COMPUTER ENGINEERING

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MICROELECTROMECHANICAL GYROVERTICAL

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Abstract**—***Gyroscopic verticals (gyroverticals) are designed to determine the direction of the true vertical on moving objects. Being one of the devices of the orientation system of a moving object, they are used as sensors for the roll and pitch angles of an aircraft (or sensors of similar angles for other moving objects) and serve to create a platform stabilized in the horizon plane on a moving object. The electrical signals taken from the measuring axes of the device are used in flight, navigation, radar systems, visual indicators, etc. Gyroscopic stabilization systems are widely used as the basis of integrated management systems on aircraft and miniature unmanned aerial vehicles for generating signals proportional to the angular deviations of the aircraft in space in terms of roll and pitch angles and for stabilizing and controlling the position in space of optical equipment. At present, sensors based on the technologies of microelectromechanical systems are widely used in small aircraft. Their important advantage is small weight and size characteristics, and the main disadvantage is low accuracy. Such sensors are used in navigation systems and automatic control systems of aircraft. In particular, algorithms for calculating the orientation angles of an unmanned aerial vehicle are known, using information from microelectromechanical angular velocity sensors. However, due to large drifts, an error accumulates in time and, as a result, the operating time is limited.*

Index Terms—Microelectromechanical system; gyroscope; gyrovertical; spatial position; roll; pitch; yaw.

I. INTRODUCTION

Gyroscopic stabilization systems (GSS) are widely used in information measuring and control systems (IMCS) on aircraft. Gyroscopic stabilization systems in the gyrovertical mode solve the problem of constructing a local vertical on board the aircraft and are used to receive signals proportional to the angular deviations of a moving object along two axes. [1], [2] GSS are used in solving the problems of aerial exploration of minerals, in monitoring the state of thermal, gas and electric main networks, studying sea currents, searching for fish schools, rescuing people in disasters, search and transport operations, and many other tasks. Gyroscopic stabilization systems are also used on aircraft to stabilize and control the position of cameras, television optical devices, thermal imagers and other devices. [3] The use of GSS makes it possible to preserve the potential capabilities of optical instruments in the area of their resolution under conditions of use on a moving base. On aircraft performing combat missions, the GSS are an integral part of the AIMS, which provides sighting of the target and guidance of the controlled aircraft on the target. Most IM&MS [4] are built on the basis of conventional gyroscopes and accelerometers. They are complex devices of precision mechanics, but they have significant power consumption, dimensions, weight and high cost. At present, abroad and in our country, work is underway to develop unmanned and miniature unmanned aerial vehicles (UAVs and MUAVs), as well as aircraft integrated management systems (AIMS) for them. Modern requirements for the GSS of MUAV optical instruments have their own specifics and are mainly reduced to a combination of contradictory characteristics: high angular resolution (provided both by using optical instruments of the appropriate accuracy class and by ensuring high accuracy of stabilization and control of the position of these devices in space under conditions of a movable base) and the minimum weight and overall dimensions of the device. In addition, low power consumption, almost instantaneous availability, low cost, high overload capability, and high reliability must be ensured. The fulfillment of these requirements is a complex and urgent scientific and technical problem that requires its solution. The development of microsystem technology, in particular, the emergence of micromechanical accelerometers (MMA) and gyroscopes (MMG) make it possible to create systems based on them that have a small mass and dimensions. However, in this case, it is necessary to develop special structural, hardware and software solutions that ensure the proper accuracy of the system.

II. PROBLEM STATEMENT

We must solve the following problems:

1) to analyze existing methods for determining the spatial position of the aircraft;

2) to analyze the existing hardware suitable for the implementation of these methods;

3) on the basis of the analysis to choose a method that would allow the calculations of roll, pitch and yaw;

4) to develop software and hardware for the implementation of the selected method;

5) to conduct an experimental study of the developed system.

III. MEASURING THE INCLINATION OF AN OBJECT

Accelerometers that measure linear acceleration can be used to determine tilt. Industrial accelerometers offer advanced functionality and are ideal for ultra-low power applications. They have a low power mode, an auto-wake function and a FIFO buffer that can be used for data storage, which reduces the load on the main processor and reduces the power consumption of the system as a whole. The entire line is equipped with a serial digital interface (SPI and or I2C) and a self-diagnostic function that allows you to check the performance of the sensor in the finished device. Sensors can generate interrupts on wakeup, free fall, and position. The accelerometer is ideal for a static inclinometer where external acceleration is negligible [5]. However, if the object is rotating and experiencing significant external accelerations, additional gyroscope measurements will be required to stabilize the tilt output. For such applications, iNEMO™ 6-axis inertial measurement units (IMUs) are available, which combine an accelerometer, gyroscope and magnetometer in a compact package and can also include a dedicated machine learning engine. Measurement of the angle of inclination by the accelerometer is based on the measurement of the projection of the gravity vector onto the measurement axis. It should be borne in mind that the accelerometer measures not only the acceleration of free fall, but also other parameters: constant acceleration of the device, centripetal acceleration due to the rotation of the device, vibration. These additional accelerations are also projected onto the axes of the accelerometer sensors and cannot be easily separated from the gravitational acceleration, resulting in measurement error [2]. Therefore, to obtain reliable results, it is necessary to carry out measurements only under static or quasi-static conditions. Other applications require the use of dynamic inclinometers and other measurement methods. Under static or quasi-static conditions, three methods can be used to determine the slope, depending on the number of measurement axes. Figures 1, 2, 3 show the calculation of inclinations angles using a 1–3 axis accelerometer

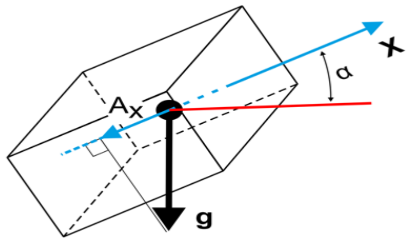

Fig. 1. Rotation of the sensor around one axis (using a single axis accelerometer)

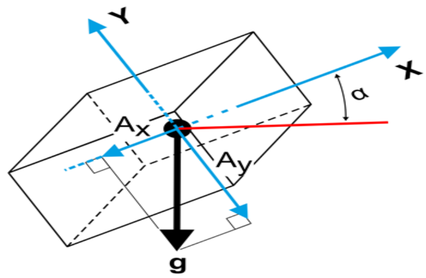

Fig. 2. Measuring the angle of inclination in two axes

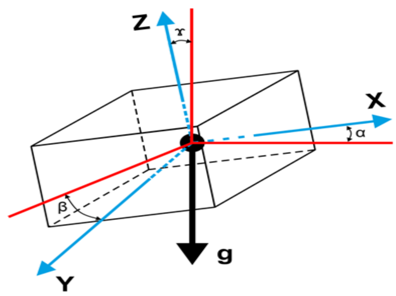

Fig. 3. Using three axes in inclination measurement

When your footing space inclination or the angle changes, the self-balancing stabilizer will maintain balance or maintain a certain angle so that the inclination does not produce adverse results. A slight modification can also be used to output pitch in three directions: pitch, roll and yaw. By processing the raw data received by the microcontroller with a six-axis position sensor, the lean angles in three directions are obtained: pitch, roll and yaw, and then the microcontroller controls the steering angle to achieve a self-balancing effect. The MPU6050

(Fig. 4) is the world's first integrated 6-axis motion processing component.

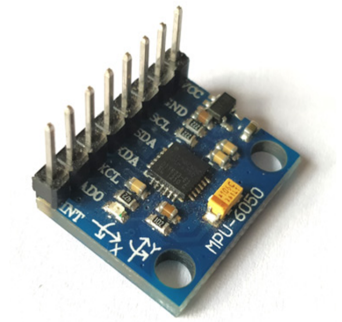

Fig. 4. MPU6050 Module

It integrates a 3-axis gyroscope and a 3-axis accelerator. It solves some of the problems that arise when combining a gyroscope and an accelerator. It also includes a built-in temperature sensor, DMP (Digital Motion Processor). DMP: can directly output the quaternion, reducing the load on complex fusion calculation data, sensor timing, position detection, etc.

IV. Gyrovertical Based on MEMS-sensor

Block-diagram of gyrovertical based on MPU6050 sensor is shown in Fig. 5. Following sensor allows to obtain following values:

- quaternion components [*w*, *x*, *y*, *z*];
- *Euler angles;*
- yaw, pitch, roll;
- real world Acceleration;
- world frame acceleration;
- teapot invent sense values.

It includes MPU6050 gyroscopic sensor that is mounted on printed circuit board with amplifier, ADC and signal processing circuitry. As a result sensor has digital output via I2C interface. Arduino Uno board was used for laboratory prototype to simplify the prototyping process and avoid designing additional PCBs.

The connections are pretty simple. Start by connecting the VCC pin to the 5V output on the Arduino and connect GND to ground. Now we are left with pins that are used for I2C communication.

Please note that each Arduino board has different I2C pins that must be connected accordingly. On Arduino boards with the R3 layout, SDA (data line) and SCL (clock line) are on the headers next to the AREF pin. They are also known as A5 (SCL) and A4 (SDA). The MPU6050 is relatively easy to install and run, and collects the raw device output. However, converting the data into something meaningful is more of a challenge, but some libraries are available to use the device.

Software part of gyrovertical includes embedded software for microcontroller that performs measurement and data transmission tasks and remote indicator software that is PC application that displays measured values of pitch, roll and yaw angles.

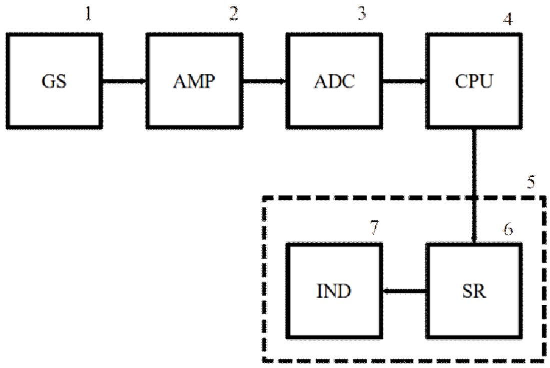

Fig. 5. Scheme of connecting the sensor to a PC: 1 is the gyroscopic sensor; 2 is the amplifier; 3 is the analog to digital converter: 4 is the microcontroller; 5 is the personal computer; 6 is the Signal receiver; 7 is the indicator

At the moment measured values are displayed as text but it is possible to create graphical representation of attitude indicator in the future versions.

V. Experimental Testing

Experimental testing was carried out by placing sensor on testing platform that is aligned with horizon plane and allows precise inclination angles setting. Then specified angles were set and measurements performed. Then the errors were calculated.

Experimental results are shown in Table I.

Measurement errors does not exceed 1 degree that allows to use such gyrovertical in navigation systems, small unmanned aerial vehicles (UAVs) and other applications where attitude measurements are required.

Table I. Experimental Results

Roll set, deg	Roll measured, deg	Error, deg	Pitch set, deg	Pitch measured, deg	Error, deg	Yaw set, deg	Yaw measured, deg	Error, deg
0	0	0	0	0	0	0	4.5	0.5
5	5.8	0.8	5	4.5	0.5	5	10.4	0.4
10	10.9	0.1	10	10.4	0.4	10	15.5	0.5

15	16	1	15	15.5	0.5	15	20.4	0.4
20	21	1	20	20.4	0.4	20	25.4	0.4
25	25.9	0.9	25	25.4	0.4	25	30.5	0.5
30	31	1	30	30.5	0.5	30	35.4	0.4
35	35.8	0.8	35	35.4	0.4	35	40.5	0.5
40	41	1	40	40.5	0.5	40	45.5	0.5
45	45.7	0.7	45	45.5	0.5	45	50.5	0.5
50	51	1	50	50.5	0.5	50	55.4	0.4
55	56	1	55	55.4	0.4	55	60.4	0.4
60	61	1	60	60.4	0.4	60	65.4	0.4
65	66	1	65	65.4	0.4	65	70.5	0.5
70	71	1	70	70.5	0.5	70	75.5	0.5
75	76	1	75	75.5	0.5	75	80.5	0.5
80	81	1	80	80.5	0.5	80	85.4	0.4
85	86	1	85	85.4	0.4	85	90.4	0.4
90	91	1	90	90.4	0.4	90	0	0
0	0	0	0	0	0	0	-4.6	-0.4
-5	-4.3	-0.7	-5	-4.6	-0.4	-5	-9.5	-0.5
-10	-9.2	-0.8	-10	-9.5	-0.5	-10	-14.4	-0.6
-15	-14.1	-0.9	-15	-14.4	-0.6	-15	-19.6	-0.4
-20	-19.2	-0.8	-20	-19.6	-0.4	-20	-24.6	-0.4
-25	-24.2	-0.8	-25	-24.6	-0.4	-25	-29.5	-0.5
30	-29.3	-0.7	30	-29.5	-0.5	30	-34.6	-0.4
-35	-33.1	-0.9	-35	-34.6	-0.4	-35	-39.6	-0.4
-40	-49	-1	-40	-39.6	-0.4	-40	-44.7	-0.3
-45	-44	1	-45	-44.7	-0.3	-45	-49.5	-0.5
-50	-51	1	-50	-49.5	-0.5	-50	-54.5	-0.5
-55	-54.2	-0.8	-55	-54.5	-0.5	-55	-59.5	-0.5
-60	-59	-1	-60	-59.5	-0.5	-60	-64.4	-0.6
-65	-64	-1	-65	-64.4	-0.6	-65	-69.6	-0.4
-70	-69	-1	-70	-69.6	-0.4	-70	-74.7	-0.3
-75	-74	-1	-75	-74.7	-0.3	-75	-79.5	-0.5
-80	-79	-1	-80	-79.5	-0.5	-80	-84.5	-0.5
-85	-84	-1	-85	-84.5	-0.5	-85	-89.6	-0.4
-90	-89	-1	-90	-89.6	-0.4	-90	4.5	0.5

V. CONCLUSION

Software and hardware were developed to implement the chosen method of calculating roll, pitch and yaw angles using the MEMS sensor in the Arduino environment. The MPU6050 sensor I have chosen helps us measure acceleration, speed, orientation, motion and many other parameters related to the movement of a system or object. This module also has a digital motion processor (DMP), which is powerful enough to perform complex calculations and thus frees the microcontroller. The module also has two auxiliary contacts that can be used to connect external modules. This module also has well-documented and redesigned libraries, so it is very easy to use with well-known platforms such as Arduino.

Experimental testing suggests that such systems error does not exceed 1 degree so it is possible to use such gyrovertical for different navigational and stabilization tasks.

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М. П. Василенко, М. В. Магась. Мікроелектромеханічна гіровертикаль
Гіроскопічні вертикалі (гіровертикалі) призначені для визначення напрямку істинної вертикалі на рухомих об'єктах. Будучи одним із пристроїв системи орієнтації рухомого об'єкта, вони використовуються як датчики кутів крену і тангажу літака (або датчики подібних кутів для інших рухомих об'єктів) і служать для створення платформи, стабілізованої в площині горизонту. на рухомий предмет. Електричні сигнали, що приймаються від вимірювальних осей приладу, використовуються в польотних, навігаційних, радіолокаційних системах, візуальних індикаторах тощо. Системи гіроскопічної стабілізації широко використовуються як основа інтегрованих систем керування на літальних апаратах і мініатюрних безпілотних літальних апаратах для генерації сигналів пропорційного для кутових відхилень літака в просторі за кутами крену і тангажу і для стабілізації і контролю положення в просторі оптичного обладнання. В даний час датчики, засновані на технологіях мікроелектромеханічних систем, широко використовуються в малій авіації. Їх важливою перевагою є малі масогабаритні характеристики, а головним недоліком – низька точність. Такі датчики використовуються в навігаційних системах і системах автоматичного управління літаками. Зокрема, відомі алгоритми розрахунку кутів орієнтації безпілотного літального апарату з використанням інформації мікроелектромеханічних датчиків кутової швидкості. Однак через великі дрейфи помилка накопичується з часом і, як наслідок, час роботи обмежений.
Ключові слова: мікроелектромеханічна система; гіроскоп; гіровертикаль; просторове положення; крен; тангаж; рискання.

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М. П. Василенко, М. В. Магась. Микроэлектромеханическая гировертикаль
Гироскопические вертикали (гировертикали) предназначены для определения направления истинной вертикали на движущихся объектах. Являясь одним из устройств системы ориентации движущегося объекта, они используются в качестве датчиков углов крена и тангажа самолета (или датчиков аналогичных углов для других движущихся объектов) и служат для создания платформы, стабилизированной в плоскости горизонта. на движущемся объекте. Электрические сигналы, снимаемые с измерительных осей прибора, используются в пилотажных, навигационных, радиолокационных системах, визуальных индикаторах и т. д. Системы гироскопической стабилизации широко используются в качестве основы комплексных систем управления на самолетах и малогабаритных беспилотных летательных аппаратах для формирования сигналов,

пропорциональных к угловым отклонениям самолета в пространстве по углам крена и тангажа и для стабилизации и управления положением в пространстве оптической аппаратуры. В настоящее время датчики на основе технологий микроэлектромеханических систем широко используются в малой авиации. Важным их преимуществом являются малые массогабаритные характеристики, а основным недостатком - низкая точность. Такие датчики используются в навигационных системах и системах автоматического управления летательными аппаратами. В частности, известны алгоритмы расчета углов ориентации беспилотного летательного аппарата с использованием информации от микроэлектромеханических датчиков угловой скорости. Однако из-за больших дрейфов ошибка накапливается во времени и, как следствие, ограничивается время работы.

Ключевые слова: микроэлектромеханическая система; гироскоп; гировертикаль; пространственное положение; крен; тангаж; рыскание.

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