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PhD Thesis Abstract

PERSONS AND OBJECTS LOCALIZATION USING SENSORS

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1 Introduction

In recent 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 determines the development of inside building location systems such as infrared based location systems, Radio-Frequency (RF) based location systems, Inertial Navigation Systems (INS), ultrasonic based location systems, etc. Among all of them, inertial technology is the most promising one. This is 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. Also, recently, Micro-Electro-Mechanical Systems (MEMS) technology has become one of the most exciting development areas of inertial sensors. The performances of these new MEMS sensors increased, while the cost, size and power consumption were kept low. A key component of any INS is the gyroscope sensor. Based on the data collected from this sensor, the heading can be computed with respect to the initial position. This means that the accuracy of the INS is affected by its initial alignment.

In the first part of this thesis a gyrocompass system was proposed. The purpose of this device was to initially align the INS. For this, the magnitude of the Earth's rotation rate was measured using a MEMS gyroscope sensor. Based on these measurements the North direction was estimated and the INS aligned. Furthermore, a precise alignment is even more important if the INS is designed to be used for long periods of time and without the support of an additional navigation system.

In the second part of this thesis an indoor navigation system was proposed. The position of the user was computed based on the signals collected from several MEMS sensors. More exactly, a three axis accelerometer sensor was used in order to determine the traveled distances, while the heading of the user was obtained by integrating the angular rate data collected from a gyroscope sensor.

Finally, in the last part of the thesis we present a hybrid navigation system that combines the performances of the proposed indoor navigation system with the ones offered by the GNSS technology. From this merge, we expect to obtain a continuous navigation solution even when the line-of-sight between the satellites and the GNSS receiver is lost.

2 Thesis Objectives

The structure of this thesis follows three main objectives. The first one consists in developing and testing a gyrocompass system able of determining the true North direction with high accuracy. This device will be further used to initially align an INS.

The second objective consists in implementing an indoor navigation system based only on MEMS sensors. Furthermore, for periods of approximately 30 minutes the errors from the navigation solution must be under 10 meters.

Finally, the last objective consists in integrating the proposed indoor navigation system in a Global Positioning System (GPS). From this association a continuous navigation solution is expected even when the GPS receiver is off-line.

3 Thesis Outline

The research work undertaken in this thesis is structured as follows.

Chapter 1 introduces the topics, gives some of the related work, and presents the outline and the contributions of the PhD thesis.

Chapter 2 presents the main sensors used by the current indoor navigation systems, along with the localization algorithms.

The aim of *Chapter 3* is to provide the readers with the necessary theoretical background on Kalman filtering. Later on these filters were used to improve the precision of the proposed gyrocompass system.

In *Chapter 4* the Allan variance was used to determine the stability of several gyroscope sensors. Based on this result, the SCC1300-D02 sensor was chosen to be used in the physical implementation of both gyrocompass and inertial navigation system. Furthermore, at the end of this chapter a study was conducted in order to determine the g-sensitivity of the selected gyroscope sensor.

Chapter 5 presents the design and implementation of a gyrocompass system based on the sensor chosen in the previous chapter. The proposed system estimates the true North direction by measuring the Earth's rotation rate. Also, by using an extended Kalman filter the precision of the system was increased. The purpose of this device was to initially align an INS.

In *Chapter 6* is presented an indoor navigation system, which uses accelerometer sensors to determine the traveled distances, a gyroscope sensor to determine the heading and some barometer sensors to determine the exact floor on which the user is located during the measurements. Based on the results obtained, we can conclude that for periods of approximately 30 minutes, the navigation errors were adequate for indoor navigation.

Chapter 7 uses the results obtained in *Chapter 6* to implement a hybrid navigation system. More exactly, the proposed indoor navigation system was adapted and integrated in a car along with a GPS receiver. By combining the data from the two systems a continuous navigation solution was obtained, even for the areas where the GPS receiver was off-line.

Chapter 8 provides the main conclusions, along with the future development possibilities that arise from the research work undertaken in this thesis.

4 Author's Contributions

The main contributions of this thesis are mentioned bellow:

- Using Microsoft Visual Studio 2008 we have implemented a program for reading and saving the data from the SCC1300-D02 sensor.
- A new method was proposed for measuring the Earth's rotation rate along with an experimental measurement setup.
- The experimental results showed that by using the proposed Kalman filter, the Earth's rotation rate was measured with a much higher precision.
- An extended Kalman filter was implemented for measuring the Earth's rotation rate and also for estimating the true North direction.
- We have implemented an indoor navigation system based only on inertial sensors.
- An algorithm was developed to compensate the angle between the sensitive axis of the gyroscope sensor and the local vertical.
- We determined a relation between the ambient temperature and the bias from the angular rate data.

- Through experimental results we have demonstrated that for periods of approximately 30 minutes, the indoor navigation system was able to determine the user position at room level.
- A method was proposed to integrate the indoor navigation system with a GPS receiver in order to obtain a continuous navigation solution even when the GPS was off-line.

5 Conclusions and Future Work

In the work presented here we have developed a gyrocompass system, an indoor navigation system and at the end a hybrid navigation system. The purpose of the gyrocompass was to initially align the indoor navigation system in order to increase its precision.

The most important component in both gyrocompass and indoor navigation systems is the gyroscope sensor. By using the Allan variance we were able to determine the sensor instability. Based on the result obtained, we established that if the main error sources that affect the output data of the gyroscope sensor are properly compensated for, then it is possible to measure very small angular rates (like the Earth's rotation rate). This conclusion is sustained by the experimental results which show that a measurement error of approximately $0,334°$/hour was obtained for measuring the Earth's rotation rate. Furthermore, by using an extended Kalman filter a precision of approximately $4°$ can be achieved with the proposed gyrocompass system, even if only half of the Earth's rotation rate can be detected by the gyroscope sensor at the latitude of $61,449°$N.

As future work, more sophisticated initialization algorithms to obtain the initial state for the extended Kalman filter and to resolve the sign ambiguity should be developed. The FFT- based initialization used in this requires fairly many samples in order to work reliably. The proposed setup needs hours of time to reach a five-degree-level accuracy, which is infeasible for real-life applications. However, in the future, as the MEMS gyroscope technology progresses, shorter and shorter averaging times can be used, enabling faster North seeking. In conclusion, the results obtained in this study demonstrate the accuracy potential that can be attained using a low-cost thumbnail-size sensor with small power consumption.

The proposed indoor navigation system uses a Pedestrian Dead Reckoning (PDR) algorithm to compute the user position. More exactly, a three axis accelerometer was used to determine the traveled distances while the heading of the user was obtained by integrating the angular rate data collected from a gyroscope sensor. The main contribution to the development of this system consists in compensating the following error sources: non-stationary bias errors, the angles formed during the navigation phase between the sensitive axis of the gyroscope sensor and the local vertical (also known as offset angles) and finally, the development of a relation between temperature variations and the output data of the gyroscope sensor. For determining the offset angles we used the signals collected from a three axis accelerometer sensor, while the temperature relation was established by using the VT7010 temperature control chamber. Even though the system uses a fixed length for each determined step, during all the measurements the user position was determined at room level. Furthermore, by combining the data obtained from a barometer sensor with our 2D navigation solution, the position of the user can be computed in 3D coordinates.

Future work will be focused on developing a step length estimation algorithm and also on finding a more robust solution for compensating the temperature variations from the output data of the gyroscope sensor.

Based on the previous results, the proposed indoor navigation system was adapted and integrated in a satellite based navigation system. From this merge, the continuity of the GPS navigation solution was maintained during the entire measurement, even for the areas where the line-of-sight between GPS receiver and the satellites was lost. Furthermore, the precision of the modified indoor navigation system was similar with the one offered by the most of the commercial GPS receivers.

Regarding the future developments of the proposed hybrid navigation system, we will attend to achieve a hardware synchronization of all the signals and also to develop a printed circuit board that will bring together both devices.

List of Publications

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