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BUILDING AND CONTROLLING THE QUADROCOPTER

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Summary: Quadrocopter it's a flying object, which flies with a help by four propellers placed on the end of a cross construction. Main features this device are stability, small weigh and maneuverability. At present is popular for his advantages.

Key words: quadrocopter, PID, controller

INTRODUCTION

Quadracopters are with us almost one century. First experiments with him started at the beginning 20th century. The first functional quadracopter was built in year 1920 by Etienne Oehmichen. At first were created devices that should to carry a weight of human body. Actual trend is creation small unmanned quadrocopters. The main reasons for this situation are ability to easy control and maneuverability. Quadrocopters are used by enthusiastic modellers, but also find an application in the professional sphere, such as the police or the army.

Here (2) and (3) it's described a construction and a stabilization of the quadropter. In (2) is applied the CHR-6d as a position sensor. The author solves stabilization by using the DCM (Direct Cosine Matrix) algorithm. The position sensor CHR-6d has the onboard EKF (Extended Kalman Filter) for pitch and rolls angle estimation, so I wanted try use on the quadrocopter.

In (2) and (3) is the control of quadcopter solved by using a RC remote control. This solution is a natural, but I wanted use something else. Currently many people have a mobile device with Bluetooth technology, so is good idea using a mobile device as a remote control for the quadcopter, is need only a Bluetooth module, which it is not too expensive.

This article discusses about a construction of the quadrocopter, which was built in cooperation with my colleague Ing. Pavel Rozsíval. Also discusses a principle of control, a question of stability and possibility to using the quadrocopter for many applications.

1. QUADROCOPTER

The quadrocopter (Fig.1) it's a flying object, which flies with a help by four propellers, therefore is so called. Two opposite propellers rotates in one direction, for take-off. First pair opposite propellers (Fig. 2) rotates in one direction for keeping balance in the X axis. Second pair opposite propellers rotates in opposite direction, for keeping balance in the Y axis (Fig. 3). The main reason for opposite rotations of opposite pairs it's the elimination a rotation the quadrocopter in the Z axis.

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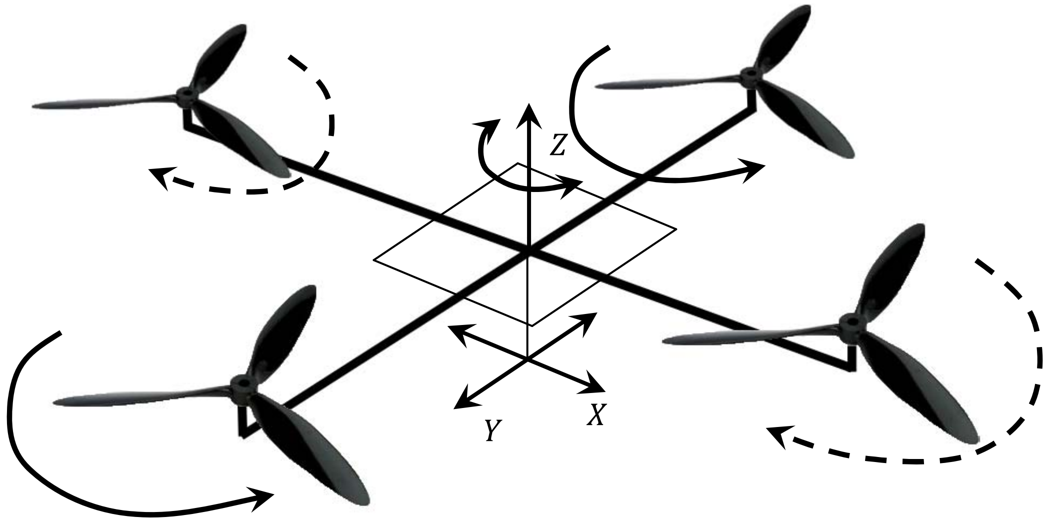

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Fig. 1 – The principle function of quadrocopter

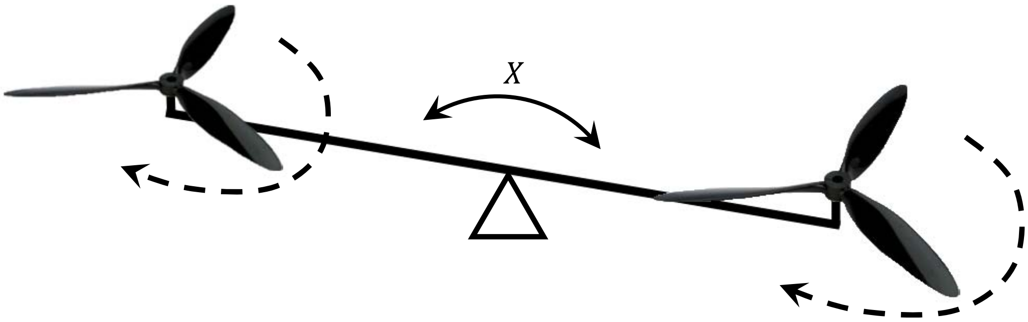

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Fig. 2 – The principle function the first arm

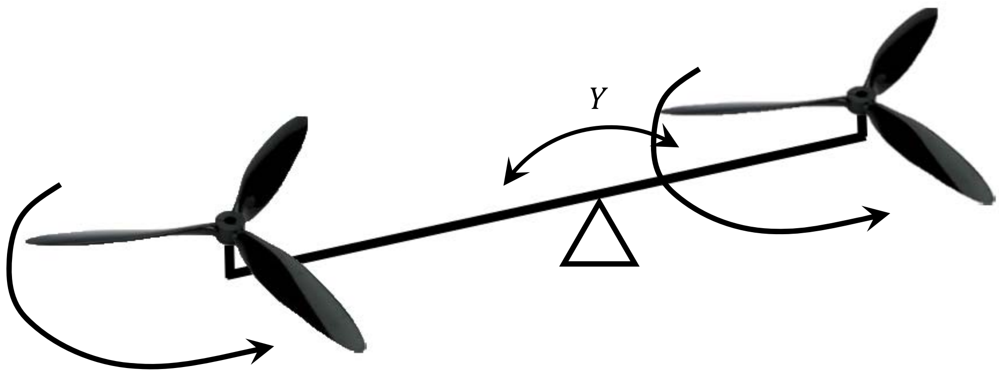

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Fig. 3 – The principle function the second arm

In the question of the control, is good to separate the problem into three independent parts. The first part is control in the X axis (Fig. 2), where is important a balance on the lever, the second part is similar the first, in the Y axis (Fig. 3). The last part of control is the rotation in the Z axis (Fig. 1), which must be prevent.

1.1 Motors and rotate regulators

In solving the control, the stabilization and for example display some data is needed a higher computing power, for this reason it used a kit with MCU. The MCU on the kit is the ARM Cortex-M3, which is a 32bit MCU. The block diagram of the motor connection is on the next figure (Fig 4):

Source: Author

Fig. 4 – One motor connection

The quadrocopter needs relatively a high thrust of a motor. For this purpose are good AC brushless motors. The thrust is possible continuously control with PWM pulses. Generated PWM pulses for motors are form output ports of a kit whit the MCU brought on an ESC (Electronics Speed Control) of each motors. An ESC needs to know the position a rotor of motor. Is possible to use a motor with a build-in sensor, but the problem is with the compatibility a motor and an ESC. Currently are used motors without a sensor and for detection the rotor position serve a special method. Simply said an ESC sends into windings high frequency impulses and evaluates their reverse induced reflections, which depend on the magnet polarity, which is closest to the coil.

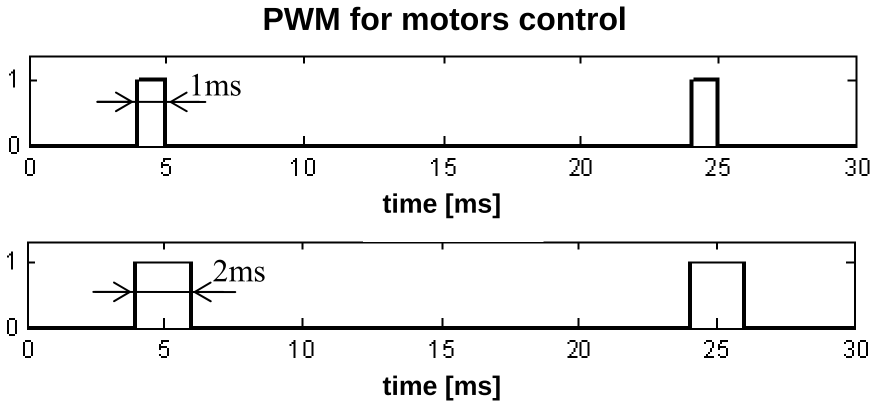
Advantage this solution is the lower price of a motor, he doesn't have the position sensor and no need more wires for an ESC, because an ESC needs to has five wires for the position sensor. Current ESC has only three wires and the exchange of two wires between an ESC and a motor causes the change of a motor rotation.

For flying is better use outrunner motors. A motor of this construction has important feature in the high torque. AC motors are about 30-50% lighter against DC motors with a same performance and have up to half the greater efficiency. AC motors have a beneficial torque. The optimal trust of DC motor it's only on the maximum speed, but good designed AC motors are able fly whit only twenty percent of the maximal performance. This all allows construct lighter models, which are able to reach the longer fly.

When selecting motors, it must be used the adequate ESC on appropriate performance. Most important thing for build the quadrocoper is choosing the optimal performance of motors, which ensure takeoff the device with the concrete weight, but is good to have some reserve, to avoid overload of motors.

1.2 Motors control whit PWM

The way to control AC motors is based on principle control a servomotors. The basic signal has a width 1 ms of a logic one with the period 20 ms. After turn on the quadrocopter must have the PWM pulse a width 1 ms, which mean a motor is stopped (Fig. 4 up). With a pulse width greater than 1 ms an ESC won't let wind off a motor for the safety reasons. For start-up motors is need the pulse width 1 ms. Continuously increasing the pulse width from 1 ms up, motors begin to spin. The upper limit of the pulse width it's 2 ms (Fig. 5 down), when a motor has a maximal performance.



Source: Author

Fig. 5 – Control whit PWM pulses

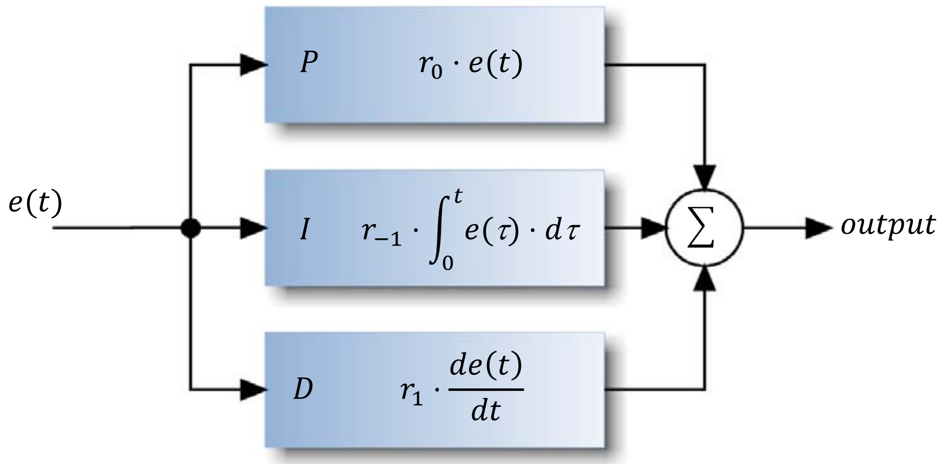
A continuity of changing the rotation is critical for stabilization. In case of the step change the pulse width is need to ensure, that the change will not cause too great a change of the motor rotation, because it may cause high change of a output value the controller and this can lead to destabilization quadrocoper.

2. PID CONTROLLER

A proportional–integral–derivative (PID) controller is a generic control loop feedback mechanism. The PID controller calculates whit error value $e(t)$ as the difference between a measured process variable (PV) and a desired setpoint. With this error value is counted each actions of controller (Fig. 6). The controller attempts to minimize the error by adjusting the process control inputs. The main equation of the parallel PID controller (1):

$$output = r_0 \cdot e(t) + r_{-1} \cdot \int_0^t e(\tau) \cdot d\tau + r_1 \cdot \frac{de(t)}{dt} \quad (1)$$

The block scheme of the parallel PID controller is on the next figure (Fig. 6).



Source: Author

Fig. 6 – Parallel PID controller

$e(t)$ error
r_0 gain(proportional action)
r_{-1} integrate action
r_1 derivative action
P, I, D blocks each controllers (proportional, integrate and derivative)

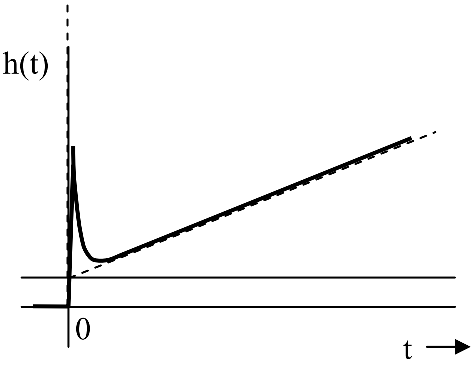


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Fig. 7 – The transfer function of the PID controller

The transfer function of the PID controller (Fig. 7) clearly shows the influence each action of the controller. The gain r_0 means the increase level. The derivative action r_1 makes a rapid decline the level of process action and the integrate r_{-1} increase the action level in time. After the step change of the error dominate an influence of the derivate action and after that begin exercise the integrate action in time.

The proportional action P reflect the actual deviation, the integrate action accumulate deviation in past and the derivative action is estimate the next deviation. On controlled systems, which aren't with the good describe, it's using of the PID controller suitable. This type of controller doesn't always represent the best controlled solution, but with optimal parameters settings is able resist instability. Worse parameters settings cause longer time of regulation the error, therefore is appropriate take a time for settings of parameters.

2.1 Settings of controllers

For settings of controllers is used the method Ziegler-Nichols. According to the table (Tab. 1) is necessary find two important parameters r_{0k} – the critical gain and T_k– the critical period.

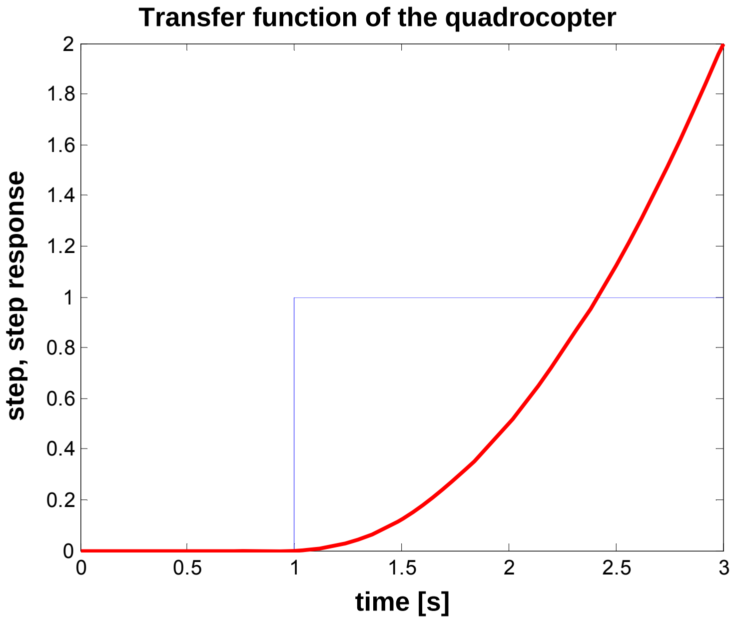
Tab. 1 – Parameters settings for the method Ziegler-Nichols

Controller type	r_0	r_{-1}	r_1
P	$0{,}5 \cdot r_{0k}$		
PI	$0{,}45 \cdot r_{0k}$	$0{,}85 \cdot T_k$	
PID	$0{,}6 \cdot r_{0k}$	$0{,}5 \cdot T_k$	$0{,}125 \cdot T_k$

Source: Author

The proportional action of the controller is increased with a little steps, until is achieved the periodic oscillation on the limit of stabilization, when the output value of the controller periodically oscillates around the state of equilibrium. From the recorded process is determinate the critical period as a one cycle of oscillation. After that are the remaining controller actions calculated from the table.

In the case control of the quadrocopter it goes about integration system, which has the transfer function still increasing to infinity (Fig. 8) and for the controls constant was necessary using an experimental method.

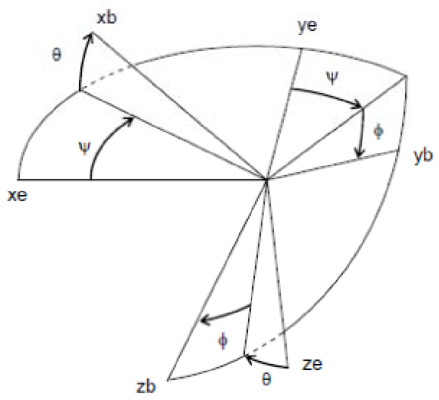


Source: Author

Fig. 8 – The transfer function of the quadrocopter

3. ORIENTATION IN SPACE

For describe the motion of the quadrocopter it's necessary to define a suitable coordinate system. For most problems dealing with aircraft motion, two coordinate systems are used. First coordinate system is fixed to the Earth and may be considered for the purpose of aircraft motion analysis to be an inertial coordinate system. Second coordinate system is fixed to the airplane and is referred to as a body coordinate system. The next figure (Fig. 9) shows the two right-handed coordinate systems.



Source: (3)

Fig. 9 – Body fixed frame and Earth fixed frame

The orientation of the airplane is often described by three consecutive rotations, whose order is important. The angular rotations are called the Euler angles. The orientation of the body frame with respect to the fixed Earth frame can be determined in the following manner:

1. Rotate the body about its zb axis through the yaw angle Ψ
2. Rotate the body about its yb axis through the pitch angle Θ
3. Rotate the body about its xb axis through the roll angle ϕ

$$pitch\ (\Theta) = \frac{180}{\pi} \cdot atan\left(\frac{accelerationY}{accelerationZ}\right)\ [\,°] \tag{2}$$

$$\boldsymbol{roll\ (\phi) = \frac{180}{\pi} \cdot atan\left(\frac{accelerationX}{accelerationZ}\right)}\ [\,°] \tag{3}$$

Another possibility how can be determined rotations angles show the following expressions:

$$\Theta = \Theta + gyroY \cdot \Delta t\ [\,°] \tag{4}$$

$$\Phi = \Phi + gyroX \cdot \Delta t\ [\,°] \tag{5}$$

Data from the output of gyroscope are the angular speed. Time Δt is time between two samples and from the expression to calculate distance (6):

$$s = v \cdot t\ [m] \tag{6}$$

is possible to calculate the angles. The expressions (2) and (3) describe the angular distance.

4. COMPLETE SET

Source: Author

Fig. 10 – Quadrocopter – the complete set

On the end of quadrocopter cross (Fig. 10) are mounted four outrunner motors. The cross is created from the carbon prisms. On the center are mounted the two carbon plate (on top and bottom) for fixing the PCB and Li-Pol battery, which supplies all components. On each motor is connected the ESC. The main reason for using carbon parts is the complete weight of device. With a smaller weight is the quadrocopter able fly much longer, because isn’t necessary too high thrust of motors and batteries use less power.

The complete set controls a MCU, which receive information about the position from the position sensor (CHR-6d). Received data are evaluated for controllers, which controls PWM pulses for motors and ensures stability of a flying object. To the MCU is also connected the LCD display for showing the internal state of the MCU. The quadrocopter is controlled via Bluetooth in the version two. This version of the Bluetooth includes the SPP (Serial Port Profile), which emulates a virtual serial line. Many mobile devices have the Bluetooth interface, so it’s possible to control quadrocopter almost with anything.

5. CONCLUSION

The quadrocopter is now able to takeoff and reach a steady state at height, but occasionally small corrections are still needed to keep the quadrocopter in one spot. Better settings of controller, for example with using another method for finding the controller actions or use a better control method it may help for a better stabilization. Also it possible to refine the positioning in space by adding more sophisticated filters. On flight of the quadrocopter acts also the wind effect, therefore it is needed to include this effect into the overall stabilization.

The remote control over a mobile application works very well. Now is implemented a basic control of the quadrocopter with possibility turn on/off controllers. Into the future can be added some advanced control functions for special maneuvers.

For improvement functions of quadrocopter can be added some another sensors like a camera or altimeter. One of the many advantages of the quadrocopter is ability to fly on places, which are for human complicated to reach or so quickly as he and with the help of a camera is possible explore inaccessible locations. With added devices we can to determinate a flight path or track some objects.

6. ACKNOWLEDGEMENT

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