Acronyms

UAV Unmanned Aerial Vehicle.

Chapter 1

Introduction

1.1 A brief history of drones

UAVs (Unmanned Aerial Vehicles), more commonly called drones, are defined as flying vehicles without human operators on board. They can be remote-controlled, or controlled by on-board computers. The earliest recorded use of UAVs dates back to 1849, when Austria launched about 200 unmanned balloons armed with bombs against de city of Venice [5]. Due to unfavorable wind conditions, this attack failed, and the experiment was not repeated. The first functional UAVs were made towards de end of World War 1 and their use was, like the Austrian balloons, military. One example is the Kettering Bug (Figure 1.1), which was a torpedo with wings and a propeller developped by the US Army in 1918 [6].

Figure 1.1: The Kettering Bug (1918)

Throughout the 20th century, UAVs become more and more sophisticated, and were used more and more, but always for military purposes. In the more recent years, civilian UAVs have started to appear on the markets and their number quickly exceeded that of military UAVs. In february 2017, the FAA (Federal Aviation Administration) of the United States estimated that around 1.1 million units were in use in the US alone, and expected that number to rise to 3.55 million by 2021 [4]. These civilian drones are very different from military drones, in both their form and their function: civilian drones are usually smaller, and use rotors to take off vertically. They are used in a wide variety of applications.

1.2 Motivation

The ability to remote-control small and agile flying objects over large distances through the air, and to bring them to previously inaccessible locations, makes many new things possible. With the increasingly lower prices and better performances of civilian UAVs, people keep finding more and more uses for these high-tech gadgets. Some examples of these applications are: crop monitoring in agriculture [1], delivery of mail or parcels, construction [2], cinematography, entertainment, or search and rescue operations. In all these applications, the more autonomous a drone is, the more efficient it will be at its task. One of the main challenges to achieve autonomy is for an UAV to be able to correctly identify its surroundings, and localize itself within them. In outdoor environments, GPS systems allow UAVs to know their position with great accuracy, but this is not possible in GPS-denied environments, such as indoors. The main subject of this thesis will be fully autonomous navigation by a quadcopter in a GPS-denied environment.

1.2.1 Ethical considerations

The new possibilities brought by drones also pose ethical questions about security and privacy. Even though this technology can improve people's quality of life, it also has the potential to diminish it. If drones start to be widely used comercially, we could reach a point where the sound nuisances that they cause seriously impacts people who live in densely populated areas. Also, they can make us feel less at home, knowing that we could be observed from the sky. For this reason, it is important to adopt strict reulations regarding the use of drones in public spaces. Fortunately, many countries are already adopting legislation in this direction.

1.3 Context

This thesis is part of a project at the UCL that spans over several years and several masters theses. This project was launched by professor Julien Hendrickx in the 2012-2013 academic year, and had as long-term goal to develop a program that would enable low-cost UAVs to navigate autonomously in indoor environments. This means creating a map of their environment, localizing themselves in this map, and avoidig obstacles during exploration, using only on-board sensors. Another goal is to allow several drones to collaborate to speed up exploration. Five theses have already been written on this subject, each taking the work of the previous a little further.

2012-2015: First three theses In each of the three academic years (2012-2013, 2013-2014, 2014-2015), one masters thesis on the subject of indoor navigation for autonomous low-cost drones was written. These masters theses formed the base of the future work. They implemented visual SLAM methods to allow drones to build a two-dimensional map based on keypoints (first red pucks, then visual landmarks that the drone detected from a textured field of view), and to localize itself within this map. During this time, inter-drone communication was also established, and was used to allow a drone to communicate the location of a target to another drone.

2015-2016: Recent work Last year, two groups of students simultaneously wrote theses on this subject. Before doing so, they joined forces to reimplement what had been done previously, but using the ROS interface, an interface to work with robots that would make many things simpler, and allow more flexibility (see section The work of the first group of students allowed a drone to search and follow a mobile target, and call a second drone to continue this task when its battery was low.
The second group of students extended to SLAM algorithm to allow to use a 3D map to localize the drone. Unfortunately, they did not implement triangulation to allow to project seen points

into 3D space, but rather made the assumption that all points were located on the ground when building the map. The end result was a drone capable of using a 3D map to localize itself, but not capable of building one from its observations.

1.4 Objectives

For my own thesis, my goal is to continue the work of last year's second group, to allow true 3-D SLAM: to build a 3D map based on observations by the monocular camera. To achieve this goal I will follow the following steps:

- Research the current state of the art for 3D Keyframe based monocular visual SLAM
- Implement a way to triangulate points based on observations
- Bundle Adjustment
- Dense reconstruction
- Obstacle Avoidance

1.5 Structure

Chapter 2

State of the art

2.1 Hardware

When talking about autonomous drone navigation, it is important to be aware of what the current hardware is capable of doing, and how we can expect it to evolve in the near future. We will talk about the three main aspects of this hardware: the multirotor systems themselves, with the different possible configurations, the sensors, and finally the embedded computers.

2.1.1 Multirotor systems

Multirotors, ot multicopters, are defined as rotorcrafts with three or more rotors. Having more rotors enables them to maneuver in 3D space with with fixed-pitch rotors, unlike helicopters, which have articulations at the bases of their rotors. The most common multirotors have 3, 4, 6, or 8 rotors, and are respectively called tricopters, quadcopters (or quadrotors), hexacopters, and octocopters. Having more rotors has the advantage of giving more agility, at the cost of more energy consumption, and therefore a shorter battery life. A free solid object in 3D space, such as a multicopter, has 6 degrees of freedom: 3 for translation and 3 for rotation. To be able to directly control each of there 6 degrees of freedom, it must be possible to give 6 independent controls to the drone. This means that tricopters and quadcopters are always under-actuated: they can't directly control all 6 degrees of freedom. For example, quadrotors whose rotors are all in the same plane (as is almost always the case), can only directly control their translational movement along the axis parallel to the rotation of their rotors, and their roll, pitch and yaw angles, so to control their position in the plane perpendicular to the direction of gravity, they have to first adapt their roll and pitch, so that the resulting force of gravity and the thurst of their motors points inside that plane. Most hexacopters also work this way, as their rotors are also often in the same plane. Some hexrotors, however, have tilted rotors, and are fully actuated [7].
Octocopters on the other hand, are always over-actuated. One example, the Omnicopter, developped at ETH Zurich [3] can perform a 360°rotation along any axis, and move in a straight line in any direction, which enables it to perform complex and precise manoeuvres. It is able to catch thrown ping-pong balls with a little net.

2.1.2 Sensors

2.1.3 Embedded computers

2.2 Computer Vision

2.3 Simultaneous Localization And Mapping

Simultaneous Localization and Mapping (SLAM) refers to the joint task of creating a map of a robot's surroundings, while also keeping track of the robot's location in this map. The word "robot" should be understood very broadly in this context, for example it could be a simple handheld camera. Because there are countless different types of robots that do SLAM, SLAM is also a very diverse field, with different algorithms for different kinds of sensors. Here, we will focus on monocular visual SLAM, which is SLAM where the main sensor is a monocular camera.

2.3.1 Localization

2.3.2 Mapping

2.4 Bundle Adjustment

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