Unmanned Aerial Vehicle Payload Development for Aerial Survey

ENG460 Engineering Thesis

Nick Sargeant

A report submitted to the School of Engineering and Energy, Murdoch University in partial fulfilment of the requirements for the degree of Bachelor of Engineering.
Abstract

Aerial imaging is key part of remote sensing and surveying, however traditional acquisition methods such as satellite imagery and manned aircraft suffer from some limitations, namely, “high capital, operational and personnel costs, slow and weather-dependent data collection, restricted manoeuvrability, limited availability, limited flying time, low ground resolution”[1]. Unmanned Aerial Vehicle have gained increasing attention in recent years as technological advancements such as sensor minimization have made them a viable alternative for aerial photogrammetry applications.

This report outlines the design and development of an Unmanned Aerial Vehicle suited for aerial survey. The first stage of the project involved a comprehensive literature review of existing research and evaluation of existing commercial solutions.

Existing commercial solutions such as the Gatewing X100 have proved capable in industry, however a number of limitations were identified; the most prominent being that the optical payload they carry is rigidly coupled to the airframe.

As weather conditions become more adverse and wind gusts buffet aircraft, the camera’s axis no longer orthogonal relative to ground which ultimately reduces the quality of the data captured.

Research identified from the literature review showed that “payload stabilization increases useful data capture during banking and increases processing success rate thanks to overall more predictable photo properties.” [7] In addition, “even when ordered to ‘fly straight’ over ground, deviations in roll and pitch of a few degrees occur due to turbulence and require extra image overlap pre-planned. Such overlap is costly in terms of flight time and performance worsens significantly during windy weather” [7]. As such, the primary focus of this project was to design an improved imaging payload design that actively stabilized the camera.

The project started by evaluating a sub $200, open source, autopilot called the Ardupilot in a fixed wing aircraft. An appropriate camera and airframe were selected and a stabilized gimbal designed. During the project, setbacks were encountered when Cyber Technology, a company that provides ‘UAV solutions for search and rescue operations, military support, high-end surveillance, law enforcement, environmental conservation, agricultural operations, oil & gas structural inspection operations, and cinematography/photography applications’[2] showed interest and suggested that the project should instead focus on designing a surveying payload for one of their flagship products, the CyberQuad MAXI. An imaging payload was designed that satisfied all design constraints and was successfully integrated onto the CyberQuad. A flight planning parameter calculator was created and trial flights were then conducted.

The planned test methodology to evaluate the gimbal was to collect imagery of a test site, flying repeated missions with a given overlap first with gimbal stabilization enabled and then again with the stabilization disabled such that the gimbal remained fixed. By contracting licensed surveyors to conduct a conventional survey of the test site, using their data as an absolute reference, it was planned that the imagery captured could be
processed using photogrammetric software and any improvements due to stabilization be quantified.

Unfortunately the data from the ground control survey was not provided in time to be used for processing; however the gimbal did improve image acquisition. Further, in partnership with the aforementioned surveying company, a commercial test flight was conducted at Kwinana Bulk Terminal surveying an iron-ore stockpile with industry grade models generated as a result.

Development of the project will continue beyond the submission of this thesis and it is hoped that the survey data can be obtained and used for processing. This should definitively prove one of the original hypotheses of the research; using a stabilized gimbal allows for more efficient flight plans as a lower level of overlap is required. Additionally, the data generated from processing should allow an estimated function of overlap vs. model accuracy to be determined allowing future flight plans to be optimized.
Contents

Abstract .......................................................................................................................... i

I. List of Figures ........................................................................................................... v
II. List of tables ............................................................................................................. vi
III. Abbreviations and Definitions ............................................................................... viii
IV. Acknowledgments ................................................................................................... xii

1. Thesis Structure ....................................................................................................... 1
2. Introduction ............................................................................................................... 1
   2.1. Photogrammetry .................................................................................................. 1
   2.2. Unmanned Aerial Vehicles ................................................................................. 1
       2.2.1. Advantages of UAVs .................................................................................... 2
       2.2.2. Limitations of UAVs .................................................................................... 3
   2.3. Project Objectives ............................................................................................... 3
   2.4. Literature Review ............................................................................................... 4
   2.5. Existing Solutions ............................................................................................... 4
   2.6. Camera Fundamentals ....................................................................................... 6
       2.6.1. Camera Settings ............................................................................................ 6
       2.6.2. Camera Modes .............................................................................................. 6

3. Phase One: Initial Development ............................................................................. 7
   3.1. Autopilot evaluation ......................................................................................... 7
   3.1. Airframe Selection ............................................................................................. 8
   3.2. Camera Selection ............................................................................................... 9
   3.3. CHDK: Custom Camera Firmware ..................................................................... 11
   3.4. Autopilot Camera trigger interface cable .......................................................... 12
   3.5. Roll-stabilized Gimbal Design .......................................................................... 16
   3.6. Autopilot Gimbal Configuration ....................................................................... 18
   3.7. Further Test Flights ........................................................................................... 19

4. Phase Two: The CyberQuad ................................................................................... 20
   4.1. Cyber Technology .............................................................................................. 20
      4.1. CyberQuad Background ................................................................................ 20
          4.1.1. Airframe .................................................................................................... 21
          4.1.2. Avionics ..................................................................................................... 21
          4.1.3. Powertrain ............................................................................................... 22
          4.1.4. Ground control station ............................................................................ 23
4.2. Revised Camera Selection .......................................................... 23
4.3. Video Output ........................................................................... 24
4.4. Camera Triggering Interface ..................................................... 27
4.5. Gimbal Design ......................................................................... 29
4.6. Autopilot Gimbal & Camera trigger Connection ...................... 33
4.7. Autopilot Gimbal Configuration ............................................... 33
4.8. Camera Triggering Configuration ............................................ 36
4.9. Autopilot tuning ...................................................................... 38
4.10. Issues Faced .......................................................................... 40
5. Phase Three: Mission Planning, data collection and processing .... 42
  5.1. Flight Planning ....................................................................... 42
  5.2. Data Processing ...................................................................... 47
    5.2.1. Basic Model Generation .................................................. 47
    5.2.2. Advanced Image Processing .......................................... 48
6. Phase Four: Testing and Case study ............................................. 52
  6.1. Test Site ................................................................................ 52
  6.2. Case Study: Mapping an Iron Ore stockpile ......................... 56
7. Future Work .............................................................................. 58
8. Conclusion ................................................................................ 58
9. References ................................................................................. 60
Appendices .................................................................................... 63
A. Annotated Bibliography .............................................................. 63
B. Camera Evaluation Spreadsheet ............................................... 65
C. Programming the PICAXE microcontroller ............................... 66
D. PICAXE Program ....................................................................... 67
E. CHDK Camera Script ................................................................. 70
F. HDMI Plug pin-out .................................................................... 71
## I. List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Distinction between DSMs and DTMs</td>
</tr>
<tr>
<td>2</td>
<td>Perspective vs. orthorectified aerial image</td>
</tr>
<tr>
<td>3</td>
<td>Photographic Overlap</td>
</tr>
<tr>
<td>4</td>
<td>Photogrammetric technologies and their application</td>
</tr>
<tr>
<td>5</td>
<td>Orthomosaic &amp; DEM generation from aerial images</td>
</tr>
<tr>
<td>6</td>
<td>Imagery overlap with and without stabilization</td>
</tr>
<tr>
<td>7</td>
<td>Funjet UAV platform with the Ardupilot integrated</td>
</tr>
<tr>
<td>8</td>
<td>The Foamaroo platform</td>
</tr>
<tr>
<td>9</td>
<td>Relative Camera Sensor sizes</td>
</tr>
<tr>
<td>10</td>
<td>S95 running CHDK</td>
</tr>
<tr>
<td>11</td>
<td>RC Control signal theory</td>
</tr>
<tr>
<td>12</td>
<td>PICAXE 08M2 minimum circuit</td>
</tr>
<tr>
<td>13</td>
<td>USB connector pinout</td>
</tr>
<tr>
<td>14</td>
<td>Prototype trigger circuit</td>
</tr>
<tr>
<td>15</td>
<td>Completed trigger circuit</td>
</tr>
<tr>
<td>16</td>
<td>Trigger circuit schematic</td>
</tr>
<tr>
<td>17</td>
<td>Gimbal inside fuselage</td>
</tr>
<tr>
<td>18</td>
<td>Gimbal in stowed position</td>
</tr>
<tr>
<td>19</td>
<td>Printed Gimbal</td>
</tr>
<tr>
<td>20</td>
<td>Gimbal roll servo port configuration</td>
</tr>
<tr>
<td>21</td>
<td>Gimbal roll servo angle configuration</td>
</tr>
<tr>
<td>22</td>
<td>Camera trigger setting</td>
</tr>
<tr>
<td>23</td>
<td>Boomerang 40 aircraft</td>
</tr>
<tr>
<td>24</td>
<td>Failed elevator servo</td>
</tr>
<tr>
<td>25</td>
<td>Crash aftermath</td>
</tr>
<tr>
<td>26</td>
<td>Mission Planner flight log analysis</td>
</tr>
<tr>
<td>27</td>
<td>CyberQuad Maxi with HD video payload</td>
</tr>
<tr>
<td>28</td>
<td>Complete avionics stack showing GPS(t), FC-Ctrl(m) and Navi(b)</td>
</tr>
<tr>
<td>29</td>
<td>HDMI to AV converter</td>
</tr>
<tr>
<td>30</td>
<td>Camera gimbal fit</td>
</tr>
<tr>
<td>31</td>
<td>Custom HDMI cable</td>
</tr>
<tr>
<td>32</td>
<td>Sony OLED Electronic Viewfinder for NEX-5N Camera</td>
</tr>
<tr>
<td>33</td>
<td>Gimbal with CCD camera</td>
</tr>
<tr>
<td>34</td>
<td>NEX-7 with mechanical servo trigger</td>
</tr>
<tr>
<td>35</td>
<td>NEX-5N modified for electrical triggering</td>
</tr>
<tr>
<td>36</td>
<td>The Swinglet CAM's camera integration</td>
</tr>
<tr>
<td>37</td>
<td>gentLED-SHUTTER</td>
</tr>
<tr>
<td>38</td>
<td>HD Payload Base Plate and Y-yoke</td>
</tr>
<tr>
<td>39</td>
<td>Cardboard prototype</td>
</tr>
<tr>
<td>40</td>
<td>Gimbal size constraints</td>
</tr>
<tr>
<td>41</td>
<td>Solidworks motion study</td>
</tr>
<tr>
<td>42</td>
<td>Model with camera's FOV</td>
</tr>
<tr>
<td>43</td>
<td>MikroKopter Flight controller board auxiliary outputs</td>
</tr>
<tr>
<td>44</td>
<td>Transmitter calibration position</td>
</tr>
<tr>
<td>45</td>
<td>Servo splines</td>
</tr>
</tbody>
</table>
**II. List of tables**

Table 1 ATSB aviation occurrence statistics report 2002 to 2011 .................................................. 3  
Table 2 CyberQuad specifications .................................................. 21  
Table 3 Camera specifications .................................................. 24  
Table 4 Trigger configuration summary .................................................. 37  
Table 5 HDMI Pinout .................................................. 71
III. Abbreviations and Definitions

As this is an Engineering report, many readers may be unfamiliar with some of the surveying and aerial photography terminology used. As such, it was deemed appropriate to include background information and definitions of some key principles in addition to abbreviations.

2D Two Dimensional
3D Three Dimensional
AGL Above ground level
ASL Above sea level
CASA Civil Aviation Safety Authority
CCD Charge-coupled device
Camera gimbal See Gimbal
cm Centimetre
CMOS Complementary metal-oxide-semiconductor
CP Check Points
DEM Digital Elevation Model – is a digital representation of ground surface topography or terrain. [3] DEMs can be divided into digital surface models (DSMs) or digital terrain models (DTMs), the distinction being DSMs contains elevations of natural terrain features in addition to vegetation and cultural features such as buildings and roads while a DTMs are bare-earth model that contains elevations of natural terrain features only. [4]

![Figure 1 Distinction between DSMs and DTM](image)[74]

DG Direct Georeferencing
DGPS Differential Global Positioning System
Elevons Elevons are surfaces in aircraft that combine the functions of the elevator (used for pitch control) and the aileron (used for roll control) [5]
Fiducial marks Fiducial marks are fixed points in the image plane that serve as reference positions visible in the image
Focal length Distance from the optical centre of the lens to the focal plane when the camera is focussed to infinity.
For the purpose of this report DEMs and DSMs will be used collectively.

GCP Ground Control Point. An absolute reference point precisely located on both the ground and the photo found using conventional surveying equipment.

GCS Ground Control Station

Gimbal A gimbal is a pivoted support allowing for the position of an object (i.e. a camera) to remain stationary despite movement of the supporting body (i.e. an aircraft)

GIS Geographical Information System. A database system for analysing and manipulating geographical and statistical data.

GNSS Global Navigation Satellite System

GPS Global Positioning System

GSD Ground sample distance. The actual distance between pixel centres projected onto the imaged surface.

IMU Inertial Measurement Unit

LiDAR Light Detection and Ranging

m Meter

MEMS Microelectromechanical systems

MHz Megahertz

MILC Mirrorless interchangeable-lens camera - unlike a digital single-lens reflex camera, a MILC does not have a mirror-based optical viewfinder.

mm Millimetre

MTOW Maximum Take-Off Weight

OIS Optical Image stabilization

Orthomosaic in this context is an image generated by stitching multiple aerial images orthoimages.

Orthophoto An orthophoto is a geometrically corrected (orthorectified) photo such that the effects of aerial camera lens tip and tilt, image scale variations and object displacements due to ground relief are removed. [6]
Overlap is the amount by which one photograph includes the area covered by another photograph, and is expressed as a percentage. Conventional aerial surveys are designed to acquire 60 per cent forward overlap (between photos along the same flight line) and 30 per cent lateral overlap (between photos on adjacent flight lines)[7].

Photogrammetry  The practice of determining accurate measurements from stereoscopic images.

Point cloud  Surface representation in the form of a set of three-dimensional coordinate system.

PWM  Pulse width modulation

RC  Radio controlled

RMSE  Root Mean Square Error

RPA  Remotely Piloted Aircraft

SFM  Structure from Motion. Using only a sequence of two-dimensional images captured by a camera moving around a scene, SFM allows the
reconstruction of the three-dimensional scene geometry and the exact position of these cameras during image acquisition.[8]

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLR camera</td>
<td>Single-lens reflex camera</td>
</tr>
<tr>
<td>SLS</td>
<td>Selective laser sintering, a 3d printing technology.</td>
</tr>
<tr>
<td>UAS</td>
<td>Unmanned Aircraft System typically referring to the entire system including Unmanned Aircraft (UA), Autopilot, a Ground Control System (GCS) - and data link between the UA and the GCS.</td>
</tr>
<tr>
<td>UAV</td>
<td>Unmanned Aerial Vehicle</td>
</tr>
<tr>
<td>Uncontrolled</td>
<td>In this context it refers to images such as orthomosaics that have not been aligned to ground control points and as such the image cannot be accurately georeferenced.</td>
</tr>
<tr>
<td>VTOL</td>
<td>Vertical take-off and landing</td>
</tr>
</tbody>
</table>
IV. Acknowledgments

The author of this report would like to thank the following people:

Murdoch University
   Dr Gareth Lee, Lecturer
   Associate Professor Graeme R Cole, Lecturer
   Professor Parisa A Bahri, Head of School

Cyber Technology
   Joshua Portlock, CyberQuad Project Manager
   Paul Dewar, General Manager
   Chris Mounkley, Managing Director

Thanks are also due to friends and family for their support and encouragement thought the duration of the project.

To any undergraduates reading this report; every word written is a step closer to finishing...