UNMANNED AERIAL VEHICLE POWER ESTIMATION WITH NON-POLARITY CHARGING SYSTEM

AL OBAIDI MOHAMMED RMAEZ HADI

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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November 2019

Chairman : Mohd Amrallah B.Mustafa, PhD
Faculty : Engineering

This study focuses on the Unmanned Aerial Vehicles of lightweight electric vertical take-off and landing vehicles that also referred to as drones, are becoming increasingly popular in various important application areas such as surveillance, military applications, and monitor hazardous environments. One of the problems for using aerial robots is the relatively small duration of the flight because of limited power capability to achieve a long period of mission continually. The discharge capability which is the the way the battery is discharged and the charge storage capacity limitation of their lithium-ion battery can restrict their flight time endurance. Moreover, the autonomous landing and charging must be highly precise due to the lack of precision and accuracy of landing systems, Therefore, the utilization of an automatic drone's charging station is highly desirable for those robots. This thesis addresses the aforementioned UAV power limitation problems and landing inaccuracy by Proposing a power management system that includes smart design of platform and charging circuit that can overcome the landing in an inaccurate manner disregarding to the UAV orientation, which is done by proposing a new platform topology. This charging system employed six bridge diodes in this topology to integrate with a platform configuration of a consecutive positive and negative charging plate. This integration of components has created a UAV charging system characterized by non-requirement for accurate landing to adjust the charging polarity when the UAV lands on the charging platform. However, Due to complications of flight maneuvers and highly unpredictable power consumption that can occur during flight missions, its necessary to establish a power monitoring system by measuring the real-time voltage and current of the UAV battery status and determine the flight time-efficient operation manner. However, as of today all the processes in the robotic system restrict in-air movement, consume energy and thereby defining the overall operation time limit, the problem is more pronounced in battery-powered electric UAVs since different flight regimes like takeoff/landing and cruise have different power requirements and dead stick condition (battery depletion during flight mission) can have catastrophic consequences. the power rate measurements were conducted by developing a wireless monitoring circuit, which is proposed for this purpose that has the benefits of energy monitoring. The proposed wireless monitoring circuit characterized by its dependence on the RF-node embedded microcontroller to process and transmit the data to a monitoring station for more analysis. Therefore, this topology utilizes its own microcontroller and software driver to perform its functions. However, the unmonitored battery discharge is the major problem for UAVs to travel long distances, at least half of the energy in the battery must be saved to travel back to the launch site for recharging to address this issue, this work proposes an algorithm to analyze the energy data that collected through the proposed monitoring system to achieve modelling the power consumption patterns of particular drone trajectories with a specified environmental condition, which is solved by applying a robust approach called Bode Equation Vector Fitting (BEVF) algorithm and derive a measurement-based model for endurance estimation of such drone type. the results of the experimentation for a designing methodology that employed has successfully adjusted the polarity of the input power and improve the efficiency of the charging to 86%. Regarding the results of the wireless monitoring has successfully transferred the power data to the monitoring station. Moreover, BEVF algorithm has successfully reduced the RMS error equal to 1.93 in full discharge analysis between the measurement data and the modeling data in which is tuned to enhance the power modeling.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGANGGAR KUASA PESAWAT UDARA TANPA PEMANDU DENGAN SISTEM PENGECASAN TANPA POLARITI

Oleh

AL OBAIDI MOHAMMED RMAEZ HADI

November 2019

Pengerusi : Mohd.Amrallah B.Mustafa, PhD
Faculty : Kejuruteraan

Kajian ini menumpukan kepada Pesawat Udara Tanpa Pemandu (UAV) yang berlepas dan mendarat secara menegak, juga dirujuk sebagai dron, yang menjadi semakin popular dalam aplikasi pelbagai bidang penting, seperti pengawasan, aplikasi ketenteraan, dan pemantauan persekitaran berbahaya. Salah satu masalah dalam menggunakan robot udara ialah tempoh penerbangannya yang agak pendek disebabkan oleh keupayaan kuasanya yang terhad untuk mencapai misi jangka panjang secara berterusan. Keupayaan pelepasan dan batasan kapasiti storan caj bateri lithium-ion dron boleh membataskan durasi penerbangannya. Selain itu, disebabkan oleh tahap akurasi dan ketepatan sistem pendaratan yang rendah, pendaratan dan pengecasan autonomi perlu mencapai tahap ketepatan yang tinggi. Oleh itu, penggunaan stesen pengecasan dron automatik adalah sangat wajar untuk robot-robot tersebut. Tesis ini membincangkan masalah batasan kuasa UAV yang dinyatakan di atas dan ketidaktepatan pendaratan, dengan mencadangkan satu sistem pengurusan kuasa yang merangkumi reka bentuk platform pintar dan litar pengecasan, yang dapat mengatasi pendaratan dengan cara yang tidak tepat tanpa mengambil kira orientasi UAV, yang dilakukan dengan mencadangkan topologi platform baru. Sistem pengecasan ini menggunakan enam keping diod jambatan dalam topologi baru, untuk menyepadukan konfigurasi baru plat pengecasan positif dan negatif secara berturutan. Pengintegrasian komponen ini telah mencipta sistem pengisian UAV yang dicirikan oleh bukan keperluan untuk pendaratan yang tepat, untuk melaraskan polariti pengecasan apabila UAV mendarat di platform pengecasan. Walau bagaimanapun, disebabkan oleh komplikasi pergerakan penerbangan dan penggunaan kuasa yang tidak dapat diramalkan yang boleh berlaku semasa misi penerbangan, adalah penting untuk menubuhkan sistem pengawasan kuasa dengan mengukur voltan masa sebenar dan arus status bateri UAV, dan menentukan operasi masa penerbangan yang cekap. Namun, sehingga hari ini semua proses dalam sistem robotik menyekat pergerakan dalam udara, menggunakan tenaga, dan dengan itu menentukan had masa operasi keseluruhan. Masalah ini lebih ketara terhadap UAV elektrik yang berkuasa bateri, kerana rejim penerbangan yang berbeza, iaitu berlepas

/ pendaratan dan pelayaran mempunyai keperluan kuasa yang berlainan, dan kondisi *dead stick* (pengurangan bateri semasa misi penerbangan) boleh mengakibatkan bencana. Pengukuran kadar kuasa dilakukan dengan membangunkan litar pengawasan tanpa wayar, yang dicadangkan untuk tujuan ini kerana ia memiliki manfaat pemantauan tenaga. Litar pengawasan tanpa wayar yang dicadangkan dicirikan oleh pergantungannya pada mikropengawal tertanam nod RF, untuk memproses dan menghantar data ke stesen pemantauan untuk analisis lebih lanjut. Oleh itu, topologi ini menggunakan mikropengawal dan pemandu perisian sendiri untuk melaksanakan fungsinya. Walau bagaimanapun, pelepasan bateri yang tidak dipantau adalah masalah utama UAV untuk perjalanan jarak jauh, dan untuk menangani isu ini, sekurang-kurangnya separuh tenaga dalam bateri perlu disimpan untuk perjalanan kembali ke tapak pelancaran untuk pengecasan semula. Oleh itu, kajian ini mencadangkan satu algoritma untuk menganalisis data tenaga yang dikumpulkan melalui sistem pemantauan kami, untuk memodelkan corak penggunaan kuasa trajektori tertentu dengan keadaan alam sekitar tertentu, yang diselesaikan dengan menggunakan pendekatan algoritma *Bode Equation Vector* (BEVF) dan memperoleh model berasaskan pengukuran anggaran ketahanan jenis dron tersebut. Hasil eksperimen keatas metodologi yang direka bentuk telah melaraskan polariti daya masukan dengan jayanya, dan meningkatkan kecekapan pengisian hingga 86%. Keputusan telah menunjukkan bahawa pemantauan tanpa wayar berjaya memindahkan data kuasa ke stesen pemantauan. Selain itu, algoritma BEVF telah berjaya mengurangkan ralat RMS yang bersamaan dengan 1.93 dalam analisis pelepasan penuh antara data pengukuran dan data pemodelan yang ditala untuk meningkatkan pemodelan kuasa.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Mohd.Amarallah B. Mustafa, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Wan Zuha b.Wan Hasan, PhD
Associated Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Norhafiz B.Azis, PhD
Associated Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

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ZALILAH MOHD SHARIFF, PhD
Professor and Deputy Dean
School of Graduate Studies
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Name and Matric No : Al Obaidi Mohammed Rmaez Hadi, GS47826

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Signature: ______________________________

Name of Chairman of Supervisory Committee: Dr. Mohd.Amarallah B. Mustafa

Signature: ______________________________

Name of Member of Supervisory Committee: Associated Professor Dr. Wan Zuha b.Wan Hasan

Signature: ______________________________

Name of Member of Supervisory Committee: Associated Professor Dr. Norhafiz B.Azis

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Iin	Input Current
pn	Real Number
rn	Real numbers
Vin	suplly voltage
Vout	Output Voltage
Voc	Voltage Open Circuit
ADC	Analogue to Digital converter
Ah	Amper per Hour
BEVF	Bode equation Vector Fitting Algorithm
BR1	Bridge Diod Rectifier
CF	Curve Fitting model
C-rate	The Maximum Current that Battey can Supply
DC	Direct Current
ESC	Electronic Control Unit to control the speed of motor rotation
FF	Fill Factor is the ratio of the actual maximum obtainable power
GPS	Global positionning system
Ibattery	Measured Battery Current through wireless Transmitter
IH	The Discharge Current Per the Battery Capacity
I_{max}	Maximum Current
IMU	Inertial Measurment Unit
Isc	Current short circuit
I-V	Current And Voltage Measurments
KV	Kilo volts

LiPo	Lithium Ion Polymer Battery
PC	Personal Computer
PID	Proportional integration Deravitive control
Pmax	Maxium Power
R1	Resistance
RAF	Rational Approximation Function
RF	Radio Frequency
RMSE	Root mean square Error
SOC	Battery State of Charge
UAV	Unmanned Aerial Vehicle
Vbattery Vout	Measured battery voltage through wireless transmitter
Vd	voltage drop in the diod rectifier
Vdrone	voltage of the drone Bttery
VF	Vector Fitting Algorithm
WPT	Wireless Power Transfer
η	Efficiency

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter presents a design of energy replenishments and mathematical modulation For the UAV power system which is motivating for the proposed research. It discusses the problem statement, states the objectives and describes briefly the scope for the proposed research. The chapter is divided into six sections. section 1.2 background, briefing introduction about the problem background. section 1.3 summarizes the problem statement. 1.4 highlight the research goal and objectives. 1.5 scope of the proposed and limitations of the study. 1.6 summary of the chapter. 1.7 thesis layout

1.2 Background and Motivation

Nowadays, flying robots, especially quadcopter robots, can contribute an important role to shore the first response in harsh and dangerous circumference and accomplishing the critical mission on hazardous areas that require remote assisting. Quadcopter robotic solutions are well adapted to deal with local unstructured conditions of an unknown environment and can significantly improve safety and security of personnel, as well as improve work efficiency, productivity, flexibility and potentially reduce damage in hazardous areas [1], which reflects the importance of this sensing platform.

Furthermore, multirotor has significate advantage when it comes to enclosed or movement in restricted areas due to vertical take-off and landing (VTOL) capability and high maneuverability and so on, quadcopter UAV platform is lightweight, small, flexibly operated, portable and can carry the sensing equipment to a specific weight [2]. No other equipment can deal with these aspects. Hence, the flexible quadcopter UAV is having a stable performance in accomplishing specific flight missions in complex and dangerous environments. hence, the quadcopter is suitable for operating in such risky environments [3] However, multirotor inherently, They are available in a variety of shapes, dimensions, performance, and other features that allow further customization[4].

Several types of conducted research are ongoing to develop an aerial vehicle system with increasing levels of its autonomy. Typically, autonomy means demanding no direct human intervention. However, to achieve full autonomy it requires an autonomous ground charging operation, and that development is not yet extensive for UAVs [5]. That apparent fact motivates this research to design a power management system. The procedure involves a novel charging station, which accommodates UAV landing imprecision on the charging platform, and resumes the mission without constant human intervention. Therefore, this work develops an automatic charging platform with two options of primary power sources; solar PV and normal utility power to charge the onboard battery landing without requiring accurate landing, and hence providing a ground-based autonomy.

The quadcopter UAV maintains lift and propulsion using four rotors propelled by brushless high-speed Dc motor possessing high mobility and kinesis. The high motor current consumption requires high capacity batteries, which are often bulky. This battery weight prohibits long UAV mission times. These commercially available systems are generally powered by Lithium-Ion (Li-ion) batteries with a high energy density. Li-ion batteries have a long-life cycle. They can handle hundreds of charge and discharge cycles without significant degradation of their capacity. With these significant advantages in mind, Li-Poly batteries are the best choice as the power source for this UAV application [6], However, at present, power storage capacity constrains the extent and autonomy of UAVs. As of today, batteries are the major problem for UAVs to travel long distances. At least half of the energy in the battery must be saved to travel back to the launch site for recharging. The specific characteristics of a LiPo battery may affect the performance and lifetime of a UAV. This problem is more pronounced in battery-powered electric UAVs since different flight regimes like take-off, landing and cruise have different power requirements, A dead stick condition (battery shut off in flight) can have catastrophic consequences [7]. Apart from affecting the overall functionality and performance of the system, it is essential that the batteries are operated safely and reliably under a wide range of payload and weather conditions, with the operator having a clear view of the time left before he needs to land the UAV. According to the consumption characteristics, the battery voltage rapidly decreases in the final phase; due to this, the battery's remaining capacity must be higher than 30–40 % at the end of the flight [8]. Underlying any prediction is the component behavior under nominal conditions in terms of wear or fault. To that end, one needs to capture that process in the form of a mathematical model [9]. Therefore, that necessitates a real-time wireless energy measurement tool, which calculates the unpredicted energy consumption of the UAVs and estimates the flight range threshold. The hardware should be compact with minimum weight and size. The model must estimate the remaining energy in the batteries so the UAV may have enough energy to return for charging and avoid aircraft damage.

The charge profile or power curve in any power system shows the variation in demand or electrical load over a certain period of time For prediction reasons, engineers use this data to map the energy they need to generate at a certain time. The UAV power output fluctuates immensely and is only moderately controllable. Therefore, Forecasting the rate of power consumption can be particularly necessary. System technicians create systems to exploit accessible U AV resources; however, UAV energy usage is similar to the operational standpoint to the demand for traditional power that generates from fossil fuels. Moreover, the key question is how the battery power supply can be extracted to estimate the energy obtained. Hence, investigating and establishing an algorithm to obtain a mathematical model is essential for interpreting, predicting and analyzing such power curves. The difficulty is to find an objective criterion and to assign quantitative parameters that govern the trade-off between the smoothness of the power curve and its proximity to the measured data points [13].

The definition of a mathematical model can be an explanation of a system using mathematical theory and language. Modeling may help to describe a system and revise the effects of different elements, in addition to making forecasts about the system's behavior. The value of the mathematical models is how repeatably it matches the experiments performed. To derive a useful model requires a set of experiments to understand how energy consumption is affected by the different flying conditions, such as speed, horizontal and vertical acceleration:

Regression Analysis

1. plays an important part in a broad spectrum of fitting, prediction and modeling methods, which considers a statistical process for modeling or estimating the correlation between the system parameters and for combining a specific dependent variable with one or more independent variables.
2. The shape of a typical UAV power curve depends on several different factors about the conditions, such as wind speed perturbations and aerodynamic forces, air humidity variations. Other parameters quantitatively describe the load power consumption of components, such as the switching effects and the power supply structure of onboard devices.
3. This study proposes an overall method for modelling formulas that follow the behaviour of the system presented by its data point observation. This technique can fit and formulate many curve forms only based on the field measurements or experimental data

The electric models for electrical engineers are more intuitive, effective and easy to manage and have the key advantage in circuit simulators. Two X-Bee RF module networks, together with current and voltage sensors, were established to describe the power model in this study, in order to gain the current-voltage time characteristics. the obtained modelling error decreases drastically if a smoothing technique for the acquired data is adopted. In contrast, more accurate mathematical modeling can be attained when a suitable formulation is used to model the power consumption pattern and estimate the power requirements during a flight mission.

In this work, the interest is to present the discharge response of the battery during the time evolution of the mission of the UAV. Therefore, the battery lifetime estimation is not being taken to account in this work. A good trade-off between accuracy and complexity can be obtained

1.3 Problem Statement

UAVs power limitation is a major issue that has been addressed frequently in many previous works, to approach this issue, three major problems have been addressed. First, the ground charging station is one of the reliable solutions for recharging the UAV onboard battery, but the requirement of accurate landing is a significant issue.

Furthermore, to ensure UAV power system performance, a real-time monitoring system is required. However, the standard monitoring system still concealed the flight maneuverability of the UAV. Furthermore, the high fluctuation of power consumption data can be analyzed by modelling technique. However, this sharp variation of data requires a prompt formula to fit with the power measurement.

- Drones must rely on their battery capacity since it represents one of the most important limitations to their operation; similarly, drones must perform much of their function away from the stationary power-loading source. due to Limited Battery Lifetime [10] [11], Typically drones are electric vehicles, powered by onboard batteries. Hence, a limited battery lifetime constrains the performance of drones. Many drones are only suitable for short-range trips, which considerably limit their applicability [12]. However, their short run time is one of the main inconveniences of multi-rotor UAVs. This is because these vehicles always require a high amount of electrical power to generate lifting power to move around. In addition, charging was carried out by means of a direct human intervention that motivates the design of an automatic procedure to make a multicopter land on a charging station and resume mission without the need for human intervention.

  For the present Drone charging systems, a precise landing is required with smart tools and complex algorithms. A manual plugging is otherwise necessary for the charging of a self-supporting landing because of challenges such as external disturbances that lead to deviations from the required track and inaccuracies in the localization of the GPS-based landing[13] [14] [15][16].

- Even though it is important to know how to recharge a vehicle, a charging maintenance system will be less valuable if a vehicle does not return to the charging station before the power runs out [17], For every power storage system such as battery or fuel cell must be kept within their safe operating limits during flight mission [18] therefore, a need for a monitoring system is required. the Lithium-ion (Li-Ion), or more specifically lithium polymer (Lipo) Battery is a typical UAV power source because battery capacity reliance on discharge current makes it hard to determine the real energy available during the flight. Moreover , the notion of overall flight energy efficiencies is irrelevant due to the complexity of charging and discharging procedures [12], to prevent damage to the battery, the charging condition or more specifically the state of charge (SOC) of the battery must be maintained within the lower and upper load limits, If the SOC stays outside the safe battery lifetime, the battery can ignite spontaneously and cause a risky fire situation [18]. A Custom-built voltage and current sensing circuit comprise of a sensing resistor for accurate four-terminal sensing, interface with an off-shelf a NI-USB-6211 Data acquisition kit with a sampling rate of 2 samples per second, through signal conditions, via 5 m lightweight Shielded Twisted Paired Cable. While the thread can negatively influence flight dynamics, this is an ineffective monitoring system for inspecting the vehicle's energy consumption during flight maneuvers as compared with hover [19].

Thus the accurate electrical modeling of the Li-ion battery can accurately approximate the dynamical characteristics of the battery during charging, discharging and relaxation phases [20].

- For multivariable control systems, such as UAV's, the modeling of power consumption measurement is a big challenge [21] due to the complexity of data profiles that caused by a wide range of flight parameters. Several fitting model equations succeeded to approximate such measurements but with high deviations due to their including of resonance peaks and the sharp variations. BEVF approach solving this difficulty, which is employed in this study as a robust numerical method to approximate the attained measurements accurately.

1.4 Research Objective

The main goal of this work is to initiate the development of UAV power management system which includes design of efficient charging platform and derive a power endurance estimation model from the monitoring power consumption of a drone during the flight time.

1- To develop a new automatic charging system for UAV, to charge itself by docking on charging station, without human intervention, which compensates for UAV landing imprecision on the charging platform.
2- To propose a UAV onboard wireless monitoring circuit, which collects real-time power charging and consumptions measurements during flying.
3- To propose a model estimation for the power measurement of the UAV for a specific trajectory path during flight conditions based on real-time monitoring measurements.

1.5 Scope and Limitation of the Study

This research focuses on the development and implementation of the quadcopter management system to prolong the flight missions. It presents an autonomous UAV battery recharging solution that negates human intervention which includes a design for charging circuit and platform. This research also includes a monitoring system design used to monitor the UAV power measurement during flight and charging. Furthermore, employs a mathematical model, used to estimate energy requirements. The research manages to achieve its objectives by practical laboratory experiments undertaken at University Putra Malaysia. The scope of this research limited to the following. First, the design of the landing pad could not compensate for the moisture problem. The onboard circuit includes a voltage regulator to limit the current as a safety procedure, moreover the contact pins are limited to four regarding each of the four legs of the drone and the onboard modulator circuit design topology designate six bridge diode rectifiers only. Second, the monitoring system covers approximately 5km. the experiment conducted in nominal weather as mentioned in Table 1.2. Third, a specific trajectory and heights for flight missions were conducted on this experiment. This research adopts a UAV quadcopter with specifications given in Table 1.1.

Table 1.1 : Quadcopter Specifications

MODEL	SPECIFICATIONS
Parrot Bebop 2 Drone	Fiberglass-reinforced polyamide to ensure resistance and lightness frame is a light-weight foldable frame designed to be highly portable.
Lipo battery	Capacity: 2700mAh, Voltage: 3 Cell / 11.1V, Current: 21.6A Weight: 230g
Sunny Sky motor	V3508-20 KV580 RPM/V brushless motor
T-Series 1355propellers	Size: 33 x 4 x 1cm / 13 x 1.6 x 0.4 inch

Table 1.2 : Weather Conditions

WEATHER	VALUES
Wind speed	0-5km/h
Humidity	49-75%
Temperature	27-36°C
Rain or no rain	No rain

1.6 Research Contribution

This research aims to develop a fully autonomous drone recharging system, including a charging station prototype. Autonomous recharging can significantly extend the range of drones. Since the charging platforms could be strategically placed along a route.

Also, this research will contribute to the industrial sector by developing a wireless onboard monitoring circuit with lightweight to collect the real-time measurement for UAVs during the flight time. to carry out reliable UAV quadcopter energy measurement and the effect of flight parameters and the weather on.

This work analyses the electric power consumptions of a drone during the flight time and derives an endurance estimation model for the remaining energy to avoid damage for the batteries by using Bode equation vector fitting algorithm

1.7 The Layout of the Thesis

Chapter 1 presents a general introduction to the subject and the problem statement. It also introduces the aims, objectives, and contribution of the study, and gives a brief summary of the structure of the thesis.

Chapter 2 gives a description of the process steps used to develop this flying robot for its application and proposes potential searching patterns.

Gives the description of the process used to develop the charging systems for the flying robots and estimate the energy consumption using mathematic modelling

Chapter 3 describes the research methodology carried out to achieve the objectives and discusses the steps that are taken to develop this quadcopter UAV charging and power monitoring data system and using mathematic modelling for power consumption.

Subsequently, Chapter 4 presents the results with discussions and verifies the results obtained to rationally present a quadcopter charging and monitoring system and power data modelling

Finally, Chapter 5 gives a summary and the conclusion according to the findings of this research. Suggestions and recommendations for future research in this area are also presented in this final chapter.

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