INERTIAL INDOOR NAVIGATION SYSTEM

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Abstract: This paper represents a first step in developing an indoor navigation system based only on Micro-Electro-Mechanical Systems (MEMS) accelerometer and gyroscope sensors. The major advantage of the proposed inertial navigation system consists on the fact that it does not require any complex infrastructure to be able to operate. For determining the distance it uses three axis accelerometer sensors, while the direction of the user is determined from the gyroscope angular rate data. As no infrastructure is used, the cost of such a system is low, but at the same time the lack of infrastructure represents its highest limitation. More exactly, for long periods of time the errors are cumulating in the navigation solution determining the deterioration of its accuracy. This limitation can be suppressed by using robust algorithms that can estimate and compensate these errors from the accelerometer and gyroscope signals.

Keywords: *inertial navigation, gyroscope and acceleration sensors, errors compensation, MEMS technology.*

I. INTRODUCTION

In the last years, the Global Navigation Satellite System (GNSS) had evolved rapidly becoming more accurate and more accessible from the economic point of view. But, even the most accurate receivers can not be used inside buildings, especially in multi-floors concrete ones. This limitation draws the development of inside building location systems such as infrared based location systems [1], Radio Frequency (RF) based location systems [2], Inertial Navigation (IN) systems [3, 4], ultrasonic based location systems [5], etc. Among all of them, inertial technology was the most promising one [6]. This was due to the fact that the sensors are low cost, low size and low power, making them suitable for application areas that require power autonomy for long periods of time (such as: indoor navigation). A key component in any IN system is the gyroscope sensor. Based on the data collected from this sensor, the heading can be computed with respect to the initial position. Furthermore, based on the results from our previous work [7], we have concluded that if the external factors that influence the gyroscope data are properly compensated, then the navigation solution can be computed with high accuracy.

This work presents our progress in the area of inertial navigation technology. More exactly, we have developed a navigation system based only on inertial sensors, like accelerometers for determining the traveled distance and gyroscope sensors for determining the heading. By combining these two solutions the route followed by the user can be estimated. Furthermore, a special attention was provided to the methods used for compensating the errors from the gyroscope sensor in order to increase the accuracy of the proposed system.

The paper is organized as follows. At the beginning the theoretical background of this paper is presented in Section 2, measurement setup is provided in Section 3 while Section 4 analyses the results of our research. Finally, we conclude in Section 5.

II. THEORETICAL BACKGROUND

In our days, pedestrian navigation represents a challenging application for navigation technologies. A pedestrian navigation system must work in urban areas, and also indoors, where the coverage of GNSS and most of the radio navigation systems is poor. The basic principle on which these systems operate is quite simple and it consists in three phases, namely: step detection, step length estimation and navigation-solution update [4]. For determining the steps the algorithm uses a body mounted accelerometer sensor. The exact moment when a step occurs can be determined from the zero crossings or from the peaks in the accelerometer signals. In our approach we used the signal peaks for determining the number of steps, as shown in Figure 1.The data was collected while the user walked for approximately 200 seconds on the same floor level, inside a building.

The second phase of the algorithm consists in estimating the length of each step. This can be correlated with the variance of the accelerometer measurements, slope of the terrain and vertical velocity. In our case we used a fixed value for estimating the length of each step.

In order to determine the heading, the angular rate data generated by the gyroscope sensor (see Figure 2) was integrated. The result obtained is presented in Figure 3 and it was collected in the same measurement like the result presented in Figure 1. Finally, for determining the navigation solution the two results must be combined according to the following equation:

$$X(t) = X(t-1) + V(t) \quad (1)$$

where by $X(t)$ we denote the navigation solution on two dimensional space (on X and Y axes) as a combination between the current and the last known position. Furthermore, for obtaining the current position the following equation is used:

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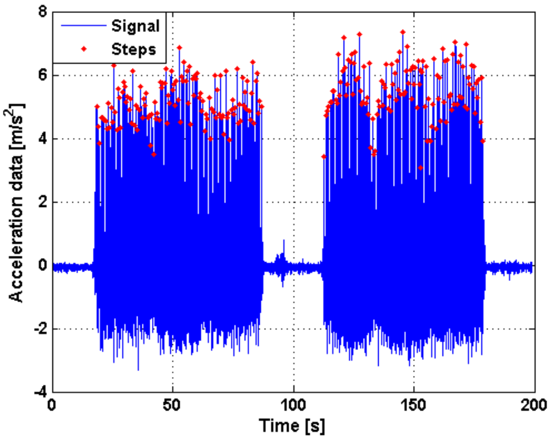


Figure 1. Step detection from accelerometer signals.

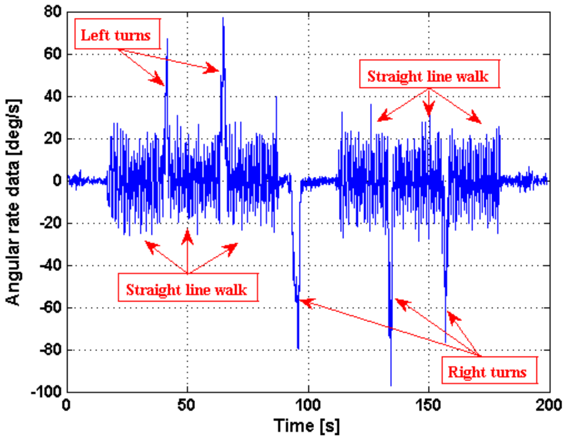


Figure 2. Raw angular rate data.

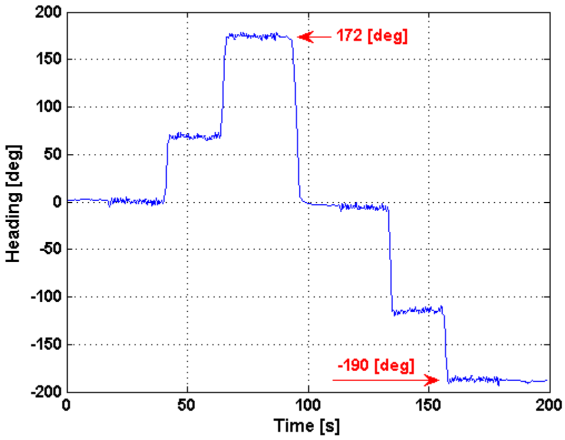


Figure 3. Heading computation.

$$V(t) = \begin{bmatrix} \cos\varphi & -\sin\varphi \\ \sin\varphi & \cos\varphi \end{bmatrix} \begin{bmatrix} 0 \\ d \end{bmatrix} \quad (2)$$

where by φ we denote the angle of rotation obtained according to Figure 3, while d represents the length for each determined step.

III. MEASUREMENT SETUP

For all the measurements presented in this paper we used the SCC1300-D02 sensor, manufactured by VTI Technologies [8]. The hardware components for the measurement setup are described below.

SCC1300-D02	A combined 3-axis accelerometer and a single axis gyroscope sensor with SPI interface for transferring the data. Manufactured by VTI Technologies and released at the beginning of last year [8].
SPI interface	We used the National Instruments NI-8451 USB device that provides I^2C and SPI communication interfaces with 8 chip select lines [9].
Voltage regulator	This component stabilizes the input voltage at 5 V and 3.3 V.
Power supply	We used a GP battery of 7.2 Vdc and 3000 mAh.
Laptop Dell	It was used to read and save the data collected from the SCC1300-D02 sensor.

The measurement setup is presented in Figure 4, while Table I contains technical specifications, offered by the manufacture, for the SCC1300-D02 sensor. Furthermore, the sampling frequency for reading both gyroscope and accelerometer sensors was of approximately 500 Hz.

After the data from the sensor was saved on the laptop hard drive, all the computations were made off-line using MATLAB 2008 software.

TABLE I. SCC1300-D02 SENSOR SPECIFICATIONS

Parameter	Sensor typical values	
	Gyroscope	*Accelerometer*
Operating range	± 100 °/s	± 2 g
Noise (RMS)	0,06 °/s	3 mg
Sensitivity	50 LSB/(°/s)	1800 LSB/g
Offset short term instability	< 1 °/h	-
Quantization	0,05 °/s	-
SPI clock rate	0,1 – 8 MHz	0,1 – 8 MHz

IV. EXPERIMENTAL RESULTS

By using the algorithm presented in Section 2, we have computed the navigation solution for the results presented in Figures 1 and 3. The result obtained is shown in Figure 5. As it can be seen the navigation solution contains a large amount of errors which are caused either by heading or by distance computation. Based on this result we can exclude the last cause (distance computation) because, as it can be seen, the traveled distance is determined quite well despite the fact that we used a fixed value for each step length. As a consequence, our work was focused on removing the errors from the heading computation. Figure 5 shows some of these errors in different stages of the measurement. For example, the heading error at the end of the measurement is of approximately 10 degrees. These errors were determined as a difference between the heading shown in Figure 3 and the theoretical

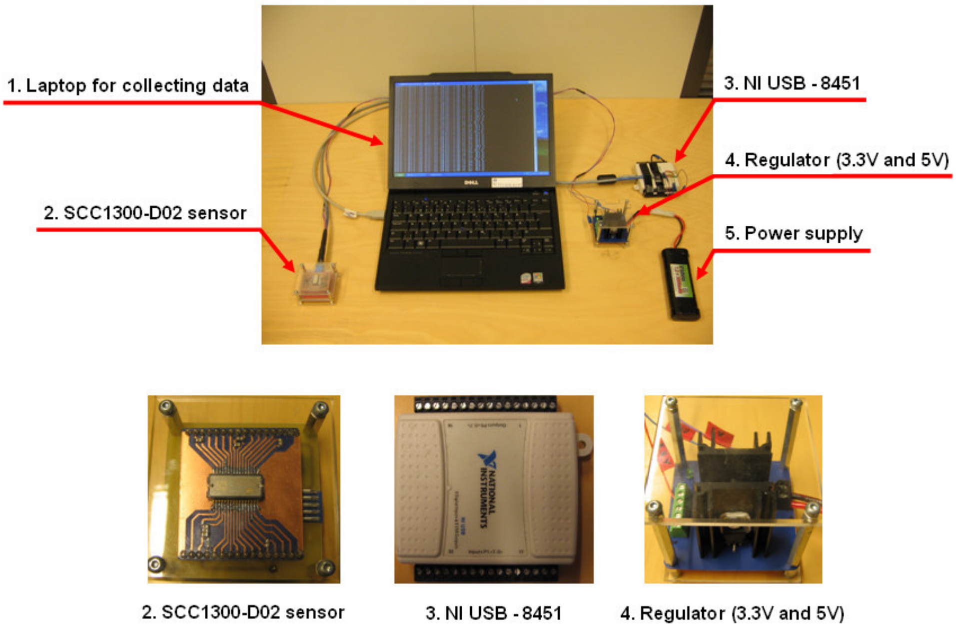
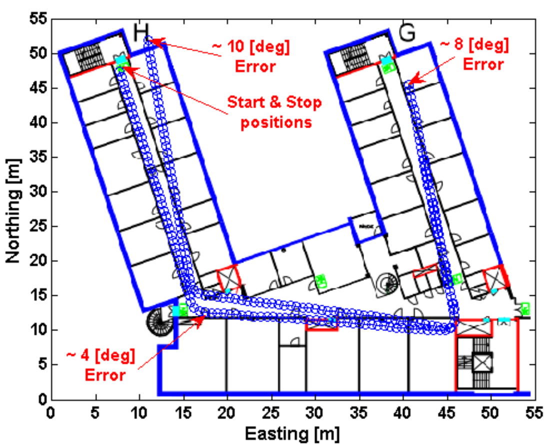


Figure 4. Experimental measurement setup.

heading values for known positions during the measurement. theoretical heading value should be close to 180 degrees, while after the last turn it should be close to -180 degrees.

In order to increase the accuracy of the proposed system, we have computed the gyroscope bias from the first ten seconds of data, but with the sensor fixed on floor level. Then we removed the bias value from the gyroscope data (used in Figure 5). The navigation solution is presented in Figure 6. As shown in this result, after the third turn the heading error was of approximately 4 degrees, which represents only half of the initial error (see Figure 5). Furthermore, the heading error at the end of the measurement is less than 1 degree. This behavior and the remaining errors can be explained by the angles formed between the sensitive axes of the gyroscope sensor and the local vertical. Basically, during the walking phase the user body moves with respect to the local vertical axes and at the same time is forcing the gyroscope sensitivity axes to form an angle with the local vertical (the sensor is fixed on the user chest). Under these conditions it is clear that if these angles are not properly compensated, than the gyroscope will not measure accurately the user rotations, propagating



As an example, after the second turn the

Figure 5. Navigation solution without any compensation.

the errors to the heading computation. Next, in order to determine and compensate these angles we used the data collected from the accelerometers during the same measurement. For each sample of the acceleration data the angle was estimated according to the following equation:

$$\cos(\mathbf{a}, \mathbf{c}) = \frac{\mathbf{a} \cdot \mathbf{c}}{\|\mathbf{a}\| \|\mathbf{c}\|} \qquad (3)$$

where **a** represents a vector containing the three axes accelerations, while **c** represents the local vertical. The content of the two vectors is presented below:

$$\mathbf{a} = \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} \text{ and } \mathbf{c} = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \qquad (4)$$

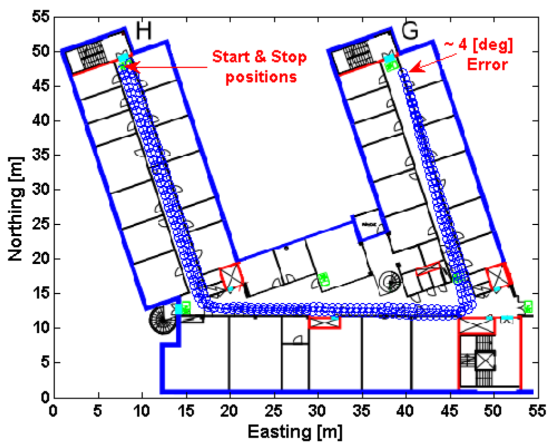


Figure 6. Navigation solution after bias compensation.

After all the angles were estimated, each sample of the gyroscope data was compensated according to these angles. This was possible because the gyroscope data and the accelerometer data were synchronized during the entire measurement. Finally, we applied angle compensation to the data presented in Figure 6. The new navigation solution is shown in Figure 7. As it can be seen, if bias and angle compensation are applied to the angular rate data collected from the gyroscope sensor, then the heading accuracy is better than 1 degree. Furthermore, in order to test the stability of our current solution we made a number of two separate measurements. For each measurement the user walked for less than 5 minutes and followed the same route like the one presented in Figure 7. The results obtained are shown in Figures 8 and 9. For both cases the heading accuracy of our inertial navigation system was better than 1 degree. As a comparison, for short periods of time this value is similar with the one reported in [3], where the others were able to keep a 1 degree heading accuracy during the entire test duration (approximately 50 minutes). For this purpose, they used a ring laser gyroscope sensor.

In conclusion, the results obtained in this paper represent a first step in developing a better indoor inertial navigation system. Future developments must count for the errors caused by step length estimation or temperature effects over the gyroscope data, in order to improve the performances of the proposed system.

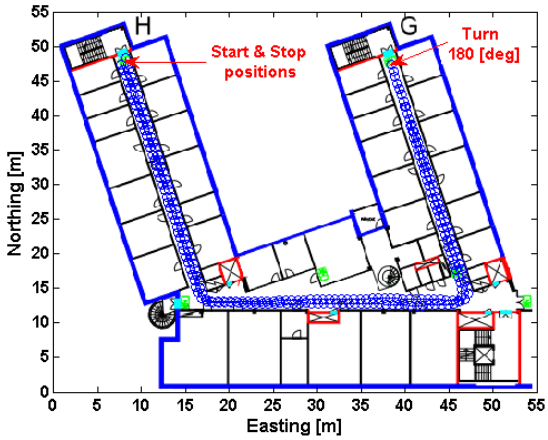


Figure 7. Navigation solution after bias and angle compensation were applied.

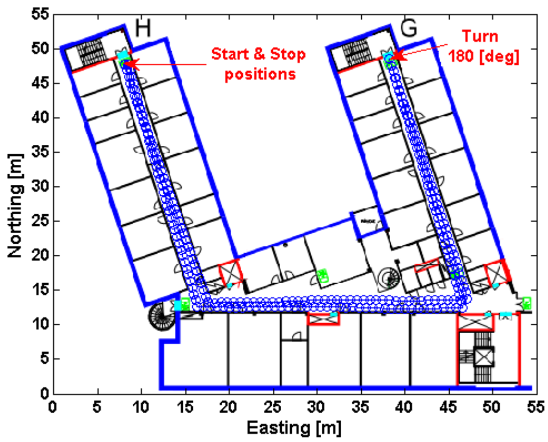


Figure 8. Navigation solution 1.

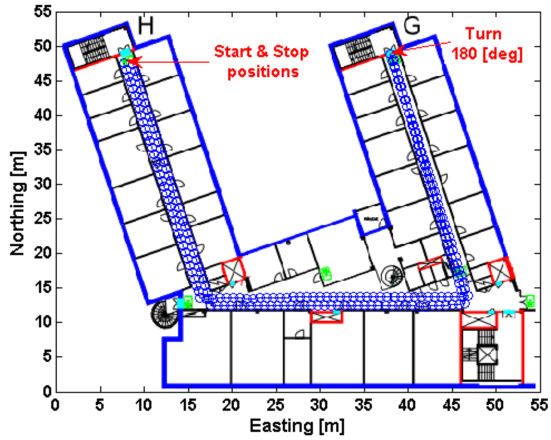


Figure 9. Navigation solution 2.

V. CONCLUSION

In this paper we have evaluated the performances of our inertial navigation system, which for short periods of time can achieve a heading accuracy better than 1 degree. This level of accuracy was possible to obtain after the bias and the angle formed between the sensitive axes of the gyroscope and the local vertical were compensated from the angular rate data. Future work will be focused on maintaining the same accuracy but for longer periods of time, like half an hour. Also, a barometer sensor will be integrated on the proposed system in order to determine the floor on which the user is located. Finally, a real-time navigation solution, displayed on a small portable device (a mobile phone for example) is desired.

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