

Adam BONDYRA, Stanisław GARDECKI, Przemysław GAŚIOR

POLISH AERIAL ROBOTICS TEAM, INSTITUTE OF CONTROL AND INFORMATION ENGINEERING, POZNAŃ UNIVERSITY OF TECHNOLOGY
3A Piotrowo St., 60-965 Poznań, Poland

A distributed control system for multirotor aerial platforms

Abstract

In a variety of microavionics systems for multirotor flying platforms, only a few are designed as open hardware and software solutions, suitable for scientific research. In this paper, we present our own approach – a modular, distributed control system. The developed solution is adaptive for new tasks, unified between each module and designed in an innovative hardware manner. The presented solution has been already developed in various designs of multirotor platforms intended for different applications.

Keywords: quadcopter applications, flight controller, microavionics.

1. Introduction

On-board avionics is the key element of every multirotor aerial platform and allows its proper operation. Such a system minimally consists of a computing unit (e.g. microcontroller with peripherals) that performs control tasks and sensors for attitude and altitude estimation. These estimates are used in control algorithms to provide stable attitude and trajectory control. Open source microavionics systems available at the market rarely fulfill the requirements of a system for scientific research purposes, e.g. simple expandability with open protocols.

In this paper, a custom, modular and distributed microavionics system is presented. The design evaluated from the previous solutions. Our approach focuses on maximizing scalability, expandability and computational power with an innovative hardware concept.

The paper is divided into five sections. The first one is introduction. Related designs of multirotor controllers are described in Section 2. In Section 3, the hardware development of the presented microavionics system is shown. Section 4 presents the structure and operation of on-board control software, while Section 5 summarizes the paper and describes evaluation of system in various multirotor designs.

2. Related work

There are many examples of open source control modules for multirotor aerial vehicles available. Some of them are Arducopter, Openpilot, Mikrokopter and Aeroquad described in [2]. Each of these systems has different architecture, software or hardware, but most of them are distributed under GPL license and are subjected of ongoing development thanks to the constantly growing community. These solutions are mostly intended for hobbyists and commercial usage, therefore they are hardware limited because of the costs of production. Hence, they do not fulfill a few requirements for being scientific research platforms, e.g.:

- High level of scalability thanks to open protocols;
- Realization of complex on-board calculations;
- Simple module replacement between alternative designs (e.g. different sensors);
- Many additional communication interfaces to connect with scientific equipment, e.g. cameras, a flight control computer or additional sensors: laser scanners, ultrasonic rangefinders etc.

Considering this issues, the concept of a modular control system evaluated during the years of research in the Institute of Control and Information Engineering was developed. The major aim of the development process was to provide a versatile solution for different aerial platforms, such as the *Hornet*, *Falcon* and the *Dropter* quadrotors [3, 5, 9]. This paper presents the most recent and advanced microavionics module.

3. Hardware concept

The presented microavionics system was designed in a modular concept. It means that every module, designed in a similar hardware manner, executes specific tasks and the whole system is formed with a set of modules connected with data buses. For proper functioning of the aerial platform, there are minimum of three modules required - *PowerBoard*, *Mainboard* and *AHRS* (*Attitude and Heading Reference System*). Assembly of all the three mentioned modules is shown in Fig. 1. A solid structure in the shape of a cuboid was obtained. Expanding the control system with auxiliary modules is possible by connecting additional layers on the top of *Mainboard* module. Every module except the *AHRS* unit is designed in the same exceptional way. These boards consists of a *PCB* plate with small vertical boards soldered on each side. Connectors located on these small *PCBs* are much easier to reach and, in addition, the outline of the whole avionics is smaller thanks to the extended copper area. On the top of the stack there is the *Mainboard* unit. This module is responsible for realization of control loop, generating *PWM* signals for *ESCs* (*Electronic Speed Controllers*, control of the propulsion units) and distributing the state vector data among other modules.

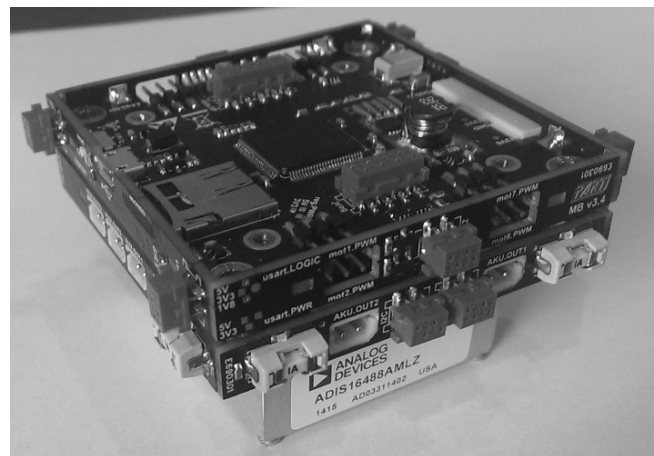


Fig. 1. The presented microavionics system

Below, the *PowerBoard* is located. This unit delivers the power from battery to every module on the board. The last module in a minimal flight setup is the *AHRS* which contains a military grade *MEMS* inertial sensor. Precise estimates of attitude and altitude are calculated based on the readings from this *IMU* sensor. Modules, which require a lot of computational power, like the *AHRS* and *Mainboard*, are equipped with an individual microcontroller. This solution distributes tasks between the modules accelerating processing of data and provides more versatility in expanding and developing new solutions for the microavionics system. The architecture is unified, so it is possible to interchange certain modules (e.g. different *AHRS* boards with different *MEMS* sensors). Further description of the module functionality is presented below.

3.1. Mainboard

The *Mainboard* unit is the key element of a microavionics system. Crucial control tasks are executed on the module

computing unit, based on the estimated values from *AHRS* and control commands coming from either on-board computer or human operator. The *Mainboard* gathers the sensory and communication data from all modules in the system and distributes the state vector via communication buses. During the flight, the most crucial data is archived on a microSD card and can be restored in the case of failure or crash. As a processing unit, the STM32F4 family microcontroller is used. Acceleration of floating point calculations is provided thanks to a built-in hardware *FPU* (*Floating Point Unit*) coprocessor.

This unit is equipped with an additional DC/DC converter which provides a stable and noise-clean voltage for the main microcontroller and its peripherals. There are various additional connectors on the vertical boards of the *Mainboard* unit, i.a. *USART* buses, $\dot{P}C$ bus (Inter-Integrated Circuit interface), PPM inputs and more. Thanks to the cuboid hardware design, the connectors are easily accessible. The inter-modular communication is based on three independent data buses. There are two main connectors between the modules in the stack. One of them is a universal programming interface that allows programming and debugging of every single module without the need to disconnect the stack. The second connector transfers the data in the stack via two main buses, consisting of *SPI* and $\dot{P}C$ interfaces. The detailed communication structure is described in Section 4.

3.2. Powerboard

This is the power distribution unit for all modules in the microavionics system. The module itself is powered from two different sources – a main lithium-polymer battery which also supplies motors and a secondary power supply completely isolated from the main power source. Every power output on the *Powerboard* is protected with safety fuses (located on vertical walls for easier replacement), current measurement sensors and remote cut-off switches. The module main element is a DC/DC converter that supplies voltage to power other units. In addition, five temperature sensors are used to monitor the heating of the components. Current measurements and the cut-off switches are controlled by the *Mainboard* via $\dot{P}C$ communication bus.

3.3. AHRS module

The *AHRS* module consists of two types of elements, *MEMS* inertial sensors (accelerometers, gyroscopes, magnetometers, barometers) and a processing unit. During our research, the variety of sensors was used, such as *MPU9150 IMU*, *BMP085* barometer and military grade *ADIS16488 10DOF IMU*. The quality of the calculated attitude and altitude estimates vary between solutions [6, 4]. Another advantage of the *AHRS* unit is full isolation of communication buses and overvoltage safety mechanisms in order to protect valuable sensors. The computing core of the *AHRS* module is another Cortex-M4 microcontroller, with support of an *FPU* coprocessor. In this case, the *FPU* is essential to process orientation and position estimation algorithms.

3.4. Auxiliary modules

Thanks to the modular structure of the presented microavionics system, a wide range of additional units can be used on the aerial platform, such as already developed the *Communication* module, with *GSM* connectivity, *GPS* receiver extension and *ISM*-band telemetry link to the *Ground Control Station (GCS)*, the *OSD* module, described in [7], which superimposes the flight data onto a video stream from the on-board camera, in order to provide the pilot's interface and the control unit for a set of manipulators, mentioned in [5].

4. Control software

As mentioned in Subsection 3.1, there are two main communication buses, used to transfer data between the modules. The *Mainboard* is the central unit and schedules the communication. In Fig. 1, the inter-modular communication structure is shown.

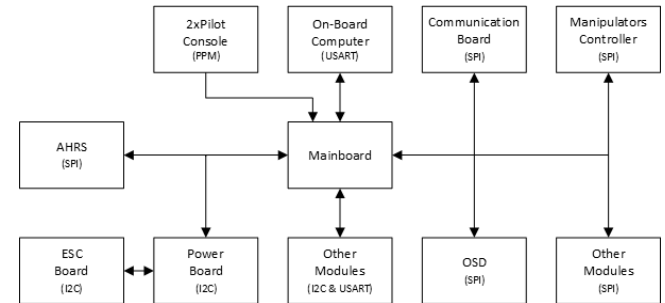


Fig. 2. The structure of avionics interconnection

The first data bus communicates the *Mainboard* with the *Powerboard* and *AHRS*. It consists of two different interfaces, *SPI* and $\dot{P}C$. The first one is used only to communicate with the *AHRS* because of high frequency, importance and size of the transferred data. The $\dot{P}C$ interface allows communicating with the *Powerboard* to control power outputs and acquire measurements of the board temperature and motor current, as well as the voltage of batteries.

The upper modules are connected by the second data bus. It consists of an *SPI* interface and some additional data lines, used to control and schedule the communication between the modules stack.

Avionics can operate in various modes: manual, semi-autonomous or fully-autonomous. In the manual mode, a pilot has complete control of attitude and altitude of the platform. Semi-autonomous is similar, but an additional altitude controller is enabled, executed on the *Mainboard* or an external flight computer. Finally, in the autonomous mode, all control tasks are performed along the programmed mission scenario. A dedicated algorithm for smooth mode switching was also developed.

Communication with the pilot is carried by a double *PPM* interface from the radio receivers and *GCS* telemetry link. The on-board flight computer is connected to the *Mainboard* with a *USART* bus. Two additional connectors with $\dot{P}C$ and *USART* interfaces are used for auxiliary modules.

5. Experimental evaluation

The distributed control system has been already evaluated in a series of recent projects. The current generation of *Façon* [5] multirotors is operated by the presented microavionics. In addition, it was used in the *ESA's StarTiger Dropter* project [8], as a key element of the terrestrial demonstrator of the Mars lander [9].

During this project, the interface with a flight control computer unit was developed. It is the exemplary use of the main advantage of the proposed design – it would be much harder to adopt the existing commercial solution to the task in which the controller was a part of a more complex, experimental setup of the multirotor flying platform. The modules on the *Dropter* vessel (Fig. 3) relied on the data from our avionics system, which allowed the whole control system to execute specific mission scenario, including autonomous flight, hazard detection and avoidance algorithms and lowering a model of Mars rover. Another example of completely custom functionality of the multirotor platform, not available in commercial solutions, is a dedicated module to control a set of on-board manipulators, as shown in [5].



Fig. 3. The Dropter multirotor platform

6. Conclusions

The developed microavionics system has proven useful for operation of aerial multirotor platforms. Thanks to easy expandability, the simple and rigid hardware structure as well as the unified, universal architecture, it is a key element allowing our research in the field of unmanned aerial vehicles. During the experimental evaluation in various projects the system turned out to be reliable with stable operation. Although it is not as much sophisticated as commercial designs in terms of the user interface and complexity, thanks to the modular hardware design, many expansion data buses and extensive computational power, the system is very suitable in scientific projects, involving more complex tasks than a regular, commercially available flight controller can provide.

7. References

- [1] Mahony R., Kumar V., Corke P.: Multirotor Aerial Vehicles: Modeling, Estimation, and Control of Quadrotor. Robotics & Automation Magazine, IEEE, vol. 19, pp. 20-32, 2012.
- [2] Lim H., Park J., Lee D., Kim H.J.: Build Your Own Quadrotor: Open-Source Projects on Unmanned Aerial Vehicles. Robotics & Automation Magazine, IEEE, vol. 19, pp. 33-45, 2012.
- [3] Gardecki S., Kasiński A.: Wielowirnikowy robot latający Hornet. Prace Naukowe – Elektronika: Problemy Robotyki Tom II, Oficyna Wydawnicza Politechniki Warszawskiej, vol. 175, pp. 655-664, 2010.
- [4] Gąsior P., Gardecki S., Gośliński J., Giernacki W.: Estimation of Altitude and Vertical Velocity for Multirotor Aerial Vehicle Using Kalman Filter. Advances in Intelligent Systems and Computing, Vol. 267, 377-385, 2014.
- [5] Bondyra A., Gardecki S., Gąsior P., Kasiński A.: Falcon: A compact multirotor flying platform with high load capability. Advances in Intelligent Systems and Computing, Vol. 351, 35-44, 2015.
- [6] Mahony R., Hamel T., Pflimlin J.: Complementary filter design on the special orthogonal group SO(3). Decision and Control, CDC-ECC '05. 44th IEEE Conference on, pp.1,6, 1477-1484, Dec. 2005.
- [7] Bondyra A.: Design of virtual cockpit system for quadcopter remote control. Innowacyjne rozwiązania w obszarze automatyki, robotyki i pomiarów, PIAP, pp. 195-203, 2013.
- [8] http://www.esa.int/Our_Activities/Space_Engineering_Technology/Dropship_offers_safe_landings_for_Marsrovers
- [9] Lutz T., Gu C., Gardecki S., Cordes F., Hormigo T., Böljes A., Bolz J., De Maagt P.: StarTiger Dropter project: Development and flight experiment of a Skycrane-like terrestrial lander demonstrator. GNC 2014: 9th International ESA Conference on Guidance, Navigation & Control Systems.

Received: 02.04.2015

Paper reviewed

Accepted: 02.06.2015

Adam BONDYRA, MSc

Research assistant in Institute of Control and Information Engineering, Poznan University of Technology. Graduated in 2014 and received a MSc diploma in Automatic Control and Robotics. Now, as a member of PART research team his areas of research are control algorithms, telemetry techniques and development of multirotor aerial platforms.



e-mail: adam.bondyra@put.poznan.pl

Stanisław GARDECKI, MSc

Received the M.Sc. degree in control engineering and robotics from Poznań University of Technology (Poland) in 2009. He was honored several times for achievements in the field of robotics. Currently he is an assistant at the Institute of Control and Information Engineering of Poznan University of Technology and a leader of PART (Polish Aerial Robotics Team). He is developing flying robots and researches their stabilization under varying load and configuration.



e-mail: adam.bondyra@put.poznan.pl

Przemysław GAŚSIOR, MSc

Doctoral student in Institute of Control and Information Engineering, Poznan University of Technology. Graduated in 2014 and received a MSc diploma in Automatic Control and Robotics with major in Robotics. Now, as a member of PART research team his areas of research are control algorithms, attitude and altitude estimation and development of multirotor aerial platforms.



e-mail: przemyslaw.gasior@cie.put.poznan.pl