QUADROTOR CONTROL SYSTEM FOR EDUCATION AND RESEARCH

Nils Gageik, Sergio Montenegro

University of Würzburg, Aerospace Information Technology (Germany)
Würzburg, March 2016

gageik@informatik.uni-wuerzburg.de, montenegro@informatik.uni-wuerzburg.de

www.qopter.de

Abstract

The following paper presents the quadrotor control system, a complete ready to go solution for education and research. It is named quadrotor control system, because it is a test case control system and combines a quadrotor with a configurable mechanical design enabling 5 different control modes. The quadrotor control system is an innovative solution with ready to go hardware, software, guides and didactic content. It is meant for teaching and development in a class room with students and addresses lecturers and universities to improve their education in the fields of computer science, control and robotics.

Keywords: Quadrotor, education, research, didactic content, control, PID, test case, real-time, embedded programming, sensors, UAV, robotics, drones

1 INTRODUCTION

In the last couple of years quadrotors became more and more popular [1 - 3]. In Dezember 2015 about one million quadrotors have been sold in the U.S. [4]. Some of the biggest IT companies in the world such as Google and Intel invest millions of dollars in robotics and drones. These facts underline, that this technology will be of great significane in the future. That's why education and research in this field is of prime importance.

Quadrotors, the simplest avaible drones, are used by hobbyists as toys, by researchers to investigate new methods and technologies and in everyday life for tasks such as aerial photography and inspections. Nowadays there are couples of available systems on the market. However, for security reasons most systems cannot be used in a class room. Furthermore, due to missing software, documentation and didactic content, they are not easily used by students and lecturers. The quadrotor control system (QCS) overcomes these drawbacks and enables to use quadrotor as a test case learning and teaching platform. The QCS consists of hardware, software, methods, guides and documentation. We also provide support and introduction to interested people.

Today, control theory is often taught very theoretically. The quadrotor control system empowers students to understand the connections of filtering and signal processing, timing, embedded programming and control. These are fundamentals for many technical fields such as robotics and moreover, the quadrotor control system provides very motivating topics, tasks and scenarios for students.

2 QUADROTOR CONTROL SYSTEM (QCS)

The QCS is a further development of the 2012 on INTED presented avionic control system. The following chapter describes all aspects of the QCS, which can be received from the university founding project and start-up called Embedded Qopter [5].

2.1 MODES and CONCEPT

A special feature of the quadrotor control system is the configurable design enabling 5 different control modes. With this feature students can investigate the typical different control situations with different

degrees of freedom (DOF) reaching from 1 DOF (2x), over 2 DOF and 3 DOF to 6 DOF. Thus, all aspects of a quadrotor can be topic of the course and a step by step development of its software and demonstration of its basic functions becomes possible.

The available 5 modes are as following:

- Mode 1: Yaw control
- Mode 2: Roll or pitch control
- Mode 3: Roll or pitch and yaw control
- Mode 4: Roll and pitch and yaw control
- Mode 5: Free flight with 6 DOF control

The modes 1 to 4 are used to develop control software for a quadrotor and to investigate the fundamentals of flight and real-time control. Mode 5 is used to evaluate the results in a real flight, but can also be used to investigate carrying on questions. For mode 5 the following couple of optional add-ons are available:

- Height sensors to control the height
- Position sensors such as GPS to control the position
- Obstacle detection sensors to map and avoid collisions
- Video cameras for aerial photographs
- Radio communication for steering, sensor data and images
- High end CPU for computer vision and image processing such as object recognition

With the mentioned concept of the quadrotor control system (QCS) containing hardware, software, guides and didactic content as well as documentation, support and introductory courses for lecturers, the QCS is a complete solution for education and research. With little effort lecturers can use it to improve their classes and teach students recent topics and connections of science.

2.2 Hardware

Figure 1 illustrates the basic hardware of the QCS, which contains the minimal required components. This includes a MCU (microcontroller unit), an IMU (inertial measurement unit) and four brushless controllers which steer the four motors. With this composition the modes 1-4 become possible already. The advantage of fewer components is a lower price.

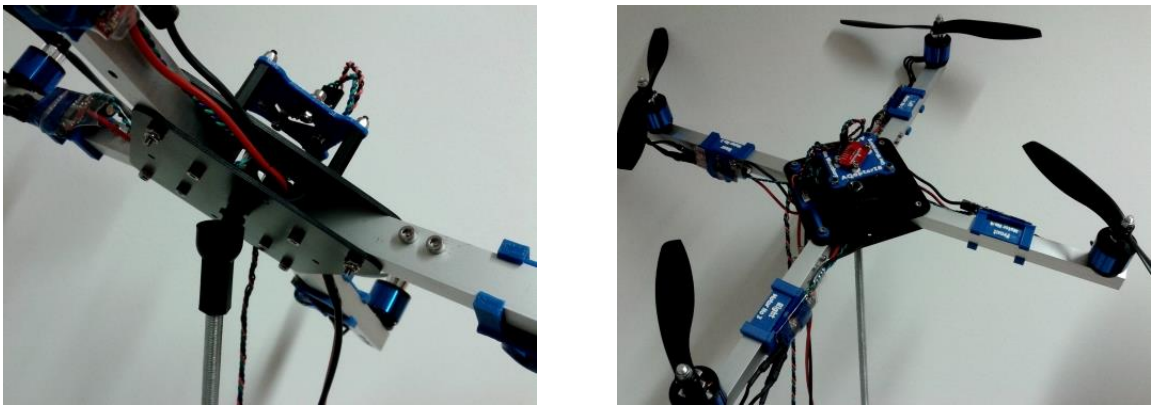

Figure 1: Quadrotor Control System (QCS)

For mode 5 the QCS can be extended by a remote control, battery, landing gear and further structural parts, which enable the system to lift. A safety ring around the propellers is available as well. The QCS can be further equipped with the already mentioned add-ons. Figure 2 illustrates a prototype equipped with a GPS module (left) and sensors for obstacle detection (right). Ultrasonic, infrared, stereo vision, PMD (photonic mixing device), LIDAR (light detection and ranging) and RADAR (radio detection and ranging) can be used for obstacle detection. For position determination GPS, cameras, optical flow and Fourier tracking sensors are available. A variety of cameras and high end processors is available

for aerial photographs and image processing such as object recognition. Communication links such as Bluetooth, WiFi and different Video Links can be used to send commands, receive sensor values as well as images and videos.

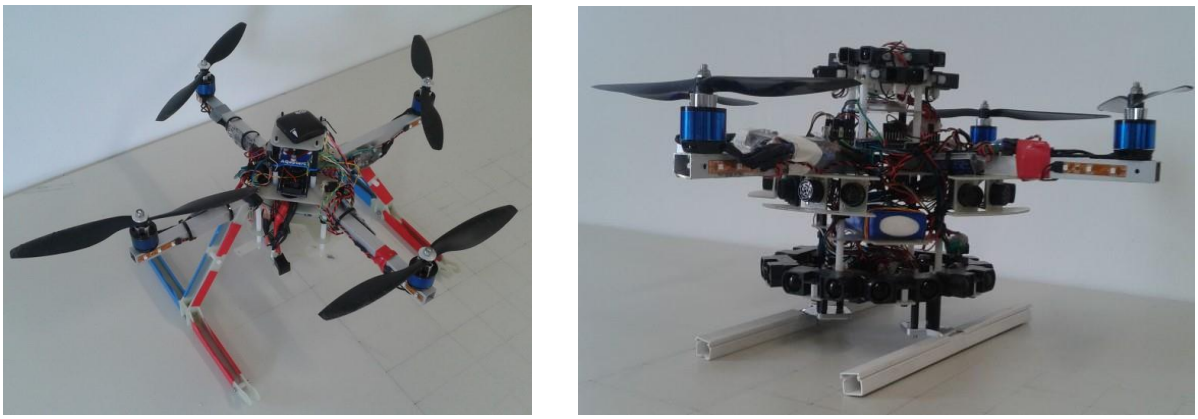

Figure 2: Quadrotor Control System (QCS prototypes) with add-ons

2.3 Software

Except a few special functions and drivers all parts of the system are open source. Hence, all relevant aspects of the system can be changed, investigated, learned and taught. The software is provided as a modular framework and is available as ready to fly solution for lecturers or as skeletal structure for students to start their own project and to implement their own solution.

The software contains easy to use functions such as reading the sensors and steering the motors with a certain speed. Controllers for all 6 DOF and a wide range of other functions are also available. For a safe step-by-step development of the control by the students an observation function for instability has been developed, which shuts down the system in case it becomes instable. This prevents accidents and damages. For flights with height control an emergency landing function is also available.

The on-board software is programmed in C/C++.The software for a ground segment to enable telemetry and telecommands between the QCS and a desktop PC, laptop, tablet or smartphone is also available as open source.

2.4 Guides and Didactical Content

A wide range of material and topics already exist, which is permanently extended. The following topics are already covered:

- Design
- Sensing, Data Fusion, Signal Processing, Filtering (Kalman Filter)
- Orientation Determination and Quaternion
- Telemetry, Telecommands
- Attitude Control, Yaw Control, 3 DOF Control, Quaternion Control
- Autonomous Flight

2.5 Documentation, Support and Introductory Courses

The entire system is well documented. Besides the mentioned guides and didactical content we provide a Wiki, literature and data sheets as well as understandable comments, support (e-mail, skype) and introductory courses. The introductory courses are meant for lecturers, who want to get an insight in the system before starting to use it for their own lessons and research. Introductory courses can be in our place, the customers place or via skype conference.

3 EVALUATION

The following chapter discusses the results of a questionnaire, which evaluates the QCS as a tool in the field of education [6].

3.1 Overview

An evaluation of the QCS and its didactical value is not easy. However, the following chapter demonstrates the benefit of the QCS for education. The QCS has been used at the University of Würzburg in the Aerospace Lab, also called QCS exercises, now for five years. After the fourth year of the Aerospace Lab, all students have been asked by mail to fill out an online questionnaire about the QCS exercises, in which the QCS is used. In total about 160 students were asked, from which 61 replied. It has also to be taken into account, that some students, which already finished their studies, did not get the mail. Under these considerations, the responses are quite numerous. The results of the questionnaire is shown and discussed in this chapter.

3.2 Questionnaire

The questionnaire consisted of 20 questions, from which only a selection of 6 questions can be discussed in more details here. The selected questions concern the value for learning and the fun of the QCS exercises and the exercises of other subjects, so a relative difference can be seen. The last two questions are about the sense and usefulness of the QCS exercises. The full text of the questions (translation from German) is:

1) During my study I learned in average a lot from the exercises of other subjects.
2) From the QCS exercises I learned in average a lot.
3) The exercises of other subjects were fun.
4) The QCS exercises were fun.
5) In my opinion programming quadrotors was a reasonable exercise to learn more about embedded programming and control.
6) In my opinion programming quadrotors was helpful for my occupational skills, because it was playful learning of technical backgrounds.

3.3 Results and Summary

In total the great majority of answers agree with question one and two. While only 16% totally agree with question 1, 62% totally agree with question 2 (Figure 3). The majority of the students (51%) think, or at least say, that they learned in average more from the QCS exercises than from other exercises. In contrast to that, only 11% answered, they learned less.

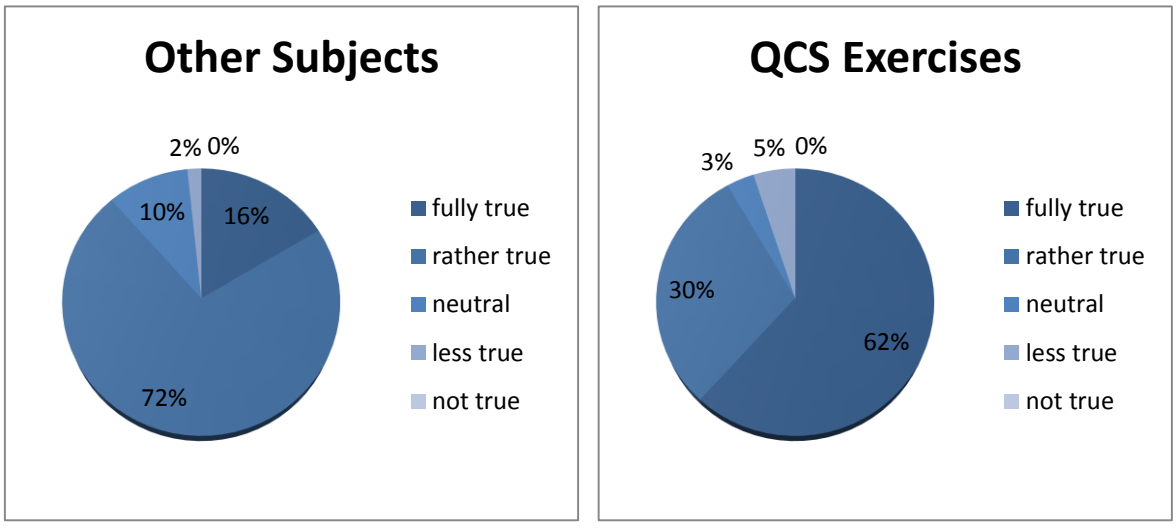

Figure 3: “Learned a lot” answers: Question 1 (left) and 2 (right)

The next two questions are about fun (Figure 4). Only 31% of the students answered, that the exercises of other subjects were fun. 50% answered neutral and said it was neither fun nor no fun. At the same time 79% of the answers said, that the QCS exercises were fun, while only 5% said, it was no fun. From these numbers it can clearly be derived, that most students say, that the QCS exercises were more fun compared to other exercises.

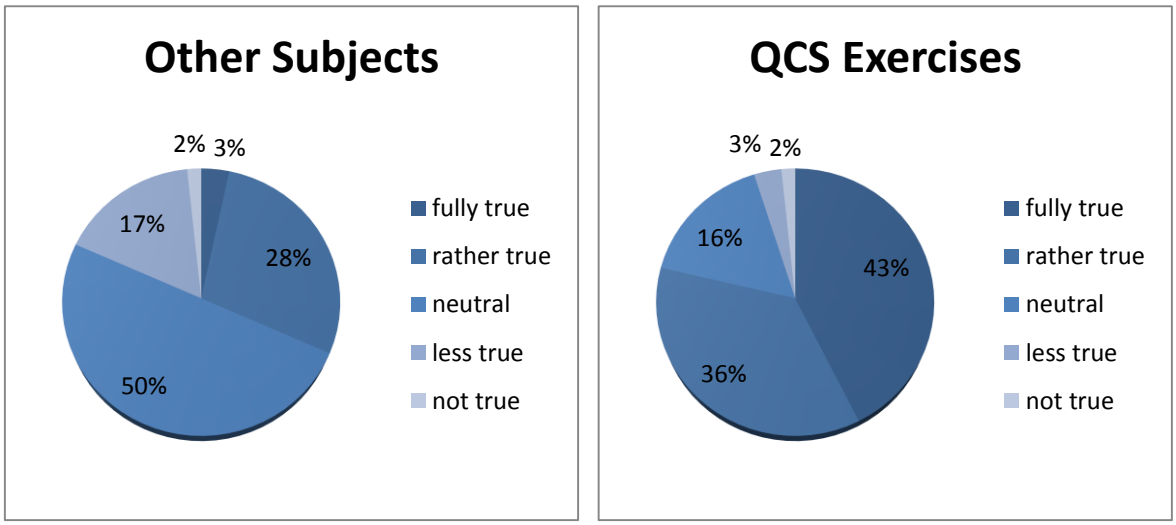

Figure 4: “Was Fun” answers: Question 2 (left) and 3 (right)

The last two questions are about the sense and usefulness (value) of the QCS exercises (Figure 5). Nobody of the answerers disagreed to these statements. 78% of the answerers fully agreed with the statement, that programming quadcopters is a reasonable exercise to learn embedded programming and control. 60% of the answerers say that question 6 is fully true, which means that they totally agree with the statement: Programming quadcopters is helpful for their occupational skills.

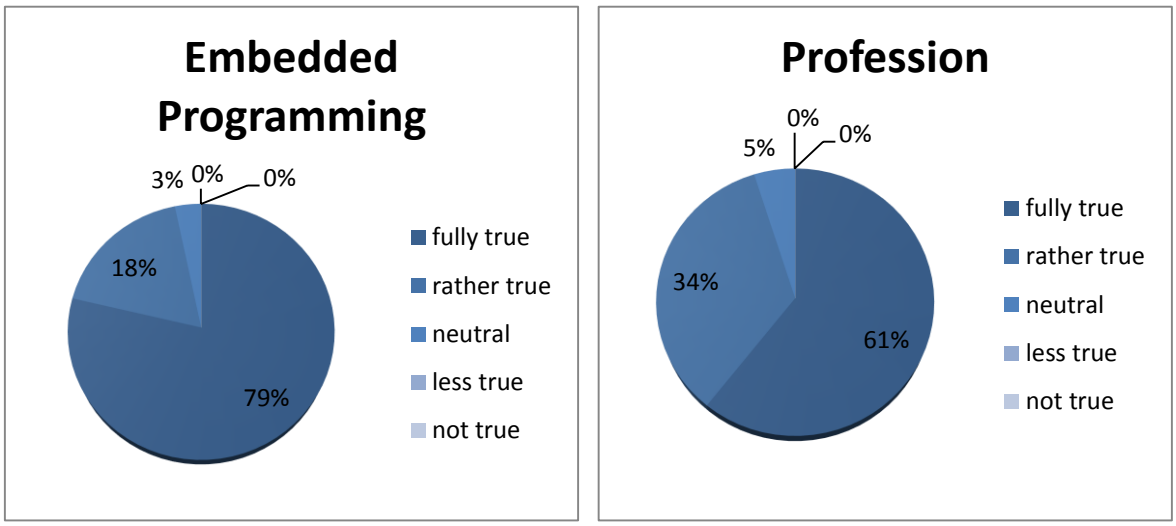

Figure 5: QCS Value for Embedded Programming (left) and Profession (right)

4 CONCLUSION

With the QCS a complete platform solution for education and research containing everything such as concept, didactical material, software and hardware for practical quadrotor exercises is given. From the results of the questionnaire the didactical value of the QCS can be derived.

ACKNOWLEDGEMENTS

The author would like to thank Paul Benz for reviewing this paper. This work was funded by the IHK Würzburg-Schweinfurt and the Universitätsbund Würzburg.

REFERENCES

[1] Autonomous Flying Robots, Spring 2010, Kenzo Nonami

[2] I4Copter: An Adaptable and Modular Quadrotor Platform, SAC 2011, Peter Ulbrich

[3] Obstacle Detection and Collision Avoidance for a UAV With Complementary Low-Cost Sensors, IEEE Journals & Magazines, 2015, Nils Gageik

[4] Erst registrieren, dann fliegen, FAZ, 28.12.2015, Roland Lindner, http://www.faz.net/

[5] Embedded Qopter, www.qopter.de

[6] Concept for practical exercises for studying autonomous flying robots in a university environment: part II, Proc. SPIE 9411, Mobile Devices and Multimedia: Enabling Technologies, Algorithms, and Applications 2015, Nils Gageik