Improved Indoor Navigation System Based on MEMS Technology

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***Abstract*— Inertial sensors have found widespread use in various applications. Recently, we have proposed an inertial navigation system based only on Micro-Electro-Mechanical Systems (MEMS) technology. The motivation for implementing such a system was to determine with high accuracy the user position inside a building without the use of any additional systems or infrastructure. In this paper we propose a compensation method for the gyroscope angular rate data based on the ambient temperature. As a result, the errors were reduced while the accuracy of the system increased. Furthermore, by using an additional barometer sensor, the navigation solution can be computed in 3D coordinates.**

I. Introduction

Micro-Electro-Mechanical Systems (MEMS) technology represents a topic that has been of a major interest for both scientific and industrial community. In the last years, MEMS technology showed a continuous development and its applicability was demonstrated in various fields. Besides the well-known applications from inertial navigation technology [1], MEMS gyroscope sensors were also used for measuring the magnitude of the Earth's rotation rate [2], gyro-compassing applications [3], [4] and even for military use (for example: in guiding missiles, etc.). Of all these topics our work is focused on the possibilities offered by the inertial navigation technology.

In a recent study [5] we have proposed some compensation methods for the gyroscope angular rate data. Based on these compensations we were able to achieve high accuracy for short periods of time (less than ten minutes) and without the use of any other additional location systems. In this work we present an improved compensation method for determining the navigation solution based only on inertial sensors. More exactly, we have correlated the fluctuations from the gyroscope output data with the ambient temperature variations. Based on this correlation, the accuracy of our system was maintained high while the measurement period increased from five minutes to thirty minutes. Furthermore, we have incorporated an additional barometer sensor on our previous measurement setup. By doing this the navigation solution can be computed in 3D coordinates.

The rest of the paper is organized as follows. Our previous work is explained in Section II. The theoretical background of this paper is presented in Section III. Measurement setup is provided in Section IV while Section V analyzes the results of our research. Finally, we conclude in Section VI.

II. Previous Work

Next we are going to briefly explain our work from [5] and try to point out some of the problems that we encountered. The principle on which our system operates it is quite simple. It uses acceleration data for determining the traveled distances while the heading is estimated from a gyroscope sensor. Finally, the navigation solution is determined as a combination between these two results. As described in [5] several error sources needed to be accounted for and removed in order to obtain a high level of accuracy for the navigation solution. Between these errors the most significant ones are:

- Bias fluctuations in the gyroscope output data;
- The appearance of an angle between the local vertical and the gyroscope sensitivity axes.

As an example, Fig. 1 presents the navigation solution obtained after the major error sources that affect the heading accuracy of the gyroscope sensor were removed. Furthermore, in this paper we propose to continue our previous work by extending the walking period from five minutes to thirty minutes. Also, an additional barometer sensor will be integrated in the measurement system. This sensor will be used to determine the floor on which the user is located.

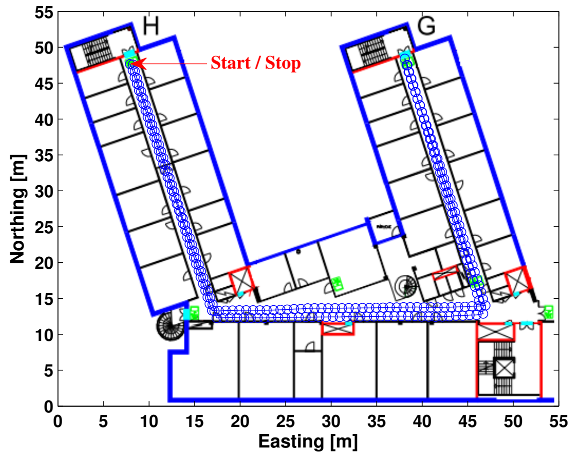

Fig. 1. Navigation solution after bias and angle compensation.

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(a) Front view (b) Side view

Fig. 2. Experimental measurement setup. The SCC1300-D02 and SCP1000 sensors are positioned on the user body in 1) and 2).

III. 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 Global Navigation Satellite System (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:* 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 acceleration signals. In our approach we used the signal peaks for determining the exact number of steps.
- *Step length estimation:* it can be correlated with the variance of the acceleration data, slope of the terrain and vertical velocity. In our case we used a fixed value for estimating the length of each step.
- *Navigation-solution update:* usually, in this phase the solution obtained from the previous steps is combined with the heading generated by a gyroscope sensor.

Finally, after these phases are completed the navigation solution is determined according to the following equation:

$$\mathbf{X(t)} = \mathbf{X(t-1)} + \begin{bmatrix} \cos\varphi & -\sin\varphi \\ \sin\varphi & \cos\varphi \end{bmatrix} \begin{bmatrix} 0 \\ d \end{bmatrix} \qquad (1)$$

where:

- $\mathbf{X(t)}$ represents the navigation solution on two dimensional space as a combination between the current and the last known position;
- φ is the angle of rotation obtained by integrating and compensating the gyroscope angular rate data;
- d represents the length of each determined step and it was approximated by 0.7 $[meters]/step$.

IV. Measurement Setup

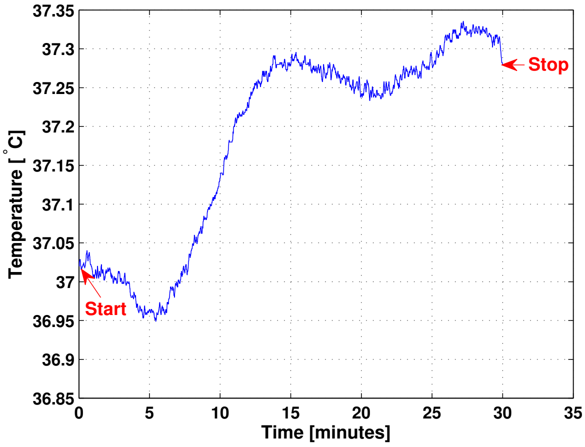
In order to collect and save the data from the SCC1300-D02 sensor a software application was developed in Microsoft Visual Studio 2008. This application uses the NI-8451 USB device as a hardware interface between the sensor and the laptop. The maximum sampling rate that was achieved for reading both gyroscope and accelerometer sensors (contained by the SCC1300-D02 sensor package) was of approximately 500 Hz. This value was limited by the NI-8451 device. Furthermore, the ambient temperature was read at each 0.5 seconds, while the sampling frequency for the SCP1000 sensor was of approximately 1.8 Hz (it was limited by the resolution used for reading this barometer sensor). In the next part, the hardware components for the measurement setup are presented:

- *SCC1300-D02 sensor:* a combined 3-axis accelerometer and a single axis gyroscope sensor; it was manufactured by VTI Technologies and released at the beginning of year 2010 [6];
- *SPI interface:* we used the National Instruments NI-8451 USB device that provides I^2C and SPI communication interfaces with 8 chip select lines [7];
- *SCP1000 sensor:* a combined barometer and temperature sensor manufactured by VTI Technologies [8];
- *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;
- *Dell Laptop:* it was used to read and save the data collected from the SCC1300-D02 sensor.

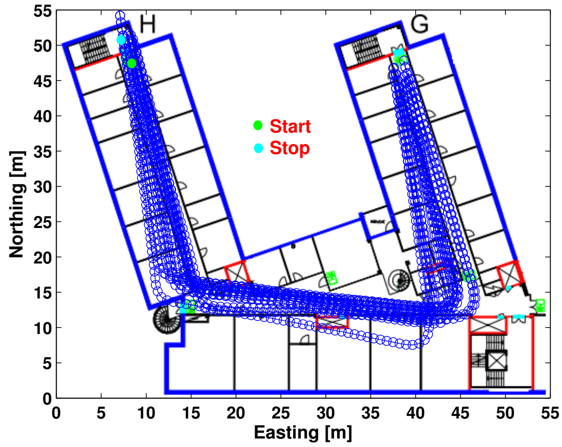
The positioning of these components on the user body can be seen in Fig. 2.

V. Experimental Results

For obtaining the results presented in this paper we used MATLAB 2008 software. Furthermore, as it was previously

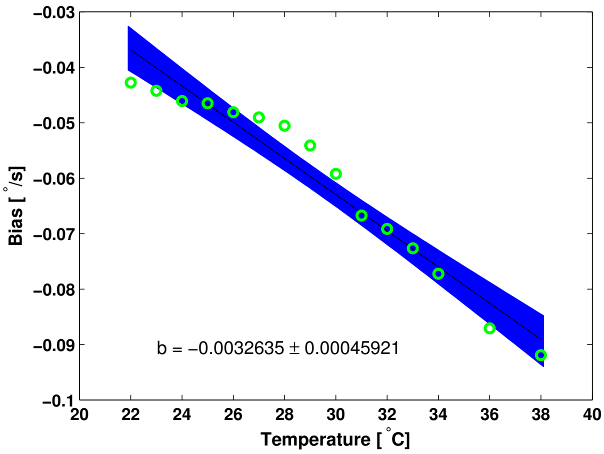


(a) Temperature fluctuations during the measurement.

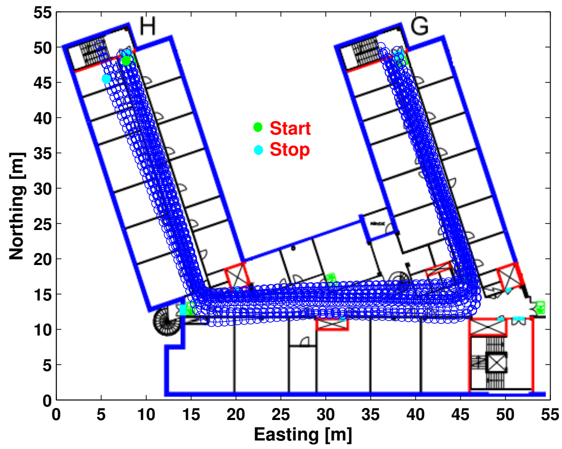


(b) Thirty minutes walking solution.

Fig. 3. Navigation solution after angle compensation was applied and the SCC1300-D02 sensor was isolated in a temperature protective layer.



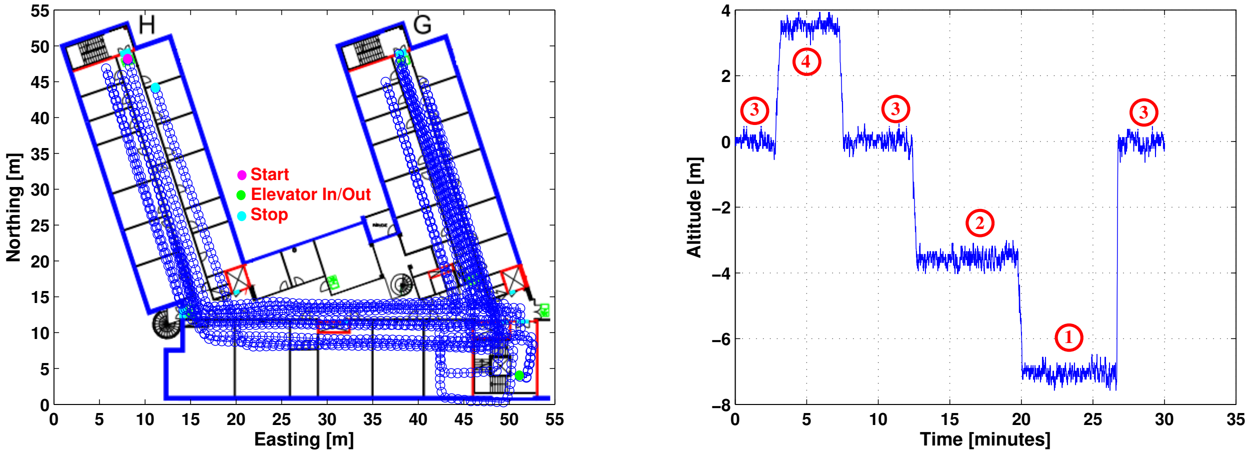
(a) Gyroscope offset over temperature.



(b) Thirty minutes walking solution.

Fig. 4. Navigation solution after angle and temperature compensations were applied.

mentioned we extended the walking period from five minutes to approximately thirty minutes. By doing this, the errors from the navigation solution are expected to increase even if the angle formed between the sensitive axes of the gyroscope sensor and the local vertical is compensated from the gyroscope angular rate data. Also, because the walking period increased, the bias was computed from the first five minutes of data collected at the beginning of each measurement (instead of the first ten seconds, like used in [5]). While collecting data for determining the gyroscope bias, the SCC1300-D02 sensor was fixed on floor level. Furthermore, as already shown in our previous work [2], for long periods of time temperature variations have a large influence over the output data of the gyroscope sensor. In order to keep the temperature as stable as possible during the measurements, we have isolated the SCC1300-D02 sensor package in a temperature protective layer. Next, the user walked for approximately thirty minutes on the same floor level. During this measurement he traveled a distance of approximately 1080 meters, cumulating a total number of 35 turns to both left and right. Figure 3(a) presents the temperature fluctuations during the measurement, while the navigation solution is presented in Fig. 3(b). As it can be seen from Fig. 3(a) the temperature changes with only 0.4 °C during the entire measurement. Even so, the heading error at the end of the measurement is of approximately 12° and it was estimated based on the result presented in Fig. 1 (which was considered as a reference). Therefore, in order to establish a relation between temperature variations and the output data of the gyroscope sensor, several measurements were carried out for different temperature values. During all these measurements the sensor was fixed inside Vötsch VT 7010 temperature control chamber. For each temperature value the sensor was sampled for approximately ten minutes. The results obtained are presented in Fig. 4(a). Each circle



(a) Thirty minutes walking on multiple floors.

(b) Altitude determined with SCP1000 sensor.

Fig. 5. By combining these two results the navigation solution can be determined in 3D coordinates.

represents the average value of one measurement, while b represents the slope of the measurements.

Next, based on the results presented in Fig. 4(a) we have determined the following relation between temperature and bias fluctuations:

$$\frac{GyroBias_t - Bias_{22°C}}{Bias_{38°C} - Bias_{22°C}} = \frac{Temp_t - 22°C}{38°C - 22°C} \quad (2)$$

where $GyroBias$ is the offset that needs to be removed from sample t of the gyroscope data, while $Temp$ represents the ambient temperature measured for the same sample. Furthermore, based on (2) we have compensated each sample from the gyroscope data used in Fig. 3(b). The re-computed navigation solution is presented in Fig. 4(b). As it can be seen, the heading error for the last measurement position was reduced to less than 3° instead of 12° like for the previous result. The remaining errors are caused by distance estimations and can be compensated by using a step length estimation algorithm (instead of using a fixed length for each determined step).

For the next measurement presented in Fig. 5(a) the user walked on multiple floors and used the stairs or elevator to change between different floors. Furthermore, for the entire duration of the measurement he had a barometer sensor fixed on his backpack, while another barometer sensor was fixed at the start of the measurement position (on third floor). By determining the difference between these two barometer signals we were able to obtain with high accuracy the exact floor on which the user is located during the measurement. This result is presented in Fig. 5(b). The numbers represent different floors. Finally, the solution presented in Fig. 5(a) has an accuracy better than 2° if we take into account only the heading. The remaining errors are being generated by the distance computation process (especially when the user changes floors by using the stairs). In addition, by combining these two results presented in Fig. 5 the navigation solution can be computed in 3D coordinates.

VI. Conclusion

This paper points out the error sources that affect the accuracy of our inertial navigation system and offer solutions for compensating them. An important improvement was obtained by determining a correlation between temperature fluctuations and the gyroscope angular rate data. Based on the proposed temperature and angle compensation the heading accuracy of the system was improved. Furthermore, by combining the result obtained from a barometer sensor with our 2D navigation solution, the position of the user can be computed in 3D coordinates. As a future development a step length estimation algorithm will be provided.

Acknowledgment

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