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Low Cost Hexacopter Autonomous Platform for Testing and Developing Photogrammetry Technologies and Intelligent Navigation Systems

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Abstract Low-cost solutions for autonomous aerial platforms are being intensively developed and used within geodetic community. Unmanned aerial vehicles are becoming very popular and widely used for photogrammetry and remote sensing applications. Today's market offers an affordable price components for unmanned solution with significant quality and accuracy growth. Every year market offers a new solutions for autonomous platforms with better technical specifications. Commercial drones for amateurs are widely offered and presents a quality and accuracy not available in past few years. In this paper an autonomous open source low cost haxacopter system for photogrammetry and intelligent navigation technologies evaluation is being presented. The system was designed and assembled for technologies testing and for educational purposes. The drone is based only on open source hardware and software. All components are based on open source and commercial of the shelf products. That approach to the drones construction provides a many capabilities to test, implement and execute new algorithms, solutions and tasks. Providing basic configuration tools system enables students to safely perform elementary setup and testing. An advanced configurations system tool and open source structure enables to execute advanced scientific test and research. Paper presents results of designed process, system configuration and specification, technical issues that was being solved during test flights and practical research results.

Keywords: drone, uav, photogrammetry, navigation, open-source, pixhawk.

Conference topic: Technologies of geodesy and cadastre.

Introduction

Low-cost solutions for autonomous aerial platforms are being intensively developed and used within geodetic community. Unmanned aerial vehicles are becoming very popular and widely used for photogrammetry and remote sensing applications (Kedzierski *et al.* 2016: 873–877). As stated in (Burdziakowski *et al.* 2016) a UAV photogrammetry introduces low-cost alternatives for a classical solution. Commercial drones for amateurs are widely offered and presents quality and accuracy not available in past few years. Based on the assumptions that a platform should be able to perform a low speed and altitude photogrammetry flight, be able to hover and circle above specified object of interested and provide open source resources for algorithm development and education purposes, using design concept and methodology presented in (Burdziakowski, Szulwic 2016), an open source low cost haxacopter system been designed and build. The system components are based on commercial off-the-shelf products. System provides a basic configuration tool to enable safely perform elementary setup and testing, as well as advanced tuning and configuration capabilities. All hardware and software components are based on open source concept.

System design and components

The system is designed based on open source hardware and software. Presented approach to the UAV design enables to perform any modification to source code and hardware used in the specific project. The market has been reviewed and basic system elements has been chosen. System basic components are:

- Aerial platform – 550 mm hexacopter frame with built in printed circuit board (PCB), 30 amps electronic speed controllers (ESC) for brushless motor control, brushless motors (MT-2216 KV810) with propellers (size 10/3,8), flight battery – 10000 mAh 2P 4S 25 C lithium polymer;
- Flight control - Pixhawk (Meier *et al.* 2012: 13–18) flight controller (FC) with integrated orientation and navigation modules,
- external navigation sensors – two GPS receivers based on U-Blox Neo M8N chip and compass module. The second GPS receiver has been modified – standard PCB 25 mm/2mm ceramic GPS antenna has been removed and a new PCB ceramic antenna 25mm/4mm soldered;

- Communication: radio control (RC) – 2.4 GHz Aurora 9 TX witch Optima 9 RX, radio modem 433 MHz for ground station data transfer, video downlink 5,8 GHz 40 CH Video TX with battery and diversity video LCD monitor for live video feed from platform;
- Data acquisition module – camera GoPro Hero 3 Black and 3 axis brushless gimbal for its stabilization,
- additional modules – on screen display (OSD) module that overlays flight information onto video stream, based on MinimOSD Board. Mini PPM Encoder to encode PWM servo output ports signal of RC receiver to a PPM pulse;
- System sensors and filter – power module for monitoring voltage and current from main battery. Low pass inductance/capacitance (LC) filters for suppressing noise in power source created by ESC and motors;
- Ground controls station – PC commuter with Mission Planer Software linked with radio modem using MAVLink protocol (Meier *et al.* 2011: 2992–2997);

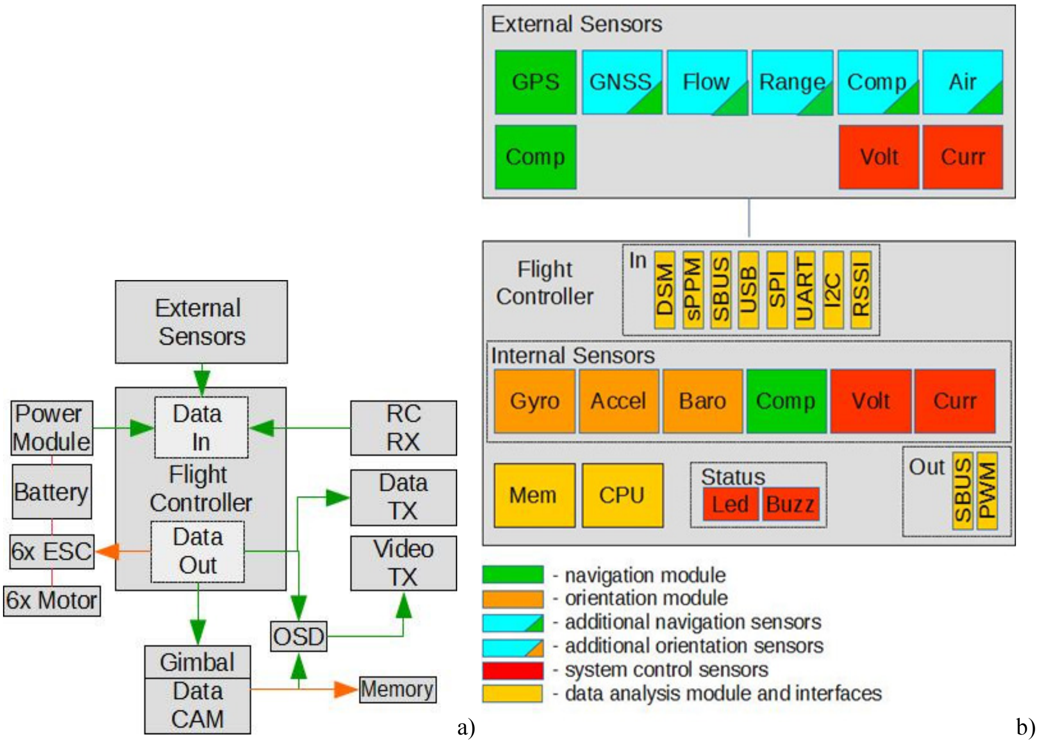

Fig. 1. The hexacopter platform's hardware modules internal communication (a) and (b) flight controller modules and communication ports

All elements and modules are connected (Fig. 1a) and integrated on board the aerial platform. The flight controller internal modules and communication interfaces are shown on Fig. 1b.

Platform's flight parameters

The system design (Fig. 2) was defined priorities like: redundancy in case of one motor or propeller failure, data collecting payload weight up to 2500 g, vertical take-off and landing. That assumption determined hardware configuration. The redundancy, in case of one motor or propeller failure, is guaranteed by 6 motors multirotor configuration (hexacopter). Four motors configuration (a quadrocopter) is not redundant. In case of one engine failure four motor multirotor will not be able to continue safe flight. Moreover, additional two motors enable to increase thrust. The motor type MT-2216 KV810, in accordance with technical specification, generates 1070 g thrust using 10/3.8 APC Propeller (Advanced Precision Composites). It means that maximum thrust generated by 6 motors used in the project is 6420 g.

During a design phase it is important to take into account many different technical specification. In case of COTS (commercial of the shelf) components, the market offer is very wide and every product has a different parameter, price, weight and quality. In order to precisely calculate and select all necessary components eCalc (Müller) online tool was used. ECalc is a online database tool with variety of components parameters delivered by community or manufacture. The tool enables to create specific multirotor calculation, using selected component available on commercial market.

Fig. 2. Hexacopter platform hardware configuration and components assembly

Flight controller – system heart

As stated in (Jha 2016), the UAV platform's FC must be designed to provide smooth and stable flight performance. Mainly, FC is designed to automatic control of angular stabilization, angular position and trajectory during flight phases (operation modes) from take-off to landing. Used Pixhawk flight controller (FC) can run an open source Arducopter firmware (Ardupilot 2016).

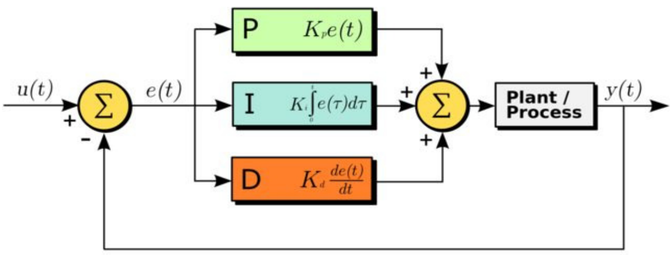

Fig. 3 PID controller to hexacopter (Liang 2017)

Basically, a the hexacopter stabilization is controlled in loop feedback mechanism, used in control systems, named PID controller (proportional-integral-derivative controller) (Fig. 3). In this particular system PID controller receives data measured by the sensors on the FC (gyros and accelerometers) and comparing that against expected values to alter the speed of the motors to compensate for any differences and maintain balance [8]. The PID controller calculation algorithm involves three separate constant parameters, the proportional, the integral and derivative values that are to be tuned for a specified construction. The Arducopter firmware 3.4.3 installed on board Pixhawk FC enables to perform auto tuning mode in which PIDs parameters for the platform can be tuned automatically. This procedure takes few minutes, and copter during flying attempts to automatically tune PID rates to provide the highest response without significant overshoot. Procedure can overshot parameters, causing copter to be too responsive for input, or a "wobbling" effect, what must be corrected manually.

In this particular firmware, there are 14 built-in flight modes, 10 of which are regularly used. There are modes to support different levels/types of flight stabilization, a sophisticated autopilot, or follow-me system. 6 of them were programed for the research tasks (Stabilize, Alt Hold, Loiter, Return-to-Launch, Auto and Circle). Flight modes are controlled through the radio (via RC transmitter switch), via mission commands, or using commands from a ground station (GCS) or companion computer (Ardupilot 2016).

Companion computers connectivity

The Pixhawk FC is responsible purely for a flight control, and its processor (168 MHz Cortex M4F CPU) is unable to perform complicated computation. For testing and developing photogrammetry and remote sensing algorithm other commutation devices are to be used. For this reason, this project configuration enables to use a companion computer, in order to perform complicated calculation and pass only a navigation decision to FC.

The companion computer installed on the vehicle communicates with (and control) the flight controller, gets all the MAVLink data produced by the autopilot (including GPS data) and use it to make decisions during flight. This functionally enables to process live vision feed from onboard camera or other onboard data source (radar, lidar) and process it to the specific navigation decision. Navigation decision is sent to execution to the FC. That hardware configuration enables to perform and test the different modern methods i.e. obstacle avoidance, visual navigation (Burdziakowski *et al.* 2016: 747–758), maritime objects following (Bobkowska 2016: 1–4), maritime and vision sensor fusion (Stateczny, Bodus-Olkowska 2015: 1123–1128; Szulwic *et al.* 2015: 9–14), inflight onboard image radiometric correction (Kedzierski, Wierzbicki 2016: 70–78; Kedzierski, Wierzbicki 2015: 156–169), lidar and vision data fusion (Janowski *et al.* 2015: 17–24) and support works in structural health monitoring (Kamiński *et al.* 2015: 471–482). The most popular companion commuters compatible with presented configuration are Raspberry Pi, ODroid, Intel Edison and NVidia TK1 and TX1. At this moment NVidia TX1 module is the most powerful companion computer and delivers enough power efficiency to run latest visual commuting algorithms with support of CUDA technology. CUDA technology enables to increase in computing performance by harnessing the power of the graphics processing unit (GPU) (Błaszczak-Bąk *et al.* 2016; Nvidia 2011: 1–227), what enables to compute visual methods in real time. That functionality is crucial to drones technology and allows them to interact with environment.

Ground station and mission planning

The flight controller is able to operate with the ground station based on different architecture. The basic GCS configuration consist of Windows PC with installed Mission Planer Software (Fig. 4). A Linux users are provided with APM Planner 2 software. A mobile GCS is based on Android phone with Tower software. The GCS communication channels can be established via radio modem for a long range, via WiFi module for a short range or Bluetooth for very short range, all using MAVLink protocol.

In order to perform photogrammetry and remote sensing tasks, the presented GCS software will play a major role. The software is divided on 5 main screens, able to control and configure UAV. Flight Data screen provides information about current flight parameters and system status and messaged. Flight Plan screen delivers basic and advance tools to prepare flight plans (missions). Initial Setup section is for initial set up and configuration of FC to prepare it for particular vehicle. Configuration Tuning part is to configure the parameters how FC is control particular UAV and how pilot is control UAV, tuning and adjusting PID loops. The simulation tool is designed to perform Software In The Loop (SITL) simulation. It can simulate particular vehicle behavior without the need for any vehicle hardware. From a researcher and educational point of view this feature allows for safe testing of experimental code and settings, and can help students to practice using this Ground Station, mission execution and perform simulated mission.

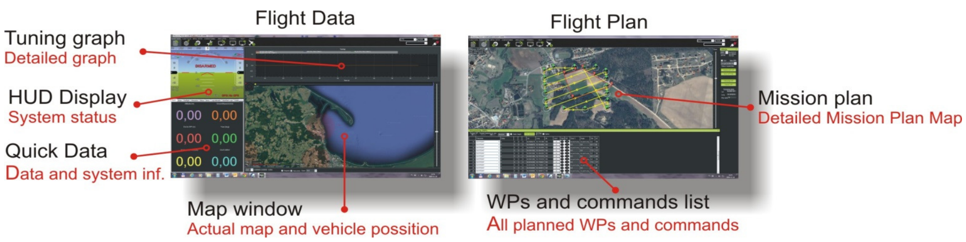

Fig. 4. Basic Mission Planner windows

Communication

A proper communication channels are crucial for UAS functionality. Military UAS are using a military licensed and not available for commercial use frequency spectrum radio bands. For a commercial use, there is a need to establish communication in ISM band. Industrial, scientific and medical (ISM) applications (of radio frequency energy) is an operation of equipment or appliances designed to generate and use locally radio frequency energy for industrial, scientific, medical, domestic or similar purposes. During last ISM bands have been shared with (non-ISM) license-free error-tolerant communications applications (wireless networks, wireless LAN in the 915 MHz, 2.450 GHz, and 5.800 GHz bands). Unlicensed devices are required to be tolerant of ISM emissions in these bands, unlicensed low power users are able to operate in these bands without causing problems for ISM users (ITU-R Report SM.2180). License-free communication equipment is used in presented project.

Main communication's device frequencies were placed in different band, in order to reduce mutual interferences (Fig. 5). A maximal transmitting power is limited by ITU regulations. In order to maximize effectiveness used radio transmitters a new tuned antennas have been used. Each antenna is tuned to a specific frequency channel in order to reduce standing wave ratio (SWR). With the aim of maximize receiving radio signal for 2,4 and 5,8 GHz band, a diversity receivers are provided. Diversity modules are checking constantly RF signal strength from two antennas, and chose more stable and stronger one. Live video feed receiver diversity module is equipped with two antennas. The first is an omnidirectional antenna for close range operations, and the second is a directional antenna for long range operations. The RC receiver uses two antennas and determines always strongest signal to control vehicle. The telemetry data 433 MHz band diversity is not required, due to a lower RF band characteristic. This band is not that sensitive to interference, and lower frequency delivers higher range. The telemetry data transmission is also not that important like vehicle control, and eventual data transfer loss not causing potentially dangerous effect or vehicle loss.

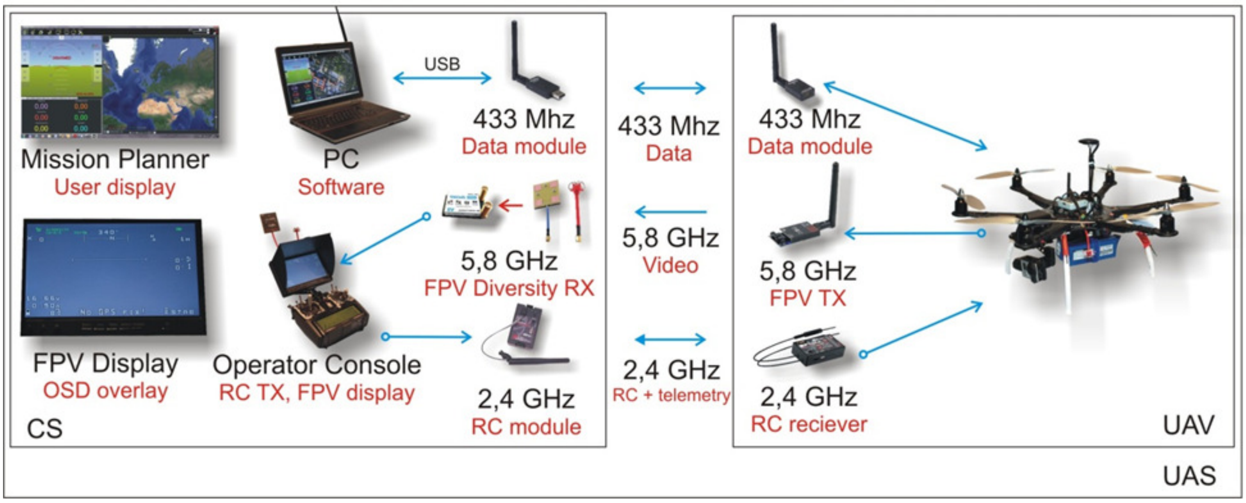

Fig. 5. Information flow and communication channels

In case of communication loss (or other defined danger situation) vehicle is equipped in a failsafe system (implemented in FC). The failsafe system enables to execute predefined command in defined danger situation. In case of battery voltage drop to a minimal value, radio control communication lost or vehicle entered a geo fence (defined by user denied for flying geographic area), vehicle executes automatically return-to-home (RTH) command and lands automatically. A home position is a take-off position (precisely vehicle arming position).

Conclusions

A presented approach to this specific construction provides a many capabilities to test, implement and execute new, recently developed algorithms, solutions and tasks. The project uses the open source hardware, which can be freely modified and used to extend its functionality. The internal cross communication compatibility is delivered by the open source protocol (MAVlink). This protocol can be implemented onboard small companion computer like Raspberry Pi or powerful NVidia TX1 with CUDA technology. All software used in the project is based on the open source initiative, in which the copyright holder provides the rights to study, change, and distribute the software to anyone and for any purpose. That tactic offers students and researchers a tremendous opportunity to implement and test new solutions and algorithms. Sharing tested solution with the open source community in scientific publication, researchers supports collaborative development and generates an increasingly more diverse scope of design perspective than any one company is capable of developing and sustaining long term (St. Laurent 2004: 193). At it is proven in presented research, the open source know-how is able to deliver a full working solutions to the UAV technology for a research community with a significant costs reduce.

Author declare that there is no competing financial, professional or personal interests from other parties, as far as presented research is concerned. Research founded form own sources.

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