International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 17 (2017) pp. 6399-6404

Sensoric and Motion System of Quadrocopter

Miroslav Marcanik, Michal Sustek and Roman Jasek

Tomas Bata University in Zlín, Faculty of Applied Informatics,
Nad Stránemi 4511, 760 05, Zlín, Czech Republic.

[1]*Orcid: 0000-0002-1212-3177 & Scopus Author ID: 57190749060*

Abstract

Robotics has rising in past few years. This article is focused on the basic description of sensoric and movement system on Quadrocopters. Each part is focused on usage and motors construction in sensoric systems. Secondary part is focused on explanation of used technologies and their specification. This article focuses on understanding the sensor construction with their pros and cons. Finally this article serves complete overview about sensoric system structure.

Keywords: 3D sensors; sensors; accelerometers, MEMS.

INTRODUCTION

Since the takeover of the first machine which was heavier than air passed more than one hundred years. The development in this field is still fast and actual. The first of these machines (aircraft) were designed for rapid transport (one or two person crew) between cities. The aircrafts found purpose also in military. During the second half of the 20th century, the development of Unmanned Aerial Vehicles (UAV) began [1].

Recently we can meet with small remotely controlled flying devices, which are called drones. These drones are important in monitoring of surface by integrated camera. That leads to using of these drones in equipment of Police and Firefighters, even TV companies. A typical representative is quadcopter. It is machine which contains of four propellers, which are placed on the tops of the imaginary square. Each of propellers have independent power source with its own motor. Maneuverability of quadcopter is caused by different pull of each motor. Accelerometers and gyroscopes, eventually Global Positioning System (GPS), determine the position. The most used motors in construction of quadcopter are Brushless Direct Current Motors (BLDC), which are known as Electronically Commutated Motor (ECM) [2][3].

Section 1 is focused on drive units of quadcopter. These units are BLDC motors. In this section are described construction and controlling of motors by sensors, which are described later. Sections 3 and 4 describes two main types of sensors for orientation in the space and basic principles of sensors. Sections 5 and 6 show basic principles of MEMS (Micro-Electro-Mechanical Systems) technology and GPS. Section 7 provides manual to substitute height sensors by pair of addition sensors for measurement of temperature and pressure.

BLDC MOTORS

BLDC motors are constructed from stator, on which are placed pole extension. Usually are used 8 to 16 extensions. On each pole extension are winded up 3-phase winding which are connected to the star. Rarely are used 2-phase winding, eventually more phase windings which are connected to triangle. The center wire is not usually carried out.

Another integral part of stator are bearing in which the rotor rotates. Rotor contains of strong permanent magnets, which are the same number like pole extensions of stator. Their number determine the step of motor and possible ripple of torque.

Due to absence of mechanical commutator, must be motor commuted electronically. To make it possible, the actual position of rotor must be known. The position can be found by two methods – sensory and non-sensory.

For use sensory is necessary to use sensors (Hall sensor, or less use encoders). Non-sensory method is based to measurement of Back Electromotive Force (BEMF) on free phase of the engine by which the position of motor is estimated. The main advantage of sensory commutation is control in low speed. In this case the non-sensory control is not effective.[4]

Construction can be seen in figure below.

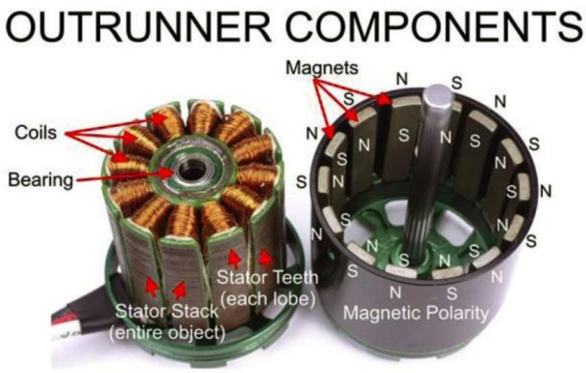

Figure 1: Konstrukce BLDC motoru[4]

A. BLDC engine control options

In many application is necessary to use BLDC motor with sensors of position. Typical applications are precise servomotors and low speed motors. It is possible to achieve a faster dynamic of engine by using of sensors. The particular sensor is usually integrated in engine. The most common sensors are Hall sensors and absolute encoders (optical and magnetic).[2]

1) Hall sensors

The Hall sensors are the most common position sensors, which are used for BLDC motors. They are placed on the edge of stator in 60° electrical intervals. Output of each sensor is binary information which is describe by polarity of magnet in their proximity. If are used 3 Hall sensors, there are 8 states, but only 6 of them can occur. Rarely are used Hall sensors with analog output. In this case, the output signal is in sinus or cosines function [2]

2) Absolute encoder

Another possible type of sensor is an absolute magnetic encoder. It is usually integrated into one integrated circuit with evaluation circuits. Circuit case are installed to the unloaded side of the shaft. The output is analog or usually 24 digital with resolution 8 to 14 bits. The main advantages are simple installation and low price. [2]

3) Non-sensory control

The principle of non-sensory control is similar to principles of sensory control with some differences. The main difference is that, the information about position of rotor is not available, but it must be estimated indirect; usually by measurement of value on motor's phases. The using value is BEMF. Rarely it can be used application which used measurement of inductance of winding. [2]

ACCELOROMETERS

Accelerometers are sensors for measurement of static and dynamic acceleration, which are appropriate for measurement of centrifugal, inertial forces and for determination of position of body, its inclination and vibration. The most known application of accelerometers is in automobile industry and UAV devices. In this section will be described structure and principles of piezoelectric accelerometers. This type is suitable for measurement of seismic activity, acceleration and vibration.

Accelerometers measure acceleration, in other words they transform acceleration to measurable electrical signal.

A. Piezoelectric accelerometer(PE)

PE used piezoelectric crystal (natural or ceramic), which generate charge proportional to the applied force, which with acceleration affect to all objects. One side of piezoelectric material is attached to fixed grip on base of sensor. So called seismic mass is connected to other side. When the accelerometer is subject to vibration, it generates force, which effect to the piezoelectric material (one can see in figure 2.) Consistent with the Newton's laws it is this force equal to the force, which is induced by acceleration of seismic mass. Thanks to the piezoelectric effect is the output charge proportional to outer force. When the seismic mass is constant, the charge of the output signal is proportional to the acceleration of the mass. [6]

$$F = m * a \quad [N] \tag{1}$$

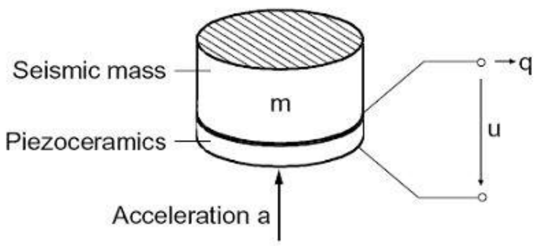

Figure 2: Principle of piezoelectric accelerometer [5]

B. Piezoresistive accelerometers (PR)

The basis of piezoresistive accelerometer (tensometric) is piezoresistive material, which due to material deformation change its electrical resistance. This is mainly the bend according to Hook's law (reversible destruction lasting for an external force and proportional to that force). Unlike piezoelectric accelerometer, the piezoresistive accelerometer is able to measure constant acceleration and its work frequency range is 0 to 13 kHz. Its main disadvantage is strong thermal dependence. It can be compensated by using of two tensometers in bridge connection. That leads to sensibility growth. [6]

$$R = \rho * \frac{1}{S} \quad [\Omega] \tag{2}$$

The principle can be seen in figure 3. It is based on using of movement/bend one of console beam from piezoresistive silicon material by influence of acceleration. The bend changes resistence, which is measured (2).

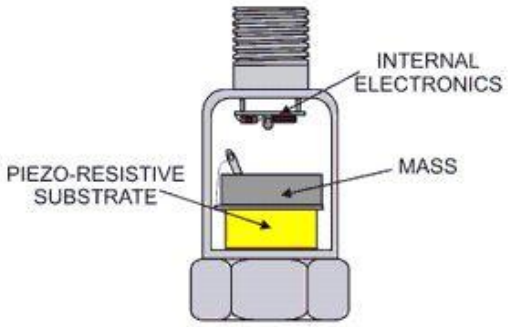

Figure 3: Principle of PR accelerometer [5]

C. Accelerometer with change capacity (VC)

Capacity accelemoter using a change of capacity according to accelerating action by change of distance of plate capacitors. As can be seen in equitation (3). It uses differential connection of capacitors, when they both have shared electrode, which is simultaneously movable and the other two are fixed (as one can see on figure 4). This principle is common in MEMS accelerometer.

$$C = \varepsilon_0 * \varepsilon_r * \frac{S}{d} \quad [F] \tag{3}$$

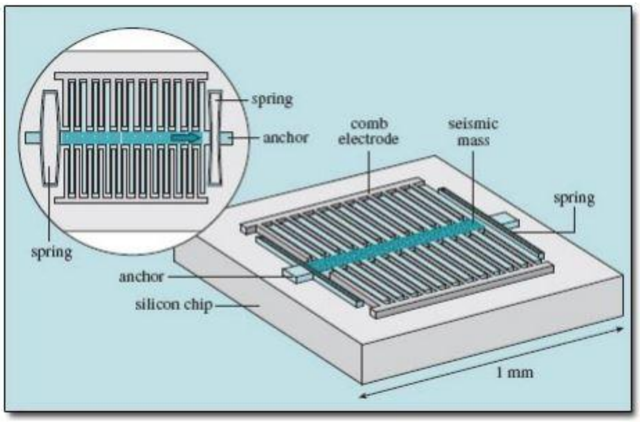

Figure 4: MEMS capacity accelerometer [5]

D. Thermal accelerometers (MEMSIC)

Thermal accelerometers use basic a physical principle, which is used in similar version in calorimetric flowmeters. It involves the transfer of heat in the gas and sensing the temperature distribution around the heat source. Heater Bar heats up air (Heated Air) in Air Cavity on constant temperature. Temperature distribution, which is depend on distance from heated bar, is measured on temperature sensors. They are realized by a system of thermocouples (made from aluminum/poly-crystalic silicon) which are placed in regular intervals. The whole system is implemented in etched trench of silicon substrate. The sensor, including the evaluation electronics, is full integrated on one CMOS sensor. [6]

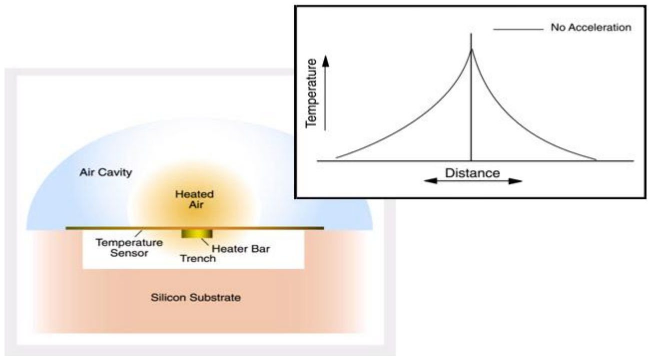

Figure 5: Idle state of thermal accelerometer [5]

GYROSCOPE

Gyroscope is a device with which is possible to measure of angular speed of rotational movement. It is a reason of using the sensor in application, where it can not rely on reach of the signal (for instance GPS or the geomagnetic field is degraded).[6]

Angular speed is physical vector variable. Its vector is perpendicular to the plane of the circle through which the material point moves by the velocity v, and place it in the center of the circle. To determine its direction is used the rule of the right hand: If we put our fingers to the circle so that the fingers point in the direction of the velocity vector v, then the raised thumb indicates the direction of the vector of angular velocity ω. The calculation of the tilt angle itself is simply the integration of the angular velocity according to the equation (4).

$$\varphi(t) = \varphi_0 + \int_0^t \omega(t)\, dt \tag{4}$$

$\phi(t)$ – measured course of tilt angle

ϕ_0 – initial angle

$\omega(t)$ – course of angular velocity

A. Rotary gyroscope

The rotary gyroscope is based on a rotating flywheel. As a flywheel is used a massive disk constructed that its momentum is as high as possible. The axis of the flywheel, which is also its axis of rotation, is often fastened in the Cardan hinges, which are connected in three mutually perpendicular axes, giving the whole structure three degrees of freedom. The rotating flywheel retains the same direction of the rotation axis until the force exerted on it deviates from this equilibrium. [6] This is given by Newton's Inertia Law (5).

$$T = I * \omega * \Omega \qquad (5)$$

T - moment of a force acting around the input axis

I - inertia of the gyroscope

ω – angular velocity of the flywheel around the rotary axis

Ω – angular velocity of the rotational axis circular around the output axis

B. *Vibration gyroscope*

Vibration gyroscopes eliminate the disadvantage of precise and sized parts of rotary gyroscope, which are not appropriately to use on commercial use. In vibration gyroscopes are flywheels substitute by periodically maintained vibration of the seismic matter of exactly known. That leads to smaller size of sensors and oscillating elements can be manufactured also by MEMS technology. [6]

The whole principle of vibration gyroscope is based on scanning of Coriolis forces, which have effect on each A material object or object that moves at a velocity in a system rotating about an axis of rotation at an angular velocity ω. The value and direction of Coriolis force is expressed by vector product of velocity and angular velocity according to equitation (6).

$$F_c = 2 * m * v * \omega \quad [N] \qquad (6)$$

F_C – Coriolis force

m – mass of seismic mass

v – velocity of movement of seismic mass

ω – angular velocity of the sensor around the measured axis

C. *Integrated MEMS gyroscopes*

Gyroscopes are designed to measure of angular velocity (ie., an indication of how quickly the measured object rotates, in degrees / second). The rotation is possible to measure with a respect to one of the three axes (x,y,z). Integrated gyroscopes, manufactured by different manufacturers as integrated MEMS circuits operating on the principle of Coriolis power.[6][8]

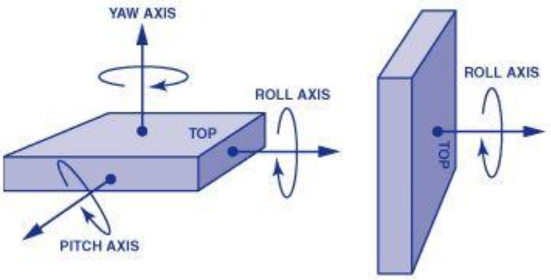

Figure 6: Principle of MEMS gyroscopes [5]

D. *Optical fiber gyroscope*

Optical gyroscopes are used to find out the angular velocity and rotation of the optical radiation properties The gyroscope works on the principle of Sagnac interferometer, which runs the laser bundles against each other on the same optical path (apart from the small transverse displacement caused by the thickness of the divider). When the interferometer path encompassing the interface path is rotated at a certain speed, the velocity of propagation of the bundles in the direction and in the opposite direction of rotation is due to relativistic velocity folding. The result is a detectable phase shift φ at the output of the interferometer. [8] In an optical fiber gyroscope, the optical path of the Sagnac interferometer is realized by optically coil-shaped coil. If an optical fiber optic gyroscope is rotated at an angle ω, the following applies (7):

$$\varphi = \frac{4\pi L r}{c\lambda}\omega \qquad (7)$$

where L is the total length of the coiled fiber, r is the radius of the coil, c is the velocity of the light in the vacuum, and λ is the wavelength of the laser radiation.[7]

MEMS TECHNOLOGY

While separate microelectronic systems are already common in the form of integrated circuits, the micromechanical systems have only begun to be used not long ago. MEMS is integration of mechanical elements, sensors, actuators, control and evaluation electronic on one silicon substrate by different manufactures technology. Electronic parts are manufactured by CMOS technology, Bipolar or BiCMOS. Micromechanical parts are manufactured by technology of selective etching or implementation of others layers. Future of MEMS component is to achieve a fully monolithic integration of MEMS with control electronics and signal processing circuits on a CMOS substrate. This solution leads to minimize and reduction of production costs by reducing a number of production steps. Using of MEMS technology allows to create small to almost microscopic systems which are composed of a transducer of a measured magnitude electrical circuits for processing the signal, communication interface and actuator. The actuator perform feedback of the system according to the measured values. [8]

Advantages:

- miniaturization
- energy efficient
- higher resistance to mechanical stress
- compact
- manufacturing low costs

Disadvantages:

- inability to repair
- expensive production in small quantities

GPS

GPS receiver is usually used in autonomous systems, which is needed to navigate without interaction with operator. Although it does not provide position information with centimeter accuracy, the measurement deviation does not increase with time. The processes taking place in each GPS receiver are characterized as determining the radius location that is intended for the intersections of spherical surfaces. The measured value is the spread of the radio signal from the satellite to the GPS receiver. Speed of transmission of signal is equal to speed of light. Each satellite in navigation administration send navigation data and ephermis information about its position. If the position of the satellite is known, the location of user can be determine. The position is determined from three equations with three unknowns. The main measurement problem is the time elapsing between transmitting a remote signal from the GPS satellite and receiving it with a user-defined GPS receiver. User GPS device generate copy of the signal, which was send from the satellite. This copy is synchronized with received signal and it measure time shift from the beginning of the copy in relation to the origin determined by its own clock. The time measurement can be recalculated to Di - pseudodistance.[2]

BAROMETER

Barometer is a sensor, which is used for measurement of atmospheric pressure. This type of sensor is not essential for control of quadcopter. However, atmospheric pressure information can be used to calculate the height at which the sensor is located. Atmospheric pressure is not depend only on height, but also on temperature. Sensor should has a thermometer for possibility of error correction according to the actual temperature. With such a barometric altimeter, it is possible to achieve a relatively good accuracy of 1 m. This kind of information is not sufficient for height fixation, it must be used range-finder. But range-finder has its limitations.[9]

CONCLUSION

As existing and constantly evolving other intelligent electronic devices that require contactless measurement of position, speed and motion detection or acceleration, the range of integrated accelerometers and gyroscopes is growing. These sensors are crucial for robots, navigation, gaming consoles, cameras and cameras, some mobile phones, and mainly aircraft, cars and boats. We can also find them in better washing machines, dryers and other white machines and devices where something is rotating, moving or vibrating.

The paper is focused on elementary insight into issue of sensory system, which are used in quadcopters and other devices.

A summary of the previous information suggests that expanding these sensors and technologies in general over time will be much more necessary than people previously thought. The use of these technologies should facilitate or mitigate the involvement of people in dangerous situations.

ACKNOWLEDGMENT

With support by grant No. IGA/FAI/2017/04 from IGA (Internal Grant Agency) of Thomas Bata University in Zlín.

REFERENCES

[1] Aerobot. Quadrocopter, Hexacopter, Octocopter, Unmanned Aerial Vehicles, UAVs, Drones, Cinestar, Mikrokopter [online]. 2017 [retrieved 2017-15-06]. Available from: http://www.aerobot.com.au/.

[2] Electric Motor Control Dc, Ac, and Bldc Motors. Elsevier Science Ltd, 2017. [retrieved 2017-15-06].

[3] Bhatta, B. Global navigation satellite systems: insights into GPS, GLONASS, Galileo, Compass, and others. Hyderabad, India: BS Publications, 2011. [retrieved 2017-15-06].

[4] Bldc motor controlling using arduino [online]. LAWRENCE, Matthew. 2015 [retrieved 2017-15-06]. Available from: https://lawrencematthew.wordpress.com/my-posts/bldc-motor-controlling-usingarduino/

[5] Automatizace.HW.cz. Elektronické výškoměry = MEMS barometry [online]. [retrieved 2017-15-06]. Available from: http://www.hw.cz/.

[6] "Sensor Business, Marketing, And Technology Developments: St Microelectronics Spearheads High-Volume Applications For Mems Accelerometers." Sensor Business Digest, November 1, 2003. [retrieved 2017-15-06].

[7] FRADEN, Jacob. Handbook of modern sensors: physics, designs, and applications. 3rd ed. New York: Springer, c2004. ISBN 0387007504. [retrieved 2017-15-06].

[8] VRBOVÁ, Miroslava a kol. Lasery a moderní optika - oborová encyklopedie. 1. vyd. Praha: Prometheus, 1994, 474 s. ISBN 80-858-4956-9. [retrieved 2017-15-06].

[9] Emerging Nanotechnology Power: Nanotechnology R & D And Business Trends In The Asia Pacific Rim. World Scientific, 2009. [retrieved 2017-15-06].

[10] Mechatronics | Introduction: Sensors [online]. 2010 [retrieved 2017-15-06]. Available from:

http://mechmes.websnadno.cz/dokumenty/pri-mn-s-10_senzory_uvod.pdf

[11] Janková, M.; Dvořák, J. The ICT possibilities in the virtual universities cyberspace. In Mathematics, Information Technologies and Applied Sciences 2014 (post-conference proceedings of selected papers extended versions). Brno: MITAV 2014, 2014. s. 59-65. ISBN: 978-80-7231-978- 7

[12] Schroeder, K. Martin, and B. Lorensen, Visualization Toolkit: An Object-Oriented Approach to 3D Graphics, 4th Edition. Kitware, December 2006. [retrieved 2017-15-06].

[13] Cordeiro, Frederick Joaquim Barbosa. Gyroscope. Place of publication not identified: Nabu Press, 2010. Print. [retrieved 2017-15-06].