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Project summary

Quadcopters are incredible pieces of technology. Software on the flight controller is able to simultaneously stabilise the drone in three degrees of freedom, follow commands from the pilot and take pictures.
200 times per second the flight controller therefore measures the current position and RC signal, calculates a correction and sets the according engine speeds.
This is a task that could never be done by a human being.

Purpose of the research

Currently two main kinds of quadcopters exist. There are commercially distributed products, which come ready, to fly and are used as toys or for aerial photography. And for more experienced users platforms as Pixhawk or Ardupilot are available. Those provide the complete software and crucial hardware parts for drones. Users build the frame and combine hardware like motors or a remote control. But there cannot be made improvements and nor can the functioning be understood by the average programmer. Projects from universities include this possibility but do not serve as tutorials and are to complexly documented. A detailed guide on how to develop a complete, amendable position control and build the hardware for a drone is missing for tinkerers and hobby programmers. Even though a demand for such instructions exists. This can be observed in forums, on posts and was found out in conversations with colleagues.
In my research this lack is met. I examined how to build a quadcopter with affordable components and searched a way to code it beginner-friendly. For programmers the procedure and product are explained on a website to learn how to develop copters that are expandable an their functioning understandable.

Procedures

All the main parts of the quadcopter were developed, implemented, tested and improved separately before combining them with the existing firmware and hardware.
The position control code was written in the Arduino programming environment for the Arduino mega 2650 board used on the copter. The advantage of this platform is the well-documented programming language and the active community.
During the project 3 different prototypes were built and used to test the current firmware.

For communication the pilot sends commands at 2.4 GHz from, which are read by the receiver on the drone. For the readout of the PPM (pulse position modulation) signal hardware interrupts are used. In the interrupt service routine the point the high-phase started and stopped is stored. Then its length can be calculated without the program having to wait during the signal.
Secondly the control for the motors was implemented. The servo library is used to create a PWM (pulse width modulation) signal. This is sent to the ESCs (electronic speed controllers), which create a phase-delayed signal for the brushless motors.

The radio control signal and the PWM signal were examined on the oscilloscope to adjust the program to it and ascertain its proper functioning.

For the measuring unit the accelerometer ADXL 345 and the gyroscope ITG 3200 have been used. Values from the gyroscopes are first filtered and then converted into angular velocity. From data of the three accelerometers the absolute orientation angle is calculated. The two results are then combined in a complementary filter to only use the advantages of both sensors
Different filter constants were calculated and their performance was visualised as graphs and analysed.

All the previous functions and a PID regulation were then combined into a position control. The PID regulation makes calculations based on the difference between actual value and nominal value of the orientation angle.
In this stage the functioning of the quadcopter has been tested on a stationary test stand. Later it was mounted on one axis and finally only held by an elastic band.

Further procedures were added when the copter performed well in the basic tasks.
One of those adapts the PID values depending on the height. When starting and landing the integral part of the regulation is reduced to not add up errors. It also allows the machine to start from lopsided ground.
Furthermore a height regulation with a P and D part was implemented using a barometer BMP085. The low pass filter for the sensor measurements has been scrutinised and improved several times.

To document the flight photographically a cameras trigger button was tweaked. Using an optocopler it can be electronically pushed by the Arduino. The user can set a time interval for photos being taken and saved with the current height.

For the website a full concept has been worked out before starting with its creation. For the approach especially the users' needs and level was taken into account. The webpage should also be constantly up to date, easy to use and have an appealing design. Respecting these guidelines a website has been made in Wordpress.
The articles were written comprehensible for novices and include visualisations and graphs for better understanding.
The steps in the tutorial are equivalent to the found solutions and used methods in my project.

Data

The programmed position regulation can successfully keep the copter stabilised in the x-,y- and z-axis. In a test, letting the set angle change quickly from -9.2° to 12.8°, it firstly overshot to 6.2° but then quickly reached a stable flight. It has minimum deviation of 3.2° after 2.2 seconds. When not taking into account the first 0.75 seconds of the correction, the average deviation is 1.1°. After the first 3 oscillations they normally have a duration of 0.5 seconds.
It could happen that, when taking off, the position control made hefty corrections. After having changed the PID values in flight mode and starting/landing mode those manoeuvres function better.
The altitude regulation works satisfactorily for the use of taking pictures at a constant height.

For the software to run smoothly on the ATmega2650 processor much respect had to be paid to the time management. The 2-wire bus speed was increased from 100 kbit/s to 400 kbit/s and the refresh interval for the PWM signal was lowered from 20 000 microseconds to 1000 microseconds. All 6 hardware interrupts on the board were used for the RC-receiver and barometer readout.
The firmwares repetition rate reaches a maximum of 200 Hz without the use of the barometer and 140 Hz with the use of it.

Due to the vibrations from the motors the accelerometer and gyroscope had to be positioned on a special anti-bumping construction. On the ground the gyro-values vary from -2.5°/s to 2.5°/s with full thrust.
The complementary filter with a constant of 0.98 is able to eradicate this noise for the most part.

The inaccuracy of the barometer was measured to be at up to 0.5 meters. For the implemented low pass filter a constant of 0.94 was chosen. This is a compromise between a good filtering and a fast reaction. The filtered values need approximately 1 sec to adapt to a new height when the ascent or descent happen immediately.

For the frame 15 mm aluminium square tubes were crossed and centrally fixed to a metal sheet with rivets.
All sensible electronics are positioned in the middle on an non-conducting plate. Over it two aluminium brackets and a polystyrene protection was constructed.
A 3 or 4 cell LiPo with 3000 mAh provides current for turnigy brushless motors with 1000kv.
The quadcopter weights 1.25 kilograms and carries up to 0.5 kg additional payload. The resulting flight time is approximately 15 minutes.

The website features detailed and understandable information about every step in the development of a quadcopter. Furthermore it provides articles about the purchase of components, lists with helpful links and a regularly updated section with news about current research. It has a desktop and a mobile version.

On the start page visitors find a tab system with dropdown menus, a short description of the website and a slider with news stories.
The site has been optimised for search engines and its pages are positioned depending on the frequency of visits. The usability has been tested with five test candidates and improved afterwards. Tags and categories, a sitemap, breadcrumbs and consistent naming were implemented to simplify the use.
The webpage has on average 20 visitors daily.

The outcome of the project has several appliances:
The product provides an valuable platform for beginners to learn about the position control of quadcopters or to develop one on their own. It also serves as a good basis for programmers to experiment with and include new features.
Furthermore the drone can be used for aerial photography. With its mounted camera and live video transmission system the copter can examine the condition of window or building facades or bridges.
Similarly forest, crop fields or grasslands can be inspected. For blue-light organisations the functionality becomes interesting to use during demonstration or in case of fires or floods.

Conclusion

Regarding the standard of the software and the methods used, the quadcopter's overall performance is surprisingly good and comes close to professionally developed products. Especially in position holding and height regulation it even outgoes beginner products sold on the market.

For the position control to function correctly the PID values and filter constants needed relatively much time to be trimmed.
The deviation of the angle and the long swing cycle could result from the test installation that lets the copter oscillate longer than in mid-air. The problems when taking off were most likely caused by the Integral part of the regulation. When the drone was positioned on lopsided ground there was a big error between the actual and the nominal value and the I-part added it up.

The optimisation of the cycle time of the program demanded unexpectedly much time and complex work. But the taken provisions were effective and especially the adapted measurement of the RC saves much time. On the other hand the time required for the communication with the barometer is excessively high and should be lowered.
The enhancements became necessary due to the low computing power of the Arduino and the high refresh rate required for a stable flight.

There appeared unusually much noise from sensor measurements so that several filters had to be applied on the values. The complementary filter is efficient but had to be extended with a low pass filter because its outcomes still vary too much. This uses a constant of 0.7 so that it follows new values promptly and does not delay the regulation. The complementary filter with a constant of 0.98 weighs the accelerometer slightly more than the gyroscope.

For the barometer measurements a relatively strong low pass filter that is still able to smoothen fluctuations in height was used. There had to be found a compromise between a good filtering and fast reaction that is working for the height stabilisation.

Drafting and constructing the website was demanding. It is difficult to write concise articles that still provide enough information. The length of the initially published articles had to be shortened to make them more pleasant for readers. On the other hand the requests for the use of copyrighted images and articles proceeded without any problems
The content management system Wordpress sometimes restricted the artistic freedom. Especially for the design and uncommon features few possibilities exist so that the concept could not be completely implemented.
The intended form of website was achieved. As stated by several testers the included functionalities, the appearance and usability are convincing and make the website look professional.
The amount of visitors is definitely satisfactorily for me and was not expected to be that high.

The goal to develop a quadcopter with less sophisticated methods that still has a resilient and competitive flight performance could be achieved. As intended my product is open for extensions and the current functionality can still be improved.
I hope the guide is going to help many users building their own quadcopter or learning about its functioning. And also fascinate for drones, programming and electronics.
Besides some exhausting phases in the project the work was incredibly interesting, educational and set free a drive to conduct further research.

【評語】100025

1. 以自製方式開發四輪旋翼，具價格低、彈性高的優勢。

2. 四輪旋翼已有商用機，如何提升與商用機有區隔也是問題。