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Gerken, Elena; Grechikhin, Valery; Bertram, Torsten

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Experimental studies of magnetic positioning system

Postgraduate Elena Gerken, Platov South-Russian State Polytechnic University (NPI), Department of Information Measuring Technics and Technologies, 346428 Novocherkassk, Russia, elenagerken@yandex.ru

Dr.-Ing., associate professor, Valery Grechikhin, Platov South-Russian State Polytechnic University (NPI), Department of Information Measuring Technics and Technologies, 346428 Novocherkassk, Russia, vgrech@mail.ru

Univ.-Prof. Dr.-Ing. Prof. h.c. Dr. h.c. Torsten Bertram, Technische Universität Dortmund, Lehrstuhl für Regelungssystemtechnik, 44227 Dortmund, Deutschland, torsten.bertram@tu-dortmund.de

Abstract

The purpose of the study is the implementation of a magnetic positioning method by creating an experimental unit for determining the location and orientation of objects in mechatronic systems. Advantages of the magnetic positioning method include high sensitivity and noise immunity, small sensor dimensions, the possibility of a flexible tool navigation along a curved path. The contribution gives a comparative evaluation and analysis of methods for describing the object rotation in the three-dimensional space. The contribution presents the most suitable algorithm for solving the sensor orientation problem in the magnetic field. The paper also presents the description of the implemented method of magnetic positioning for determining the sensor location and describes how the experimental unit works. The results of the positioning error of a movable sensor are shown with the purpose of developing methods for minimizing the error. Particular attention is paid to the measurements that allow increasing the positioning accuracy of the distance between the magnetic field source and the movable sensor. In the literature there are different approaches to the mathematical description with different solving approaches [1].

The method is based on the magnetic field generation with a known spatial distribution in the research area. The components of this field, measured by the movable sensor are compared with the calculated values for real-time decision making about location and orientation of the sensor inside the research area. The magnetic positioning method does not require line of sight between the magnetic field generator and the movable sensor. This property makes it possible to use the sensor in hard-to-reach places, for example in a navigation of a surgical instrument inside the patient's body [2,3]. Currently, using the modern technologies of information-measuring and computing equipment, the method of magnetic positioning is popular in many fields of science and technology, in each of which the problem of calculating location and orientations of the movable objects is being solved [4]. The method of magnetic positioning is based on the generation of a magnetic field and measurement of the orthogonal components of this field by the movable sensor in the research area. The location and orientation of the movable sensor are determined by solving the system of equations in (1). To determine the vector of the magnetic field strength at an arbitrary point in space, the magnetic field method of the circular current is used, which describes approximately the behavior of a small conducting body in a magnetic field. Since the distance to the observation point is many times greater than the dimensions of the sensor, the following expressions for the vector of the magnetic field strength in a spherical coordinate system is applied [5]:

$$\begin{cases} H(R) = \dfrac{M}{2\pi r^3}\cos\theta \\ H(\theta) = \dfrac{M}{4\pi r^3}\sin\theta \\ H(\varphi) = 0\,. \end{cases} \tag{1}$$

Where $H(R)$ is the radial component of the field, $H(\theta)$ is the tangential component of the field in the direction of the elevation angle, M is the vector of the field generator magnetic moment, r is the shortest distance between the source and the sensor, θ is the zenith angle, φ is the azimuth angle. To determine the sensor location in a three-dimensional space, it is necessary to use the resulting system of equations:

$$\begin{cases} x = r\sin\theta\cos\varphi \\ y = r\sin\theta\sin\varphi \\ z = r\cos\theta\,. \end{cases}$$

The magnetic positioning system is modeled using the Finite-Element-Method in ANSYS Maxwell for determining the sensor location in the three-dimensional space. This model includes the three independent sources of magnetic field with different orientations along orthogonal axes and the developed ferromodulation converter with pulse compensation. This converter can be used as a sensor.

Together with the results of the FEM simulation an experimental unit is designed. **Figure 1** presents the block structure of this unit. The positioning system based on magnetic induction, contains a group of fixed transmitting coils (sources) outside the research area and one sensor, which moves inside this area. The sources generate a magnetic field of known shape and distribution. The sensor receives a signal from each source and when the sensor's position or orientation change, the magnetic flux density B changes, too. In this case the voltage pulses U are induced inside the sensor. In terms of the magnitude and nature of the induced voltage pulses, the position and orientation of the sensor within the research area are calculated by means of the measuring block of the developed system.

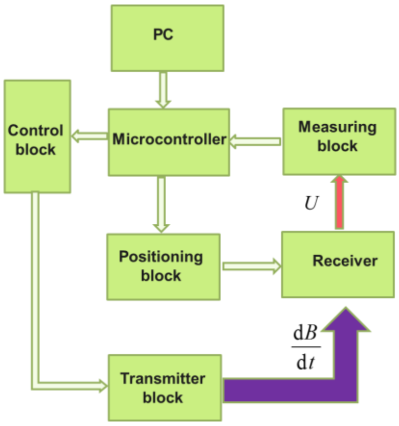

Figure 1 –Structural scheme of the positioning system of the developed unit

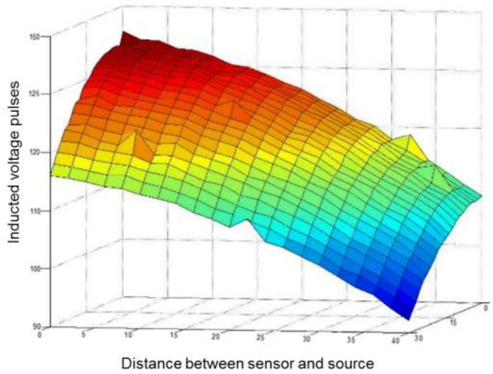

Figure 2 – Static model of the inducted voltage pulses in sensor

During the experiment, the sensor and one of the source centers are on the same plane. The sensor is moved along this plane with a step width of 1 mm. The research area is 400 × 300 mm². At each point of this area, the voltage values induced in the sensor are measured, depending on the distance between the sensor and the source and the magnetic field strength (**Figure 2**).

After the identification of the static model in which each point is assigned to a certain voltage value, which is induced in the sensor, it is possible to move the sensor to a given point of the defined space.

In this case the sensor works as a zero-organ (an element of the automatic controller that generates a signal proportional to the difference of the compared values), comparing the induced values in the sensor with those assigned to certain coordinates.

The results of this research show a high accuracy. The interval of the induced voltage in the sensor after the measurement cycle at the same point in space do not exceed an error of 0.4%. It has been confirmed experimentally that the measurement error increases significantly with an increasing distance between the transmitter and the sensor. To increase the accuracy of positioning, it is proposed to use two sources where the sensor is located on the connecting axis between this two sources. In this case, the maximum value of the measurement error will be reduced significantly.

The results of determining the position and orientation of objects in 3-dimension space by the magnetic positioning method will be compared with the results of using 9 DOF sensors (3-axis accelerator, 3-axis gyroscope, and 3-axis magnetometer) and with outcome of optical motion capture system in the same experiment.

The following parameters will be evaluated: positioning accuracy, the size of research area, system performance, complexity of calibration, overall dimensions of the system and sensors.

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