Using of Measuring System MPU6050 for the Determination of the Angular Velocities and Linear Accelerations

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Abstract: At present, the micro-electro-mechanical systems (MEMS) are widely used. Typical examples of MEMS are accelerometers and gyroscopes. This paper discusses the features of MEMS-gyroscope, which is part of the measuring system MPU6050. It also discusses the receiving of the data from its sensors. This system has a digital interface I^2C. Work with MPU6050 demands the use of STM32VLDISCOVERY evaluating board with microcontroller STM32F100RBT6B stated on it. System MPU6050 is connected to the I^2C-module of the microcontroller. The sensor is a slave and microcontroller is master. The work with the sensor is the recording of the data into controlling registers or reading of the data from the information register. The microcontroller initiates the request to read or write of the data. According the standard I^2C interface, any communication involves the following steps: generation of start-conditions by the master; sending of the address of the slave device; reading data from the slave or write to it; the generation by the master device of the stop condition. In general, the connection of devices to the I^2C bus is a standard problem in engineering, but sometimes problems do occur. This is typically due to implement features of I^2C interface at the specific device. For example, with the microcontroller STM32F100RBT6B the specific of the operation of I^2C is that when reading it is necessary generate the stop condition is necessary not after receiving the last byte, as it follows from the logic of the I^2C working, but before it. Then the microcontroller will put a stop condition signal at the right time, otherwise the line will hang. After debugging of connection with MPU6050 on the I^2C measurements of acceleration and angular velocity of the sensor were made. These data were used to determine the angle of inclination. Accelerometer data had significant emissions and distortion due to the influence of lateral acceleration. These data of gyroscope as well has a significant disadvantage: after stopping the angular velocity of the gyroscope is not zero, but has some displacement. Therefore, there is gradual drift of angle after integrating of the angular velocity. Thus, the accelerometer or the gyroscope separately from each other cannot be used to obtain the inclination angle. To obtain the correct data it is necessary to use special filters and to use the data of the both sensors.

Keywords: gyroscope, accelerometer MPU6050, STM32, STM32F100RBT6B.

INTRODUCTION

Currently, widespread microelectromechanical systems (MEMS). This was made possible due to their small size, high functionality, high reliability, low power consumption and low cost.

Typical examples of MEMS are accelerometers and gyroscopes, which are in every Smartphone, tablet computer, etc. The former are used to measure linear accelerations, and the latter, angular velocities. The combined use of the accelerometer and gyroscope allows you to determine the movement of the body in three-dimensional space.

This paper considers the features of the MEMS gyroscope, which is part of the MPU6050 and receive data from the sensors of this measuring system.

1. THE PRINCIPLE OF OPERATION OF THE GYROSCOPE

MEMS devices are made on a silicon substrate in the same way as single-chip integrated circuits, so their sizes vary from a few tens of microns to several millimeters.

There are several types of MEMS gyroscopes that differ in their internal structure, but all of them are united in the fact that their work is based on the use of Carioles' force. In each of them there is a working body, making reciprocating movements. If you rotate the substrate on which this body is located, then the Carioles' force, which is directed perpendicular to the axis of rotation and the direction of motion of the body, will begin to act on it. Fig. 1 demonstrates illustration for understanding of the principle of this force.

Knowing the linear velocity and the Carioles' force, one can determine the angular velocity.

One of the possible implementations of a gyroscope has the following structure: a frame fixed on flexible hangers, inside which a mass makes translational oscillatory movements [1]. The structure of such a sensor is shown in Fig.2.

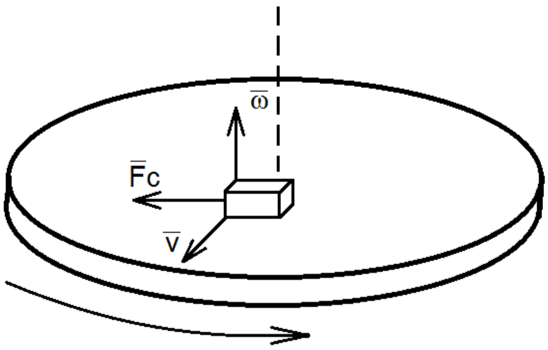

Fig. 1. The mechanism of the Coriolis force: $\vec{\varpi}$ – the vector of angular velocity, $\vec{v}$ – the vector of linear velocity, $\vec{F}_C$ – the Carioles' force

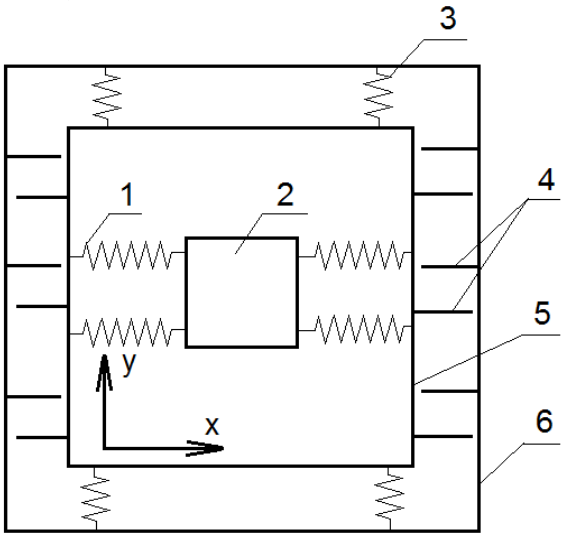

Fig. 2. The internal structure of the gyroscope: 1 – fastening mass, 2 – working weight, 3 – fastening the inner frame, 4 – sensors moving the inner frame, 5 – inner frame, 6 – substrate

Oscillations of the working mass occur along the *X* axis and are generated by electrostatic forces, and internal frame oscillations are possible only along the *Y* axis. Plates of flat capacitors (displacement sensors) are located between the inner frame and the false frame, thus measuring their capacity; it is possible to fix the frame movement relative to the substrate.

But oscillations of the inner frame can be caused not only by Carioles' force, but also by linear accelerations that act along the *Y* axis. The problem is solved by placing two frames on one substrate, each of which contains the operating mass. Both masses oscillate in anti-phase; therefore, at a particular point in time, the Carioles' force acting on the first mass is directed opposite to the force acting on the second. The signals generated by the Carioles' force will be added, and the in-phase component generated by linear acceleration will be subtracted.

Below are the technical specifications of the MPU 6050 and the built-in gyroscope [2].

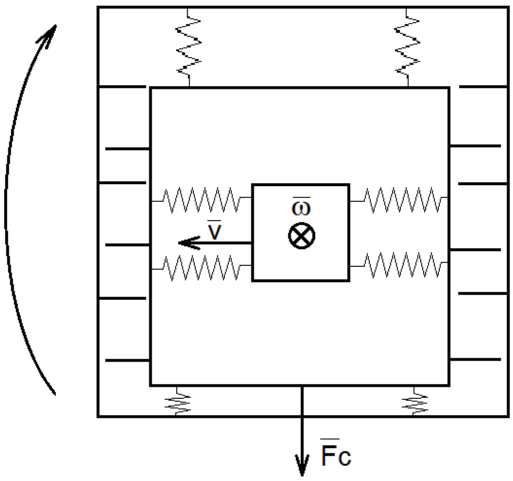

Fig. 3. The structure of the gyroscope during rotation: $\vec{\varpi}$ – the vector of angular velocity, $\vec{v}$ – the vector of linear velocity, $\vec{F}_C$ – the Carioles' force

2. SPECIFICATIONS OF THE MPU 6050 MODULE AND GYROSCOPE

2.1. Technical characteristics of the module:

• 3-axis gyroscope;
• 3-axis accelerometer;
• Thermal sensor;
• Power supply 2.375V-3.46V;
• FIFO-buffer of 1024 bytes;
• User-programmable digital filters for the gyroscope, accelerometer and thermal sensor;
• I2C interface for writing and reading device registers, operating at a frequency of up to 400 kHz.

2.2. Technical characteristics of the gyroscope:

- • User programmable measurement range: ± 250, ± 500, ± 1000, and ± 2000 ° / s;
- • Built-in 16-bit ADC;
- • Digital programmable lowpass filter;
- • Current in operation mode - 3.6 mA;
- • Standby current 5 µA.

3. ACQUISITION OF MEASURED DATA

The MPU 6050 module was connected to the STM32F100RBT6B microcontroller I2C module for sending commands and reading necessary data from the registers. After sending the command to the module about the start of measurements, the readings from all axes of the gyroscope, accelerometer and thermal sensor are constantly digitized. It remains only to read the bytes from the necessary registers. The frequency of recording new data in these registers by an analog-to-digital converter depends on the sensitivity of the sensor chosen by the user and, therefore, on the measurement range.

The sensor is connected to the microcontroller via the I2C interface. This interface has a number of features: it has master-slave architecture, that is, one device (master) makes a request to read or write slaves.

In our case, the slave is the MPU 6050, and the master I2C module located on the microcontroller. For communication uses two bidirectional lines: clocking and data. The slave device has its own address, which must be unique on this line (in our case it is 0 × D0). Lines must be pulled to the level of logical units. As a rule, devices are connected to lines through open collector (drain) pins. In fact, the devices are connected according to the “installation AND” scheme. The advantage is the ability to connect a large number of slave devices, as well as a relatively high data transmission distance. But as the range increases, the actual data transfer rate decreases. This is due to the fact that the fronts are smoothed due to an increase in the capacity of the wires.

Fig. 4 shows the algorithm of the program that reads data from the *MPU* 6050 registers. It is designed taking into account the specific features of the protocol for the sensor and the controller.

It is worth paying attention to some features associated with the operation of this algorithm. First, the need to read the SR2 register where indicated in the flowchart. Reading the contents of this register will reset some bit flags in it. If this is not done, the *MPU* 6050 module will not be able to proceed to the next stage of operation and the program will hang. The second feature is related to the termination of the communication session when reading data from the *MPU* 6050 registers. The data completion signal is the installation of a stop condition on the data line. In the case of the *STM*32*F*100 microcontroller, the command to generate a stop condition for it must be given after reading the last byte. If one byte is received, then after receiving confirmation of the acceptance of the address from the slave. If this is done after reading the last byte, the microcontroller will wait for the reception of another byte, which will not be, and the program will hang.

The flowchart presents an algorithm for reading or writing one byte, however, it can easily be added to read or write several bytes. After reading or writing to the register, the *MPU* 6050 automatically increments the register address by one, which allows reading or writing data in several registers in a row in one session.

4. EXPERIMENTAL RESULTS

Data was read from the sensor registers at intervals of 10 times per second. The gyro readings were integrated by a microcontroller to determine the angular velocities with respect to all three axes. The results are presented in Fig. 5–7. Fig. 7 shows how, due to integration, an accumulation of error occurred, the so-called zero drift: the sensor is stationary, and the angle value increases with the same speed. Fig. 5 shows that the accelerometer readings are noisy with high-frequency interference, which will lead to errors when calculating the deflection angles by using inverse trigonometric functions.

Thus, the *MPU* 6050 is a functional measuring system that includes a gyroscope and an accelerometer, which allow you to track the body's movement in space: to determine the angular velocity and linear accelerations. Determining the angle by integrating the angular velocity is inaccurate due to the accumulation of error (low frequency noise). The accelerometer also introduces high-frequency noise. The solution is to use data from both sensors and process them with an alpha-beta filter or a Kalman filter. This will eliminate the disadvantages of the accelerometer and gyroscope.

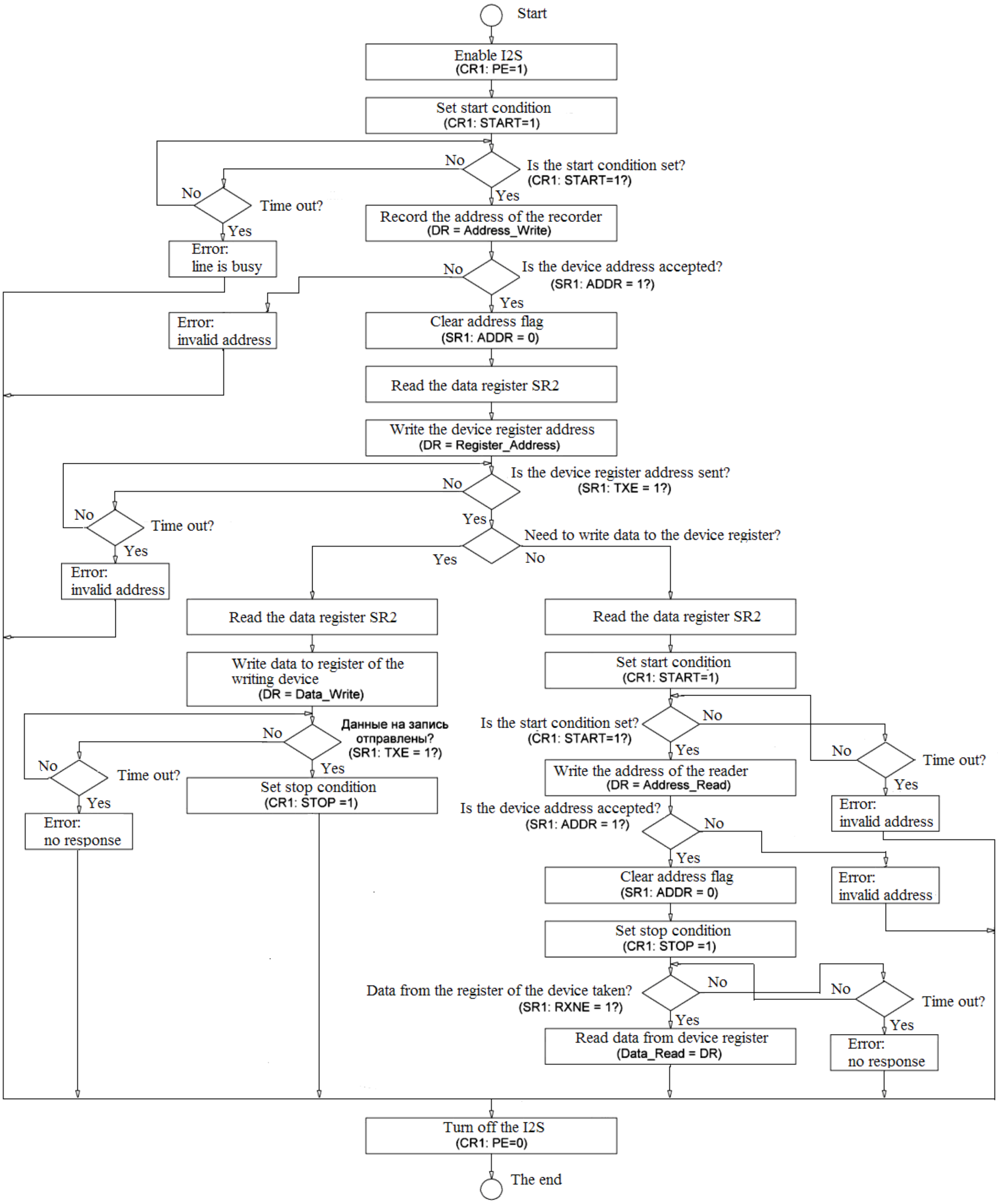

Fig. 4. Flowchart for writing and reading data from *MPU* 6050 registers

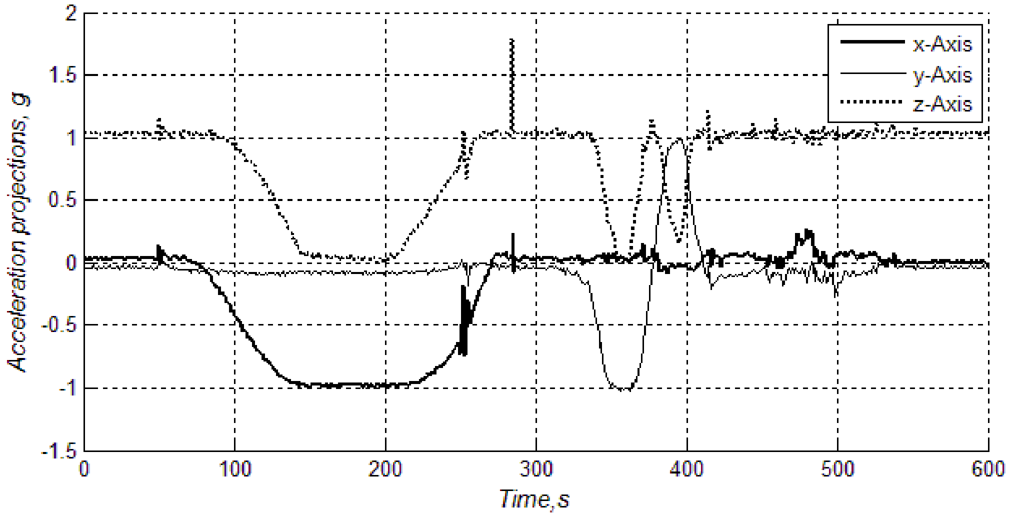

Fig. 5. Accelerometer axis indications

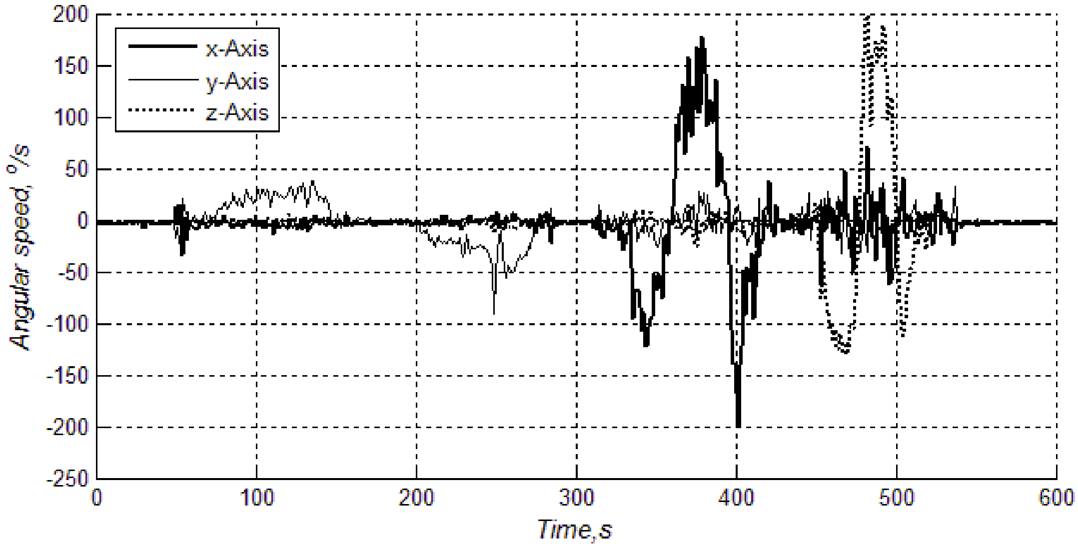

Fig. 6. Indications for the gyroscope axis

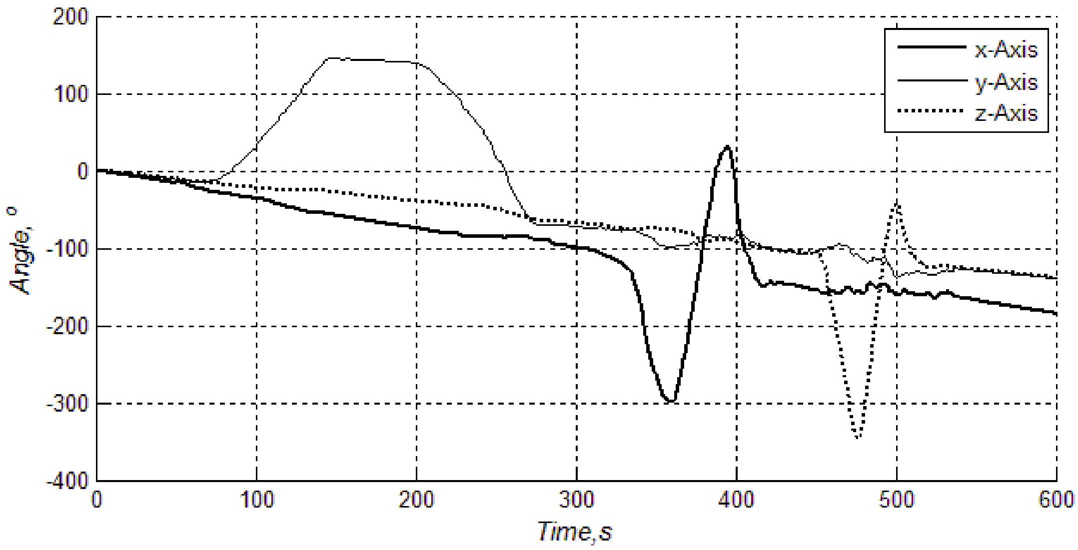

Fig. 7. The data on the angles of rotation obtained by integrating the readings of the gyroscope

CONCLUSION

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