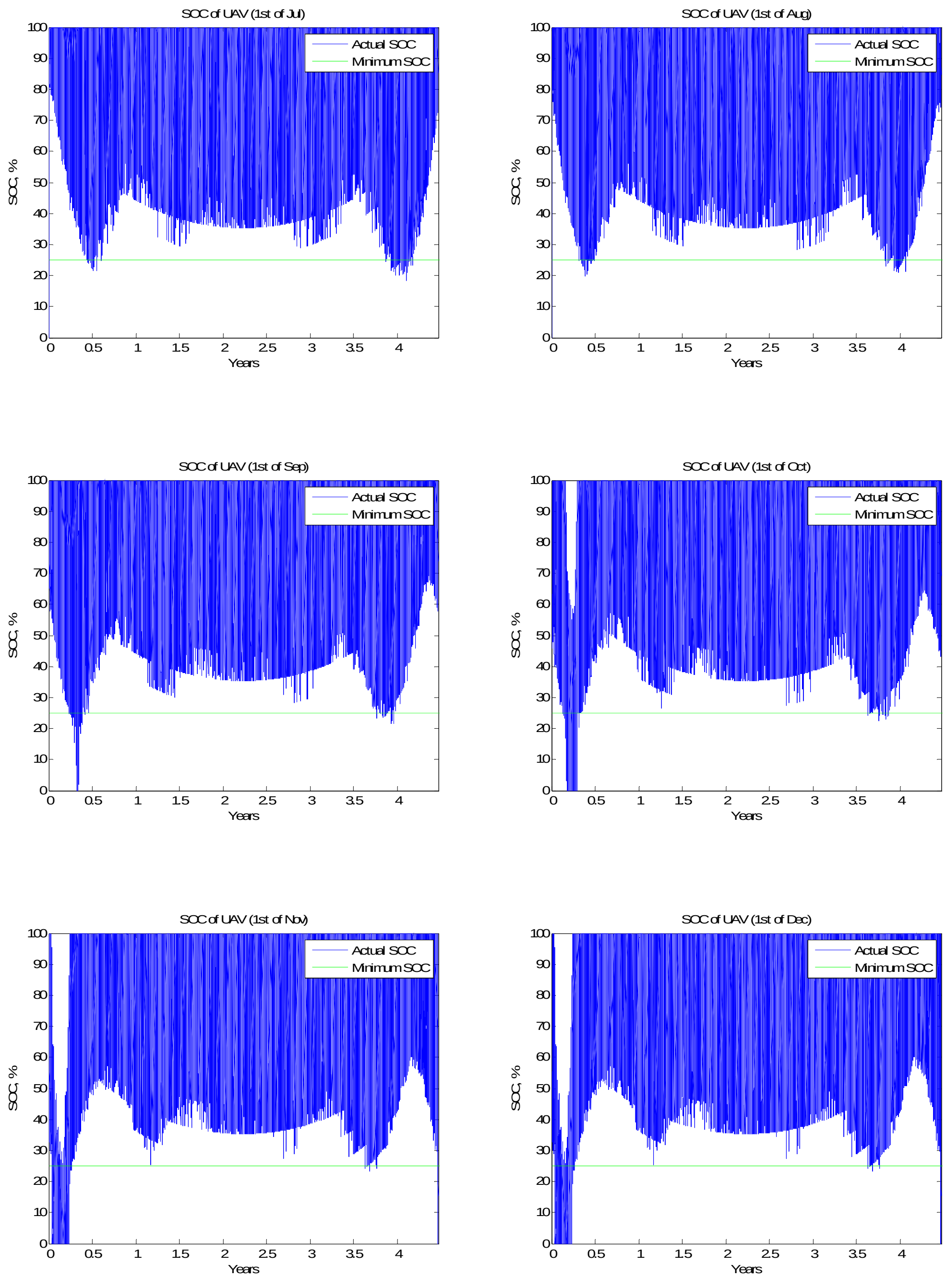

Figure 4. 1 : SOC profile of UAV (1st of each July-Dec)

The result shown that none of the simulated minimum point of SOC reached are higher than 25%. 10 out of 12 months show the SOC status hit 0% in some region of the flight path.

Further simulation by changing input parameter such as battery pack and solar panel efficiency was suspended. This is because the simulation of UAV previously simulated with best configuration. SOC profile of UAV expected hit 0% again after varying the input parameter which is meaningless. So the simulation of Zig-zag pattern (flight Path B) were proceeded.

Other than best configuration of UAV used in previous simulation, another reason why terminate simulation of flight path A is the seasons on earth. From the figures above, it is obvious that SOC profile hit 0% at the range where close to the designed flight path starting point or close to the ending point of flight path. This is because the range close to starting point are region above Arctic Circle of earth, while the range close to ending point are region below the Antarctic Circle. This two region on earth have cold weather especially in winter season. Most of the time in one day that region stay in darkness, the day time only few hours with weak solar irradiance. Hence solar powered UAV most likely impossible to perform perpetual flight in this extreme condition. The propose solution is that UAV flying with very high speed, cover these regions within half year during Spring and Summer seasons. So that UAV can avoid flying long duration in darkness. However, UAV flying with these kind of speed consume a lot of power which power generated by solar panel is not enough to cover. SOC of UAV expected hit 0% again.

4.2 Zig-zag Pattern (Flight path B)

The main concept of path planning in flight path B is avoiding UAV flying in season with low solar irradiance, such as Autumn and Winter seasons. Hence UAV is designed flying in zig zag pattern cover a section of half hemisphere of earth within Spring and Summer seasons. After half year, the UAV will continue flying in zig zag pattern cover a section of another hemisphere of earth. Thus UAV can always flying in Spring and Summer seasons along the path. The latitude cover by this method are from Arctic Circle to Antarctic Circle.

4.2.1 Time Taken to Complete 1 Cycle of Earth

The time taken for UAV to complete 1 cycle of earth is important to justify the feasibility of zig-zag pattern (flight path B). In order to understand the impact of flying altitudes versus time taken, can be simulated by changing the flying altitude. The result is shown in figure 4.3. The parameters of UAV used in simulation were listed in Table 4.2.

Table 4. 2 : Parameters used

Cruise Velocity, km/h	Altitude, km	Target Output
45.06	1.00	Figure 4.13

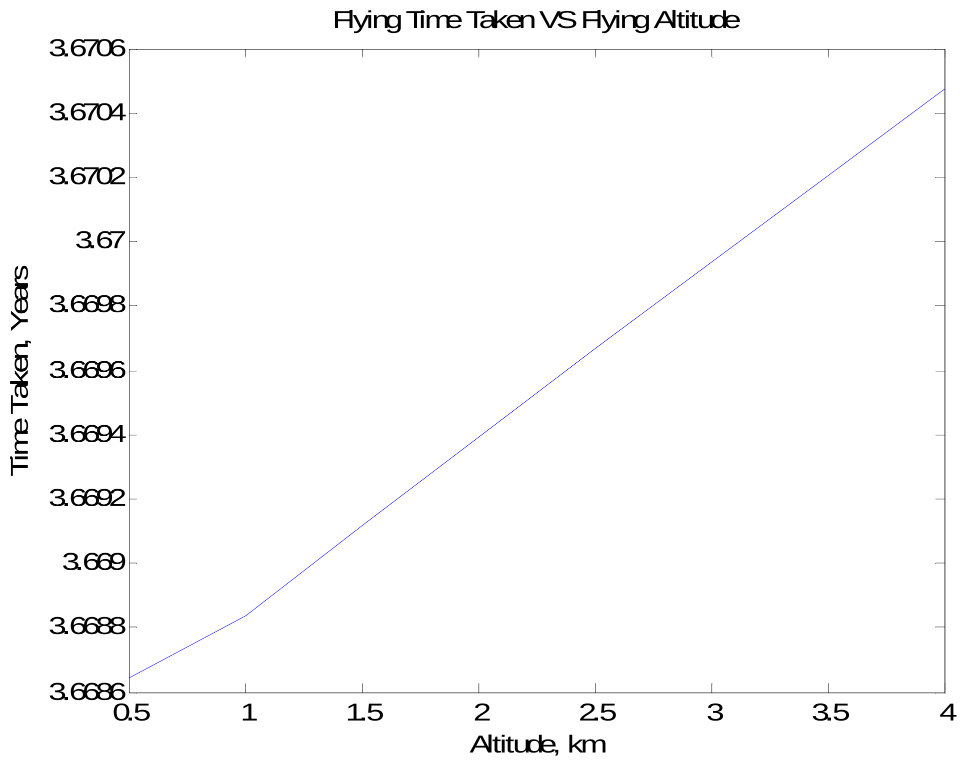

Figure 4. 2 : Flying time taken to complete 1 cycle of earth against flying altitude above digital elevation model of earth

Figure 4.3 shown as the altitude increased, the time taken to complete 1 cycle of earth also increased. The graph show positive gradient can be explained by the range of signal always constant if there is no any obstacle. As the altitude increases, region covered in the range of signal are decreases, thus the zig-zag flight path of UAV in same area are increases in order to cover all surface of the area. The increase of zig-zag flight path reflect the increase of the range of UAV, thus the time taken to complete one cycle of the earth is increased. In this case, it is recommended that the flying altitude at 1km due to having shorter time and flying above obstacles e.g. building. Therefore, the flight path is collision-free.