Pedestrian Tracking with Inertial Sensors

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Seminar on Computer Systems:
Indoor Localization
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Abstract. The Inertial Navigation System (INS) can be used indoor where GPS (Global Positioning System) signals are unavailable and it also can be used outdoor. The INS can be applied in many applications such as finding and rescuing fire fighters, location-aware computing, and personal navigation assistance. The INS uses low-costs IMUs attached in a shoe to track a person position. The experiment has shown the total drift was 0.06 percent of the distance traveled.

Contents

1 Introduction

Global Positioning System or GPS is well known and widely used to track position of objects in outdoor. It can be used to track position of objects such as cars, trains, and even position of human. To track a position of an object, the GPS devices are usually attached to objects, and devices send signal to receivers. GPS uses satellites to receive signal from the tracked objects. However, GPS signals are not always available due to radio propagation such as reflection, absorption, and scattering. The signal can be blocked by high buildings and it cannot be received for instance in the underground of buildings [5].GPS is not suitable for a navigation system that tracks location of person such as finding and rescuing firefighters, emergency first responders, and personal navigation assistance. The location of a person might be in places where it be hidden and indoors which GPS signal cannot be sent through.

The INS (Inertial Navigation System) can track position of objects indoors [1]. It is independent on the satellite signal, therefore it is a great option for indoor localization. INS uses inertial measurement units (IMUs) or also called inertial sensors for measurements. These sensors are such as micro electro mechanical systems (MEMS) accelerometers and gyroscopes. IMUs can be used to track the position and orientation of objects based on a known starting position, orientation, and velocity. The position can be calculated using strapdown inertial navigation algorithm. Also, errors can be corrected using Extended Kalman Filter (EKF) together with zero-velocity updates (ZUPTs) method. INS is widely used in the navigation system such as finding and rescuing fire fighters, location-aware computing, personal navigation assistance, mobile 3D audio, and some mobile applications [1].

The paper aims to introduce INS, the system that can track position of objects such as the position of person indoor. And, the introduction to the Inertial Navigation System will be based on [1].

The remainder of the paper is structured as follows. Section 2 provides background information. It describes the basic terminology for INS and the inertial measurement units (IMUs), also the limitations of the IMUs are described. Section 3 presents the NavShoe concept which attached the IMUs on the shoes; the concept uses EKF together with ZUPTs. Section 4 evaluates the NavShoe concept, gives the results of the experiment from [1]. Finally, Section 5 concludes the paper.

2 Inertial Navigation Systems (INS)

This section, we will start with introduction to Inertial Navigation Systems (INS). Then, we will introduce how position of objects can be calculated. Also, equipment or devices that can measure velocity, acceleration, and positions will be explained. Further, we will explain the advantages and disadvantages of each device. Also, we will introduce a solution of fusion these devices to get more accurate results.

Inertial Navigation is a technique which used inertial measurement units (IMUs) such as accelerometers and gyroscopes for measurements. IMUs can be used to track the position and orientation of objects based on a known starting position, orientation, and velocity. IMUs are typically contained three orthogonal rate-gyroscopes used to measure angular velocity and three orthogonal accelerometers used to measure linear acceleration as described in the next section.

2.1 Position Calculation

Now, we will explain how we can calculate distance from a known starting position, orientation, and velocity. There are many algorithms to calculate position using accelerometers and gyroscopes. In this paper, we will explain an algorithm or framework called “strapdown” inertial navigation algorithm. The big picture of the algorithm is illustrated in the figure 1. In the strapdown algorithm, the IMUs are mounted rigidly onto the device such as mounted onto mobile devices or handheld devices. The signals from the rate gyroscopes are “integrated” to get the orientation. Also, three accelerometer signals are calculated into global coordinates using the known orientation from the integration of the gyroscope signals. The global acceleration signals then have to be subtracted from the acceleration due to the earth gravitation .After that, the global acceleration signals are integrated two times (double integration) to obtain the position as can be seen in the figure 1.The limitations in of the strapdown algorithms will be given in the next section.

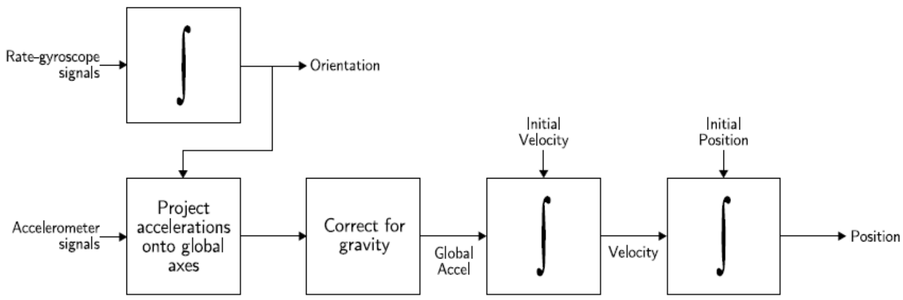

Fig. 1. Basic strap down inertial navigation algorithm [4]

2.2 Inertial Measurement Unit (IMU)

In the section 2.1 introduces the fundamental of inertial navigation system and described how we can calculate the position of an object from known parameters such as orientation, velocity, and a starting position. We can use strapdown algorithm to calculate the position. The inputs of the strapdown system are signals from gyroscopes and accelerometers, and the output of the system is the position. This section will give information about accelerometers and gyroscopes.

Accelerometer

As described in the section 2.1, we can use accelerometers to measure acceleration. Once we have the acceleration, we then integrate the signal one time to get the velocity, and integrate the signal the second time to get the position [4].

Accelerometers can be found in many devices such as smartphones, handheld devices, and in some notebooks that shutdown the hard drive, when it get dropped. There are many types of accelerometers in the market. In this paper, we will focus on MEMS accelerometers that we can attach to t-shirts, rucksacks or to the shoes. An accelerometer is working in principle based on Newton's second law of motion:

$$\boldsymbol{F} = \boldsymbol{m} \times \boldsymbol{a}$$

where $\boldsymbol{F}$ [N] is the force caused by a mass $\boldsymbol{m}$ [kg], and an acceleration $\boldsymbol{a}$ [m/s^2]. A single axis accelerometer consists of a mass, hanged by a spring in a housing as shown in the figure 2. The value of springs $\boldsymbol{k}$ [N/m] can be calculated using Hooke's law. Hooke's law states that a spring will exhibit a restoring force which is proportional to the amount it has been expanded or compressed. Specially, $\boldsymbol{F}$**=kx,** where **k** is the constant of proportionality between displacement $\boldsymbol{x}$ [m] and force $\boldsymbol{F}$ [3]. The force $\boldsymbol{F}$ causes the mass to either compress or expand the spring under the constraint that $\boldsymbol{F} = \boldsymbol{ma} = \boldsymbol{kx}$ [3].Then, we get the displacement **x=ma/k** or we can calculate the acceleration using:
$\boldsymbol{a} = \boldsymbol{kx}/\boldsymbol{m}$. To measure more than one axes, we need to attached the system along each of the required axes.

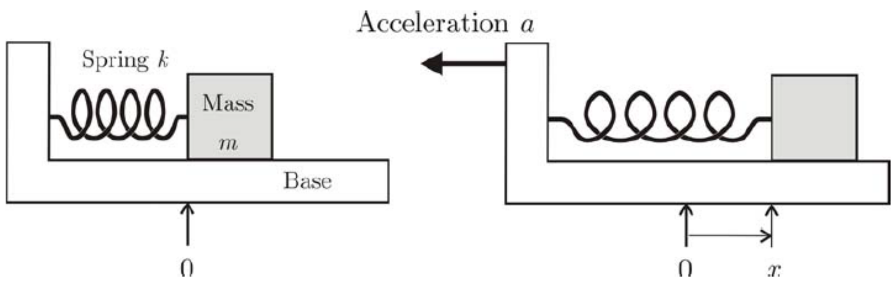

Fig. 2. A single axis accelerometer consisting of a mass hanged by a spring. No acceleration (left). Acceleration of base to the left resulting in an expanded spring (right) [3].

Gyroscope

Gyroscopes are instruments that are used to measure angular motion. There many types of gyroscope, however in this paper we are interested in only the vibrating mass gyroscopes because they are small, inexpensive and require low power consumptions. Therefore, they are suitable for human movement analysis [3]. Vibrating mass gyroscopes are MEMS (Micro-machined Electro-Mechanical Systems) devices. A vibrating resonator that can be vibrated, when it rotated, it will cause the secondary vibration orthogonal to the primary vibrating direction due to the Coriolis effect [3] .We can measure the rate of the turn by sending the secondary vibration as can be seen in the figure 3. The Coriolos force is then given by:

$$F_c = -2m(\omega \times v)$$

where m is the mass, v the momentary speed of the mass relative to the moving object to which it is attached and ω $[\frac{rad}{s}]$ the angular velocity of that object.

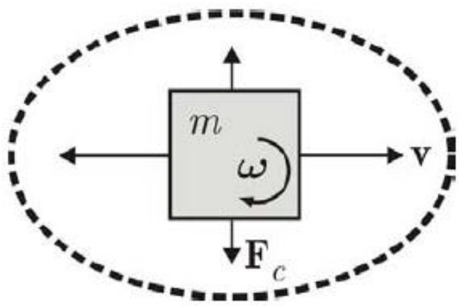

Fig. 3. A vibrating mass gyroscope consists of mass, which is brought into vibration. When the gyroscope is rotated, the mass will undergo a small additional displacement caused by the Corolis force F_c in the direction perpendicular to the original displacement [3].

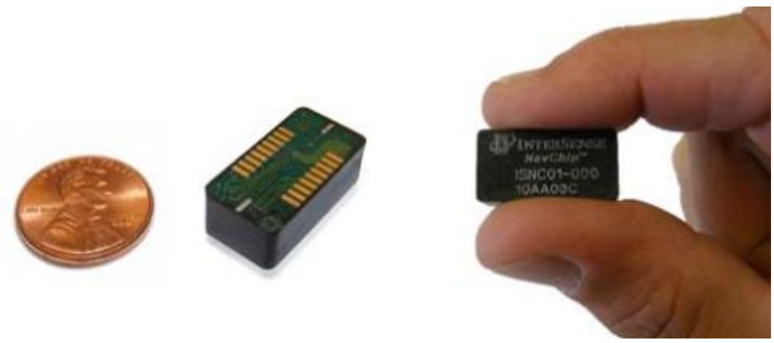

Fig. 4. An example of IMU from the IverSense company. It illustrates bottom and top views of NavChip surfacemount package [2].The chip is integrated with both gyros and accelerometers.

Limitations
In the section 2.1, we have introduced how the position of an object can be obtained using the strapdown algorithm. In [1] claims, it is impossible to track position using inertial sensing alone for more than one second due to errors from the IMUs. In [1], introduces a concept called "NavShoe" concept. The concept attempts to circumvent the problems using the Extended Kalman Filter (EKF) navigation error corrector. The errors have to be corrected in advance before they enter further calculations. Further, as described in the last section, the IMUs depends on the earth's gravitation, in the environments where no usable readings of earth's magnetic field cannot be obtained, the sensors are useless. This NavShoe concept will be described in the next section.

3 The NavShoe Concept

The accelerometer sensors attached to human body are influenced not only by the acceleration of the body, but also from the environments such as noise, the bias of the accelerometer, and earth gravity [2]. The NavShoe concept attaches inertial sensing into the shoelaces. When we are walking, our feet alternate between a stationary stance phase and a moving stride phase. Both two phases are lasting about 0.5 seconds [1]. To remove noises from the output of the IMUs and their errors, we can use zero-velocity updates (ZUPTs) as pseudo-measurements, and applyit into the EKF. When for example, our feet is in the stance phase, the ZUPT is applied, and the signal is sent into the EKF to correct the velocity error after each stride. Meaning that each stance phase, we have to set the velocity to zero and send the signal into EKF. The EKF receive the ZUPTs, learns, and corrects both the velocity error and the position error. The accuracy of this concept is 0.3% of walking distance [2]. The figure4 illustrates the IMU of the NavShoe system and its receiver. The IMU is mounted on a shoe as can be seen in the figure 6, the signal can be read from there and sent to the EKF. Further, as can be seen in the figure 5, there are two components of NavShoe; one is the wireless InertiaCube3 (IC3), and the other is its receiver. The signal can be read from the receiver into a PDA or a wearable computer (see figure 8).

Fig. 5. Wireless InertiaCude3 or IC3 (on the right), and its receiver (on the left) [1]

Fig. 6. The NavChip mounted on a shoe and the handheld PC to visualize the navigation [2]

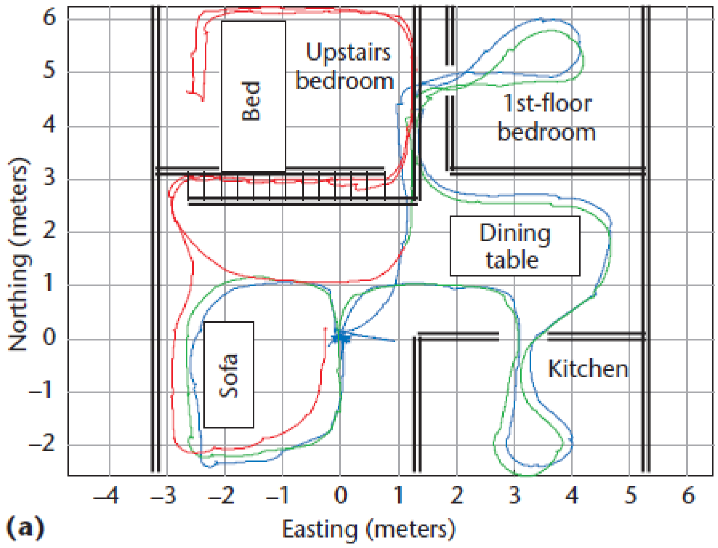

Fig. 7. NavShoe trajectory during a 118.5-meter exploratory path through a house [1]

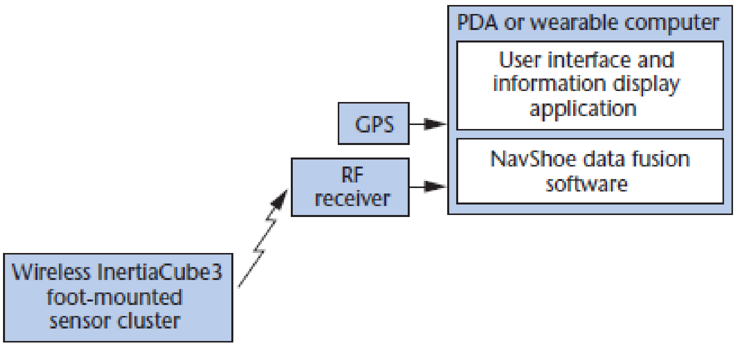

Fig. 8. The NavShoe System block diagram [1]

4 NavShoe Experiment and Results

The experiment performed indoor and outdoor. In this paper will describe only the result from indoor experiment. The experiment allowed a user walk through a typical wood-frame house. The time of walking was 322 seconds that covered 118.5 meters. The start position of the user was at (0, 0, 0) in the first floor of the living room as can be seen in the figure 7. The figure7 illustrates the experiment; the blue line shows the first journey, the green line for the second journey, and the red line represents the final journey. As can be seen, the first and the second journey are almost coinciding. The final position reported by the tracked is at (-0.32, 0.10, -0.06), that means the position of the entire journey drifted by 0.3 percent of the distance travelled [1].The experiment reported the total drift was 6 centimeters or 0.06 percent of the distance traveled, and the main error came from the heading drift [1].If we compared the NavShoe to a simple pedometer using for tracking a position of a firefighter, then the NavShoe provides advantage over a simple pedometer because it provides more accurate position. A rescuer would easy find the position of a NavShoe-tracked firefighter in which room and on which floor he/she can be found.

5 Conclusion and Perspectives

In this paper we have introduced Inertial Navigation System or INS for indoor and outdoor position tracking. This navigation system has advantage over the GPS because it is independent on satellite signals and it can be used both indoor and outdoor. The system can be used in places where GPS signals are unavailable such as in buildings and underground. INS uses inertial measurement units (IMUs) such as accelerometers and gyroscopes for measurements. The orientation can be tracked by gyroscopes, whereas acceleration can be tracked by accelerometers. By integration of the gyroscope signals, we will get the orientation. Global coordinates of acceleration can be calculated using the known orientation calculated from the gyroscopes. The global acceleration signals then have to be subtracted from the acceleration due to the earth gravitation and double integration to get the position. However, is impossible to track position using inertial sensing alone for more than one second due to errors from the IMUs.We first have to correct the errors to get the accurately position. To do so, in the case of NavShoe, it uses ZUPTs method to reset the velocity to zero for each stance phase as pseudo measurements and applies these measurements into the EKF to correct the navigation errors. The IMUs can be attached on a shoe which called IC3. IC3 is a wireless component and it has a receiver which can be attached to PDAs or wearable computing to visualize and calculate the navigation. The experiment reported acceptable results. That is, the total drift was 0.06 percent of the distance traveled. The time travel was 322 seconds with three rounds. However, the report has not described if the test person has only walked or also mixed between walking and running actions. We believe that the research in this area is growing as can be seen in [2] and hopefully, the IMU prices will soon be decreased.

6 References

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