MATEC Web of Conferences **102**, 01020 (2017) DOI: 10.1051/matecconf/201710201020
V International Forum for Young Scientists "Space Engineering"

Personal navigation system based on MEMS gyroscope

Lo Van Hao[1,*], and *Tamara* Nesterenko[1]

[1]National Research Tomsk Polytechnic University, 634050 Tomsk, Russia

Abstract. The paper presents a configuration of the modern personal navigation system and a new method of calculation of the distance traveled. The proposed navigation system is used to estimate a person's position and consists of three micromechanical gyroscopes: two at the knee and one at the waist. The knee attached gyroscope gives the distance traveled information, and the waist attached gyroscope gives the heading information. During the leg movement, the angular displacements of knees repeat at each period (each step of the walking person). By summing up all the stride lengths, the distance that a person has walked can be determined.

1 Introduction

In the field of space research, civil and military technology, navigation systems are being intensively developed for and applied to solving problems of orientation and navigation of mobile devices [1-2]. Currently, navigation systems are extensively utilized in the field of personal navigation. There is a variety of the implementation techniques for the personal navigation system. One of the most popular is the Global Positioning System (GPS) which, however, does not always provide the access to indoor operations and restrained urban conditions. Therefore, to track a person, considerable attention should be paid to a self-contained pedestrian navigation system with inertial sensors, *i.e.* inertial navigation system.

In typical inertial navigation systems, the source information is measured with the angular and translational movement sensors (gyroscopic devices and accelerometers) [3-5]. This information is processed by a computer module with a view to obtain such navigation parameters of mobile objects as walking speed, orientation, and position. In order to minimize the size and the number of sensors, the authors present a personal miniature inertial navigation system consisting of three micromechanical gyroscopes.

2 Circuit configuration of personal navigation system

The personal navigation system presented in this work consists of three uniaxial micro-gyroscopes of the LL-type in which the inertial mass executes a plane-parallel motion. Micromechanical gyroscopes comprise the electromechanical and circuit modules. Its operating principle is based on the energy transfer at an angular rate of an object between

* Corresponding author: lovanhao.pro@gmail.com

the two perpendicular directions (primary and secondary oscillations) [6]. Sensor converts the angular rates of an object into changes of capacitances transformed by the circuit module, based on lock-in technique [7-8], into the output signals proportional to the measured rates.

Figure 1 presents a generalized flow chart of the personal navigation system. Radio channel transmits and receives the personal navigation signals which are displayed on the monitor. MMG measure the angular rate within the coordinate system of the device, and the object rotation relative to its original position can be calculated using the digital integration of the gyroscope time readings and the time interval between the recordings. The personal navigation system operates as follows. Gyroscopes measure the angular rates and convert them into digital signals which then transfer to the computer module. The obtained distance is transferred from the computer module to the computer *via* the radio module which incorporates the LabVIEW [9] system-design platform to display the signal.

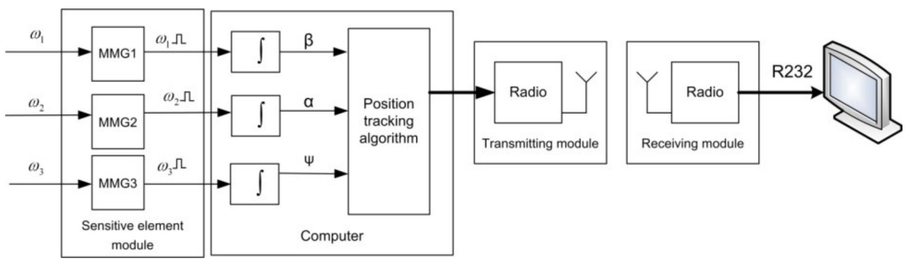

Fig.1. Generalized flow chart of personal navigation system.

3 Distance calculation method

The proposed system of personal navigation is based on MMG which measure the angular rate of walking speed. Here, we propose to use three micromechanical gyroscopes, two attached near knees and one attached to waist as illustrated in Figure 2. Angular rates of the leg movement are measured by the two knee attached gyroscopes. The angular rate of the upper body swing is measured by the waist attached gyroscope.

From Figure 2, two knee gyroscopes are attached such that the sensitive axis should be parallel to *OY*-axis. Let us consider the first step of a person. The left leg is a lever which turns around *O*1 reference point by β angle. The angular rate of the left leg is measured by the knee attached gyroscope *1*. The right leg is a lever which turns around *O*2 reference point by α angle. The angular rate of the right leg is measured by the knee attached gyroscope *2*. And the angular rate of a person around *Z*-axis is measured by the waist attached gyroscope *3* and gives us the angle of person's rotation.

However, the MMG output signal contains the error which accumulates as long as there is integration. To bound the error, the MMG should be calibrated and the data should be filtrated. Moreover, a new method, called Zero Angular Displacement Update (ZADU), is introduced in this work.

The key idea of this method is integration provided separately at each period. The first step is carried out during T1 period and measured by gyroscopes *1* and *2*. As can be seen from Figure 2, the right leg carries out not only the angular but also translational movement.

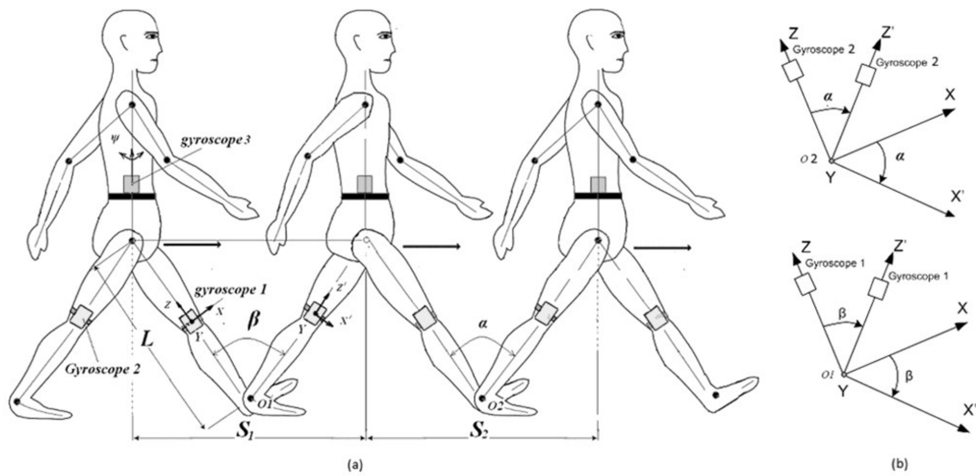

Fig.2. Sensor deployments: a – walking person; b – coordinate system.

The translatory acceleration has a strong effect on the MMG accuracy in its sensor mode. Therefore, the movement information is not given by gyroscope *2* attached to the right leg. The left leg being the lever *L*, carries out the step by the displacement angle β which is calculated by the integration of the angular rate obtained by gyroscope *1*. During the next period of T2, the second step is carried out. In this case, the signal from gyroscope 2 is not received because of the effect of the translatory acceleration, so gyroscope 2 should be used. The displacement angle α produced by the right leg is calculated from integration of the angular rate provided by gyroscope *2*.

Figure 3 demonstrates signals measured by gyroscopes *1* and *2*.

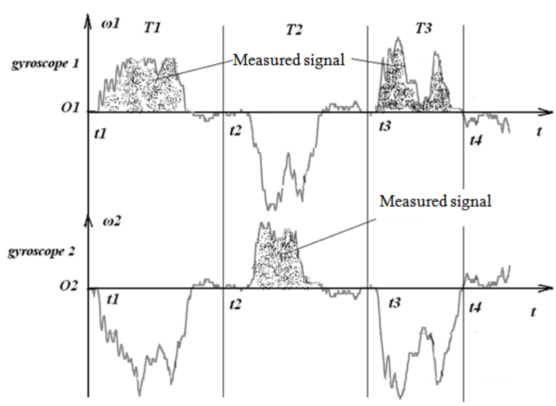

Fig.3. Signals measured by gyroscopes.

The data integration obtained by the gyroscopes is performed in series. During the first period, the data from gyroscope *1* are integrated and recorded for the calculation of the angular displacement. And after this period of time, the MMG angular displacement value is reset back to zero. During the second period, the data from gyroscope *2* are integrated and recorded for the calculation of the angular displacement. Similar to the first period of time, after this period the MMG angular displacement value is also reset back to zero. Thus, in ZADU method the initial value of each time integral is always zero, and the next calculation does not include the errors from the last calculation. So the output navigation signals contain the minimum error.

Angles β and α can be measured by discrete integration of the angular rate. The heading information is obtained *via* gyroscope *3*.

$$\beta=\beta_0+\int_{t1}^{t2}\omega_1\times dt\ ;\ \alpha=\alpha_0+\int_{t2}^{t3}\omega_2\cdot dt\ \ ;\ \psi=\psi_0+\int_{t1}^{tn}\omega_3\cdot dt\ , \tag{1}$$

where ω_1, ω_2 are the angular rates of human legs measured by knee attached gyroscopes *1* and *2*; ω_3 is the angular rate of upper body swing measured by the waist attached gyroscope *3*.

Thus, the following equation is obtained for the stride length *S*:

$$S=S_1+S_2=L\cdot\left[\sqrt{2\cdot(1-\cos\beta)}+\sqrt{2\cdot(1-\cos\alpha)}\right], \tag{2}$$

where *L* is the leg length; *S*1 is the stride length of the first period; *S*2 is the stride length of the second period as shown in Figure 3.

By summing up all the stride lengths, the distance that a person has walked can be determined. Let *N* be the total number of strides, the distance covered then can be written as

$$\sum S=\sum_{i=1}^{N}L\cdot\left[\sqrt{2\cdot(1-\cos\beta_i)}+\sqrt{2\cdot(1-\cos\alpha_i)}\right] \tag{3}$$

4 Conclusions

The flow chart and the algorithm of the personal navigation system based on three gyroscopes were discussed. The proposed navigation system has the advantage of simplicity, small size, low cost and self-contained sensors. However, certain efforts should be provided to keep the angular displacements errors bounded. For this purpose, the Kalman filter and calibration of high-precision MMG were employed. In view of the absence of the feedback, most of MMG are characterized by unsteady operation under the dynamic loads. Therefore, the gyroscopes of compensation type used as inertial sensors will be the most promising.

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