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Design, Control and Application of Quadcopter

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Abstract

Quadcopter is an unmanned aerial vehicle, which can be implemented in different applications. In paper it will be represented a development of a quadcopter system and potential application in which it can be implemented. Quadcopter structure model, basic components with block diagram, hovering stability, dimensions, and description of basic movements will be represented and discussed. Control algorithms with steps in empirical methodology will also be presented. Current civil and military application will be examined, and future applications will be suggested.

Key words: *quadcopter, design, application, control*

1. INTRODUCTION

In the last few years we have witnessed significant climate change in both the region and all over the world. Climate change is a lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions or in the distribution of weather around the average conditions (i.e., more or fewer extreme weather events) [1].

Many factors have been identified as significant for climate changes such as: plate tectonics, variations in solar radiation received by Earth and human activities, which has caused global warming increasing greenhouse gas levels.

Analysing climate change occurring around the world, it was determined that these changes, have more negative impact on both the people and the economy. Some of the disasters that have happened in the last few months on the territory of Serbia and region, which are caused by climate change, are: floods in Serbia (June 2013, April/May/Jun/July 2014) and region, the team snow drifts in Vojvodina (February 2014), fires caused by thunderstorms and wildfires (Serbia, Croatia, Greece, Russia, etc.).

These data clearly indicate that it is necessary to develop a system for defining evacuation / safe way in case of natural disasters and accidents.

The system described in this paper consists of quadcopter equipped with cameras to capture different terrain (land or water), and a processing unit for processing the recorded state, which is placed on the vehicle / vessel or used as a handheld device.

This system can be used in different kind of applications for example in: advertisements when taking pictures of sightseeing (tourism), buildings, etc., scenes in movies, performances and air shows with lights, fireworks, aerobatics, etc., industrial applications for lifting tools and materials, diagnostics (observation of inaccessible places), finding missing persons, etc.

2. DESIGN OF QUADCOPTER

Quadcopter is a kind of unmanned aerial vehicle (UAV). UAV can generally be defined as a device used or intended to be used for flight in the air that has no on-board pilot [2].These devices are sometimes referred to as drones, which are programmed for autonomous flight, and remotely piloted vehicles (RPVs), which are flown remotely by a ground control operator [3].This fact in many cases can result in high maintenance and deployment costs particularly speaking in the industrial domain applications. Some applications implement an autonomous flight mode, however the autonomy here is intended as a simple path planning through several given points.

Quadcopter can be used in applications such as aerial recognition, search-and-rescue, industrial monitoring missions among others. For instance, the Predator and Reaper, two drone built by General Atomics, which were used by the United States Air Force to recognition and combat over several countries [4]. A more pacific application of UAVs is monitoring agriculture as done by the company AGX Tecnologias that developed several configuration of aerial vehicle to map different varieties of plantations [5].

Dimensions of quadcopters can vary from the size of an insect to a size of a professional aerial vehicle. Dimensions differ according to the type of application in which this UAV are going to be implemented and the equipment they are taking. For example in application where there is a need for detecting toxic substances in the air, quadcopter needs to be equipped with sensors (in most cases they are light) so the quadcopter can be small. In military applications, where the quadcopter needs to be equipped with camera, sensors, and sometimes weapons, quadcopter needs to be much larger.

Camera and adequate software can be used to provide imaging-based automatic inspection and analysis for such applications as automatic inspection, process control, and robot guidance in industry [6]. A quadcopter is a multirotor UAV that is lifted and propelled by four rotors. Quadcopters are classified as rotorcraft, as opposed to fixed-wing aircraft, because their lift is generated by a set of rotors (vertically oriented propellers). One of applications is in Amazon.com Inc., the world's largest online retailer. They announced their Prime Air service which is a new shipment system where a multi-rotor delivers packages to customers [7].

A quadcopter uses four propellers for trust and has them configured in either a cross or plus format. The quadcopter robot can take off and land vertically which is a big advantage as it lowers the requirements for alanding platform. Also, it allows the quadcopter to hover in place with considerable stability.

Hover stability prevents the quadcopter from crashing in the event of strong wind or due to its weight. Fig. 1 shows the six degrees of freedom of the quadcopter. In Fig. 1(a) (birds eye view), x and y represents the translational motion along the x- and y-axes respectively and ψ represents yaw, the rotational motion about the z-axis, while in Fig. 1(b) (frontal view), θ represents roll, the rotational motion about the x-axis,ϕ represents pitch, the rotational motion about the y-axis and z represents the translational motion in the direction per pendicular to ground. The label '1' signifies the front propeller [8].

With a hover control unit, the quadcopter can hover at a constant height z (see Fig. 1(b)), with its roll and pitch angles stabilised by the gyroscope. The person at the command base will only need to control the quadcopter's motion along the x- and y-axes and also its rotation about the z-axis (to turn corners), reducing the degree of complexity from six to only three.

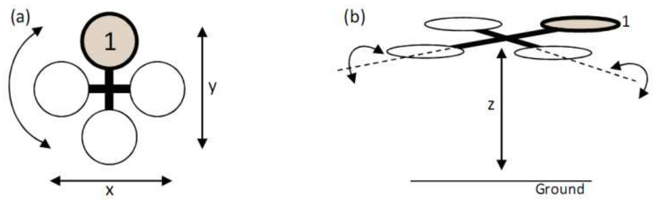

Figure 1. The six degrees of freedom of the quadcopter [8]

2.1 Quadcopter model

Quadcopters use 2 sets of identical fixed pitched propellers; 2 clockwise (CW) and 2 counter-clockwise (CCW). These use variation of RPM to control lift and torque. Control of vehicle motion is achieved by altering the rotation rate of one or more rotor discs, thereby changing its torque load and thrust/lift characteristics.

The front and the rear propellers rotate counter-clockwise, while the left and the right ones turn clockwise. This configuration of opposite pairs directions re-moves the need for a tail rotor (needed instead in the standard helicopter structure). Fig. 2 shows the structure model in hovering condition, where all the propellers have the same speed [9].

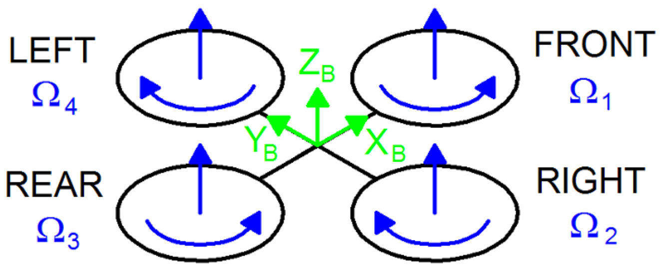

Figure 2. The quadcopter structure model in hovering condition [9]

In Fig.2 a fixed-body B-frame of quadcopter is shown (X_B, Y_B, Z_B). Also the angular speed of the propellers is represented. In addition to the name of the velocity variable, for each propeller, two arrows are drawn: the curved one represents the direction of rotation, the other one represents the velocity. This last vector always points upwards hence it doesn't follow the right hand rule (for clockwise rotation) because it also models a vertical thrust and it would be confusing to have two speed vectors pointing upwards and the other two pointing downwards. All four propellers rotate at the same speed which is represented as Ω [rad s^{-1}] to counterbalance the acceleration due to gravity [9].

Even though the quadcopter has 6 DOF, it is equipped just with four propellers. Thanks to its structure, four best controllable variables can be chosen related to the four basic movements which allow the quadcoper to reach a certain height and attitude. It follows the description of these basic movements:

- Throttle (U_1 [N]) - increasing (or decreasing) all the propeller speeds by the same amount. It leads to a vertical force which raises or lowers the quadcopter. If the quadcopter is in horizontal position, the vertical direction of the inertial frame coincide. Otherwise the provided thrust generates both vertical and horizontal accelerations in the inertial frame.
- Roll (U_2 [N m]) - increasing (or decreasing) the left propeller speed and by decreasing (or increasing) the right one. It leads to a torque with respect to the X_B axis (Fig. 2) which makes the quadcopter turn. The overall vertical thrust is the same as in hovering, hence this leads only to a roll angle acceleration (in first approximation).
- Pitch (U_3 [N m]) - similar to the roll and is provided by increasing (or decreasing) the rear propeller speed and by decreasing (or increasing) the front one. It leads to a torque with respect to the Y_B axis (Fig. 2) which makes the quadcopter turn. The overall vertical thrust is the same as in hovering, hence this leads only to a pitch angle acceleration (in first approximation).
- Yaw (U_4 [N m]) - increasing (or decreasing) the front-rear propellers' speed and by decreasing (or increasing) that of the left-right couple. It leads to a torque with respect to the Z_B axis (Fig. 2) which makes the quadcopter turn. The yaw movement is generated thanks to the fact that the left-right propellers rotate clockwise while the front-rear ones rotate counter clockwise. When the overall torque is unbalanced, the quadcopter turns on itself around Z_B. The total vertical thrust is the same as in hovering, hence this leads only to a yaw angle acceleration (in first approximation) [9].

2.2 **Control algorithms**

The PID (Proportional-Integral-Derivative) control algorithm has been considered and implemented in literature to control the hover altitude of the quadcopter [10], [11]. PID control is a type of linear control that is widely used in the robotics and automation industry [12]. The PID algorithm is popularly used mainly because [13]:

- It has a simple structure
- It provides good performance
- It can be tuned even if the specific model of the controlled plant or system is not available

A PID controller functions by calculating the error, or difference between a measured output and a desired setpoint and adjusts the system control inputs such that the calculated error is minimised. The PID algorithm consists mainly of three control parameters, P – Proportional, I – Integral and D – Derivative. The mathematical expression of the discrete-time PID algorithm is given in (1). P determines the reaction to the current error, I determines the reaction based on a sum of recent errors while D responds to the rate at which the error has been changing.
Calculation of the control input by control algorithms such as PID control may return a control input gain which may be too high for the quadcopter system. This results in a large control input magnitude which may be out of the limits recognisable by the system. To solve this problem, the linear quadratic regulation (LQR) method can be employed. LQR is a form of linear optimal control regulation which aims to reduce the magnitude of the control input without affecting the performance of the control algorithm [14]. The LQR algorithm is used to obtain the parameter settings that will minimise the undesired deviations (in this research, altitude) while at the same time limiting the energy expended by the control action by using a mathematical algorithm that minimises a cost function or performance index with weighting factors. The cost function or performance index refers to the sum of deviations of measured values from its desired values [14]. For a discrete-time LQR, the performance index is defined as (1). By adjusting the weight parameters Q and R, the optimal control sequence that minimises the performance index is given by (2) [8].

$$J = \sum_{k=0}^{N} (x_k^T Q x_k + u_k^T R u_k) \tag{1}$$

$$u_k = -F_k x_{k-1} \tag{2}$$

The steps involved in the empirical methodology to obtain control parameters are shown in Fig. 3.

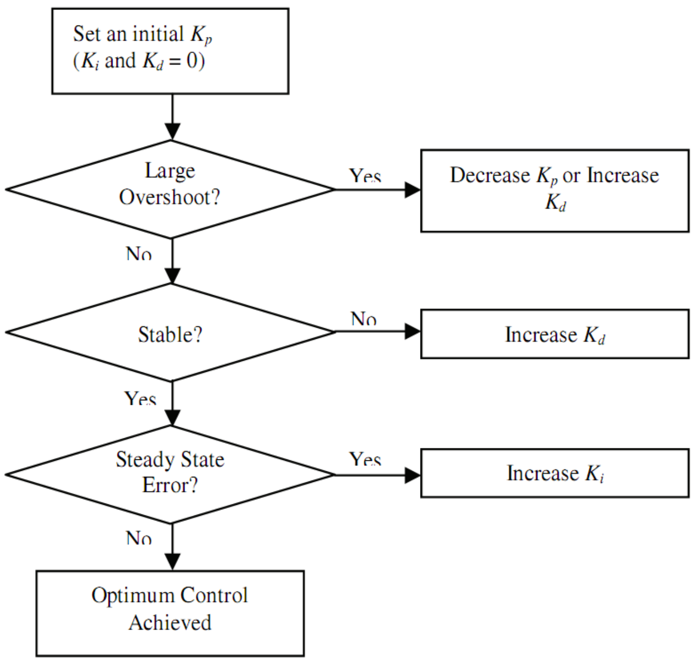

Figure 3. Steps in empirical methodology

Different approaches have been developed for formation of flight control. Linear formation flight controller has been discussed in [15], [16].
The advantage of the linear control is that it is intuitive and easy to synthesize, but it cannot handle the constraints directly and may not be valid for large operation range since it is designed around a fixed operating point.

Some researchers addressed the nonlinear formation flight control problem by using feedback linearization [17] and adaptive control [18], [19]. Although these nonlinear control methods can deal with the unmodelled dynamics, they cannot handle the constraints directly and the implementation of such controller may result in ill-defined control inputs.

3. HARDWARE COMPONENTS OF QUADCOPTER

Each quadcopter can have a very different hardware component which mostly depends on application in which it will be implemented. Standard components are: microcontroller, sensors, motors, Global Positioning System (GPS) power supply and telemetry devices. Fig. 4. is representing a primer of block- diagram of quadcopter.

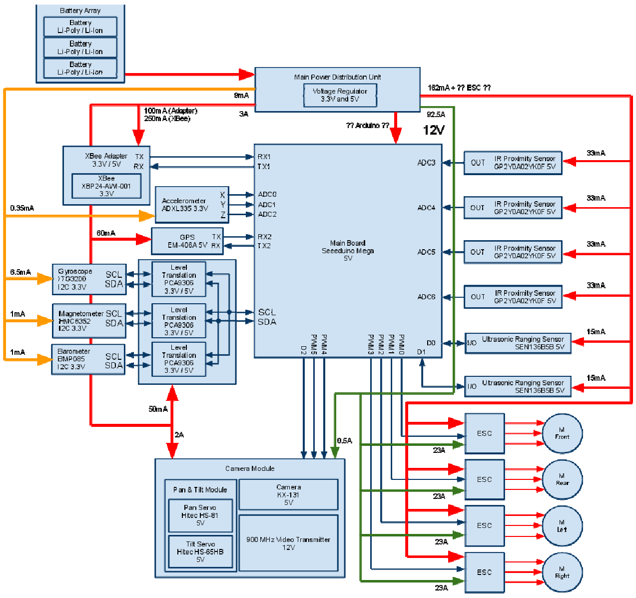

Figure 4. Quadcopter block diagram [20]

Basic component of each quadcopter is frame. The arms and centre plate of the quadcopter frame is in most cases are made of carbon fiber. Connections between the centre plates and arms, as well as the motor mounts can be made of aluminium. The modular integration of the frame allows components to be replaced easily if necessary. The frame, illustrated in Fig. 5, is 485 cm long from motor to motor and weighs approximately 450 g. The propulsion system is mounted directly onto this frame.

Figure 5. Empty frame of the quadcopter platform [21]

Another important part of quadcopter is propulsion unit. The propulsion unit for the quadrotor consists of four brushless DC motors and four electronic speed controllers. The power source for the system can be cell lithium polymer battery. Propellers mounted on the motors must be several cm lengths and have a fixed pitch angle. This propulsion configuration allows safe operations of the frame and ensures excellent lift and thrust performance for all of the flight.

Beside microprocessor and inertial measurement unit with accelerometers, magnetometer and gyroscopes there is a need for external sensors.

In most cases, as external sensor, infra-red sensors and ultrasonic sensor can be used. They can be used for the collision avoidance schemes and for altitude control. GPS modul is another type of equipment which is mandatory for navigation purposes.

In Fig. 6. and Fig. 7. a primer of the quadcopter with all necessary components is represented.

Figure 6. Integrated quadcopter [21]

Figure 7. Integrated quadcopter with camera [22]

4. APPLICATIONS OF QUADCOPTER

Quadcopters have been used, are being used or are actively being considered for different applications all over the world. They have range of potential environmental or commercial applications (emergency response, pollution detection, crop spraying, etc.). Also, they can be deployed in surveillance applications against civilians, such as applications in policing and border surveillance. Some police departments in

Europe and North America have been using quadcopters since 2006. At least five police forces in the UK (Essex, Merseyside, Staffordshire, Derbyshire and the British Transport police) have purchased or used micro-quadcopters. The range of potential applications is clear to police forces, where, for example, the South Coast Partnership between Kent Police and five other police forces in the UK is seeking to introduce drones (quadcopters) ‘into the routine work of the police, border authorities and other government agencies’ across the UK [23].

Police forces use quadcopters to monitor large crowds, prevent or detect crime and assist in incident responses. UK police have used quadcopters to monitor festivals, to monitor protests and to monitor the Olympic ceremony. In 2007, quadcopters were reported over political rallies in New York and Washington, DC. The CannaChopper has been deployed in the Netherlands and Switzerland against cannabis smokers, football fans at the European football championship in 2008 and “troublemakers” at the NATO summit in 2009. India has also recently begun using quadcopters to help secure sensitive sites and events [24].

A North Carolina county is using quadcopters with infrared cameras to monitor gatherings of motorcycle riders and to detect marijuana fields. In this deployment, the quadcopters flies a few hundred feet in the air, which is close enough to identify faces. Six police departments in Canada are using quadcopters in populated areas to record crime scenes and Canadian police are responsible for the first photographs taken by a quadcopters being admitted as evidence in court after the local police force used a quadcopters to photograph a homicide scene in 2007 [25].

Quadcopters may also be used to assist police in incident response. Merseyside police are credited with the first UK arrest using a quadcopter, where a car thief was tracked through undergrowth by the quadcopter’s thermal imaging camera. Once the teenage suspect’s location was detected by the AirRobot flying at 150 feet (45.7 m), the information was relayed to ground forces who arrested the youth. In Los Angeles, a sheriff’s department deployed their SkySeer drone to seek missing persons in rural areas, monitor accident or crime scenes and assist police in pursuits [26].

Quadcopters have been used in border surveillance operations in the USA since 2002. The US is one of the most well documented users of UASs in this capacity along the US/Mexico border and the US/Canada border. In 2002, a US Marine operated Pioneer quadcopter intercepted people who were attempting to smuggle 45 kg of marijuana from Canada into the US [27].

In 2005, Predator quadcopter along Arizona’s border with Mexico were integrated into a surveillance system that included seismic sensors, infrared cameras and laser illuminators. If the seismic sensor is triggered by drug smugglers, the Predator can investigate and, upon finding drug smugglers, tag them with its laser illuminator. With the GPS coordinates and the infrared illuminator, agents have no difficulty intercepting the smugglers [23].

5. CONCLUSION

Quadcopter is a special kind of vehicle, which can be implemented in different applications. In this paper basic principles of quadcopter design as well as current applications are represented. In the future applications, quadcopter could be used for a variety of new policing functions. Quadcopter could be used for safety inspections, perimeter patrols around prisons and thermal imaging to check for cannabis being grown in roof lofts and other not easy to access locations. The police could use them to capture number plates of speeding drivers, for detecting theft from cash machines, railway monitoring, combat fly-posting, fly-tipping, abandoned vehicles, waste management.

Future research will be in field of search and rescue. In future an effort will be directed to development of a system for defining evacuation/safe path in case of natural disasters and accidents. The system will consists of quadcopter which is equipped with a camera to capture different terrain (land or water) and a processing unit for processing the recorded condition which is placed on the vehicle/vessel or in form of handheld device. In addition to the situations of natural disasters and accidents it is possible to use this system in cases of climatic changes that affect the safety and health of the population, or in cases where it is endangering the functionality of different economic systems.

6. REFERENCES

[1] America's Climate Choices: Panel on Advancing the Science of Climate Change; National Research Council (2010). Advancing the Science of Climate Change. Washington, D.C. The National Academies Press. ISBN 0-309-14588-0.

[2] Aviation Safety Unmanned Aircraft Programme Office, in McBride Paul. Beyond Orwell: the application of unmanned aircraft systems in domestic surveillance operations (2009). Journal of Air Law and Commerce Summer Vol. 74, No. 3, pp. 627-628.

[3] Bolkcom, C. (2004), Homeland security: unmanned aerial vehicles and border surveillance. Congressional research service reportfor Congress.

[4] U.S. Air force (2010), “MQ-9 Reaper”, available at: http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104470/mq-9-reaper.aspx (accessed: 15 August 2014).

[5] http://www.agx.com.br/n2/pages/index.php, (accessed: 15 August 2014).

[6] Herakovic, N., Simic, M., Trdic, F. and Skvarc, J.(2011), “A machine-vision system for automated quality control of welded rings,” Machine vision and applications, vol. 22, no. 6, str. 967-981, doi: 10.1007/s00138-010-0293-9.

[7] http://www.amazon.com/b?node=8037720011, (accessed: 15 August 2014).

[8] Meng Leong, B.T., Low, S.M. and Po-LeenOoi, M. (2012), “Low-Cost Microcontroller-based Hover Control Design of a Quadcopter”, Procedia Engineering, Vol. 41, pp. 458 – 464

[9] Bresciani, T. (2008), “Modeling, Identification and Control of a Quadrotor Helicopter”, master’s thesis, Department of Automatic Control, Lund University, Sweden.

[10] Erginer, B. and Altug, E. (2007), "Modeling and PD Control of a Quadrotor VTOL Vehicle," IEEE Intelligent Vehicles Symposium, pp.894-899.

[11] Tayebi, A. and McGilvray, S. (2006), "Attitude stabilization of a VTOL quadrotor aircraft," IEEE Transactions on Control Systems Technology, vol.14, no.3, pp. 562- 571.

[12] Nonami, K., Kendoul, F., Suzuki, S., Wang, W. and Nakazawa, D. (2010), “Autonomous Flying Robots – Unmanned Aerial Vehicles and Micro Aerial Vehicles”, Tokyo: Springer, pp.48-52.

[13] Heong Ang, K., Chong, G. and Yun Li (2005), "PID control system analysis, design, and technology," IEEE Transactions on Control Systems Technology, vol.13, no.4, pp. 559- 576.
[14] Prasad, L.B., Tyagi, B. and Gupta, H.O. (2011), "Optimal control of nonlinear inverted pendulum dynamical system with disturbance input using PID controller & LQR," 2011 IEEE International Conference on Control System, Computing and Engineering (ICCSCE), pp.540-545.
[15] Pachter, M., D'Azzo., JJ. and Dargan JL, (2001),"Tight Formation Flight Control", Journal of Guidance, Control, and Dynamics, Vol. 24, No. 2, pp. 246-254.
[16] Hall, J., (2000), "Three Dimensional Formation Flight Control", (Master thesis), Air Force Inst of Tech Wright-Pattersonafb, OH.
[17] Boskovic, J. (2002), "Formation flight control design in the presence of unknown leader commands, in: American Control Conference, Woburn, MA, USA, pp. 2854–2859.
[18] Ganji, F., Joshi, S.S. and Bayard, D.S. (2006) "Adaptive Formation Control for Rovers Traveling over Unknown Terrains", Journal of Guidance, Control, and Dynamics, Vol. 29, No. 3, pp. 714-724.
[19] Singh, S.N., Chandler, P., Schumacher, C., Banda, S. and Pachter, M. (2000), "Nonlinear Adaptive Close Formation Control of Unmanned Aerial Vehicles", Dynamics and Control, Vol. 10, No. 2, pp. 179-194.
[20] Arturo Cabral Mejía, R, (2010), "Quadcopter Project" available at: http://blog.ricardoarturocabral.com/2010/09/quadcopter-project.html (accessed: 25 August 2014).
[21] Chee, K.Y. and Zhong, Z.W. (2013), "Control, navigation and collision avoidance for an unmanned aerial vehicle", Sensors and Actuators A, Vol. 190, pp. 66– 76
[22] Quadcopter-The Unmanned Aerial Vehicle (2014) available at: http://aermech.com/quadcopter-unmanned-aerial-vehicle/ (accessed: 29 August 2014).
[23] Finn, R. L. and Wright, D. (2012), "Unmanned aircraft systems: Surveillance, ethics and privacy in civil applications", Computer Law & Security Review, Vol. 28, No. 2, pp. 184–194.
[24] Deccan Herald, (2010) IANS [Indo-Asian News Service]. Tirupati temple may get UAV surveillance. available at: http://www.deccanherald.com/content/105844/tirupati-temple-may-get-uav.html. (accessed: 29 August 2014).
[25] Homeland Security News Wire (2011), Canadian police push limits of civilian UAV laws. available at: http://homelandsecuritynewswire.com/canadian-police-push-limits-civilian-uavs-laws. (accessed: 30 August 2014).
[26] Lawrence Mark (2008), Setting matters straight. AirRobot UK News, available at: http://www.airrobot-uk.com/air-robot-news.htm. (accessed: 30 August 2014).
[27] Sia Richard (2002), Agencies see homeland security role for surveillance drones. Congress Daily, available at: http://www.govexec.com/dailyfed/1202/121202sia.htm. (accessed: 31 August 2014).

Projektovanje, upravljanje i primena kvadkoptera

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Apstrakt:

Kvadkopter je bezpilotna vazdušna letelica koja može da se implementira u različitim primenama. U radu će biti predstavljen razvoj kvadkopter sistema i moguće primene u kojoj može da se implementira. Biće predstavljeni i razmatrani konstrukcijski model kvadkoptera, osnovne komponente sa blok dijagramom, stabilnost lebdenja, dimenzije i opis osnovnih pokreta. Takođe će biti predstavljeni i kontrolni algoritmi sa koracima empirijske metodologije. Sadašnja civilna i vojna primena biće istražena, a buduće primene biće predložene.

Ključne reči: *kvadkopter, dizajn, primena, kontrola*