Twirre V2: Evolution of an architecture for automated mini-UAVs using interchangeable commodity components

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ABSTRACT

Twirre V2 is the evolution of an architecture for mini-UAV platforms which allows automated operation in both GPS-enabled and GPS-deprived applications. The first version of Twirre was implemented and showed good results for indoor navigation, however it had some limitations: the main software components were intertwined and only a limited number of mission states were implemented. This second version separates mission logic, sensor data processing and high-level control, which results in reusable software components for multiple applications. The concept of Local Positioning System (LPS) is introduced, which, using sensor fusion, would aid or automate the flying process like GPS currently does. For this, new sensors are added to the architecture and a generic sensor interface together with missions for landing and following a line have been implemented. V2 introduces a software modular design and new hardware has been coupled, showing its extensibility and adaptability.

1 INTRODUCTION

Nowadays, it is common to use GPS to control an Unmanned Aerial Vehicle (UAV). This has several outdoor applications such as waypoint navigation. In GPS-deprived environments though, other sensors need to be used to aid or automate the flying process. At the IMAV 2014, the NHL Center of Expertise in Computer Vision introduced Twirre, a new architecture for mini-UAV platforms designed for automated flight in both GPS-enabled and GPS-deprived applications [1]. This architecture consists of two pipelines: manual and automated navigation. A pilot intervention switch on the transmitter controls which one is active. Twirre was built with four design principles in mind:

1) the platform consists of low-cost commodity components, *2*) is upgradable and extensible, *3*) is useful in multiple applications and *4*) should be able to switch instantly and reliably between manual and automated control using only hardware components.

Tests of the first version demonstrated good results in automated flights in a GPS-deprived environment. However, the implemented system had some limitations. In the test application the software for the mission logic, the sensor data processing and the high-level control system were intertwined. Moreover, only a limited number of task performing mission states were implemented. Several steps have been taken to overcome these limitations.

This article will introduce the separation of the previous intertwined components into distinct components. The corresponding architectural adaptations and changes in both hardware and software are described. Furthermore, this paper will describe two new mission states: Following a line and finding and landing on a target, using computer vision. For navigation in GPS deprived environments, research on several optical flow algorithms has been conducted.

The paper starts with an overview of the improved automated pipeline and its parts in Section 2. The realization of these hardware and software modifications are presented in Section 3. Section 4 contains the conclusions about the evolution of Twirre to version two. Finally, Section 5 lists the future steps to take.

2 SYSTEM OVERVIEW

In order to build reusable, non-application specific software components, the mission logic, the sensor data processing and the high-level control system from the test application had to be separated. These parts are now organized into individual components as can be seen in figure 1.

The high-level control system uses cascade PID controllers whose output is sent as steering signals to the flight controller. The high-level control system can get position measurement data from the GPS or the Local Positioning System (LPS). The mission logic can access this position information from the high level control. This method allows complete separation of pose estimation logic and sensor data processing from the mission logic.

Section 2.1 will describe the LPS in more detail and subsequently Section 2.2 will outline the architecture for the mission logic.

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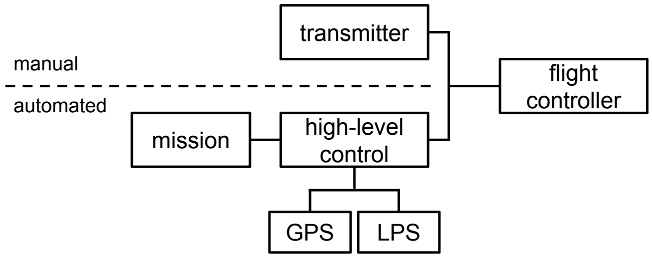

Fig. 1: Overview of Twirre V2.

2.1 *Local Positioning System*

One of the key new concepts is the LPS. Using sensor fusion, this system is able to determine the pose of the UAV. Thus, the flying process can be aided or automated the same way as it would be done with GPS, for instance for flying waypoints.

All the sensors used by the LPS are placed on-board, hence all the information obtained is relative to the UAV. With the sensor data, the pose of the aircraft is determined. The pose can be obtained, for instance, by fusing the sensor information of a 360 degree laser scanner, an ultrasonic sensor and an Inertial Measurement Unit (IMU). To estimate the pose with higher accuracy, additional sensors which provide redundant information can be used, even a GPS receiver.

2.2 *Mission Building Blocks*

The mission logic is split into reusable states, which are generic and exchangeable. These states can be configured and used together, creating a mission-specific state machine. Examples of these states are *take-off*, *approach point of interest*, or *hovering*. Some of these states were already tested in the first version of the architecture, but were fixed-function blocks. In the new architecture these states are configurable and reusable.

Configuring states is done by setting parameters, but also by using different 'providers'. For instance, the *hover* state requires a target-provider to control hovering. The LPS can be used for this, providing distance and direction to a requested hovering position. Another possible provider is a computer vision routine, using the camera to provide distance and direction to a certain point of interest to hover above. In this way the same general state logic can be used for different objectives.

The mission-specific state machine is created by defining configured instances of states and transition procedures for each state instance which control switching between states. This allows reusing generic states for completely different missions and objectives. A mission can also be used as state for a larger mission.

3 REALIZATION

To achieve a reliable Local Positioning System and therefore accurate control of the UAV, new sensors have been added to Twirre. These sensors are described in Section 3.1. A generic sensor interface for the new hardware was desired. This interface has been implemented and is outlined in Section 3.2. Furthermore, two new mission states and research on optical flow are also described in that section.

3.1 *Hardware*

Twirre's design requirement *"The platform is upgradable and extendable"* allowed easy incorporation of new technology in the architecture. For Twirre V2 several new sensors have been added. Also the MicroWii microcontroller board has been upgraded.

Arduino Due The ATmega32U4 based MicroWii [2] has been upgraded to an Arduino Due [3]. The Due has a 32-bit ARM core compared to the MicroWii's 8-bit AVR CPU. A selection of specifications are compared in Table 1. The increasing number of connected sensors demanded a faster microcontroller board. Also the embedded software size exceeded the maximum programming space of the MicroWii. An Arduino based platform was chosen because it allows fast prototyping, is open-source and low cost. Considering these requirements the Due model was selected.

	Arduino Due	MicroWii
Clock speed	84 MHz	16 MHz
SRAM	96 KB	2.5 KB
Programming space	28 KB	512 KB

Tab. 1: Several specifications of the Arduino Due and the MicroWii compared.

RP-Lidar and UTM-30LX Two lidars (Light Detection And Ranging) have been coupled to the Twirre architecture. The addition of a lidar sensor allows mapping of rooms. It also makes obstacle detection or avoidance possible. The first is the RoboPeak RP-Lidar, which is a 360 degree laser scanner [4]. The second lidar is the Hokuyo UTM-30LX, which has a 270 degree scanning range [5]. There is a large difference between the system specifications and prices. Table 2 lists a few specifications of both devices.

Fig. 2: The RP-Lidar and UTM-30LX, respectively.

The RP-Lidar will be mainly useful for indoor environments, where the UTM-30LX can also be used outdoors.

	RP-Lidar	UTM-30LX
Distance range	0.2 - 6 m	0.1 - 30 m
Distance resolution	< 0.5 mm	3 mm
Angular resolution	≤1 deg	0.25 deg
Scan rate	5.5 Hz	40 Hz
Weight	200 g	210 g
Price	€440	€4800

Tab. 2: A selection of specifications the RP-Lidar and UTM-30LX.

myAHRS+ The Withrobot's myAHRS+ is a low cost attitude and heading reference system (AHRS). It includes a triple axis gyroscope, accelerometer and magnetometer [6]. The myAHRS+ uses on-board extended Kalman filtering which improves measurement quality. This sensor replaces the gyroscope, accelerometer and magnetometer that were on the MicroWii board.

Piksi The Swift Navigation's Piksi is a GPS receiver which uses Real Time Kinematics (RTK) for position estimation with centimeter level accuracy [7]. The Piksi is a relatively cheap RTK system of approximately $1000. The Piksi makes it possible to perform missions that require high accuracy GPS navigation. Examples are the inspection of agricultural fields and wind turbine rotor blades.

3.2 *Software*

The next paragraphs show the improvements and changes of the Twirre software architecture. A generic sensor interface has been developed as well as two new mission states. Finally, research on different optical flow algorithms has been performed.

Generic sensor interface Twirre uses multiple sensors to determine the pose of the UAV. Adding new sensors to the architecture has led to the necessity of implementing a generic sensor interface: TwirreLink. This interface tries to get as close as possible to be able to plug and play sensors into Twirre. An overview of this system is given in Figure 3.

This interface can then be used by the LPS to access the different sensors of the UAV. It can then fuse all available sensor information to determine the pose. A generic serial protocol has been designed and implemented, which allows data transfer for all kind of sensors, and replaces sensor specific protocols.

Landing and line following states Two new mission states have been developed. The first is to locate a platform using a camera placed in a downward-facing gimbal and land automatically [8]. The deviations from the x and y axes of the camera are used to control Roll and Pitch respectively. The throttle is controlled based of the values of an ultrasonic sensor. Figure 4 shows the test setting for this state.

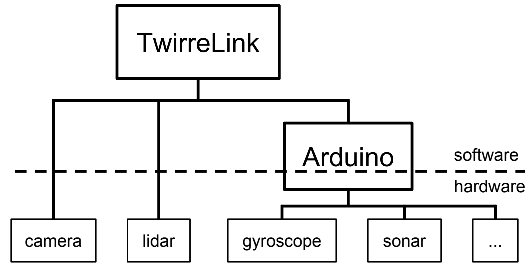

Fig. 3: Overview of TwirreLink.

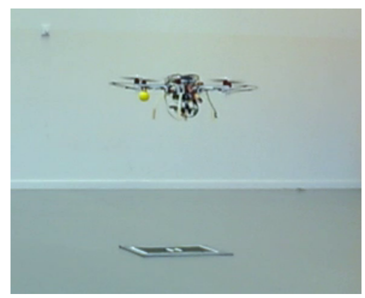

Fig. 4: Experiment with the target finding and landing state.

The second state is to follow a line drawn on the ground. It is similar to the first, although this mission lacks of a point of interest to keep as a reference. Therefore, the goal of this state is to maintain a constant speed while following the line.

Optical flow In the first version of Twirre optical flow is used as an alternative to GPS, specifically for GPS-deprived environments. For V2 further research has been conducted on single camera optical flow techniques [9]. During this research several optical flow algorithms were evaluated to see if different algorithms yield different results in terms of quality and CPU time.

Characteristic performance differences were found in terms of both computation time and quality. Choosing between algorithms therefore can increase flow estimation quality or reduce CPU time usage.

4 Conclusion

With the second version of Twirre various improvements have been introduced. The software is no longer intertwined, but is separated into multiple components: high-level control, mission logic, and LPS. To connect sensors to Twirre with ease, the TwirreLink generic sensor interface has been designed and implemented. This separation allows significantly faster development of new missions and additional mission logic components.

Several new sensors have been coupled with the architecture in order to achieve a reliable LPS. This system is able to determine the pose of the UAV both in indoor and outdoor environments, as GPS presently does only in outdoor environments. In turn, this allows the high-level control system to provide automatic navigation in both environments.

The addition and adaption of hardware and software proves that Twirre is easily extendable and adaptable.

5 FUTURE WORK

This new version of Twirre represents a major shift both in software and hardware components. Thus, intensive testing has to be done to prove the reliability and usability of the new modular design. New states have to be implemented in order to have multiple mission software blocks that can be used for different applications. Waypoint flying using LPS, for instance, should be implemented.

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