COLOUR BASED OBJECT DETECTION AND TRACKING FOR AN AUTONOMOUS QUADROTOR

BY

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A dissertation submitted in fulfilment of the requirement for the degree of Master of Science (Mechatronics Engineering)

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ABSTRACT

Useful applications of Unmanned Air Vehicles (UAVs) include aerial surveillance in hostile military zones or search and rescue operations in disaster stricken areas. The increased visual capacity of UAVs also helps support ground vehicles during scouting missions or to extend communication beyond insurmountable land or water barriers. Computer vision techniques provide a simplistic means to convey information for motion control of a UAV. Hence this work focuses on the development of a vision based image processing algorithm for autonomous navigation of a quadrotor UAV. A camera was used to capture an aerial field of view and transmit a video stream of its perspective to a base station- where OpenCV 2.3.1 vision processing software was used to implement a vision processing algorithm. The algorithm comprises of colour thresholding, the use of image moment and blob detection to detect and track an object within the camea view. Experimental readings of an object's displacement at three altitudes; 1.5m, 2.0m and 2.5m were used to derive pixel-to-cm conversion equations based on the target's pixel coordinates on the viewing window. Through a statistical analysis of variance and standard deviation conducted on 15 experimental readings of displacement ranging from 5cm to 25cm; it was shown that the vision system is best suited for tracking displacements at lower altitude flights. Hence, the best result for variance and standard were achieved when using the derived equation and were 0.64 and 0.8 respectively. The equation derived was also used to derive GPS locking coordinates. Pixel coordinates of a target on the camera display were then used to produce GPS locking coordinates for the quadrotor to track a target object.

ملخص البحث

تطبيقات مفيدة من استخدام المركبات الجوية من دون طيار(VsUA) تشمل المراقبة الجوية في مناطق الحرب أو عمليات البحث والإنقاذ في مناطق الكوارث. زيادة القدرة البصرية في هذه المركبات يساعد أيضا دعم المركبات البرية خلال البعثات الكشفية أو لتمديد الاتصالات خارج المناطق لا يمكن التغلب عليها عن طريق البر أو البحر. تقنيات رؤية حاسوبية تقدم حل فعال لتحكم حركة هذه المركبات. من ثم يركز هذا البحث على استخدام معالجة الصورة الرقمية و تقنيات رؤية حاسوبية لتحكم حركة quadrotor UAVs. وضعت كاميرا لالتقاط المنظور الجوي وأحالته إلى محطة معالجة- حيث يستخدم برنام OpenCV 2.3.1 لتنفيذ نظام الحلول الحسابية. هذا النظام يتكون من العتبة للألوان, استخدام image moments و blob detection لتكتشف وتتبع كائن معين. تسجلت قراءات إزاحة الكائن, الذي لونهو واضح وفريد من وجهة نظر الكاميرا, من ثلاث ارتفاعات الكاميرا (1.5m, 2.0m and 2.5m)- هذه تمثل طيران uadrotorq. هذه كانت استخدمت لحصول معادلات التي تحول الإزاحة من بكسل إلى سنتيمتر. بعد ذلك تحليل إحصائي تطبق على 15 تسجيلات إزاحة تتراوح بين 5cm و 25cm. نتيجة تحليل التباين والانحراف المعياري تثبت أن الإعداد المستخدم في هذا البحث هو انسب للطيران على ارتفاعات منخفضة. هكذا أنسب نتيجة لتحليل التباين كانت 0.64 و أنسب نتيجة لانحراف المعياري كانت 0.8. المعادلات المشتقة استخدمت إلى أنتج إحداثيات نظام تحديد المواقع لأجل quadrotor UAV تتبع الكائن المعين.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Mechatronics Engineering.

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…………………………………..
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DECLARATION

I hereby declare that this dissertation is the result of my own investigation, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Hani Hunud Abia Kadouf

Signature………………………. Date ………..................

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LIST OF ABBREVIATIONS

3D	Three Dimensions
APM	Ardupilot Mega
ADC	Analog-to-Digital Converter
cm	Centimetres
CMY	Cyan, Magenta and Yellow
ESC	Electronic Speed Controller
FET	Field Effect Transistor
GPS	Global Positioning System
GCS	Ground Control Station
FPV	First person View
I2C	Inter-Integrated Circuit
IMU	Inertial Measurement Unit
km	Kilometres
lat.	Latitude
lon.	Longitude
mAh	milliampere-hour
MAV	Miniature Air Vehicle
MCU	Main Controller Unit
MPC	Model Predictive Control
PID	Proportional Integral Derivative
PPM	Pulse Position Modulation
PWM	Pulse Width Modulation
RC	Remote Control
RF	Radio Frequency
RGB	Red, Green and Blue
HSV	Hue, Saturation and Value
HSL	Hue, Saturation and Luminescence
UAV	Unmanned Aerial Vehicle
USB	Universal Serial Bus
RPM	Revolutions per Minute
SI	International System of Units
NED	North-East-Down
QVGA	Quarter Video Graphics Array

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

Robotics has become a fundamental component of modern society leading to more advanced research. With reducing costs and evident simplicity, robotic applications are no longer limited to the confines of factories but have also proven their usefulness in the offices as well as in homes. McCall and Corder (1997) described unmanned aerial vehicles (UAVs) as aircrafts that do not require the presence of a pilot for navigation or to perform numerous other tasks. They are powered vehicles that can be either remotely piloted or controlled autonomously and have been discussed extensively in literature (Weibel and Hansman Jr., 2004; Raffo, Ortega, and Rubio, 2010; Guenard, Hamel and Mahony, 2008).

The field of aerial robotics in particular opens new venues for a multitude of important tasks and services that utilize an aerial perspective. Tarhan and Altug (2011) discussed its applications may include surveillance in hostile military zones, search and rescue operations, mapping, inspection and maintenance wherever land and sea navigation is cumbersome. Due to their overwhelming advantages, a substantial interest in aerial robotics has grown in recent years. The main areas of research interest include innovative designs, autonomous missions, guidance, navigation and control, as well as multi-vehicle coordination.

One of the early editions of UAVs is the drone which was launched with the aim of gathering information for higher risk missions that involve combat UAVs (Blom, 2006). The term “drone” was coined in 1959- the year that the modern UAV was born; and was used to describe aerial controlled aircrafts and aerial targets (Weibel and Hansman Jr., 2004). It was also required to fly out of the operator's sight, without any intelligence though they had a pre-programmed route that brings it back to the base. Information such as photographs is only retrievable after its return to base (Austin, 2010).

Modern UAVs on the other hand are usually equipped with a degree of intelligence that allows for communication with its controller while in flight. They are also capable of sending send payload data collected such as thermal TV images or their primary state information; such as altitude and attitude information. They can also send "housekeeping data" such as fuel levels or component temperatures. Modern UAVs are also equipped with safety mechanisms in case of faults occur in its components or subsystems. They may take corrective measures automatically or notify its operator. For example, in the event of a communication breakdown between a UAV and its control station; the UAV may be designed to automatically search for a radio signal to re-establish communication or it may switch to a different frequency to re-establish communication.

UAVs are produced in various different of sizes, shapes, configurations and characteristics. Tarhan and Altug (2011) also discussed how they have clear advantages to piloted aircraft as they possess a higher maneuverability, low cost, decreased radar signature, strength, and a decreased risk to human life.

1.2 QUADROTOR UAV RESEARCH

Recent technological advancement has led to the development of autonomously controlled UAVs, which have the capability to carry out preprogrammed flight plans (Coelho, 2012). Leishman (2001) described the mechanics of a quadrotor, which was first experimented in 1907 by Breguet and Richet. Initially, it was as a large, heavy, manned vehicle reportedly able to lift into flight only over a small height and for short duration. Zul Azfar and Hazry (2011) discussed the evolution of the quadrotor into a small UAV with a lift generated by four rotors that can be controlled by autonomous alteration of the speeds of its motors relative to each other.

Bouabdullah, Becker, de Perrot, and Siegwart (2007) describe the quadrotor as an under-actuated dynamic vehicle with four input forces to control the six degrees of freedom system; thus, when considering its motion control, there are three main parameters involved. These are the angles of rotation about the vehicle's center of mass, which are known as: the pitch, roll, and yaw. Both Balas (2007) and Bresciani (2008) used control techniques to alter these parameters either individually or together enabling the motion of the vehicle to be influenced or altered as needed.

Altug (2003) investigated the control of the quadrotor, whereby control of its 6 degrees of freedom (DOF) is done by using feedback from different on-board and off-board sensors. Since a quadrotor helicopter has four fixed pitch angle rotors, unlike regular helicopters that have variable pitch angle rotors, it allows for a higher payload than single or dual rotor UAVs. This makes it safer and more suitable to carry various on board sensors. It also has greater maneuverability.

As was detailed by Azrad, Kendoul and Nonami (2010), the hardware of most autonomous UAVs includes a diverse range of mechanical and non-visual sensors such as rate gyros, accelerometers, inertial measurement units (IMU) and global positioning systems (GPS). They are used to determine attitude and position of the UAV; whereas, for systems that carry out more complex applications such as tracking and detection, more sensors- such as visual or audio sensors, are consequently required (Saripalli et al., 2005). The problem arises when the payload limitations of

UAVs in handling Many sensors occurs and hinders its optimal performance. Hence payload management is an important issue that has to be taken into consideration in the hardware design (Habrare and Sukhatme, 2003; Castillo, Lozano and Dzul, 2005; Meijas, Saripalli, Campoy and Sukhtame, 2006).

There are several structural benefits to the use of quadrotors over traditional-rotor helicopters and other fixed-wing aircrafts. This is in reference to their simplistic design, their ability to hover, their capacity for vertical takeoff and landing (VTAL), their maneuverability, and capability of indoor and outdoor flight (Alexis, Nikolakopoulos and Tzea, 2010). With smaller rotors, the quadrotors have less kinetic energy, making them safer and less prone to causing a lot of damage when colliding with other objects. For these reasons the quadrotors have been gained substantial popularity as a platform for UAV research.

1.3 VISUAL SERVOING

The use of vision to control a robot is not a new theory and has been discussed since the late 1970's. Hill and Park (1979) first introduced the term visual servoing in reference to a system that directly makes use of vision in its feedback loop rather than traditional methods of look then move. It was this revolutionary concept that was then successfully applied in the manufacturing industry for several decades since.

In more recent times, as precision became a major concern in the field of visual robotics, a wide range of research has been initiated to deal with many factors ranging from real time image processing techniques to camera calibration on a variety of platforms (Proctor, 2006). Most of the past visually controlled robots have had a fixed base with equal numbers of actuators as degrees of freedom and a well-defined set of possible configurations. This led to the development of vision based control theories and further research on the dynamic effects of using vision sensors in feedback loops (Corke and Good, 1996). There is however a difference when using an aerial platform, as the position and attitude are unconstrained. (Mikawa, Maru and Miyazaki, 1994) have also extensive research on the expansion of visual servoing from the basic holonomic robots, such as those used in manufacturing industry, to nonholonomic systems like mobile robots. This however is still in the early stages exploration with little theory on the use of vision in control and navigation of UAVs. Figure 1.1 shows the general block diagram for a visual servoing system.

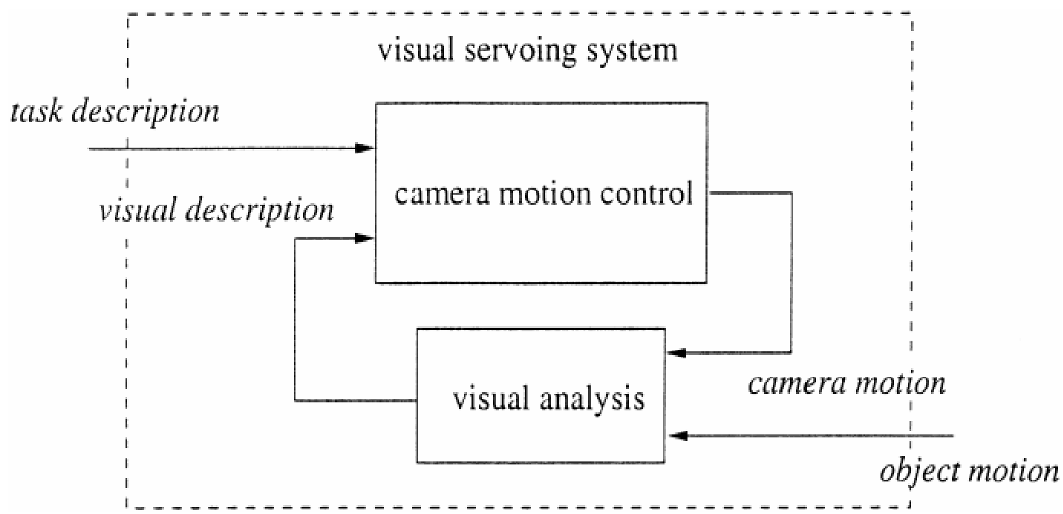

Figure 1.1 General Block of Visual Servoing System (Conticelli, Allotta, and Colombo, 1999)

1.4 PROBLEM STATEMENT AND SIGNIFICANCE

Although navigation of quadrotor UAVs has been extensively discussed in literature, the main focus has generally been on human based remotely controlled systems rather than autonomous systems. Some recent works shift the focus into visual servoing on the UAV which targeted application such as the development of vision-based control methods for basic control of quad rotor. These include autonomous take off, landing, stabilization and navigation. With the advancement in application of image processing algorithms, it is possible to extend functionality of quadrotors to perform other autonomous tasks such as detection and tracking. This enables the human user to focus on tasks other than directly influencing the quadrotor. Hence, this research will investigate the development of a UAV system with robust target detection and tracking.

1.5 RESEARCH OBJECTIVES

The objectives of this research are as the following:

1. To construct a quadrotor UAV prototype with visual servoing capability.
2. To develop a robust object detection algorithm suitable for the UAV system.
3. To develop a formula to interpolate the relative distances in the image plane to incorporate the target detection algorithm for UAV tracking.

1.6 RESEARCH METHODOLOGY

The research methodology is explained in this section.

- Literature review: The literature review will compose the assessment of recent available research on image processing algorithms.
- Prototype Assembly: The physical development of the quadrotor platform on an autonomous agent conforming to the needs of real time video image transmitting and receiving.
- Software Development: Detection and tracking algorithms with the use of OpenCV Library are developed in this programming phase. The aim is the

development of an algorithm capable of detecting an object that is uniquely coloured within its surrounding.

- Implementation of tracking algorithm: The algorithm is implemented in the generation of GPS tracking coordinates.
- Testing and Evaluation: An analysis of the results is conducted and options to improve performance in detection and tracking operations are discussed.

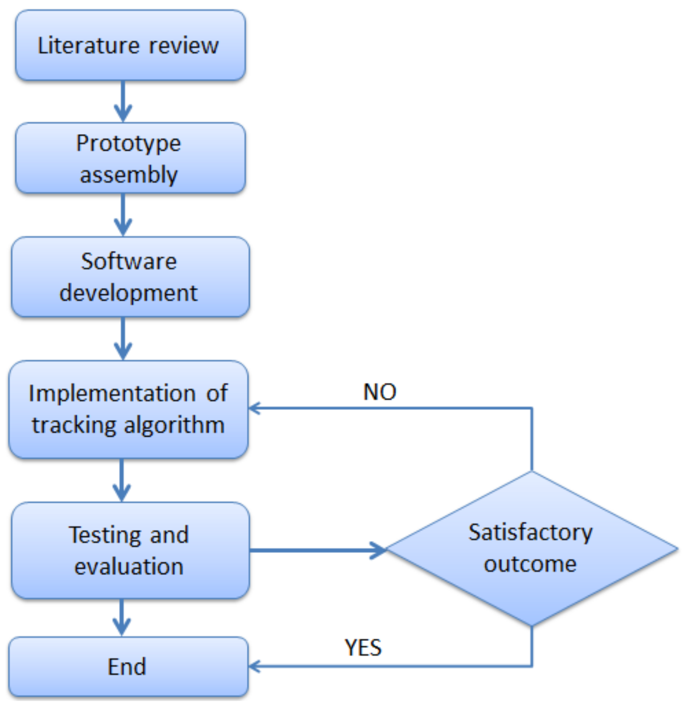

Figure 1.2 Research Methodology Flowchart

The summary of the Research Methodology is depicted in the flow chart shown in Figure 1.2.

1.7 RESEARCH SCOPE

The scope of this research is to develop a quadrotor UAV system with object tracking capability. For this project, some assumptions were made, which are as the following:

1. For the image processing it is assumed that the camera on the UAV is always looking downwards perpendicular to the ground.
2. It is also assumed that the object to be tracked by the UAV has a distinguishing colour and never goes out of the view of the camera.
2. This project only deals with low altitude flight due to the limitations of resources. However, it can be assumed that the methodology is valid for high altitude flight.
3. It is also assumed that the accuracy of the GPS on the UAV is ideal, with zero errors and the minimum resolution of the camera on the UAV is at least QVGA (640 x 480) resolution.

1.8 DISSERTATION ORGANISATION

This thesis is organized in the following manner; Chapter one is an introduction to the research where an overview of the quadrotor system is given, along with the problem statement and objectives. Chapter two is a review of relative literature that provides the platform for this work. An emphasis is made on the field of computer vision and its application on quadrotor UAV navigation. Chapter three is a discussion of the development of the vision based quadrotor system. Chapter four is an explanation of the hardware and software and their interaction in the system. Chapter five shows the results achieved in the research. Chapter six is a review of the achieved objectives and recommendations for future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Vision systems, when integrated with UAV functionality can play a commanding role in accomplishing various tasks as they provide a vast source of information- once extracted and analyzed. Due to the natural connection between vision and human driven tasks, the potential for its uses and applications is enormous as vision is the main interface for humans to interact with their surroundings (Campoy, Correa, Mondragón, Martínez, Olivares, Mejías and Artieda, 2009).

Treacherous work done by helicopter pilots and camera men who perform important tasks within the infrastructure inspection industry provides an opportunity for vision systems to be utilized. In such cases, wastage of resources may be reduced with the use of multipurpose UAVs such as quadrotors. These can be used to obtain an aerial perspective of any chosen terrain for further analysis (Puri, Valavanis and Kontitsis, 2007). This approach may also be applied to the imaging of oil pipelines, power lines or road inspection. In this manner the use of vision systems is proven to be a cheaper and more efficient alternative. UAV autonomous missions can also be carried out via the integration of vision sensors to perform otherwise human driven tasks.

In this chapter we will examine some of the problems in vision based navigation systems, with a brief review of the already existing autonomous quadrotor