
Sensor Fusion on a mini Unmanned Vehicle

INTEGRATING VISION-BASED ALGORITHMS ON AN PARROT AR.DRONE TO AUTONOMOUSLY
FOLLOW LINEAR SHAPED STRUCTURES IN A LANDSCAPE.

Camiel R. Verschoor
10017321

Bachelor thesis
Credits: 18 EC

Bachelor Opleiding Kunstmatige Intelligentie

University of Amsterdam
Faculty of Science
Science Park 904
1098 XH Amsterdam

Supervisors

Dr. A. Visser

Informatics Institute
Faculty of Science
University of Amsterdam
Science Park 904
1098 XH Amsterdam

Drs. G. Poppinga

Defense Systems
Aerospace Systems
National Aerospace Lab
Anthony Fokkerweg 2
1059 CM Amsterdam

July 24th, 2012

Abstract

To be written.

Acknowledgements

To be written.

Contents

1	Introduction	4
1.1	Platform and Framework	5
1.2	Research questions and objectives	5
1.3	Outline	6
2	Related Work	6
3	Platform: Parrot AR.Drone	7
3.1	Quadcopter	7
3.2	Hardware	8
3.3	Software Development Kit	9
4	Framework: AR.Drone SLAM	10
5	Computer Vision	10
5.1	Basic Algorithm	10
5.1.1	Colour Filter	10
5.1.2	Gaussian Smoothing	10
5.1.3	Canny Edge Detector	10
5.2	Combined Algorithm	10
5.2.1	Motion detector	10
5.3	Probabilistic Hough Line Transform	10
5.4	Tracking	10
6	Navigation	10
7	Experiments	10
8	Results	10
9	Discussion	10
10	Conclusion	10

1 Introduction

In robotics one of the main goals is to develop mobile robots that can operate autonomously in the real world environment. These autonomous robots have various purposes and are used for a wide range of applications such as inspection, exploration and rescue. In rescue, robots are expected to operate in dangerous environments without putting human lives at risk in example, during disasters or life rescue operations. Even though reasonable developments have been made in the robotics field, robots cannot operate autonomously in the real world yet.

One of the main requirements of an autonomous robot is the ability to navigation in the environment. The traditional approach to navigate through the outdoor environment is via pre-planned paths based on a Global Positioning System (GPS). The main shortcoming of GPS is that it cannot be used in every environment as it needs to receive data signals from four different satellites. Inside buildings and in several outdoor areas GPS is not available. In urban areas GPS is found to be especially unreliable. In order to navigate through these environments other sensors and navigation techniques need to be applied. Since there are several linear structures in the environment such as rivers, roads and power lines, line-following is one possible approach to navigate through an environment. Line-following is a classic technique in robotics as it has been successfully used for ground robots numerous times. For other robots and sensor configurations, open problems still remain. One of these is navigation for micro aerial vehicles (MAVs), which have a limited sensor composition due to their limited payload.



Figure 1: The Black Widow was the first operating micro aerial vehicle system developed by AeroVironment for Defense Advanced Research Projects Agency (DARPA). The Black Widow can fly for up to 20 minutes and carries a very small color video camera.

A micro aerial vehicle (MAV) is a subclass of the Unmanned Aerial Vehicles. Due to their small size, the MAV can operate in numerous robotic applications, for instance, search & rescue, inspection and exploration. AeroVironment Black Widow (figure 1) is the first MAV operating in the field. Another type of MAV is the quadcopter, which is controlled by four rotors. Quadcopters provide manoeuvrability and stability, which is suitable for indoor and urban flights. As a result of recent developments, small quadcopters with on-board stabilization can be purchased conveniently. Due to this, the research regarding this platform is moving towards intelligent applications, which demand information of the surrounding environment. Nevertheless, the fast

movements and the limited amount of sensor combination mean that it is still a challenge to develop navigation methods for these platforms.

1.1 Platform and Framework

The Parrot AR.Drone (figure 2) is a radio controlled flying quadcopter built by the French company Parrot. The quadcopter is made of plastic and foam and is about 30 centimetres long. It carries a horizontal and a vertical camera opening the door for the development of various visual application. The inertial measurement unit in combination with optical flow and a ultrasound sensor provide on-board stabilization during flights allowing the quadcopter to hover in the same place.



Figure 2: The Parrot AR.Drone is equipped with two cameras and several inertial sensors. The development is driven by commercial, government, research and military purposes. The small quadrotor allows remote observation of hazardous environments inaccessible for humans and ground robots.

AR.Drone SLAM is a framework for the Parrot AR.Drone, a quadcopter, developed and proposed by N. Dijkshoorn. This framework contains a realtime Simultaneous Localization and Mapping (SLAM) implementation based on a down-pointing camera. Therefore, it allows a MAV to know its position and movement in the environment by generating a feature map of the environment so the MAV can localize itself on this map. Furthermore, the framework contains a 3D mouse controller, a keyboard controller, a visual map and an elevation map. Due to the framework the robot acquires more information of the environment. This information can aid the robot in navigation.

1.2 Research questions and objectives

In robotics one goal is to develop mobile robots that can advance robustly and truly autonomously in real world situations. One of the main requirements is the ability to navigate autonomously. Since there is no GPS signal available in urban and indoor environment, robots need to rely on other sensors.

Line-following is proven to be a simple navigation task for ground robots. However, this navigation task is not implemented yet on unmanned aerial vehicles. Since there are various

linear structures in the environment, line-following should be a suitable navigation technique.

Therefore, the main research question is to find a robust vision-based approach to autonomously navigate over linear shaped structures. This main research question is divided up in the following sub-questions:

- What type of sensors does the AR.Drone carry?
 - What type of down-pointing camera?
 - What other sensors?
- How to detect and track a line?
- What is the performance and robustness of different vision-based methods to navigation over a linear structure?
- How should the vision-based algorithms be evaluated?

In order to perform line-following navigation, first, a line should be detected. Secondly, the angle between the quadrotor and the line is calculated. Finally, the quadrotor adjusts its movements in order to navigate over the line. These steps are repeated until the end of the line has been reached.

1.3 Outline

Chapter two gives an overview is given over the related research regarding line-following on unmanned aerial vehicles. The robotic platform, Parrot AR.Drone, is discussed in chapter three. The construction of the platform is explained, the hardware it contains will be listed and the software development kit will be addressed. Chapter four will give an overview of the framework AR.Drone SLAM. The main architecture and functionalities will be briefly discussed. In chapter five the Computer Vision algorithms are illustrated. The navigation techniques will then be discussed in chapter six. In chapter seven the experiments are illustrated and in chapter eight the results will be presented. Chapter nine will discuss the results found in the experiments and elaborate on them. Finally, in chapter ten the conclusion of this thesis will be presented and directions for future research will be proposed.

2 Related Work

One of the essential requirements of a autonomous robot is the ability of navigation in the real world environment. One of the main problems in navigation is that no sensor is reliable enough to function in every environment. The most commonly used sensor currently for outside navigation is the GPS. GPS receiver requires to receive data signals from four different satellites to be able to localize itself. Additionally, the measurements can contain errors due to the influences (ie.

signal reflection) of the surrounding environment. Due to these restrictions GPS cannot operate inside buildings and in several outdoor urban environments. Therefore, to navigate through these environments other sensors and navigation techniques have to be investigated.

3 Platform: Parrot AR.Drone

One of the basic steps for the development and testing of intelligent applications in robotics is to find an applicable robot platform for the defined problem. A common choice is to use a quadcopter, which is mainly designed to be a Unmanned Aerial Vehicle (UAV). The small size and manoeuvrability allows both indoor and outdoor flights. Moreover, quadcopters have a simple design due to the fact that they do not require mechanical connections to vary the pitch angle of rotor blade.

As a result of technological developments in aerospace engineering of UAV's, a small quadcopter with on-board stabilization can be purchased conveniently. Because of this, research regarding this platform is moving towards more intelligent applications, which demand information of the surrounding environment. The specific platform selected for the experiments in this research is the Parrot AR.Drone quadcopter. The advantages of this platform are its on-board stabilization, lightweight and the affordable price of the platform. The AR.Drone is carrying a front and bottom camera that provide live video streaming through the data link. Additionally, it has an ultrasound sensor and an inertial measurement unit that measures the pitch, roll, yaw and accelerations of the platform. The platform is controlled via WiFi, which allows the user to send commands and receive data of the platform.

In this section, the AR.Drone platform is described. The operational part of the platform is discussed, the hardware the platform contains is described and the software development kit is briefly described.

3.1 Quadcopter

A quadcopter consists of four rotors that are attached to a main frame, which commonly has a cross-shaped form (see figure 3). Every rotor produces thrust T and torque τ over the center of rotation, whereas it also produces drag force D_b in the opposite direction of flight. Thrust T is the force that is generated by increasing and decreasing acceleration the mass in one direction. The acceleration of the mass will result in a force of equal magnitude but in the opposite direction of the platform. Torque τ is the force that rotates an object around its axis. Drag D_b is the force that is in opposite direction to the motion of the aircraft through air. This force is inclined on the velocity of the quadcopter and de-acceleration will take place if insufficient thrust is generated. The rotors together should generate sufficient thrust to stay airborne during flights.

In order to fly the quadcopter relies on differences in thrust and torque. Pitch, roll and yaw (see figure 4) is the naming of flight dynamics to indicate the rotation angles in three dimension of the center mass of the quadcopter. The opposing rotor pairs (pair 1, 3 and pair 2, 4) turn

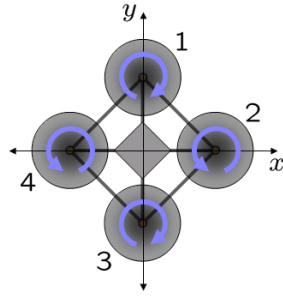


Figure 3: Diagram of the reaction torques on each motor of the quadcopter, due to the rotors. Rotors one and three are spinning clockwise, whereas rotor two and four spin counter-clockwise, causing opposing force for control

in the same direction. One of the pairs is turning clockwise, while the other pair turns counter-clockwise. This causes the platform to have no angular acceleration, when all rotor pairs have the same angular acceleration. Alternating the angular speed of the rotor pairs will cause angular acceleration about the yaw.

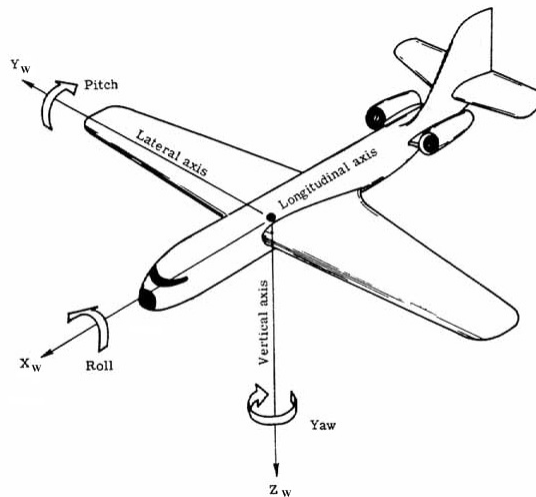


Figure 4: Diagram of pitch, roll and yaw rotations on an aerial vehicle

Vertical movements are accomplished by changing the thrust from each rotor alike, which is causing the resulting thrust to change and the differential torque to remain zero. Moreover, when the thrust is kept constant the vertical velocity remains the same. Horizontal movements are caused by changing the pitch and roll angle. Angular accelerations over the pitch and roll angles can be generated independently. Each pair of opposing rotors controls either pitch or roll rotation of the platform. A torque balance is kept for yaw stability during differential torque over the roll and pitch by increasing the speed of one rotor, while decreasing the speed of the opposing rotor.

3.2 Hardware

The AR.Drone is a remote-controlled quadcopter developed by the french company Parrot SA for consumer use. The main frame is made of carbon fibre and high resistance plastic. The AR.Drone has an indoor and outdoor hull, which is used for protection of the system. The rotors are powered by motors, whom are connected to a lithium battery allowing the system to fly ten minutes.

The AR.Drone has an on-board computer running a custom Linux operating system. A mini-USB connector is included on the system for software maintenance and additional external sensors (e.g. GPS sensor). The integrated wireless card provides network access for external devices that control the vehicle. The software of the AR.Drone is available for all platforms, however, the most supported software is written for iOS devices (ie. Apple iPhone). Nevertheless, it is possible to create controlling applications for the Windows and Linux platforms. Furthermore, the AR.Drone has a sensor suite containing an six degrees of freedom Inertial Measurement Unit (IMU), a bottom camera and a ultrasound altimeter used for automatic stabilization. The IMU consists of a three axis accelerometer, a two axis roll and pitch gyrometer and a single axis yaw gyrometer. The IMU reports on the system its velocity, orientation and gravitational forces. The ultrasound altimeter measure the altitude of the system and in combination with the bottom camera it calculates the optical flow of the system. All the above sensors contribute to the on-board stabilization module of the quadcopter, which allows the quadcopter to hover in one place. Additionally, the system carries a frontal camera to provide the operator with visual feedback.

3.3 Software Development Kit

Parrot created a open source Software Development Kit (SDK) providing developers the opportunity to create intelligent applications for their platform. The SDK comes with source code, multiplatform examples and documentation. The SDK does not provide software that is embedded on the AR.Drone itself. The SDK implements the following four channels of communications with the platform:

1. Configuration and control of the platform.
2. Status of the platform (ie. altitude, attitude and speed).
3. Video stream.
4. Control port for communication of critical data.

These four channels of communication can be used for designing intelligent applications for the AR.Drone.

4 Framework: AR.Drone SLAM

5 Computer Vision

5.1 Basic Algorithm

5.1.1 Colour Filter

5.1.2 Gaussian Smoothing

Gaussian Smoothing is the result of blurring an image by a Gaussian Function. Smoothing is applied to reduce noise and detail in the image. Gaussian smoothing is a well know technique mostly used in computer vision algorithms as a pre processing technique in order to enhance image structures at different scales. Gaussian Smoothing is the same as convolving the image with a gaussian function. The 2D gaussian smoothing function is represented by the following equation.

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (1)$$

5.1.3 Canny Edge Detector

5.2 Combined Algorithm

5.2.1 Motion detector

5.3 Probabilistic Hough Line Transform

5.4 Tracking

6 Navigation

7 Experiments

8 Results

9 Discussion

10 Conclusion