University of Southern Queensland

Faculty of Health, Engineering & Sciences

Inspection of Power Transmission Lines using UAVs

A dissertation submitted by

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Abstract

Power transmission line inspection is an essential task carried out by power companies for the maintenance of a power network. The lines are exposed to the elements which increases the rate of deterioration of small faults and when not repaired in a time efficient manner they can become a serious problem. Current methods for inspection are labour intensive, expensive and are tedious and error prone for humans to perform. A possible solution is a UAV to perform the dull, dirty and dangerous task of power line inspections.

As of August 2013, 16 companies were listed with CASA as licensed UAV operators for the purpose of power line inspection. With the maturing of the UAV and related sensors the technology is now accessible to researchers to adapt UAV technology to power transmission line inspections. The next step in the maturing of the technology will be to prove reliability and gain human acceptance.

This dissertation will research on UAV technology and present a method for controlling a UAV autonomously using visual navigation and analysing pictures taken in real time for the inspection of power transmission lines. The dissertation will research the combination of automation and picture analysis in a field environment.

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Limitations of Use

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

Date

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Chapter 1

Introduction

Power transmission lines were involved in a major incident resulting in a loss of life in the Victorian bush fires in February 7, 2009. It has been alleged that SPI Electricity, in its negligence in failing to maintain power lines, sparked the Kilmore East blaze that killed 119 people and destroyed 1242 homes (Merhab 2013). The fire allegedly started in Kilmore East around 11.45am when a 1,043 metre power line broke, recoiled and discharged electricity, causing vegetation to ignite (Portelli 2013).

Incidents like these place political pressure on power companies to ensure that power transmission lines and associated infrastructure are maintained, so electricity is delivered safely. This must be balanced with resources available to the maintenance planners to be directed to line faults. An Australian Productivity Commission inquiry in June 2013 has found the 70% rises in the cost of electricity in the past five years came down to spiralling network costs and flaws in government regulation(Newsdesk 2013). If the perception of the users is that there power costs are too high and energy networks are being 'gold plated' then planners need to be able to justify maintenance programs with reliable data.

1.1 Background

The State of Queensland supplier Ergon Energy has over 700,000 customers spread over one million square kilometers, or 97 % of the state. The infrastructure they manage is over 150,000km of powerline and almost one million power poles and associated assets. A significant component of their cost of supply is in the condition monitoring of the powerline assets and the vegetation in the powerline corridor. Ergon spends $80 million annually on inspection and clearing vegetation(Ergon 2013*a*).

The inspection tasks that Ergon performs not only includes condition monitoring of the power line corridor but also ancillary inspections including; route access, vegetation monitoring and emergency inspection and repairs. The two main methods of inspection are performed manually or by helicopter. Performing these tasks manually, involves inspectors driving or walking along the power line corridor and assessing the power line by visual methods. This method is very inefficient as an inspector may only be able to walk 5km a day if no vehicle access track is present and some steep banks may be inaccessible, also it relies on all the inspectors visually inspecting the lines to the same standard. Using a helicopter involves a high cost, involving aircrew and inspectors flying close to power transmission lines with pictures taken from different angles for each tower making a standard assessment of the health of the component hard to judge. The quality of the information available to planners from these methods effects operational decisions on where finite maintenance resources will be directed.

Routine inspections of power transmission lines is a task performed around the world. The primary reasons for inspecting the lines are:

1. To provide a safe environment that prevents harm to human life.
2. A reliable electricity supply is expected by the community.
3. To meet community expectations of safety standards, enforced by regulation.
4. For maximum use of available network resources and efficiency.

In the past three years many papers have been written on the use of UAVs on power transmission line inspection and in 2010 the first International Conference on Applied Robotics for the Power Industry was held in Montreal, Canada. The International Conference bought together many scientists in the spatial science area to collaborate to improve the UAV technology for the power industry. The cost and efficiency of UAV has improved due to the parallel development of sensors used in 'smartphone' technology including GPS, gyroscopes and cameras.

1.2 Aim

AIM– The Aim of this dissertation is to investigate the use of UAV in the inspection of power transmission lines to decrease risk and cost of maintenance and inspection.

1.3 Objectives

Objective– The Objectives for this dissertation have been drawn from the Accepted Project Specification by the Faculty of Engineering and Surveying included in Appendix A. These objectives are:

1. The first objective of the dissertation will be to perform basic navigation of the AR Drone controlled by WiFi.
2. The main objective will be to take high definition photos of objects and send them back to a computer using WiFi.
3. If time permits the photos will then be analysed to check on the health of the object.
4. If further time permits the drone will fly a pre-programmed path and send pictures back to the control center for analysis.

The end objective is to simulate a drone taking high resolution photos and sending them to a control station in real time. The photos will be analysed and the health of the transmission line and supporting infrastructure can be quantified.

1.4 Ethics and Implications

1.4.1 Engineering Ethics

The Engineers Australia Code of Ethics defines the values and principles that shape the decisions we make in engineering practice. The related Guidelines on Professional Conduct provide a framework for members of Engineers Australia to use when exercising their judgment in the practice of engineering.

The managers of companies often measure success in profit, therefore an engineer needs to be adequately equipped to influence decisions to comply with the Code of Ethics. With a detailed analysis of maintenance required provided by UAV power transmission line inspection the engineer will ensure that the best possible decisions are made based on his professional conduct. This is beneficial to both the users and the company in providing cost efficient electrical power.

1.4.2 Privacy Concerns

In the case of UAVs privacy for private residents is a major concern that prompted government action in 2002 to regulate the Civilian UAV Industry. As an engineer we should consult with the community to manage this area of UAV technology.

> *"I think that there needs to be public debate about the use of this technology."*
>
> **Australian Privacy Commissioner Timothy Pilgrim**(Moses 2012)

Australian Privacy Commissioner Timothy Pilgrim said he was "particularly worried that this equipment can be easily purchased and used by individuals in their private capacity - the Privacy Act doesn't cover the actions of individuals in those circumstances.

In Australia the equipment required to operate and fly a UAV can be purchased by unlicensed operators. Licensed Operators use UAVs and are employed by real estate agents, miners, marketers, environmental surveyors, even lifeguards. The most famous use of the UAV technology was when Channel Nine TV show, 60 Minutes was barred from filming at Christmas Island and used a UAV to gain footage inside the refugee camp.

The concern of members of the public is that military style UAV and cameras can be used by other private citizens to spy on them. The UAV would not be over private property but with camera technology could see what they are reading in the paper or the time on their watch. These invasions of privacy are not protected by current law.

1.4.3 Implications

Using UAV in Australian industry to automate mining trucks, cameras, perform helicopter tasks and surveying has already begun to fill the role previously carried out by human workers. As the technology matures it will increasingly be used in more industries to increase efficiency and decrease risk.

An implication using UAV for Australian workers in the power industry is that jobs are being made redundant by technology, and new jobs created. A board of a company must make sound decisions for the future of the company and the shareholders. Technology that is mature and can be presented to the managers of the company as a cost viable alternative will be considered. The UAV will be able to undertake the role of the inspections, for a lower cost and provide a higher level of certainty in decisions.

The effect of a cheaper alternative is that riggers who climb the towers will still be needed in a repair role, but not inspection. Technology once again will be making some jobs redundant while others such as UAV analysts, strategist and risk managers will grow.

If a UAV can be programmed to fly autonomously it may be used for purposes not considered by Engineers. The UAV used in this dissertation only has a range of 50 meters and the high noise created makes it difficult for footage or photos to be taken undetected.

Chapter 2

Literature Review

2.1 Chapter Overview

This chapter discusses the developments in UAV and transmission powerline inspection technology. Both these technologies will be discussed as both have a technical background that is relevant to this dissertation. The chapter contains reviews of site visits that gave a practical understanding of what was required to support unmanned vehicles when deployed in a harsh environment.

2.2 Past USQ Dissertation

The dissertation, "The Autonomous Scale Model Surveillance Aircraft", (Keeffe 2003) has been analysed to gain a further insight into research already conducted on the subject. It is important as a starting point to review and acknowledge and work performed by previous students at University of Southern Queensland.

The research conducted in 2003 was into using a UAV for surveillance purposes. I analysed in the dissertation what the authors objectives were, and the use of the technology applied that was available at the time. I compared the UAV technology used in 2003 to current technology to gain an understanding of the progress made in this area of technology. For example the author used a Motorola HC12 processor to control the airframe and had to program the controls for the flight and use dead reckoning for the autonomy. Technology in 2013 has increased so that now that small lightweight and affordable autopilots are available with global positioning systems, compass and gyro in one small lightweight package. They use open source programming and basic programs are available on the internet.

2.3 Current USQ and Ergon Research

Currently PhD Candidate Andreas Helwig is conducting PhD research in this area, in conjunction with Ergon Energy, and has recently delivered USQ research papers at Australian Universities Power Engineering Conference, (AUPEC) on 1st October 2013. These papers were delivered in a Plenary session that was presented by CEO Ergon Energy, Ian McLeod, and focussed on ”Creating a virtual world for real world savings: ROAMES - A Smart Asset Management Solution”.

Ergon Energy has a Geographical Information Systems, (GIS) group that is projected to save $60 million in the next five years by improving thier spacial mapping using Google Mapping software. The product is called Google Maps Engine and Ergon will use it to map its entire network of over 150 000 km of poles and wires for vegetation management.

Ergon started using earlier versions of Google Maps in 2006 but late last year it went live with its most ambitious map project. Called Remote Observation Automated Modeling Economic Simulation, (ROAMES) it uses light planes and helicopters to map the entire network each year(Fitzsimmons 2013).

The sensors on the aircraft capture images to centimeter level and Ergon is using the data to generate 3D models of vegetation growth to guide its pruning program(Fitzsimmons 2013).

2.4 ROAMES

Ergon Energy currently use ROAMES for infrastructure and vegetation management(Ergon 2013*b*). ROAMES technology, developed by Ergon Energy and partner organisations, creates precise, 3D geo-spatial representations of network assets such as substations, poles and wire infrastructure to be displayed in a Google Earth-like database. The sheer size of Ergon Energys distribution area, which covers approximately 97 per cent of Queensland and 150,000 kilometers of network, was a key motivator for finding smarter ways of managing the assets and the surrounding environment. It is anticipated that the information ROAMES provides will result in reduced maintenance and planning costs, while also increasing the safety and reliability of electricity supply for our customers and communities(Ergon 2013*b*).

ROAMES is currently using two Cessna aircraft fitted with sensors that include photographic and LiDAR distance measurement equipment. The Cessnas are being used while the specially designed Seabird Seeker aircraft is awaiting accreditation by the Civil Aviation Safety Authority(Ergon 2013*b*).

It is planned that ROAMES will complete an annual survey of the network, an improvement on the previous whole of network surveys which took three years to complete(Ergon 2013*b*).

While ROAMES is the first step towards the future of a complete map of the network it focusses on vegetation. There is no mention of using this mapping software for inspection of electrical hardware which would be a good adaptation of this technology.

2.5 Types of UAV for Power Line Inspection

The literature review is focussed on the UAV but a paper 'New Robot for Power Line Inspections'(J. Katrasnik, F. Pernus, B. Likar 2008) focusses on the main achievements in the field of robotic power line inspections. Different solutions in climbing and flying robots are critically assessed in the paper and a new concept for robot-assisted power line inspection combining both flying and climbing principles is researched.

The paper (J. Katrasnik, F. Pernus, B. Likar 2008) talks about the need, for a robot-assisted inspection that can be carried out faster, cheaper and more reliable, improving the long term stability of the power supply. The inspection of the power industry workers would also be improved.

2.5.1 The Heli-climber

A new type of robot that is both climbing and flying is proposed by the paper(J. Katrasnik, F. Pernus, B. Likar 2008) to include the advantages of both and the solution is then critically assessed and related to other robots in terms of design, construction, inspection quality, autonomy and universality.

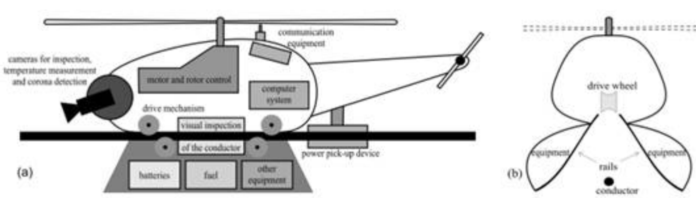

Figure 2.1: The proposed robot (J.Katrasnik,2008)

In (J. Katrasnik, F. Pernus, B. Likar 2008) the proposed solution would combine a helicopter that could fly over obstacles and a special drive mechanism for traveling on the conductor up to an obstacle. Figure 2.1 shows a what the possible robot would resemble.

2.5.2 Ducted fan solution

A different robot was proposed in 'Power Line Inspection - An UAV Concept'(Dr Dewi Jones 2005) where the robot pictured in Figure 2.2 would hover over the power line using a ducted fan configuration. The ducted fan configuration is efficient at hover due to the low speeds expected during inspection and the cowl gives protection from the propellers if a fault condition causes it to fall to the ground.

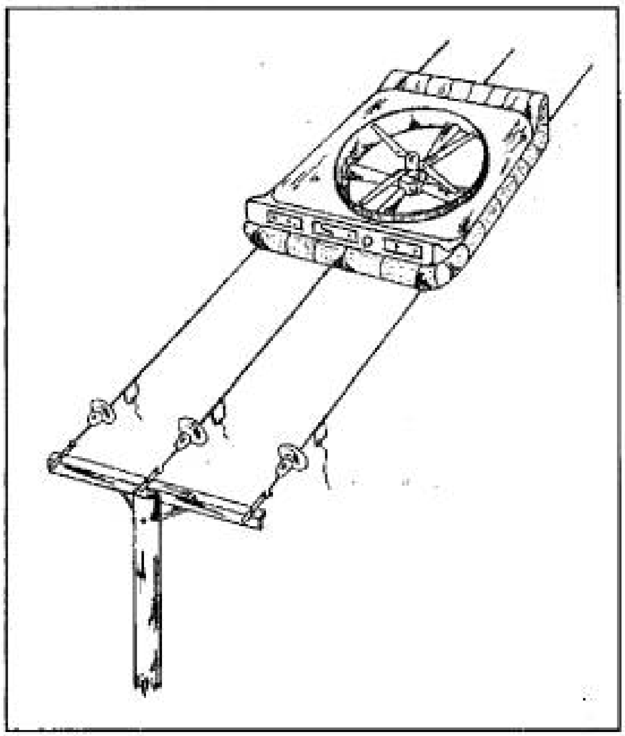

Figure 2.2: Artists illustration of the concept (Jones,2005)

The robot proposed in (Dr Dewi Jones 2005) would use no fuel, and have a minimal battery as it would pick up a charge using a mechanism like an active pantograph. The limited battery makes the vehicle light and effectively tethers it to the transmission line, only providing power for manoeuvring over small obstacles in the line. It does have the drawback of only being able to be used on energised lines. A dynamic model of the ducted fan unit has been derived and programmed onto the Air Vehicle Simulator facility at CSIRO in Brisbane.

2.5.3 Linewalker

A power transmission line climbing robot was purposed in (L. Wang, F. Liu, Z. Wang 2010) that would walk underneath the power line. The mechanism that joins the two legs in Figure 6.3.2 enables the centroid of the robot to concentrate on the hip joint to minimize the drive torque of the hip joint and keep the robot stable when only one leg is hung on line. This enables the robot to navigate around obstacles. A camera for inspection purposes would be located in the pod between the two legs to carry out the line inspection

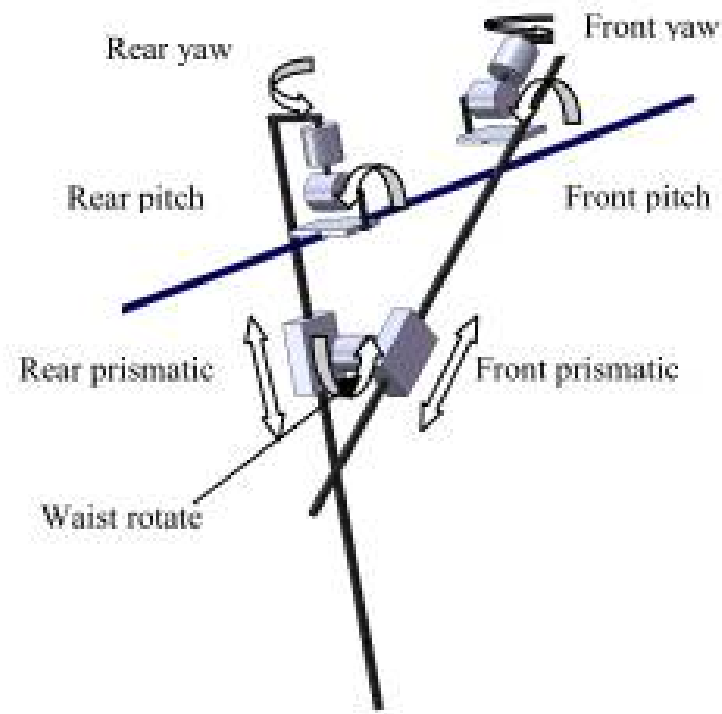

Figure 2.3: Structure of a line walking robot (L.Wang,2010)

The method in the paper (L. Wang, F. Liu, Z. Wang 2010)is limited to only inspecting power lines and this limitation makes it inferior to other technology previous discussed, which can inspect multiple parts of the power transmission infrastructure, vegetation and route access.

2.6 Power Line Inspection with a Flying Robot

Since the 1990's power line inspection and operation by helicopters are being applied more and more in the electric power industry(G. Yan, J. Wang, Q. Liu, L. Su, P. Wang, J. Lui 2007). The cost of inspection and operation of helicopters was found to very high and the risk of flying close to power lines has resulted in several reported accidents happening during inspection all over the world.

A paper was written in 2010 on Power Line Inspection with a Flying Robot (Binhai Wang, Xiguang Chen, Qian Wang, Liang Liu 2010) and researched the use of unmanned flying robots in power line inspection. The paper researched the use of two Unmanned Autonomous Helicopters,(UAH) to inspect the power line corridor including power lines, poles, towers and vegetation which is common inspection work in the power industry.

The research by (Binhai Wang, Xiguang Chen, Qian Wang, Liang Liu 2010) used two UAH to design a flying robot called SmartCopter for inspecting power line corridors. Where previous research had focussed on autonomous control of UAH and vision guidance, this paper focussed on besides flight control, the inspection system design.

The SmartCopter in (Binhai Wang, Xiguang Chen, Qian Wang, Liang Liu 2010) was designed to; fly at low height; hover for careful inspection and did not require a takeoff or landing area. The inspection control system consisted of a thermal and a visual camera.

The results of the experiments in (Binhai Wang, Xiguang Chen, Qian Wang, Liang Liu 2010) concluded the SmartCopter can safely fly 50 meters away form power lines. At that distance SmartCopter can use the digital camera and thermal camera to inspect power lines. The thermal inspection did not meet the expected requirement, but there was a way to improve it. The SmartCopter could be used for other applications in the power industry and extended or modified for other infrastructure including railways, pipelines and cellular phone towers.

The idea of low cost autonomous helicopters has been researched in the paper 'Development of low cost autonomous minihelicopter for power line inspections'(A. Barrientos, J. del Cerr, I. Aguirre 2001). The research focused on the use of an artificial vision system to obtain the information required by the UAV for the vehicle guidance by automatic detection of the cable lines and 3D co-ordinates. Navigation was performed using inertial measurements to obtain the attitude of the craft.

The helicopter used in (A. Barrientos, J. del Cerr, I. Aguirre 2001) was a prototype being developed by the robotic group at the University of Madrid. The information from the vision system was used to control the helicopter trajectory, but the helicopter exhibited very non-linear systems with strongly coupled nodes. In the experiments on the model of the minihelicopter, the movements were adjusted and controlled using a Linear Quadratic Gaussian controller for pitch and roll movements and a PID for Yaw.

2.7 The Future of Power Line Robotics

The paper 'About the Future of Power Line Robotics' (S. Montambault 2010) presented the authors view on how mobile robotics should evolve to maximize its impact on power line inspection and maintenance practices. The paper researched high performance robotic design as it will eventually lead to autonomous systems, capable of accomplishing high-dexterity maintenance tasks and how robotics is part of the solution to developing a smart transmission grid.

The paper (S. Montambault 2010) discusses practical considerations when implementing a robotic solution for power line inspection. Some of these considerations were; working on energised lines, dealing with existing live-line working methods; covering the variety of physical conditions, challenges and constraints in a power network; dealing with existing structures and the benefits of power line robotics. Interestingly (S. Montambault 2010) spoke of other factors including; technology acceptance; deployment considerations and operating costs; field operation and constraints and what-if emergency retrieval methods. The considerations discussed should all be a factor when considering the total cost of implementing a robotic solution to power line inspection.

The deployment related constraints that effected robotic design including deployment related constraints were pointed out as strategic considerations for achieving successful implementation in maintenance operations. The paper (S. Montambault 2010) discussed critical design issues and high value applications where robotics could be implemented as the main driver for robotics research.

2.8 Advanced Aerial Inspection of Electricity Towers

A project that provided the fundamental basis for further projects in Airborne Powerline Inspection Technology Improvements for Ergon Energy was successfully completed in 2010(ARCAA 2013). A three year CRC-SI project conducted by Australian Research Centre for Aerospace Automation, (ARCAA) into 6.07 for Spatial information Business improvement applications at Ergon Energy focussed on precision guidance of aircraft over powerlines, asset and vegetation detection using LiDAR imagery, and detection and classification of tree species.

In 2011 the paper 'Advanced Aerial Inspection of Electricity Towers'(G. Earp, R. Eyre-Walker, A. Ellam, A. Thomas 2011) researched an innovative technique for inspecting steel lattice electricity distribution towers was used successfully in the UK to inspect approximately 20,000 electricity towers across six Distribution Network Operators. This paper discussed using an aerial inspection technique that uses high resolution images taken from a helicopter to perform a detailed condition assessment of towers inspected.

The paper(G. Earp, R. Eyre-Walker, A. Ellam, A. Thomas 2011) researched a Condition Based Risk Management Tool, (CBRT) to calculate health indices for various parts of a tower as well as for the network itself. This provided a powerful asset management tool for gauging and predicting the health of the network based on degradation models, together with a forward view of the expected network performance for periods in excess of 10 years.

The research in (G. Earp, R. Eyre-Walker, A. Ellam, A. Thomas 2011)discussed current methods of; foot patrols, climbing inspections and helicopter inspections. These inspections all had advantages and disadvantages, the helicopter inspections offered the greatest area for improvement because traditionally the helicopter inspections had not been used to gather detailed condition information at component level, but instead focussed on identifying major defects or safety related issues.

Helicopter inspection and picture acquisition in (G. Earp, R. Eyre-Walker, A. Ellam, A. Thomas 2011) was undertaken using high resolution still images and stabilised images, typically 30-50 images per tower. This was proven to produce superior results to video for this application.

The conclusions of (G. Earp, R. Eyre-Walker, A. Ellam, A. Thomas 2011) were that inspections of electricity distribution towers from a helicopter using high resolution imaging can be combined with condition assessment and CBRT to provide a complete and unique solution to tower asset management. The technique has been used by the industry in the UK were demonstrated through the Central Networks and CE Electric UK case studies.

Australia has a section at CSIRO called Australian Research Centre for Aerospace Automation, (ARCAA)that are currently developing Airborne Powerline Inspection Technology Improvements.

2.9 Site Visits

To fully understand the capability of military UAVs the author was able to conduct site visits at military bases in Afghanistan. Three deployed UAV systems were visited to understand the UAV capability in the surveillance sphere. This gave the author a good understanding of the human and materiel resources infrastructure required to operate a UAV.

2.9.1 Heron

The Heron UAV is operated by the RAAF to provide surveillance support to the Coalition efforts in Afghanistan. It uses sensors on the airframe to monitor enemy activity and provide real time information to units on the ground.

Capable of staying aloft for up to 24 hours it gives the advantage of a long loiter time, allowing the pilot and analysts to work in shifts. The pilots are all qualified to fly manned aircraft and are backed up by a support team. The support team and equipment included:

1. A control center to co-ordinate the flight and data.
2. An operation cell to co-ordinate the operation of the fleet of drones and personnel.
3. A contractor who supplied the maintenance support to the Heron UAV.
4. Analysts to record the information and supply a post activity report.
5. Intelligence experts to direct the flight path and operation of sensors.
6. Large hanger and ground operation facilities.

2.9.2 Shadow

The Shadow UAV has been operated by the RAAF for two years and is a Tactical UAV. It provides a different capability to the Heron because it is a smaller drone, more agile at lower altitudes.

The Shadow is limited by electronic line of sight, and is capable of staying aloft for 6 hours, at a distance over 100 km away from the control center,(CS).

The maintenance is conducted by a team of three RAAF personnel, the same way any aero-nautical product is maintained. The advantage of the maintenance of the Shadow is that the majority of parts can be bought of the shelf from a range of suppliers. The example given from the maintenance crew was that when testing the Shadow UAV in a remote locality a fan became unserviceable and could be purchased from a local computer shop.

When Shadow is operation the information from the sensors is sent back to to a control station. The control station has UAV operators, analysts and intelligence personnel to direct the Shadow to areas of interest. The pilots are trained UAV operators and not qualified Pilots.

Shadow has a tactical automated landing system which aids the pilots to land the UAV. This does require a landing strip, which had to be purpose built for a cost of over one million dollars, and will need to be removed when Australia leaves in the near future for a further cost. The UAV is launched from a purpose built hydraulic launcher which propels the UAV into the air. It uses 3000psi of pressure to release the UAV at 50-60 knots. This requires over 1000 Amps of power and nitrogen gas to build up the pressure, so when a UAV is launched it can take over 30 minutes to build sufficient pressure up to launch another UAV.

In the event of an emergency, when the airspeed falls below 40 knots a parachute deploys to protect the sensors, the deployment of the parachute ensures the UAV lands upside down protecting the sensors. This is an important design feature as the camera on the Shadow UAV is worth over $600 000. Three of the Shadow UAVs had been crashed in two years with two still flying and one sent back to Australia for a major rebuild.

2.9.3 AeroStat

The AeroStat UAV is a Stationary UAV which operates from a fixed position. It is capable of operating from heights of up to approximately 6000 meters carrying a payload of sensors as required by the operators. The AeroStat in the site visit was carrying two cameras and a laser designator to allow constant surveillance of the immediate area around a Forward Operating Base,(FOB).

The AeroStat cameras were set up on an automatic program which rotated and focussed the camera on an incident automatically. If there was an insurgent attack on the FOB the cameras on the Aerostat would automatically be able to provide intelligence and designate the targets with a laser to co-ordinate a response. So the UAV was also providing a visible deterrent function to any attackers who were aware of its function as a surveillance UAV.

This UAV has the advantage of staying aloft for up to 30 days, but this is weather dependant because it is vulnerable to gusty conditions. If the AeroStat UAV does break away from its tether it can be remotely controlled using line-of-sight radio frequency, links and helium is released until it lands safely.

The data link is provided by a fibre optic cable which runs along the tether cable, and there is two extra fibre cables for redundancy. This cable runs to the control station where all the AeroStat UAV vital operating parameters are monitored as well as the data feeds from the sensors. The weather is also closely monitored with on-board sensors so the AeroStat can be lowered ahead of bad weather.

The AeroStat can be transported on the trailer which it is tethered to, but it is a semi-permanent installation once set-up in location.

A small maintenance crew existed to service the equipment on the AeroStat UAV, this included hydraulic pumps lines and switches and tether cable.

2.10 Australian Standards for Power Transmission Lines

Power transmission lines are built and inspected in accordance with AS/NZS 7000/2010 which details overhead line design. The objective of the standard is to provide electricity industry network owners, line maintenance service providers, designers, structure designers and pole manufacturers with an industry standard.

The power transmission line infrastructure is inspected against this AS for all new lines after 2010, but are not applied retrospectively to the routine maintenance and ongoing life extensions of existing lines. The existing lines must comply with the original design standards and remain safe and fit-for-use.

The aim of dissertation Objective three was that photos taken by the UAV will then be analysed to check on the health of the object. When checking the health of the object in a real electricity network care must be taken to use the correct AS, if not older lines constructed to different design standards of the day will not pass the inspection and be flagged for replacement.

2.11 Government Regulations

Flight by UAVs in controlled airspace and over populous areas presents problems to the regulator Civil Aviation Safety Authority Australia,(CASA) in terms of ensuring the safety of other users of airspace and people on the ground.

To address the issue the Australian Government introduced legislation that govern the civilian use of UAV in 2002. Civil Aviation Authority Regulation (CASR) 101 consolidates the rules governing all unmanned aeronautical activities into one body of legislation

To provide guidance on the operation and construction of UAVs, safely and legally, CASA has created CASA Advisory Circular, (AC) 101-1(0) that governs the operation of all unmanned and radio-controlled aircraft in Australia.

Currently CASA has over 50 licensed UAV operators in Australia and 16 have listed powerline inspection as their Operator Certificate (CASA 2013). This indicates that research in this area is beneficial to the industry and has potential to further mature the technology.

2.12 Asset surveys in a network

Asset management is a important area for a supplier such as Ergon who supplies 97% of the State of Queensland with a large variance in climate and terrain. Asset failure in supply networks are usually due to insulator failure (phase earth fault), phase to phase fault (line clash in winds or other vegetative or animal bridging between phases), or mechanical fatigue mechanisms in ties to insulators, shackles to poles / towers, cable fatigue (thermal / mechanical) (Ian McLeod 2013).

UAV technology could be applied to improve the asset aging surveys and developing fatigue faults. These areas are further broken down into sub elements:

Survey of power line towers Loss of corrosion protection survey, damage and insulator mechanical / electrical condition. This is based on digital high resolution photography, thermography, EMI emission from partial discharge from the HV and EHV cable insulators. Requirements here is a navigation proximity survey based both on visual, EMI and near magnetic resonance sensing controls, so that a whole tower could be automatically surveyed with a specific flight algorithm and pattern, as well as proximity clearance. This allows better planning of asset maintenance / repair or replacement of failing insulators, line clips / ties and mechanical shackles and other tower components. This is of particular importance, as many of the main power link lines traverse very remote areas that area costly by helicopter or ground survey. This is a significant preventative measure to phase earths resulting from tower or pole insulator failure, particularly after long dry spells followed by light fog or drizzle. This further can prevent aerial cable drops to earth, that if not on the supply side are a hazard to public and farm animals, and difficult to detect(Andreas Helwig 2013).

Thermography survey of line cables (SWER and three phase) . This provides hotspot identification of fatigue breakage beginning to occur, as well as thermal indication of possible earths in SWER lines(Andreas Helwig 2013).

Power line sag survey particularly during hot weather and heavy loads. This survey is of importance in prevention of phase to phase faults occurring in moderate winds or worse(Andreas Helwig 2013).

Vegetation control around power line assets Regular seasonal survey is required in many regions to plan and check vegetation control measures to prevent impingement or animal access to power lines that cause outages as a consequence, or during storm and lightning strike, or damage due to animals bridging between phases(Andreas Helwig 2013).

A UAV benefits would also be in fault/disaster recovery and residual reliability. Power supply is considered an essential service and when it is disrupted causes economic and human consequences. This could include insurance or government compensation for loss of power, or the evacuation of nursing homes due to lack of backup power.

One of the main benefits of a UAV in a major emergency would be the exclusive use by Ergon, with other manned air assets prioritised to loss of life incidents, or bushfire surveys, it will be longer before an aerial survey could be conducted of power line assets. The UAV could be used to identify route access and resources required at the earliest possible time to repair the network.

Ergons aerial survey group identified in the recent Tasman Peninsular bushfire disaster, the main supply line breaks, long before normal ground survey groups could be allowed in the area. Reducing supply recovery time after fires, flood and cyclones is much reduced by aerial survey, and UAV technology could play a significant role in this. Similarly, for SWER (Single Wire Earth Return) rural power supply, where average outages due to fault are 6 24 hours, UAVs could considerable shorten response times by identification of breaks, lines down etc. Ergon is similarly using aerial survey in flood prone areas in Brisbane, Gympie and Rockhampton to help identify how 11KV and LV sectionaliser switches should be configured to reduce the number of power off affected customers as flooding rises and falls(Ian McLeod 2013).

A UAV could provide planners with flexibility to plan new supply routes. Google earth provides engineers an intuitive tool to identify routes for new power lines, and while ROAMES will be surveying existing assets annually to improve the age of the data, it will be under high stress to achieve this task. The additional task of surveying for new asset development in remote areas will need to be achieved using the traditional methods of binocular photography and light aircraft using LiDAR to optimise route planning. The use of a UAV to improve the current methods can speed up response as well as reduce costs of new supply design and supply.

2.13 Chapter Review

This chapter reviewed relevant papers and journals written on the dissertation subject, the site visits in Afghanistan gave the author a feel for the practical considerations and operation of a UAV for surveillance purposes. Papers on current inspection technology and UAV technologies both current and present were analysed to understand the current state of UAV power line inspection methods and technology.

Current technology that Ergon is using for mapping its network was discussed and this type of mapping is seen as a step into the future of asset management.

No UAVs were currently working commercially inspecting power transmission lines, and currently the most efficient industry practice was an aerial inspection technique that uses high resolution images taken from a helicopter to perform a detailed condition assessment of the towers inspected. This information could be placed into a health report to give planners a asset management tool. Ergon were currently doing this using Google Maps for vegetation but not for the maintenance of electrical hardware.

Chapter 3

Problem Statement and Methodology

This chapter will begin with a statement to define the power line inspection problem. This problem statement will be further discussed and analysed leading into a methodology to research the problem, including experiments to test the proposal.

3.1 Power Transmission Line Problem Statement

In order to provide a reliable supply of electrical power at minimal cost to its customers the power industry needs power line inspection methods that are safe, efficient and accurate; however, there is a finite amount of resources for power transmission line inspection and maintenance planners must direct the available resources to where they think the highest priorities are in the power system. The planners use the available inspection data to form a decision on where the highest priorities are.

The current situation of high cost aerial inspections and resource intensive manual inspections is unlikely to get cheaper or faster. If a technology which will conduct an increased amount of inspections and be safer, efficient and accurate can be developed it will give planners qualitative information to base decisions on where the priorities in the power system are.

3.2 Discussion of Problem statement

A planner or operations manager in the power industry must base decision on where to direct power company resources and at the same time remain within an operating budget. The general population has been told by politicians that the power system is being "gold plated" (Newsdesk 2013) and so the maintenance budget is politically under heavy scrutiny. The power companies have also contributed to this public perception by increasing charges for poles and wires, a fixed charge on the electricity bill, as consumers have decreased the amount of power used due to various government campaigns to conserve energy.

Planners in power companies are obliged to save costs in the short term but must balance this against the safety, reliability and efficiency of the system long term. A customer may not see the need to replace components or inspect the entire power system on an annual basis, but when they do not have power they will be asking questions why the power system was not maintained adequately.

An Engineer as part of the Australian Engineers professional charter must seek to use new technology, to improve the human race and also to leave a better situation than when he found it. This is a situation where the introduction of UAVs into this industry will provide an improvement in efficiency and safety. The physical operation of the UAV will be very visible to members of the public so the engineers in development of this technology must also manage public perception in regards to safety and privacy.

The industry currently uses both fixed wing and rotary manned airframes to conduct patrols of assets. The inspections are more detailed with rotary airframes because they involve flying spans at relatively slow speeds and circling or hovering at each structure which is significantly more reliable for detecting defects than fixed wing inspection; however, with manned helicopters these patrols are also significantly more expensive and dangerous for the crew. Using a UAV for this purpose would improve the economic and decrease the potential human cost compared to manned helicopter flights.

Rotary airframes have other advantages for inspecting power lines over fixed wing; the ability to fly at low height, which makes the inspection close to power lines and it does not require a large takeoff and landing area.

Once the utility provider has formulated the information required to achieve their inspection objectives the type of UAV can be selected. The UAVs that would be suitable for power transmission line inspection are fixed wing and rotary airframes, both having advantages and disadvantages. In addition the sensors required to gain the information would dictate the size and type of the airframe.

The economic benefit of UAV can be seen with the comparative mass of the manned aircraft required of 750 kg compared to the UAV of 35 kg. When the operational costs are broken down into the maintenance, storage and fuel cost they are cheaper due to this fact. Other factors that improve the economic viability are acquisition, insurance and labor costs. These costs make the operation when compared to manned aircraft considerably cheaper with the UAV and control station being 40 - 80 per cent of the cost of an aircraft and the operating cost 40 per cent of a manned aircraft(Austin 2010).

Due to the size and mass of a UAV it will cause less environmental disturbance or pollution than a manned aircraft performing the same task. This is beneficial in power line inspections where low noise and visual signature will be seen by the local community as an improvement over standard helicopter inspections.

Currently Ergon is using ROAMES and UAV technology is a direct competitor in this information collection task. The use of photographic high resolution technology, thermography, and EMI emission detection from partial discharges can also be conducted by a UAV.

After conducting a literature review in Chapter 2 and comparing the benefits of a UAV against the current Ergon surveys in Chapter 2.12 the UAV technology would be best suited to parts of the inspection of power transmission lines, this includes:

1. Conduct out tower survey using photography, EMI emission recording, thermography.

2. Line thermography.

3. Cable sag and ground clearance survey.

In order for a UAV to conduct these surveys it would need the technology for automation of navigation. Such self-navigation ability would require the platform to have variations and combinations of sensors including; radar, GPS, visual, thermography, magnetic resonance sensing of steal tower or reinforced concrete towers and EMI emission.

3.3 Military and industry use of UAVs

The Military has a long history of using UAVs in warfare and they are now used extensively in the current military environment in Afghanistan.The Military use the UAV for the 'Three Ds', that is using UAVs in Dull, Dirty and Dangerous environments and also where there is an economic benefit.

Flying a helicopter close to power lines is similar to the military using aircraft for a surveillance role requiring the air-crew to analyze information and fly aircraft for long periods of time in a dangerous environment. The repetitive nature of this task will result in a dull experience for the air-crew. When this experience is repeated for long periods of time it also results in a loss of concentration and therefore a loss of effective inspection data. This makes the choice of a UAV for this tasks in the Three D environment worthy of further research.

3.4 Methodology and Constraints

As discussed in paragraphs 3.1 to 3.3 an improved method must be found to inspect power transmission lines for safe and efficient delivery of power. There are many possible solutions to inspect power transmission lines these include:

1. A robot custom built to ride on the transmission lines.
2. A UAV that operates with six degrees of freedom like a helicopter.
3. A UAV that hovers above the power transmission lines.
4. Improving the existing method of aerial inspections by helicopter to decrease the environmental footprint and mitigate the time spent in danger by the air crew.

Chapter 2 discussed the development of UAV technology and its current advantages over manual and helicopter inspections. The advantages of UAVs in power transmission line inspection would be expected to result in:

1. A decrease in the amount of human resources placed in risk adverse situations.
2. A decrease of operating costs of like helicopter inspections.
3. The environmental impact should be reduced relative to the size of the UAV compared to a helicopter, leading to decreased sound and pollution emissions.

3.5 Hardware

A rotary or quadrotor platform was chosen for the dissertation. This type of platform was chosen after reviewing the literature review and the evidence in this chapter. Researching this platform will give the best understanding in the technology available.

The Parrot AR Drone has been chosen as the research platform and will be used for all the experiments, detailed specifications on the AR Drone are in Chapter 4. It is a quadrotor UAV that is small, lightweight, inexpensive and parts are easily sourced. The AR Drone has two cameras and commands are sent to an onboard control unit which interprets the commands and controls the UAV to fly, takeoff and land.

It has the ability to by operated by WiFi which is a standard feature to enable control using a smartphone. This ability to be controlled using WiFi will be used to control the AR Drone with a computer. The control of the AR Drone with a computer will enable pictures to be analysed by software. The AR Drone has an API and Open Source programs available different websites to explore control and automation.

3.6 Proposed Experiments

There were three proposed experiments to test the technology, they are testing the Objectives outline in the first chapter. The experiments evolved as the research in the different areas moved forward.

3.6.1 Experiment 1 - Transmission of Video and Photo

The first experiment will be conducted with the AR Drone taking pictures of a power transmission line with a transformer installed. The AR Drone must take pictures from different angles and transmit these back to the controller. This experiment will test Objective 1 of this dissertation.

The results of this experiment will identify in practice WiFi connectivity has been achieved, pictures can be transmitted to the controller in real time and basic autonomy has been achieved.

3.6.2 Experiment 2 - Autonomous control using visual navigation

The second experiment will involve building on previous experiments form other sources. The AR Drone must navigate using commands from a flight path, to do this it must first build a 3D map of a previously unknown area and use this as a staring point to fly the desired path.

3.6.3 Experiment 3 - Autonomous flight of a power transmission line

In this experiment the AR Drone will fly to a power line marked with a colour that is recognisable. Once the colour is recognised it will fly a preplanned path and take pictures and planned spots on the flight path.

This will satisfy part of the Objective to fly autonomously and take pictures that are sent back for picture analysis.

3.6.4 Experiment 4 - Picture Analysis

This experiment will build on experiment 3, the pictures transmitted from the drone will be analysed by software for recognition.

This will satisfy part of the Objective 3 to fly autonomously and take pictures that are sent back for picture analysis.

3.7 Chapter Review

This chapter began with a statement to define the power inspection line problem. This problem was further discussed and analysed leading into a methodology to research the problem. Four experiments were conceived to test the proposed solution to the problem and gain a further understanding of current UAV technology.

Chapter 4

AR Drone

4.1 Hardware

This chapter introduce the AR Drone describes its hardware specifications and software programs used in the conduct of the research.

4.1.1 AR Drone Hardware

The AR Drone was released to the market in 2010 and originally intended as a high-tech toy for augmented reality games, the drone quickly caught the attention of universities and research institutions, and is currently being used in several research projects(Vojtech Vonasek, Daniel Fiser, Jan Faigl 2011). The range of sensors that the AR Drone is equipped with, compared with high cost commercial quad rotor helicopters with similar sensors, made the AR Drone a choice for this dissertation. During the planning stage of the dissertation, breakdowns and planned maintenance of the AR Drone was identified as a risk. To mitigate this risk the low cost, ease of fitting and availability of spare parts was also considered as a strength of the AR Drone.

At the Cornell University, the AR-Drone has been used for experiments in UAV visual autonomous navigation in structured environments. Moreover, machine learning approaches were applied to predict the position errors of the UAV following a desired Flight path. Other research groups used the drone as an experimental platform for autonomous surveillance tasks, human-machine interaction, and even as a sport assistant, which aids the athletes by providing them external imagery of their actions (Vojtech Vonasek, Daniel Fiser, Jan Faigl 2011).

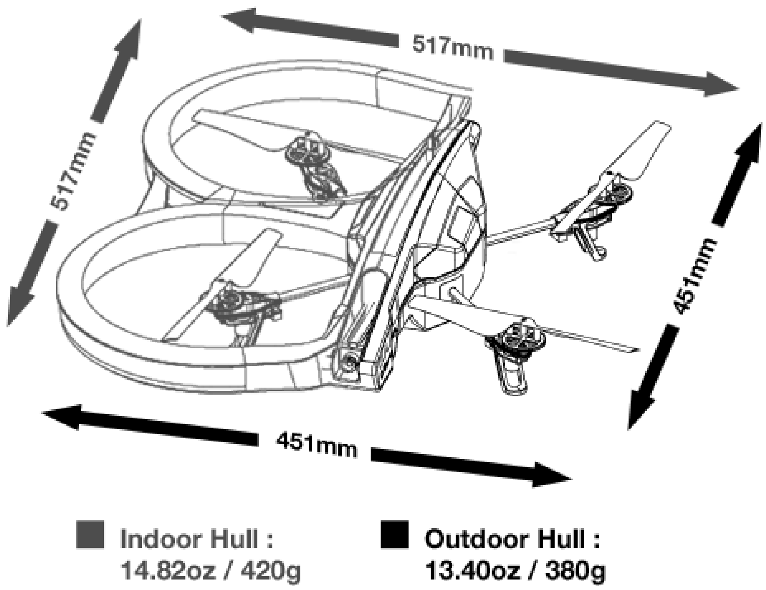

Figure 4.1: AR Drone Specifications

AR Drone is an electrically powered quad-rotor design and its physical specifications can be seen in Figure 4.1. Its chassis is a carbon fibre cross brace supports four brushless inrunner motors and the center section which contains the battery, optional GPS, sensors and control board. The control board and software lock the propellers in the event of a foreign body contact and assists the user to takeoff and land. The AR Drone is provided to the user with an outdoor and indoor hull which can be removed according to flying conditions, the indoor hull is the heavier of the hulls but provides the propellers with protection from foreign objects.

The original method by the designers to operate the AR Drone was using a smartphone, but development in the user community have seen the drone able to be controlled using an RF link and WiFi link using a computer.

The amount of yaw, pitch, roll and vertical speed can be set by the user on an interface such as an application on a smart phone, in the case of the dissertation this is set using an application on a computer. The onboard control board accepts the inputs and adjusts the motor speeds to stabilize the AR Drone at the required position. The Drone can obtain speeds of 5 m/sec 5 m.s -1 and its standard 1100 mAh battery can provide flight times up to 13 minutes. Recent developments have seen users using higher capacity 2000 mAh Lithium Polymer batteries which has increased flying times by up to 50%.

The on-board control computer gives the user precision control and automatic stabilization features. The computer uses a 1GHz 32 bit ARM Cortex A8 processor with 1Gbit DDR2 RAM at 200MHz, using Linux 2.6.32 as its operating system. A manufacturer provided API allows the user to communicate with the AR Drone using an ad-hoc WiFi network. The API not only allows to set drone required state, but also provides access to preprocessed sensory measurements and images from onboard cameras(Vojtech Vonasek, Daniel Fiser, Jan Faigl 2011). The AR Drone also has a USB 2.0 high speed for extensions, this could include a USB Data device for recording, or an optional GPS unit to allow for greater accuracy in navigation.

The AR Drone sensory equipment consists of a 6-degree-of-freedom inertial measurement unit including; 3 axis accelerometer +-50mg precision, 3 axis gyroscope 2000/second precision; 3 axis magnetometer 6 precision; Pressure sensor +/- 10 Pa precision; and Ultrasound sensors for ground altitude measurement(Parrot 2013). Data from the IDG-400 2-axis gyro and 3-axis accelerometer is fused to provide accurate pitch and roll, the yaw is measured by the XB-3500CV high precision gyro. The pitch and roll precision seems to be better than 0.2 degrees and the observed yaw drift is about 12 degrees per minute when flying and about 4 degrees per minute when in standby(Vojtech Vonasek, Daniel Fiser, Jan Faigl 2011).

The vertical camera used by the AR Drone for ground speed measurement is a 60 frames per second QVGA. QVGA is short for Quarter Video Graphics Array, and is the term used to describe computer displays that use 320x240 resolution (320 pixels horizontally by 240 pixels vertically) or 240x320 resolution if the display is taller than wide. This display is commonly used in smartphones, digital cameras and other hand held computing devices.

The horizontal High Definition, (HD) camera has a wide angle lens providing a 92 degree view at 720p and 30 frames per second. This allow the operator to stream HD video and send photos to the controlling device over WiFi (Parrot 2013).

4.1.2 AR Drone Software

The AR Drone is a quad-rotor drone so is inherently unstable relying heavily on the on-board processor to stabilize flight and to provide the user assistance in take-off and landing maneuvers. The control board uses using Linux with the 2.6.32 kernel as its operating system and uses the vertical camera to process the drone speed relative to the ground, which improves the AR Drones stability.

The AR Drone is capable of WiFi b,g,n resulting in a maximum range of 50 meters, and a peak uplink and downlink of 600 Mbits/sec. A device can connect to the AR Drone using an ad-hoc WiFi network and a fetched IP address from the AR Drone DHCP server. Once a link has been established the external computer can communicate with the AR Drone using three channels with different UDP ports they are:

Command Channel this channel is used to request the drone to take-off, land, calibrate sensors, set power on individual motors, the most used command sets the required pitch, roll, vertical speed, and yaw rate of the internal controller. The channel receives commands at 30 Hz.

Navdata channel provides the drone status and preprocessed sensory data. The status indicates, whether the drone is flying, calibrating its sensors, the current type of altitude controller, which algorithms are activated etc. The sensor data contain current yaw, pitch, roll, altitude, battery state and 3D speed estimates. Both status and sensory data are updated at 30 Hz rate. Moreover, the drone can run a simple analysis of the images from the frontal camera and search for a specially designed tags in the images. In the case the tags are detected, the navdata contains estimates of their positions.

Stream channel provides images from the frontal and/or bottom cameras. The frontal camera image is not provided in actual camera resolution, but it is scaled down and compressed to reduce its size and speed up its transfer over WiFi. As a result, the external computer obtains a 320 240 pixel bitmap with 16bit color depth. A slight disadvantage of the camera system is that a user cannot obtain both camera images at a time. Rather than that, the user has to choose between bottom and forward camera. Switching the modes is not instant (takes 300 ms) and during the transition time, the provided image contains invalid data.

4.2 Chapter Review

This chapter detailed the specifications of the AR Drone that will be used in the following chapters as a research platform. This UAV has been used in previous research due to its low cost and high specification when compared with similar UAVs on the market. There is a large amount of software and papers written on the AR Drone due to the high use by researchers and Parrot release an API to aid researchers with development of software.

The AR Drone would not be used commercially as a UAV due to its low power and short flight time, but is being used to research current technology available to inspect power transmission lines.

Chapter 5

Automation equipment and software

5.1 Chapter overview

This chapter will present a background of UAV automation and discuss how it will be applied to my dissertation experiments. These experiments will be conducted to test the automation outcomes of a UAV for power line inspections.

5.2 Automation Background

Automation of a UAV for power line inspections will allow it to be less dependant on time critical communication and bandwidth. The higher level of automation will also allow the operator to focus on gathering data, or a decreased size team required to operate the UAV.

Automation of a UAV does not have a exacting definition in the UAV industry. This is because the definition of the level of automation varies from a UAV that is programmed with way points and fly a set path, through to a UAV that is given a list of tasks and can calculate the best route path using the least resources. The objective of increased automation is to decrease the reliance of a UAV on time-critical communication and communication bandwidth with the control station.

Improved levels of automation would allow the operator to focus on the current task, rather than operating the UAV. The concept of automation was observed in site visits detailed in Chapter 2 where some of the crew flew the UAV while other staff analysed the information or operated sensors. This observation was not automation, but displayed how being able to focus on one aspect of the UAV allows for a more detailed assessment of the information and leads to enhanced time-critical decision making.

Automation can be achieved using a navigation method based on GPS,way points, or using visual based navigation. GPS technology has improved significantly, using differential algorithms and multiple GPS satellites to improve the accuracy to within 1 meter; however, visual navigation has the advantages of the unmanned vehicle being able to avoid new obstacles such as vegetation or debris. The collision avoidance achieved using visual navigation brings a new level of automation to the UAV.

Research into UAV was cost prohibitive for many universities in the past and they could not justify research in this area. This changed in 2010 with a UAV made by Parrot called the AR Drone, which was designed for virtual reality games using smartphones. Universities started using the AR Drone as a research platform due to its low cost and high number of sensors. A paper was written by a university from Czechoslovakia into the using the AR Drone for Educational Research(Vojtech Vonasek, Daniel Fiser, Jan Faigl 2011). This paper presented the idea of using the AR Drone in various experiments with varying degrees of automation. The automation relied on using large amounts of processing power including an dedicated CPU to process images in real time. The result of the paper was automation that used dead reckoning from a known location or a slow analysis rate due to the off board processor.

The authors of AR Drone for Education Research, have taken there research further, using a different Drone with a higher payload to carry additional CPU hardware to allow for real time processing of video on the Drone, decreases the time for signal processing and automation to occur.

The AR Drone was released with an Application Programming Interface,(API) which could be used by developers to develop automation software. The API is a set of routines, protocols, and tools for building software applications, but is released under a license for use. The Parrot AR Drone API intention is to make it easier to develop a program by providing all the building blocks.

The Robotic Operating System, (ROS) is a Open Source Operating system available for download on the internet and developers were release software to control the AR Drone on a basic level using the ROS. This involved using a laptop to control and receive video and pictures back from the AR Drone. A program was released in 2011 for basic control of the AR Drone and has been updated with bug fixes and for the new AR Drone 2.0 since its release, this was very similar to the software released by AR Drone for Educational Purposes. Both these experiments will be replicated and analysed later in this chapter.

The ability to automate UAVs has been significantly increased with developments in sensor technology and processing of video and pictures in real time. This increase in technology has increased exponentially since 2010 when low cost Drones became available to university researchers and programs have been developed to exploit APIs provided by manufacturers and incorporate these into open source programming.

Developments in size and weight of sensors in this decade saw the automation of UAV increase rapidly due to the miniaturisation of sensors including GPS, gyroscopes, and magnometers. This was in part due to the technology of smartphones being developed in parallel and the economy of scale of producing the sensors for smartphones.

5.2.1 Legal requirements for experiments

The experiments conducted in this research will not break any restrictions imposed by CASA. The AR Drone is in the small category and CASA do not impose any restrictions on the use or piloting of the small category of UAV. There are some guidelines to be followed including; a maximum height range of 400 ft, remain clear of designated airspace, aerodromes and populous areas. The pilot should also ensure to operate the UAV safely and remain clear of other air traffic and structures and power lines. They also recommend a reconnaissance of the area to be flown.

5.3 Experiments - Automation

5.3.1 Overview - Automation specific software

The research will focus on automation control using a laptop going from basic manual control to the AR Drone performing visual navigation. This is an objective of the dissertation and once met further objectives will be researched as time permits.

The experiments will be using a 10 year old laptop, AR Drone and programs freely available on the internet. Recreating the experiments in this chapter will prove that the experiments work, but also that a commercial UAV with a larger capital investment could fly with a high level of automation, using current technology.

5.3.2 Experiment 1 - Automation Basics

The first and second objectives of this dissertation involved a low level of automation. The start of this would be establishing a link with the AR Drone and then communicating both ways using the communication channels previously discussed in Chapter 4. These channels were designed to be used by a smartphone in gaming, but for the experiments needed to be accessed using a laptop computer.

Research found a paper on the use of the AR Drone for educational purposes (Vojtech Vonasek, Daniel Fiser, Jan Faigl 2011) and this paper had produced a software program that allowed for the development of the AR Drone capability without having to recreate the basic code to communicate with the AR Drone. The developers had found the proprietary API code was difficult to use so had developed a code that was easier to use for development.

In this experiment the program to control the UAV could be used by the Microsoft Operating System. During the conduct of the experiment I found this method to be a difficult installation and implementation process, this was a factor in converting to a Linux operating system. The programming code was downloaded from the AR Drone for Education Purposes website and installed on the destination laptop, it was found that several supporting libraries were required to run the package. The developers of the program had assumed a base level of knowledge of the operating system and Linux library that was above my current level. The download and installation of many supporting packages was required to allow the installation and implementation of the application to control the AR Drone from the laptop.

The Robotic Operating System,(ROS) website is a open source operating system, to further develop research into robotics. The website had its own software program to control the AR Drone using a laptop and WiFi connection. This program was a package on the website that was downloaded and installed on the Ubuntu desktop. The ROS AR Drone software package had the ability to be expanded to use the object recognition function in the AR Drone API, which is used by the AR Drone in its virtual games. Although basic it allows the AR Drone to pick up basic colours visually and track them.

Both of these programs were downloaded and the software installed on the controller. The AR Drone was connected to a battery and a connection over WiFi was established with the computer. It was found a connection was established using the programs and a screen appeared on the controller showing a video feed. The key-map had to be determined as the key-map in the help file associated with the program was designed for a different style of keyboard. The key board on the controller was used to manoeuver the AR Drone around the test area.

When WiFi communication was established, full control of the AR Drone was possible and photos could be taken and transmitted back to the laptop. There was also the additional function for the user to identify an object of a striking colour and the UAV would track this item and hover.

The first experiment satisfied the first two dissertation objectives using WiFi as the communication medium, a WiFi extender of RF communication could have also been used to increase the 50m range. The advantage of trialing two different methods to achieve the results at this stage of experimentation was that the operating system that offered the most potential for development could be chosen. To further develop the code in the (Vojtech Vonasek, Daniel Fiser, Jan Faigl 2011) would have taken a great understanding of the original software developers ideas. The alternate software using the ROS will now be used in future experiments and developed due to its compatibility with the Parrot API and further development using the ROS.

5.3.3 Experiment 2 - Visual Navigation

The next step in automation experimentation was to develop the AR Drone program on the ROS website to navigate in GPS denied environments, requiring the use of visual navigation. Using visual navigation will allow a UAV to identify power line components and take pictures of them, also it will allow a greater degree of accuracy when flying. To research this area of automation papers on the AR Drone for object recognition were reviewed.

Research into the autonomous AR Drone subject found a program called tum_drone on the ROS website. This program was developed by J Engel who did a Master Thesis on the subject and with the help of a research team wrote two papers on this subject(J. Engel, J. Sturm, D. Cremers 2011*a*)(J. Engel, J. Sturm, D. Cremers 2011*b*).The program allowed a user to connect with the AR Drone and navigate previously unmapped areas without the aid of a GPS. The program tum_drone was downloaded and installed, after several attempts the initial bugs were found and connectivity established. It was found the user could also upload flight plans to the autopilot and the AR Drone will fly a path in relation to the map it creates on initial operation.

The original authors experiments can be seen on youtube:

http://youtube/tZxlDly7lno

http://youtube/eznMokFQmpc

The AR Drone was flown in a gym at first to gain control and recreate the original authors experiments. The AR Drone struggled to create a 3D map that allowed it to identify its current position. This area had to be scaled back to an office indoor environment to allow for more static clutter in mapping. It appeared that the program for visual navigation worked best in rooms that were smaller and had clutter.

Experiments in a large office with tum_drone program found the positioning when the AR Drone had a map established to be very accurate. After a map was established a basic command was given via the auto pilot and this was carried out. The next experiment was to get the AR Drone to fly a 3 meter by 3 meter box and the AR Drone carried this out and then hovered awaiting its next command. The AR Drone was making small corrections at all times in relation to the map of the environment, and its end position was within 50cm of its start position. This experiment of the 3 meter box was repeated 10 times with the same accuracy achieved 9 times.

The limitations of the experiment was scale estimation performance noted at the start of the experiment where the gym did not provide enough static clutter and objects were too far away for a good estimation. This has implications using this technology outdoors in a larger scale where objects will not be static. Also the flying worked best if objects were only 2 - 10 meters away, which would mean the drone would need to very close to the power transmission line for this method of automation.

This limitation was further amplified when demonstrating visual navigation at the 2013 Project Conference. Depth becomes a major problem and the UAV was unable to determine its position and resulted in a run-away drone.

Another drawback of this program was noted during the experiment that the AR Drone cant track well during rotation, which would be needed on a larger scale to take pictures of power transmission line components on a tower.

5.3.4 Experiment 3 - GPS navigation

A GPS was purchased for the AR Drone and an open source program called Q-Ground Control station and MAVLink protocol was downloaded to operate the AR Drone using GPS way points. This was experimented between two small residential power poles, a distance of approximately 30 meters and the controller was placed in a position in the center of this distance. This experiment and was successful in guiding the drone from one power pole to the next following the power lines approximately 3 meters above the power line. The camera could be toggled from the forward facing to the bottom facing allowing for inspection of the line as the drone transited between the two power poles. The experiment was conducted with no wind present as the AR Drone moved greatly when any degree of wind was present.

The problem encountered in the experiment using the GPS was that it was not accurate enough and when the AR Drone was blown off course, it needed to continually keep correcting and missing parts of the transmission line. When the GPS guidance was at the power pole the distance between the components of interest was too small to differentiate with a GPS co-ordinate. The GPS used had a accuracy of +- 2 meters so this was to be expected.

For a Drone to use a GPS and use sensors to gather data it must be able to hold station in a wide variety of conditions, only being able to operate on a windless day would restrict its operation and there fore its use. The AR Drone was used as a platform but it has shown this attribute of a Drone used for this purpose needs to be addressed in this technology.

5.4 Chapter Review

This chapter reviewed relevant papers and journals written on automation and discussed previous research in this area. Experiments were conducted using the AR Drone to attain a current level of automation that could be achieved with a small investment and available current technology.

In the first experiment the AR Drone was controlled with propriety Application Program Interface,(API) that Parrot has released for use by developers. It is noted that in the paper (Vojtech Vonasek, Daniel Fiser, Jan Faigl 2011) found the AR Drone API was hard to use and the research team implemented their own version of programming to control the AR Drone. The ROS was chosen as the basis for software and experiments after experiment one and this flowed onto to the next experiments. Visual and GPS navigation was established using the ROS and Q-Ground Control and it was found on their own, do not make the methods suitable for larger scale UAV operations.

A combination of visual and GPS navigation would best suit power line inspection to use the advantages of both methods. This will be further researched in Chapter 7.

Chapter 6

Picture Analysis

6.1 Chapter overview

The research into inspection of power transmission lines using a UAV will now focus on the area of picture analysis. The picture analysis was Objective Three in the dissertation. The use of Linux and open source programs will be used in the research in this area.

6.2 Picture analysis research

The use of an dedicated development environment micro-processor to use run software program to analyse pictures from the drone is beyond the scope of this dissertation so an approach that uses existing analysis of pictures using the existing research laptop will be used.

Linux was chosen for the area of picture analysis because of the large amount of research and open source programs already written using this operating system. It allowed for basic information regarding picture analysis to be learned readily.

A software program to analyse the picture or video taken from the AR Drone will need to be used in the research. A constraint will be the use of appropriate software, so the use of an open source analysis program will be a possible solution, or the loan of software from USQ or a similar educational facility may be examined. There are a variety of Windows based programs and Linux has a software program or library called OpenCV which is used in conjunction with an Independent Design Environment,(IDE) to analyse video and pictures. There is also another program called MATLAB that can analyse picture and Video. Due to the high cost and availability of the Windows based software packages, OpenCV and MATLAB will be experimented with in the research phase to analyse picture and video.

Considered for use in this area was Speeded Up Robust Features,(SURF) processing which used an off Drone processor to process video data to map the environment and navigate using the map visually (Svab, Krajnik, J.Faigl & Preucil 2009). Further research indicated this used a FPGA development board which was a substantial cost and increased the complexity of this dissertation considerably, for this reason this method was ruled out as beyond the scope of this dissertation.

Another method to process video was the use of the processor on the graphics card to process data, freeing the main processor for the main program. This was able to be implemented using NVIDIA video cards which have been developed for high end video gaming, which requires a large amount of processing power. The OS program CUDA used this extra processing power to allow for parallel processing which greatly decreased the time taken to analyse video data and feed directions back to the Robot to allow for real time navigation of a environment. The cost of high end laptops with NVIDIA graphics cards capable of being used with CUDA was cost prohibitive for the outcomes of this dissertation and was therefore ruled out as beyond the scope of this dissertation.

A open source program that was available to use in the dissertation was OpenCV, this program could be used to analyse pictures. Although unfamiliar with the use of this software package, it fell within the scope of this dissertation. The package OpenCV was loaded to the Linux laptop, and it was found that OpenCV is not itself a executable program, but a library that can be used by an IDE. The IDE selected to use with the OpenCV was CodeBlocks, an Open Source IDE with a large number of developers supporting the Open Source.

OpenCV was chosen as the software analysis tool for this dissertation for the following reasons:

1. Open source computer vision library in C/C++.
2. Optimized and intended for real-time applications.
3. OS/hardware/window-manager independent.
4. Generic image/video loading, saving, and acquisition.
5. Both low and high level API.
6. Provides interface to Intel's Integrated Performance Primitives (IPP) with processor specific optimization (Intel processors).

It also features:

1. Image data manipulation (allocation, release, copying, setting, conversion).
2. Image and video I/O (file and camera based input, image/video file output).
3. Matrix and vector manipulation and linear algebra routines (products, solvers, eigenvalues, SVD).
4. Various dynamic data structures (lists, queues, sets, trees, graphs).
5. Basic image processing (filtering, edge detection, corner detection, sampling and interpolation, color conversion, morphological operations, histograms, image pyramids).
6. Structural analysis (connected components, contour processing, distance transform, various moments, template matching, Hough transform, polygonal approximation, line fitting, ellipse fitting, Delaunay triangulation).
7. Camera calibration (finding and tracking calibration patterns, calibration, fundamental matrix estimation, homography estimation, stereo correspondence).
8. Motion analysis (optical flow, motion segmentation, tracking).
9. Object recognition (eigen-methods, HMM).

10. Basic GUI (display image/video, keyboard and mouse handling, scroll-bars).

11. Image labeling (line, conic, polygon, text drawing)

The OpenCV features will make the real time capture and analysis achievable in the experiments, also OpenCV and ROS, as used in the automation experiments in Chapter 5, can work together(Yuvraj 2013).

6.3 Experiments - Picture Analysis using OpenCV

The OpenCV library had an inexpensive book to allow the user to gain experience using it fast, and over three days and many failed attempts there was no progress. After consulting with many bulletin boards and posting questions on the subject it was discovered there were many mistakes in the book, in examples and implementation of OpenCV. The mistakes in the book were noted and corrected in implementation and OpenCV was then used in conjunction with CodeBlocks to do some basic examples.

The experiments in Chapter 5 have provided access to vision of the AR Drone and in this chapter will conduct experiments to learn how to use OpenCV hence opening the doors of further analysis of computer vision. The features in OpenCv used in particular that will aid in the experiments will be; optimised and intended for real time applications, object recognition, image manipulation and basic image processing.

The experiments presented are intended to form a basis for further research and have been documented by a researcher in (Yuvraj 2013). They will be recreated and analysed for their use in power line inspection.

It should be noted for further research that OpenCV is open source and not intended for commercial purposes. For this dissertation it use in experiments is intended to show that visual analysis can be performed using a UAV to improve power line inspection.

6.3.1 Experiment 1 - Picture Analysis Basics

To use OpenCV with ROS this first experiment will create a node to be used with the AR Drone ROS. It will do basic edge detection of the video data feed received. This experiment will be recreated from an internet tutorial (DASL 2013)and I will seek to replicate the outcomes and analyse the results.

The first step I conducted was to create a node in ROS, I had a problem here as the Ubuntu distribution I was using was different to the example in the original experiment. I had to find a different node to drive the AR Drone communication and modify the node example given as parts called for programs that did not exist in my version of ROS, used with the Ubuntu distribution of Linux.

This did bring up an important part of the experiment that was to get OpenCV to communicate with ROS. The problem files were associated with this function. The file cv_bridge and Cv_Bridge were different files, but both had been created in ROS to allow for communication with OpenCv. I had to modify the ROS groovy software packages included in my Ubuntu distribution to include Cv_Bridge. This works, but crashed after five minutes of use in the experiment, so is suitable for testing but requires more analysis and modification to avoid the crash.

OpenCV has in-built edge detection algorithms and the one used in this experiment will be Canny Edge Detection. The Canny Edge Detection algorithm takes the derivative of an image to find the gradients, then determines the direction of these gradients (vertical, horizontal, diagonal up, diagonal down). Then if the amplitude of a given gradient is high enough (the high threshold), the algorithm will trace along that gradient in its direction until the amplitude falls below the low threshold, or the gradient changes direction sharply. The algorithm will also suppress local non-maximums around the edges. The inputs are the two images to be used, the thresholds, and the aperture size of the convolution kernal (Kuntz 2013).

When the problem was solved with the AR Drone driver and communication between the software, I then created the ROS node that would allow the video feed from the AR Drone to be analysed.

The AR Drone research platform will be used again using controls from previous experiments in automation from Chapter 5. A furniture crowded, office environment was used to identify maximum lines.

The ROS nodes required were launched and the video feed from the AR Drone was relayed back to the computer where basic edge detection occurred using the canny method.

Although not a straight forward experiment to replicate I was able to build a node and OpenCV was able to communicate with ROS. The implication for power line inspection would be that the software for both the operation of the UAV and the picture analysis need to work seamlessly to allow for analysis in real time of pictures and relay navigation commands back to the UAV. The practical environment would use many straight lines on a power transmission line, that would distinguish the materiel to be inspected from the natural environment where straight lines seldom occur. This experiment has demonstrated that this is possible using very limited hardware and software, on a small scale application.

6.3.2 Experiment 2 - Detecting Lines using OpenCV

The ability for a UAV to detect and follow a line visually would be highly desirable for power line inspection, OpenCV has several algorithms available for use to aid with this. Line detection is one of the most basic algorithms in computer vision technology. Line detection is involved in the basic level in algorithms for pattern recognition, object comparison, lane detection and SLAM.

OpenCV offers two types of line detection; Progressive Probabilistic Hough Transform(PPHT), Standard hough transform(SHT) and Multi Scale Hough Transform(G. Bradski, A. Kaehler 2008).

The model used in the Standard Hough Transform is that any point in a binary image could be part of some set of possible lines. Each line is parameterized by a slope 'a' and an intercept 'b' and then a point in the original image is transformed to a locus of a points in the (a,b) plane corresponding to all lines passing through that point. If we convert every non-zero pixel in the input image into such a set of points in the output image and sum over all such contributions,then lines that appear in the input image will appear as local maxima in the output image. Since each point's contributions is being summed the (a.b) plane is called accumulator plane(G. Bradski, A. Kaehler 2008).

The PPHT is derived form the standard hough transform. It takes in the extent of the lines than just the orientation of the lines. The reason its called Probabilistic is that accumulates only a fraction of the points in the accumulator plane and not all of them(G. Bradski, A. Kaehler 2008).

A new ROS node was built to allow the use of the different hough transforms and the node was recompiled. The make file in Linux needed to be reconfigured also, to allow for the new file to be compiled.

The AR Drone has the capability to use its frontal camera or its horizontal camera to detect lines. The camera toggle functionality on the AR Drone driver will be used to test both cameras for this use during the experiment.

This experiment will build on the outcomes from experiment one and detect lines using the PPHT and the SHT. This will use allow for a comparison of the two types of hough transform.

An experiment was conducted in a gym to replicate the collision and line following ability of a UAV. The AR Drone platform had been researched for this purpose by (Yuvraj 2013). The website had a good source of knowledge on the control of a drone using visual navigation and the practical ways to implement it, like how to make ROS and OpenCV work together. A program was downloaded from (Yuvraj 2013) to test the ability for a drone to be able to navigate and avoid obstacles autonomously which is very desirable for an automated UAV. Also the ability for the drone to toggle cameras and follow a line has high potential in power line inspection for its possible use in following power lines from one power pole to the next.

A video of the original developers experiment is contained at youtube here:

http://www.youtube.com/watch?v=LOiJIaQvAPM

I recreated the experiment in a gym with a large amount of lines marked on the ground, which confused the navigation. An area that only had one basketball court marked was found and the AR Drone was able to follow the lines. The anti-collision ability required a large amount of time to calibrate using a light small projector to attach to the AR Drone, so I just experimented with the line following ability. This also tested the ability for OpenCV and ROS to work together so has implications with further experiments. The information and experiment will be further utilised in Chapter 7.

6.4 Chapter Review

This chapter recreated experiments conducted on picture analysis using OpenCV as an analysis tool. The experiments allowed me to understand the relationship between OpenCV and ROS and how to implement image detection with the AR Drone. The experiments were chosen to assess the suitability of different analysis for power transmission line inspection. The knowledge I gained will now be used in Chapter 7 to formulate a way to integrate and achieve Objective three and four.

Chapter 7

Powerline Inspection

The research into inspection of power transmission lines using a UAV in Chapter 5 and 6 has recreated previous experiments in automation and picture analysis using the AR Drone. The experiments were then analysed for thier relevance to power line inspection and discussed in the chapters. This chapter will experiment and modify previous experiments to analyse power transmission lines and associated components in real time.

7.1 Automation Inspection Overview

The next phase of the research was for the UAV to recognize a particular type of power pole and fly a path that would allow it to take pictures of the major components. There was no previous development found in this area on the ROS website, an API however did exist on the Parrot website for basic object recognition using colours. The experiment would; have the AR Drone fly a prescribed height according to AS for the given power transmission line; take pictures of two components on the power pole with the forward camera; fly a prescribed distance from the AS following the power transmission line with the bottom camera taking video; take pictures of two components on the second power pole with the forward camera and land. This experiment will replicate a UAV inspecting power transmission lines and sending data back to a laptop.

This experiment will start on a small scale using a freestanding washing line with poles at each end and several lines stretched in between. This was chosen as a model so the auto pilot could be easily adjusted. The colours to allow the Drone to identify the object will be placed on each pole, acting as a reference and once the AR Drone had the reference it will move left and right and take two pictures, it pivot 180 degrees load a new map and transit 3 meters after switching camera to look downwards, after the transit it locates the object moves left and right and takes two more pictures.

To further investigate object recognition and not requiring the use of colours, real time signal processing would need to take place to recognize power components. When the components were recognized it would allow the map to adjust in relation to the component and take the required pictures or video. The next step was to conduct research and experiments using picture analysis.

7.2 Experiment - Automation Inspection

The Detecting Lines experiment used the visual navigation from Chapter 5.3.3 and measurements were taken of the poles at each end of the outside washing line and the distance in between. The measurements were written into a file and loaded into the auto pilot of tum_drone. In the first experiment the UAV on autopilot had to rise 200cm, fly to the left 75 cm and to the right 150cm, back to the left 75cm, rise 30cm, then fly 600cm and repeat the reverse process and land.

The UAV struggled to define its location in the experiment before the autopilot could be run. This resulted in four out of the five test runs failing, with the UAV flying off course. The experiment was run in a cluttered office space indoors and the UAV performed much better, establishing its location quickly and following the path of the autopilot. This experiment did not test the ability of the UAV to turn 180 degrees as it has already been established in Chapter 5.3.3 that the AR Drone cant track well during rotation.

The experiment in Chapter 6.3.2 was the next to be used on the washing line. The line used on the washing line was only 3mm thick and the algorithm failed to pick up the thin line. The line in the original experiment in 6.3.2 used a thick line approximately 5cm wide. The UAV was tried at different heights, from 5 cm to 30cm, above the lines to improve the performance. It was found at 5cm height the UAV could follow and partially at 10cm, but this resulted in a large amount of crashes during the experiment from flying so close to the line and small gusts pushing the AR Drone into the line.

Modification to both nodes was attempted but did not result in noticeable gains in accuracy in an outside environment.

The failures with the basic application of the methods from Chapter 5.3.3 has meant this area of research requires further time or a different approach than used with tum_drone. The method of visual navigation is limited to indoor cluttered environments.

7.3 Discussion

The experiments in this chapter sought to apply the experiments from the previous chapters to the task of power line inspection, which did not meet with a great deal of success. The experiments from the previous chapters worked well on a small scale, in an indoor environment. When the same methods were used in an outside environment, with a limited amount of clutter, the techniques contained within the methods failed. This resulted in a runaway UAV.

To continue on with this research of automation and picture analysis I would need to re-evaluate the methods used. More financial support would be required to investigate methods such as using a GPU parallel processing or dedicated CPU for signal processing.

7.4 Chapter Review

This chapter sought to implement the methods of automation and picture analysis used in previous chapters. This required modification of previous methods to achieve the outcome; however, the modification of nodes did not produce the desired outcomes. The operation of the software from Chapter 5.3.3 did not translate well to a scaled outdoor model. The limits of using old laptop and this has resulted in a failure of adapting the technology to this area of the research.

Further research in this area would need to be conducted for visual navigation to work in an outside environment. Papers that were researched in previous chapters used NVIDIA GPU or a dedicated development CPU for signal processing.

Chapter 8

Cost Comparison

Currently the military as identified in Chapter 2 operate the UAVs in a dull, dirty and dangerous environment where the risk of an aircraft being shot down is high. This means that the cost associated with purchase and operation of the UAV can be offset by the safety of the operators. The civilian risk has different parameters, so must compete with manned aircraft on an economic basis with risk to the aircrew as a mitigating factor.

8.1 Current UAV cost

The only UAV system operating in Australia that are designed to carry the sensors required and had a long endurance was the Yamaha RMAX UAV. The Yamaha RMAX helicopter is not sold as a piece of equipment, but operators lease the equipment for flying hours. This UAV is not currently performing power line inspections.

There is a rotary wing UAV designed in Japan by Hirobo limited for the purpose of power line inspection, called the Sky Surveyor. The Sky Surveyor is a full autonomous system used in Japan for industrial uses, I was unable to establish contact with the company in Japan to obtain a cost.

No electric UAVs were considered for this cost comparison, as the operating time of the current UAV did not make the UAV practical for this purpose. There were civilian fixed wing electric UAVs that had long operating times but did not have the sensor carrying capacity.

8.2 Yamaha RMAX UAV

RMAXs have been used to inspect active volcanoes, disaster zones and otherwise inaccessible sites. RMAX is used by many universities and research institutions. They are a stable and reliable platform for; photography, surveillance, photogrammetry and information gathering.

The Yamaha RMAX UAV current main application in Queensland to spray cane fields. Full specifications for the UAV can be found in on the Yamaha website (Australia 2013) but a brief of the specifications are:

1. Weight carrying capacity of 28kg
2. Visual operating range (400m)
3. Engine 246cc, two stroke
4. Speed 20km/h
5. Overall length with rotor 3.6m
6. Overall height 1m
7. Fuel unleaded with two stroke oil
8. operators trained by Yamaha Australia
9. The UAV can travel at 20km/h and operate for one hour without refueling

The main specifications important in powerline inspections are; the 28kg weight carrying capacity and that it is a stable and reliable platform.

8.3 Cost of Yamaha RMAX UAV

I contacted Yamaha Australia to identify the cost and compare it to a manned aircraft and it could only be leased at $500.00 per hour. The UAV could not be purchased by a company or individual for the following reasons:

1. International Treaties in Arms,(ITARS) place restrictions on operation on export, import and ownership of high capability unmanned vehicles. Yamaha Australia must know the exact location of the UAV and usage at all times.

2. To ensure that maintenance, responsible usage and environmental standards are met.

3. A fully maintained rental agreement is tax effective for the operators.

The cost of the UAV in the rental agreement was $500.00 per hour, which the company representative Mike Johnson said was not economically competitive with a manned aircraft. The cost of operating the UAV did not include:

1. Fuel.

2. Cost of transport to and from location.

3. Suitable cameras, sensors, gimballs or equipment.

4. Insurance.

The representative offered the information that the RMAX was not competitive economically when compared to large open field operation but had some uses where it was cheaper. He said the UAV is cheaper to operate in environments where:

1. The cost of flying a manned aircraft to the sight is cost prohibitive and the UAV can be transported by road and launch on-site.

2. In steep terrain where tasks were previously done by riggers taking two days the UAV could do this in two hours.

8.4 Current Regulation

CASR101 is the regulation that covers unmanned aircraft. It was promulgated in 2002, and was the first operational regulation for unmanned aircraft in the world. This stipulates the type of aircraft and operating procedures. This has been detailed in Chapter 2.11.

In practice a CASA UAV Controllers Certificate is required for the pilot to operate a UAV and a business will need a CASA Operators Certificate. If power line inspection operations are planned then both the operators certificate and controllers certificate will need to be endorsed for this.

The CASA UAV Controllers Certificate requires the operator of the UAV to have a civilian pilots licence to operate the UAV using visual line of sight, to operate beyond this the operator requires an instrument rating in accordance with CASR101.295(2)(c). This instrument rating would require a civilian pilots license that has been upgraded.

The main things that deter people from UAV operators certification is:

1. Cost, the UAV is probably the cheapest part of the setup costs. With a mikrokopter as stable camera platform available for aproxamately$5000. You also have to add the costs of CASA administration, which they quote at about $8000. An operators course will set you back about $2,500, and also the cost of public liability insurance.

2. Admin paperwork, aviation is a very paperwork and administration heavy environment. The drawing up of an operators certificate is a long and potentially painful process, with reams of paperwork.

3. Theory. The theory involved in learning about aviation and its niches and standards, as well as the skills involved, can be a very steep learning curve for aspiring UAV operators.

8.5 Insurance

A hidden cost of UAV operations is insurance, I contacted Civil Aviation Insurance Australasia for a cost of insurance. This type of insurance includes:

1. Public Liability Insurance up to 5 Million Dollars
2. Ground Risk Insurance in motion
3. Ground Risk Insurance not in motion
4. Hanger and maintainer insurance
5. In-flight insurance.

Ground risk hull insurance not in motion, provides coverage for the insured aircraft against damage when it is on the ground and not in motion. This would provide protection for the aircraft for such events as fire, theft, vandalism, flood, mudslides, animal damage, wind or hailstorms, hangar collapse or for uninsured vehicles or aircraft striking the aircraft. The amount of coverage may be a blue book value or an agreed value that was set when the policy was purchased.

The use of the insurance term ”hull” to refer to the insured aircraft betrays the origins of aviation insurance in marine insurance. Most hull insurance includes a deductible to discourage small or nuisance claims.

Ground risk hull insurance in motion (taxiing), this coverage is similar to ground risk hull insurance not in motion, but provides coverage while the aircraft is taxiing, but not while taking off or landing. Normally coverage ceases at the start of the take-off roll and is in force only once the aircraft has completed its subsequent landing. Due to disputes between aircraft owners and insurance companies about whether the accident aircraft was in fact taxiing or attempting to take-off this coverage has been discontinued by many insurance companies.

Insurance costs can be significant depending upon your operations and unique situation. Based on experience for a fairly straight forward UAV operation the Public Liability Insurance can be around $4000 to $6000 per year (AeroSDB 2013).

An insurance quote for a $12,000 Octocopter, cost $4,500 and that is limited to public liability only, they refuse to insure the airframe.

8.6 Chapter Summary

This chapter examined the economic cost of using a UAV when compared to a manned equivalent. A currently operational Yamaha RMAX UAV was used to compare, as it is a rotary airframe and capable of lifting sensors required. The chapter included cost both economic and regulatory as a fair comparison and as the UAV industry is small the cost of these is high and does not include coverage for the airframe.

Chapter 9

Results

The research into inspection of power transmission lines using a UAV has resulted in key findings into its use and application. These results were developed with the intent of improving the problem discussed in Chapter 3 most notably to provide the planners in the power industry greater access to power line condition data in order to efficiently use maintenance resources.

These key findings were:

Automation A high level of automation could be achieved indoors with a low cost computer and UAV.

Picture Analysis The picture analysis algorithms are mature and can identify lines and objects.

Field testing The methods used in automation and picture analysis did not translate well to an outdoor environment.

Cost The regulation and operating cost of a UAV is higher than a manned aircraft.

9.1 Automation

The key finding in automation was experiments have proved technology is available to automate UAVs, with light and cheap sensors and communication. The control stations do not need to be complex but could be a rugged laptop computer. The constraint for this research was the use of cheap computers and UAV platform which lead to a poor performance in an outdoor environment.

The experiments conducted resulted in basic automation of the AR Drone using GPS and visual navigation. This satisfied objective one and two of the dissertation. This was achieved by researching the AR Drone using ROS and open source programs.

The first experiment showed basic automation with manual control of the AR Drone using a laptop keyboard sending messages over WiFi. Video was returned on both the vertical and horizontal cameras and displayed on the laptop. In this experiment ROS was chosen as the operating system for the rest of the experiments because of its ease of use and also a large amount of developers contributing.

Degrees of automation of Visual and GPS navigation was established using the ROS and Q-Ground Control and it was found on their own, do not make the methods suitable for larger scale UAV operations. A combination of visual and GPS navigation would best suit power line inspection to use the advantages of both methods.

9.2 Picture Analysis

The experiments on picture analysis using OpenCV as an analysis tool, allowed me to understand the relationship between OpenCV and ROS and how to implement image detection with the AR Drone. The experiments were chosen to assess the suitability of different analysis for power transmission line inspection.

Basic edge detection could be achieved using Canny edge detection and Hough line transform for using OpenCv and was quite successful for edge detection in an indoor environment. This was used to detect lines in line detection for the bottom camera, which worked on lines that were 5cm in width but much smaller lines on the scale model were not picked up until the AR Drone was very close to line the model resulting in crashing the AR Drone.

The result was a good comparison between the PPHT and the SHT. I was impressed by the ability of both line detection techniques. The experiments were performed with objects at a maximum range of ten meters and the AR Drone camera worked well.

9.3 Power Transmission Line Analysis

The key finding of power transmission line experiments was when previous methods of automation and picture analysis were applied to a scale model in an outside environment, the methods failed. The methods were found to work in an office environment where clutter existed from 2 to 10 meters, but when used in an outside environment the method of mapping failed and the UAV was unable to establish its position.

9.4 Cost Analysis

The cost of operation of a UAV that could carry up to 28kg of sensors was in excess of a manned helicopter. The extra cost of operating a UAV compared to a manned aircraft would be increased regulation and insurance also. The cost of sensors to allow the rotary aircraft to operate at safer distances was approximately $600 000 and would be the most expensive part of the UAV.

The insurance companies contacted for quotes on operation of UAVs are not prepared to insure UAV airframes, but will provide third party insurance for $4000 to $6000 depending on circumstances. If high value sensors were installed the risk of a crash would be unable to be adequately managed as a $600 000 camera would need to be financed and the finance conditions would require insurance.

To operate outside line of site a qualified pilot would be required with an instrument rating, regardless of automation of the UAV, negating the cost saving of using less qualified employees.

9.5 Discussion

Theoretically a UAV could be used for various roles in the power network that include; fault and damage assessment for a line, damage assessment after an extreme event, planning and forecasting work, vegetation control management, right of way access work, line inspection and condition assessment and line security. This must be researched in practice against current technology maturity and the current regulation and insurance environment.

The ROAMES project conducted by Ergon and detailed in Chapter 2.3 as the capacity to map vegetation across the entire network. This uses fixed and rotary wing assets and after the initial mapping will be updated annually. If this project was expanded to include powerline hardware it would become a powerful tool. The software behind this is Google map engine which is able to be modified to achieve this result unlike current GIS software used by Ergon.

The benefits of using a UAV for Ergon are discussed in Chapter 2.3 and further in Chapter 3.2 and and the UAV was best suited to:

1. Conduct out tower survey using photography, EMI emission recording, thermography.
2. Line thermography.
3. Cable sag and ground clearance survey.

To achieve the surveys above, experiments in this dissertation were conducted using the AR Drone to attain a current level of automation that could be achieved with a small investment and available current technology.

The main limitations of the AR Drone one was its:

1. Ability to work in a light breeze to to its low power.
2. Visual navigation had limits of 10 meters and required a specific cluttered environment.
3. Operating area restriction due to using WiFi was 50m.
4. Battery power was limiting to only small run times.

The AR Drone was selected for this dissertation because of its availability and cost it did have some deficiencies that are common to all aerial drones. Due to its small size and rating these were amplified, but should be considered in further research in this field.

The AR Drone has four light motors and a very light frame, while aerodynamic when working at heights over 3 meters any breeze effected the ability for the AR Drone to hove and take video and pictures. This was negated in testing by using gyms and large rooms for experiments or taking advantage of perfect weather periods. This would by a high consideration when selecting a UAV for the purpose of inspection power transmission lines, that it had the capability to hover and hold position in a wide variety of weather conditions.

The operating area of 50 meters using WiFi communication was a limitation in real practice due to the height of power transmission lines. Later using the GPS unit for control it became a large limitation, this was mitigated by using a WiFi card and antenna with a 5dB gain. The 5dB gain increased the operating area by more than double, but if WiFi was used as a medium to control a UAV for the purpose of power transmission line inspection in the future higher gain antennas would be required or the use of another communication medium such as RF or Satellite would be considered for further research in this area.

When used in an scaled model, in an outside environment, the methods of picture analysis and automation failed. Research in this area to improve signal processing time and accuracy would need to be conducted for visual navigation and GPS to work in an outside environment. NVIDIA GPU or a dedicated development CPU could be used for signal processing, increasing the cost and weight of the UAV required to carry the sensors.

The cost of operating a UAV in Australia is not economically viable when compared to manned aircraft. The current base cost is $500.00 per hour, this does not include cost of regulations, insurance and sensors. The camera used in Shadow in Chapter 2 was a $600 000 camera and was the most expensive part of the UAV. The cost of a crew to operate the UAV will increase with each complexity, such as operating in regional areas and beyond line of sight. Insurance must also be considered as part of the cost of operation as a part of a risk mitigation strategy. The cost is more economic when used for niche applications such as steep terrain.

9.6 Chapter Review

This chapter presented the results form the three areas of research and discussed these and how they apply practically to inspection of power lines using a UAV. The chapter started with a brief summary of the problem statement and the key findings of the experiments. It further detailed the results in individual areas. The most important key finding was that a UAV is not viable as a replacement for manned aircraft for this application.

Chapter 10

Conclusions and Further Work

This dissertation has researched the inspection of power transmission lines using UAVs and has identified that it is not feasible at this time. The main reasons why UAVs are not suitable is government regulation and economic cost. There are also smaller considerations such as privacy concerns and technology adoption by industry.

A technology which will conduct an increased amount of transmission power line inspections and be safer, efficient and accurate is helicopter inspections with enhanced picture analysis and a database capable of a health report. This will give planners qualitative information to base decisions on where the priorities in the power system are. The ROAMES project is a good example of using Google maps and GIS to provide users with an intuitive product that is easily understood with minimal training. If this approach was applied to power line inspection more improvements could be made both in time to repair faults and economically.

The technical improvements since the last dissertation at USQ on this subject have been rapid due to parallel technology, but the capital and operating cost of UAV is far beyond equivalent aerial inspections by manned rotary and fixed wing assets.

The dissertation has researched methods to automate a UAV with a limited budget and has been able to automate a UAV using visual and GPS navigation; however the visual method would need a significant investment of NVIDIA GPU processing or a dedicated development CPU.

The signal processing used basic algorithms available with open source programming and was able to do line detection with Hough Line transform transforms. The open source program is also able to do object detection so with further time would be able to detect power line specific objects to allow automation of pictures being taken from a helicopter.

10.1 Achievement of Project Objectives

The following objectives have been addressed:

1. The first objective of the dissertation will be to perform basic navigation of the AR Drone controlled by WiFi.
2. The main objective will be to take high definition photos of objects and send them back to a computer using WiFi.
3. If time permits the photos will then be analysed to check on the health of the object.
4. If further time permits the drone will fly a pre-programmed path and send pictures back to the control center for analysis.

The following objectives were not fully addressed:

1. If time permits the photos will then be analysed to check on the health of the object.
2. The end objective is to simulate a drone taking high resolution photos and sending them to a control station in real time. The photos will be analysed and the health of the transmission line and supporting infrastructure can be quantified.

10.2 Further Work

The UAV concept may not be feasible at this point in time due to regulation and economic reasons, but the picture analysis and health report is worth researching further. The ROAMES system for power line vegetation should be researched for expansion to include power line hardware.

Improving the existing method of aerial inspections by helicopter will decrease the environmental footprint and mitigate the time spent in danger by the air crew.

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Appendix A

Dissertation Specifications

ENG 4111/2 Research Project

Project Specification

For:	**Nigel Ellis**
Topic:	Inspection of Power Transmission Lines using UAV's
Supervisors:	Dr Tobias Low
Sponsorship:	Faculty of Engineering & Surveying
Project Aim:	To develop the use of UAV technology to improve inspection methods of power transmission lines. This will involve analysing the main areas of the topic and identifying an area where improvement can be made.

Program:

1. Research the background information on UAV, UAS, and existing Inspection Methods.
2. Critically examine the UAV method of inspection of power lines and focus on an area where improvement can be made.
3. The test platform (AR Drone) will be able to navigate using a basic level of autonomy.
4. When an area of the UAV is identified, research and practice in the field.
5. Test the new development to see if it is repeatable.

As time and resources permit:

1. Get the AR Drone to follow a pre-prepared flight plan and take photos
2. Develop a second area where improvement could be made.

Agreed:

Student Name:	Nigel Ellis
Date:	13 Mar 2013
Supervisor Name:	Dr Tobias Low
Date:	13 Mar 2013
Examiner/Co-Examiner:	Chris Snook
Date:	16 Apr 2013