UNMANNED SYSTEMS WITH THREE ROTORS

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Summary. The aim of this article is to specify a basic overview of multirotor-type unmanned aerial vehicles, constructional design and realization of a tricopter based on mechanical components and electronics available at the Department of Aviation Technical Studies. The tricopter is the simplest multirotor design. The electrotechnical part of the basic tricopter version doesn't require programming of complex control algorithms, because the stabilization is provided by the pre-programmed microcontrollers, one in each gyroscope. Flight data acquisition and automated control system can be situated onboard. In the future the implementation of various sensors, IMU and performing controlling microcontroller can be realized. There is also a perspective of implementation of algorithms for pre-programmed and in-flight updated tasks.

Keywords: tricopter, unmanned aerial vehicle, multicopter, control signal

1. INTRODUCTION

People dealt with the problematics of unmanned aerial vehicles (UAVs) already during the World War II, their use was mainly for military purposes. Nowadays UAVs are globally enforced in the civil sector (field monitoring, recreational flying, etc.) [1-6]. Whereas Faculty of Aeronautics didn't have a real functional airplane, we tryed to work at least with unmanned aerial vehicles. Our task was to design and construct a vehicle with three rotors – tricopter. The realized tricopter model should also serve as a prototype for measurement of basic flight parameters (barometric pressure, acceleration, angular rates, magnetic field) which should allow us to reconstruct the flight trajectory [7].

2. CONSTRUCTION

For the construction design, theoretical basis from technical papers and discussions and our own experiences in the area of RC models were used. A modular design that is sufficiently strong, but flexible to overcome tough landings or lighter crashes was chosen. Based on our requirements, we decided for a design consisting of cuprextit plates and aluminum arms.

Two cuprextit's plates connected via 1 cm spacing tubes formed the centre part of the tricoper. In the place between cuprextit's plates there was an on-board battery, a receiver and a servo.

For the arms a 10x10 mm Jokel profile with a thickness of 1 mm was used. In the arms power supply wires for engines were placed. Tricopter's landing gear was made of three aluminum strips with a thickness of 3 mm and width of 30 mm. Due to weight reduction, there were cut annular holes in the cuprextit plates.

Figure 1 Central plates from aluminium Jokel

For the yaw movement creation it is needed to rotate a rear rotor of the tricopter. In ussual tricopter designs, the servo (used for rotation of rear rotor) is placed at the end of the rear arm, what makes the rear arm mechanisation very vulnerable. A uniqueness of our design was a method of rear rotor rotation. In our concept the servo was placed between central cuprextit plates and was used to rotate the shaft, where the rear rotor was mounted. The shaft was kept inside the rear arm in a special casing design

Figure 2 Final version of the tricopter

3 DESCRIPTION OF TRICOPTER'S ELECTROTECHNICAL PART

Tricopter's flight was provided by three right-hand propellers GWS 10 x 4.7 powered by electronically comutated motors TR 2217. As DC current source a high quality Li-Pol battery with 3000 mAh capacity was chosen. Battery provided enough energy for 8 minutes flight duration. During flight tests when a payload of 500 g was carried, flight time was decreased to 6 minutes. For the tricopter stabilization, four single-axis gyroscopes HK 401B were used. On the board various sensorics equipment for in-flight measurements realization can be situated. [7]

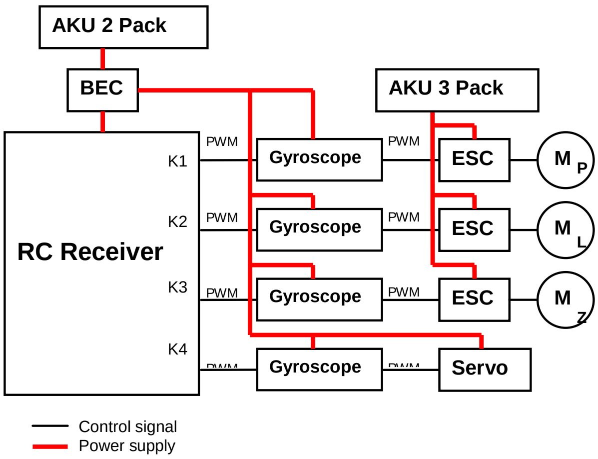

Figure 3 Block diagram of the electrical part

4 ANALYSES OF THE CONTROL SIGNALS

Receiver processes the received signals from RC transmitter and creates control signals, pulses of the same voltage value (the pulse length carries the required information). This type of modulation is called pulse width modulation (PWM). Number of PWM signals depends on the number of channels the receiver is able to provide. For controlling of a tricopter, at least 6 channels are required. We can control thrust, the forward, lateral and rotational movement and residual two channels are used for adjusting gyroscopes sensitivity. Frequency of controlling PWM signal is 50 Hz, so the period is 20 ms. The time duration of the pulse varies between 900 μs and 2.1ms [7].

Figure 4 illustrates motor control signals measured during simulation of lateral movement to the left side. Pulse duration from left engine is reduced, causing a reduction in thrust, and pulse duration from the right engine was extended. Thrust in the right engine is increased and tricopter starts slightly to move to the left. Thrust of the rear engine remains unchanged until the gyroscope detects "falling of tail". [7]

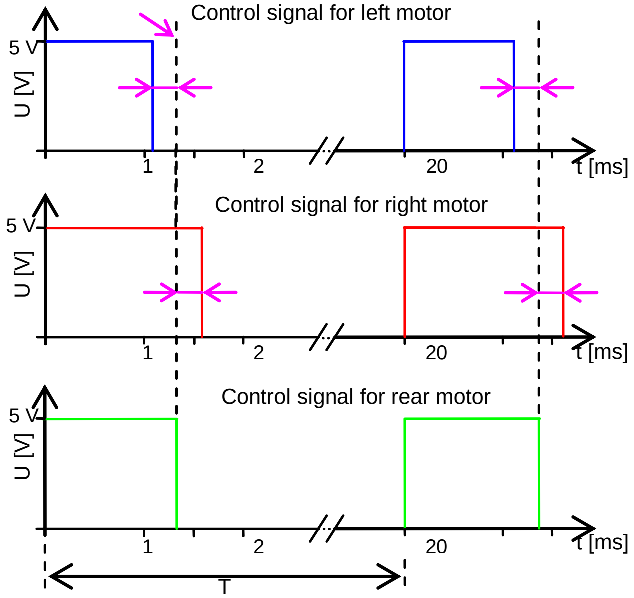

Figure 4 Control signals for lateral movement

After successful completion of construction and verification of sufficient robustness as well as setting on-board electronics elements, we had to think about the possibilities of onboard measurements and data saving. For these measurements microcontroller Arduino Duemilanove was used. Arduino uses a microprocessor ATmega 168 with the clock frequency of 16 MHz. The microcontroller has 10-bit analog to digital converters, that were used for battery voltage measurements and also supports I2C and SPI interface used for communication with the IMU. [8-10]

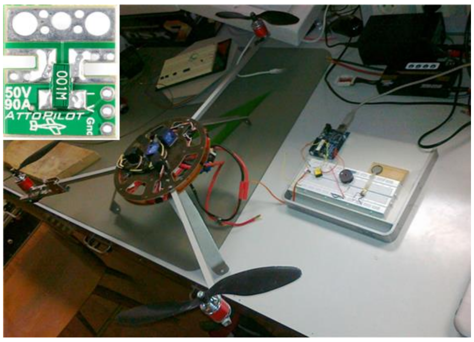

Figure 5 Current and voltage measuring

Initially we performed measurements of current consumed by the motor and the voltage of onboard battery with sensor AttoPilot 90A [7,10].

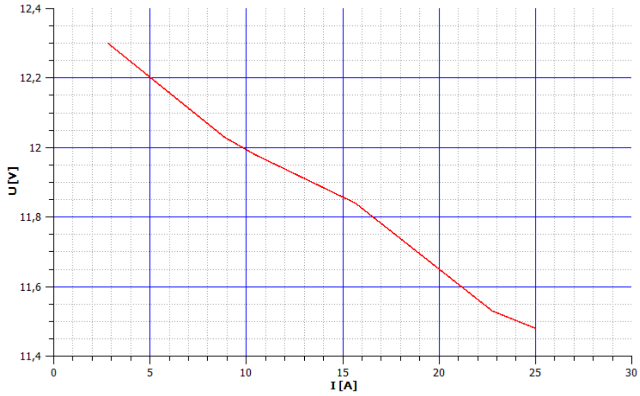

Figure 6 Current and voltage of onboard battery measurement

We also used XBee telemetric modules for the data transfer. The first microcontroller - Arduino with the Xbee module (transmitter) was situated on the tricopter board and it was processing sensors' data. The second Arduino with the Xbee module (receiver) was on the ground control station and was used for received data logging to a memory card using the OpenLog module. The OpenLog module communicated with the Arduino microcontroller by serial communication. The first measurements of flight parameters were performed in a closed space without the influence of external wind – in the Hall of UAVs testing, where we simulated flying in the square.

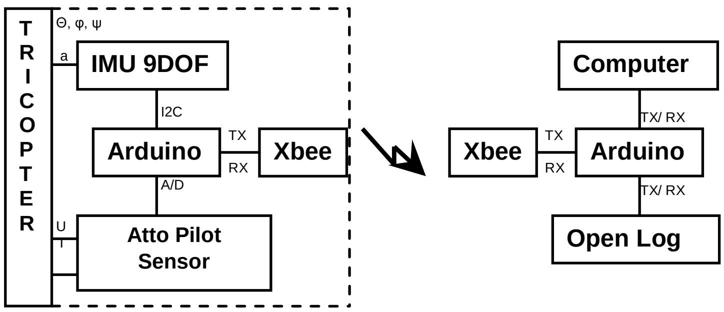

Figure 7 Block diagram of the measurement chain

For the acceleration, angular velocity and magnetic field measurements, the inertial measurement unit - IMU 9 DOF stick was used. Dimensions of the IMU unit are only 11 x 35 x 1.9 mm and its weight is 2 g. IMU 9 DOF includes three-axis ADXL345 accelerometer, three-axis HMC5843 magnetometer and three-axis ITG3200 gyroscope [9]. Weight of this on-board measurement station does not exceed 100 g. For the correct measurements and precise position angles determination all used sensors were calibrated [11,12]. The position angles (pitch, roll and heading) measured during the demonstration flight are illustrated on the Figure 6 [7].

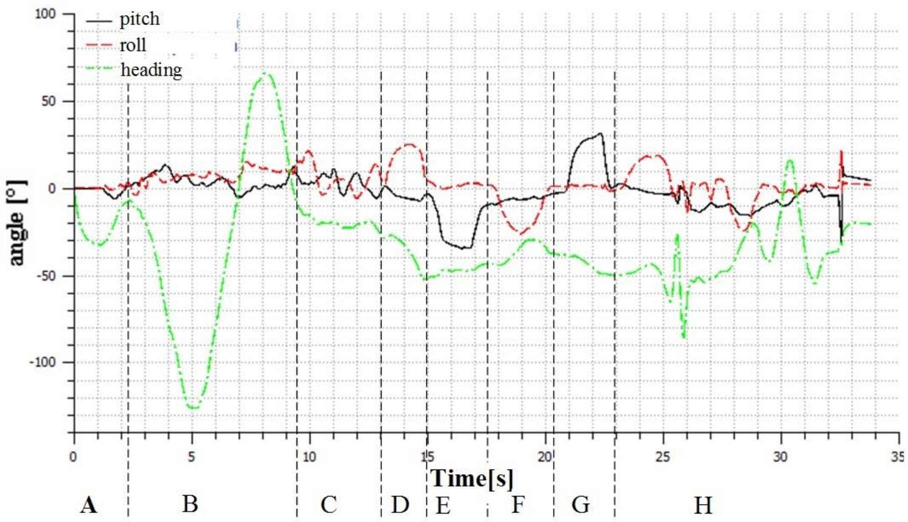

Figure 8 The selected flight parameters

In the "A" phase the UAV took off. Green shape in the "B" phase shows the rotation around the vertical axis. In the "C" phase the tricopter was hovering at the same point, so position angles were changing minimally. Increasing the roll angle in the "D" phase means that the tricopter rotated around the longitudinal axis, causing its movement to the left side. In the "E" phase the pitch angle was decreased, as a result of flying forward. After this maneuver, the tricopter moved to the right - roll angle decreased as is shown in the "F" phase. In the "G" phase pitch angle increased until we flew to the place from where we had taken of. In the last "H" phase the tricopter landed. [7]

5 ANALYSIS OF ELECTROMOTOR CONTROL SIGNALS

The aim of this analysis is the measurement of electromotor control signals in different motor regimes (loaded motor, unloaded motor, motor at full and low throttle). Measurements were realized with a special laboratory equipment NI DAQ-6251 designed for quick scanning and data acquisition at a sampling frequency of 250 kHz. Electromotors were using three-phase excitation of stator winding so we measured all three phases at three analog inputs with 16-bit resolution. The DAQ system was connected to a computer, where all measured data were saved using the NI LabView software [7].

The following figure shows the measured signals (three phases) in the unloaded engine with low throttle. The phases are mutually shifted by the angle of 120°. The time period of the excitation signal is approximately 2.5 ms, which corresponds to 3500 rpm [7].

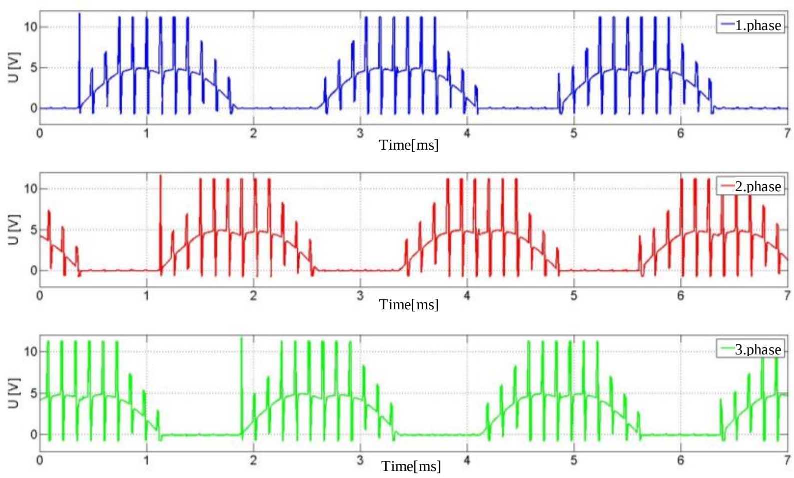

Figure 9 Control signals of motor

6 CONCLUSIONS

The result of our work is the theoretical description and practical realization of the basic tricopter platform. Strength of the proposed lightweight aluminium construction was successfully verified by many flights that also confirmed responsible functionality of used avionics. Developed algorithms for signal preprocessing, position angles determination and filtering were onboard tested. Measured flight data were transferred via telemetric system to ground station, where the tricopter position and flight data information was visualized.

The vision for the future research and work is in implementation of the various sensors, inertial navigation unit and a GPS receiver, serving not only for the tricopter stabilization, but also for a fulfillment of pre-programmed and during the flight updated tasks. Precise study of the BLDC motors' control signals allows us to propose own BLDC motors' controllers. Possible inertial system and the autopilot can be used for similar small UAVs. For this reason the thorough study of inertial sensors' signal processing, simulation and control of tricopter has to be done.

Used electronics, knowledge of its functionality and experiences reached during tricopter development are applicable in all multirotor applications (quadrocopter, hexacopter) and also in fixed wing airplanes applications.

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