Inertial Navigation System for Emergency Responders
A Foot Mounted Dead Reckoning System

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Abstract: It comes as no surprise that the jobs of first responders like police and firemen can be, and often are very perilous. Police teams entering a building to arrest crime suspects, or fire-fighters entering an ablaze building, bring with them serious hazards. For these kinds of situations, some sort of navigation module to keep track of a person's location at all times would be a solution. However, the fact that these situations occur mostly inside buildings, complicates the picture. This paper presents research done on a foot mounted inertial navigation system using zero velocity updates. These updates are done based on steps detected by a pressure sensor. Current results show that this is a promising technique but there are still problems with magnetic deviation due to metal in the building. Future work consist of adding other sensors such as a barometric pressure sensor for floor height and ultrasonic range finding to perform simultaneous localization and mapping (SLAM).

1 INTRODUCTION

Not knowing exactly where someone is can be problematic for both the first responders actually going in, as well as for commanders who supervise their operations and try to coordinate them as well as possible. In case of building collapse, for instance, the position of the fire fighters in the debris is usually not precisely known, making rescue attempts troublesome. For a commander, knowing where his men are could be crucial to the operation's success. For these situations, some sort of navigation module to keep track of a person's location at all times would be a solution. However, the fact that these situations occur mostly inside buildings, complicates the picture. The physical structure and behaviour of materials interferes with traditional methods of navigation such as GPS systems and compasses.

Several methods for indoor navigation are not suitable for these kinds of applications. For instance segment scanning where a building is divided into distinct segments or triangulation where signal strength is used require external hardware. Setting up these external devices is often not an option for first responders. Other options such as using UWB (Stromback et al., 2010); (Bellusci, 2011), existing WIFI (Evennou and Marx, 2006) connections or building blueprints are not always available, especially in older buildings. Therefore this project aims at a standalone navigation device to be worn by the police or the fire fighters.

2 HARDWARE

In this project we use a VN-100 sensor (Vectornav, 2012) (Figure 1) for measuring the acceleration, angular rate and magnetic field strength in the three inertial axes.

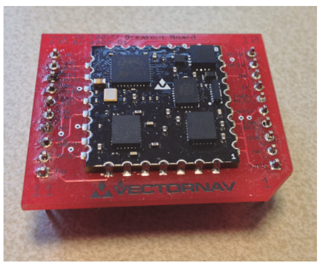

Figure 1: The VN-100 IMU, produced by VectorNav and which is central to this project.

The most important features of the VN-100 are its MEMS based sensors. Each VN-100 chip contains a 3-axis gyroscope, 3-axis accelerometers

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and 3-axis magnetometers. These sensors are constantly sampled, with raw values being written into registers that can be read out by users. The VN-100 however, can already perform a lot of the calculations necessary to convert these measurements into an attitude solution. To estimate attitude, the sensor employs quaternion mathematics. This is done automatically by the chip, and takes into account the offsets created by, for example, gravity and the earth’s magnetic field.

Because data can be noisy and problems like sensor drift could account for some errors in measurement, the VN-100 makes use of an extended Kalman filter to both reduce noise and give the best estimate as to the current attitude solution. Because this filter is run on the chip, no detailed information about the mathematical model is necessary to work with it. What is important to know is that the parameters of this filter can be adjusted by the user, to tweak the sensor for optimal performance in a desired situation.

To interface with the sensor, read out its registers and perform the necessary calculations to come to the position solution, the SunSPOT was used as the sensor platform (Oracle Labs, 2012) (Figure 2). The SunSPOT is a prototyping platform developed by Sun Microsystems. It is programmable in the JAVA language, and offers a series of inputs/outputs to interface with sensors or other peripheral hardware. Using a build-in radio, the SunSPOT is capable of wireless communication up to 20m in theory, although this range can be increased by connecting for example an XBee radio.

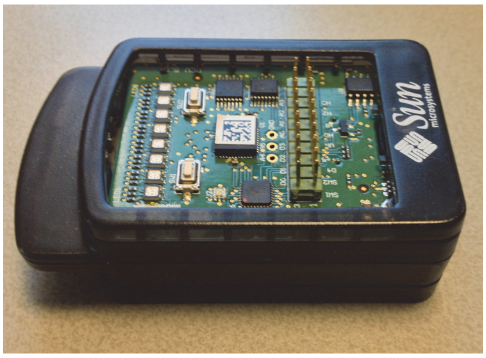

Figure 2: The SunSPOT, developed by Sun Microsystems, and which is used as prototyping platform for this project.

3 INTEGRATION

With the accelerations and attitude in the earth inertial reference frame coming from the VN-100 sensor we can calculate the distance travelled for all axes using double integration. However when calculating velocity and distance from these measurements by integration an integration error is accumulated. The sensor's velocity and thus distance keeps increasing even when the IMU is stationary. By using low cost IMU's for navigation purposes the errors accumulate in such a rapid rate that it is no longer suitable for the application.

3.1 ZUPT

Zero Velocity Updates (ZUPT), a method used to improve the long-term accuracy of the IMU is used in this project. Since the application we are developing is supposed to track the position of a person in a building, the sensor node needs to be placed somewhere on the user’s body. In order to improve long term accuracy of the INS the sensor node is placed on the foot of the user. After each step there is a moment in which the foot is stationary, thus the velocity of the foot is zero. Because we know the velocity should be zero at mid-stance we can set the calculated velocity back to zero, meaning that the errors previously accumulated will not have an effect on future measurements, thus improving long term accuracy (Park and Suh, 2010); (Skog et al., 2010). To detect a footstep this project uses a pressure sensor located beneath the middle of the foot. Figure 3 shows the detection of the ZUPT periods in between the acceleration. The pressure sensor allows us to detect a footstep regardless of how fast you walk. Other methods such as magnitude or variance detection tend to lose accuracy at higher speeds.

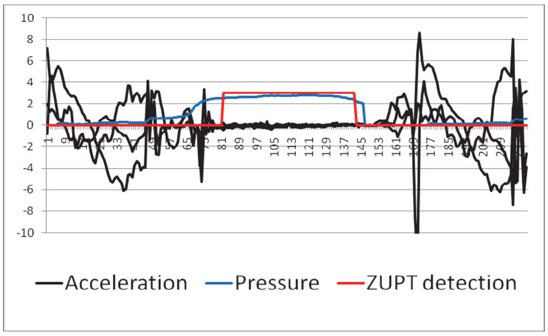

Figure 3: ZUPT detection using a pressure sensor.

There is however another source of error in determining distance. Despite having very dense data sets with roughly 100 measurements per second, the integration is never perfect. Sudden abrupt movements have been found to be

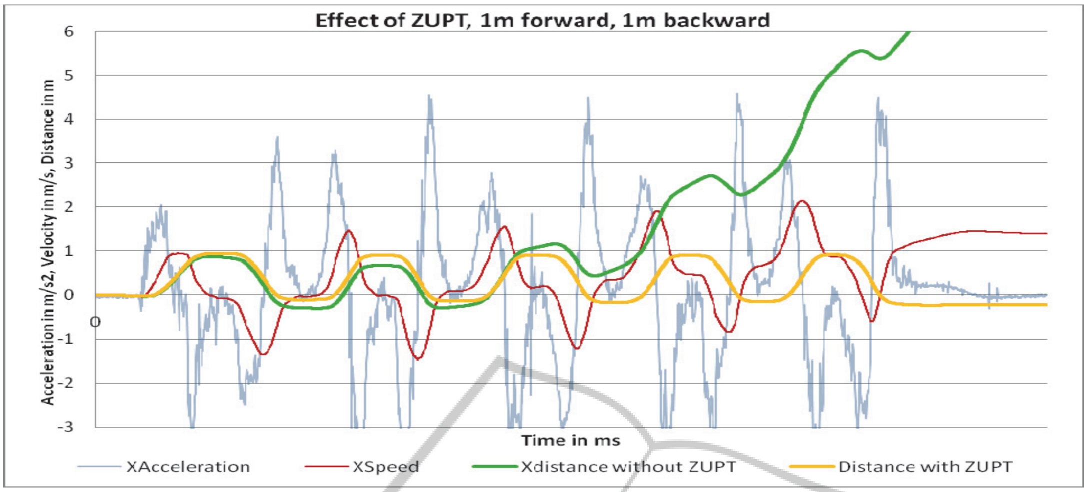

Figure 4: Effects of ZUPT on a data set.

particularly harmful to the quality of the sensor data. In theory, when the ZUPT method kicks in to reset the velocity to zero, the result of the first integration giving velocity should also yield zero. This is however, almost never the case. In most cases, the velocity just before ZUPT differs minimally from zero (in the order of 0.01-0.1 m/s), but sometimes this deviation after a step is larger.
Observation of larger datasets taken over a period of walking, seem to suggest the error is linear in nature, slowly increasing the error in velocity over time, which is best seen in datasets with ZUPT turned off. This leads to the conclusion that to adjust for the error, the red shaded triangle in Figure 5 needs to be subtracted from the overall integral.

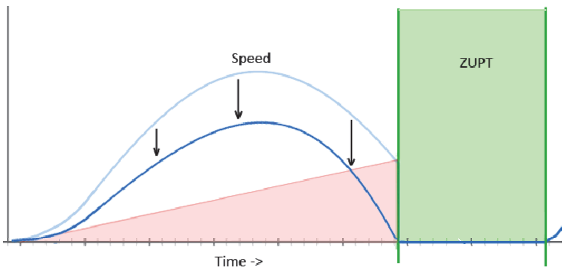

Figure 5: Correction of the integration. Subtraction of the area in error results in moving the velocity graph down, which is shown to produce an increase in displacement calculation accuracy.

The effect of this ZUPT method is shown in Figure 4. It is clearly visible that using this kind of feedback method is essential to the accuracy of an inertial navigation system based on these sensors. This test represents a person continuously stepping 1 m forwards and backwards.

4 CURRENT STATE

Currently the following test result can be displayed, see Figure 6. This picture displays someone walking through our building and getting back to the starting place.

There are however moments where the sensor chip looses orientation due to metal in the building. The VN-100 sensor already has a filter that can try to correct this, but unfortunately this is not enough. Figure 7 clearly shows what happens when the orientation gets lost.

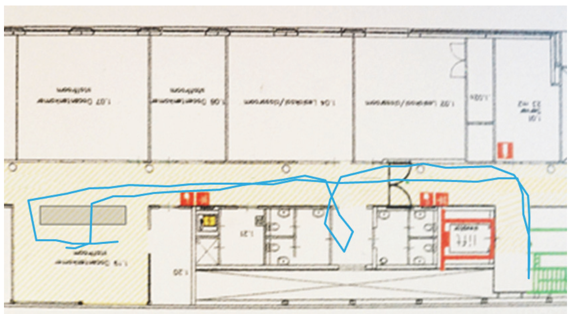

Figure 6: Test walk through the building.

We are looking into other feedback methods to help the navigation system calculate the location. One of these is a barometric pressure sensor to detect floor levels. Results of this sensor can be seen in Figure 8 showing a person walking down three floors and back up again.

However the barometric pressure will change rapidly in a burning building, therefore a combination between sensors should be found.

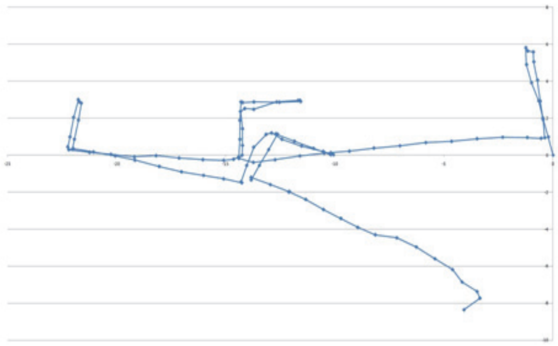

Figure 7: Orientation loss resulting in a wrong calculated path.

Next to that we are working on integrating the proof of concept seen in Figure 9 into the shoe, making the solution more robust.

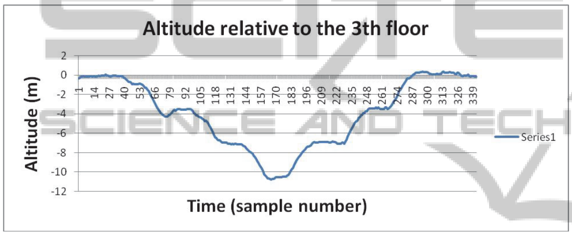

Figure 8: Barometric pressure sensor detecting floor levels.

Figure 9: Current proof of concept.

5 CONCLUSIONS

Overall we conclude that an indoor navigation system based on inertial dead reckoning is feasible but will inevitably result in errors due to magnetic interference and sensor inaccuracy. Therefore other feedback / aiding systems are required to keep navigation accurate for an extended period of time. Zero velocity updates on footsteps detected by a pressure sensor and floor detection using a barometric pressure sensor are examples of that. Further research is to be done on heading correction using e.g. ultrasonic sonar mapping of walls.

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