PNI White Paper

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Accurate Position Tracking Using Inertial Measurement Units

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This white paper presents an overview of inertial position tracking using an Inertial Measurement Unit (IMU). Following the overview is an explanation of the primary challenges to successful inertial position tracking with an emphasis on the impact of inaccuracies which occur in the presence of magnetic anomalies. Finally, results from one of the leading inertial position tracking systems using the PNI SpacePoint Fusion sensor will be shown.

Inertial Position Tracking

Inertial position tracking can be accomplished using IMUs containing triads of orthogonally mounted accelerometers, magnetometers, and angular rate sensors. The accelerometers measure the sum of linear acceleration due to movement and gravitation acceleration. The magnetometers measure the direction of the local magnetic field. The triad of angular rate sensors delivers a measure of three dimensional rate of rotation of the module. Measurement of the direction of Earth's gravitational and magnetic field vectors along with the angular rates allow estimation of the orientation of the sensor module using one of several data fusion techniques. These orientation estimates in turn can be used to transform acceleration measurements from the moving body coordinate frame to an Earth fixed reference frame and allow the subtraction of gravitational acceleration from the total acceleration measurement. The remaining acceleration can be double integrated to estimate position relative to the initial starting point.

This sensor set is self-contained, allowing it to be used in almost any location without fixed infrastructure or prior knowledge of the environment. Other tracking systems either rely on an external reference system (i.e. GPS satellites, cameras, or stationary sensors) or require line of sight for mapping and localization (i.e. ultrasonic systems, mobile cameras, laser scanners).

Challenges of Inertial Position Tracking

Position tracking through the use of Inertial Measurement Units has long presented challenges. There are two primary obstacles to accurate position or movement estimation for IMUs.

- Accurate orientation estimation of the IMU relative to earth's gravitational and magnetic fields.
- The quadratic growth of in position error due to double integration of acceleration data containing bias and drift errors.

Accurate Orientation Estimation and Field Magnetic Anomalies

Having an accurate measurement of the orientation of the IMU is absolutely essential to successful position tracking. In the approach described here, the gravity and magnetic field vectors act as "fixed" references. For a stationary sensor in an environment free of magnetic anomalies, it is simple to determine the orientation by measuring earth's gravitational and magnetic fields along all three axes of the orthogonally mounted sensors. The combination of the two resulting vectors can be combined to provide complete yaw, pitch, and roll information. In more dynamic applications, high frequency angular rate information can be combined in a complementary manner with accelerometer and magnetometer data through the use of a sensor fusion algorithm.

As mentioned above, orientation estimates are used to both subtract gravitational acceleration from the total acceleration measurement and to transform acceleration measurements to an Earth fixed reference frame where they can be double integrated to estimate position. Poor orientation estimates cause errors in two ways.

First, if the estimate of the sensor relative to the vertical is erroneous, an accurate separation of acceleration due to gravity and movement will not be possible. Following double integration, this will result in error in the magnitude of movement. In most cases, proper turning of the fusion algorithm for the speed and frequency of movement and the selection of appropriate gains or the use of adaptive gains can mitigate this type of error.

Second, poor estimates of orientation overall, especially relative to the horizontal plane can produce inaccurate transformation of accelerometer data to the Earth fixed frame. In effect, such errors cause the estimate of movement to point in the wrong direction.

Pitch and roll can be accurately estimated using only accelerometers. However, rotations about the vertical or gravitational axis will cause no change the sensed acceleration. Thus, magnetometers and their measurement of the magnetic field vector are necessary determine the direction of movement relative to the horizontal plane or azimuth. Filtering algorithms typically treat the direction of the local magnetic field as a fixed reference. However, the presence of ferrous objects in the tracking area can cause the magnetic lines of flux to bend. This problem is particularly acute in an indoor environment where, sources of magnetic interference are constantly present and can include common items such as ferrous metals, computer monitors, fluorescent lighting and powered electrical wiring. If not properly handled by the sensor fusion algorithm, there variations can cause large position estimation errors even if the estimate of total distance traveled is highly accurate.

Fusion algorithms, such as PNI's SpacePoint API, combine angular rate and acceleration data with magnetic field readings to filter out and reject variations caused by magnetic anomalies. Assuming the estimate of total distance traveled is accurate, such algorithms make it possible to produce accurate dead reckoning position estimates.

Inertial Position Tracking In Practice

The results of an experiment comparing the use of different Inertial Measurement Units (IMU) for Self-Contained Inertial Position Tracking (SCIPT) are presented below. SCIPT is a pedestrian inertial tracking system that uses foot mounted inertial sensors. SCIPT takes advantage of periods of known zero-velocity during each stride to correct velocity and position estimates.

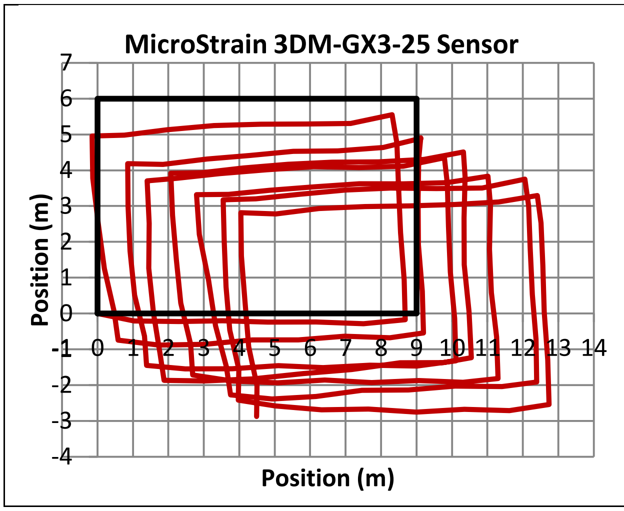
Indoor Position Tracking Results

Two trials were conducted to assess the impact of different IMUs on the accuracy of SCIPT. The two IMUs that were selected for comparison are the MicroStrain 3DM-GX3-25 and the PNI SpacePoint Scout. The MicroStrain 3DM-GX3-25 is an expensive, high quality IMU capable of operating at up to 1000Hz. The 3DM-GX3-25 has been used with SCIPT for several years and has proved to be very reliable. The second IMU under evaluation is the PNI SpacePoint Scout, an IMU developed for gaming and human motion tracking that operates at 125Hz. The PNI SpacePoint Scout is significantly less expensive, currently about 1/20th the cost of the MicroStrain 3DM-GX3-25; however it contains the very sensitive, high resolution, PNI RM3000 geomagnetic sensors. A third trial introduces the use of the SpacePoint API, data fusion algorithm developed by PNI. The SpacePoint API provides more stable heading information in the presence of local magnetic distortions, which are common in indoor environments.

Each trial consisted of a seven laps around a rectangular path with a 30m perimeter for a total distance of 210m. Five trials were conducted for each of the three test conditions and each trial begins and ends in the same physical location. The distance between the initial and final estimated positions represents the total drift or error accumulated during the walk. All trials were conducted in the same location with the same user. Plots of the resulting position estimates under each test condition are shown in *Figures 2-4*. *Figure 5* presents the results overlaid for easy comparison. The black line in Figures 2-5 represents the physical path that was used. *Table 1* presents a summary of the results of the five trials under each test condition.

	Average Drift – Percent of Total Distance	**Standard Deviation**
MicroStrain 3DM-GX3-25	2.33%	0.48%
SpacePoint Scout - Raw Sensor Data	0.89%	0.42%
SpacePoint Scout - SpacePoint® API	0.36%	0.11%

Table 1: Summary of Indoor Results Under Moderate Conditions



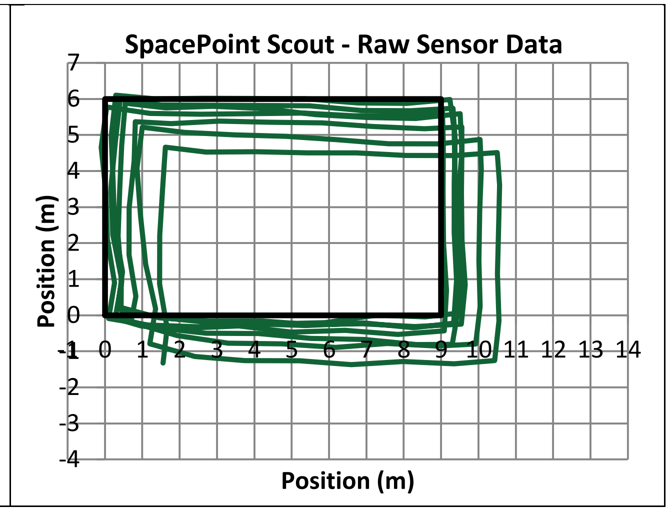
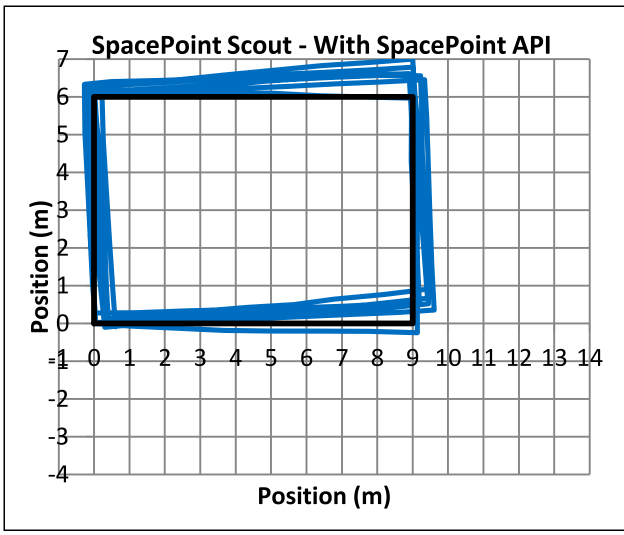


Figure 2: 210m Walk with MicroStrain 3DM-GX3-25

Figure 3: 210m Walk with SpacePoint Scout



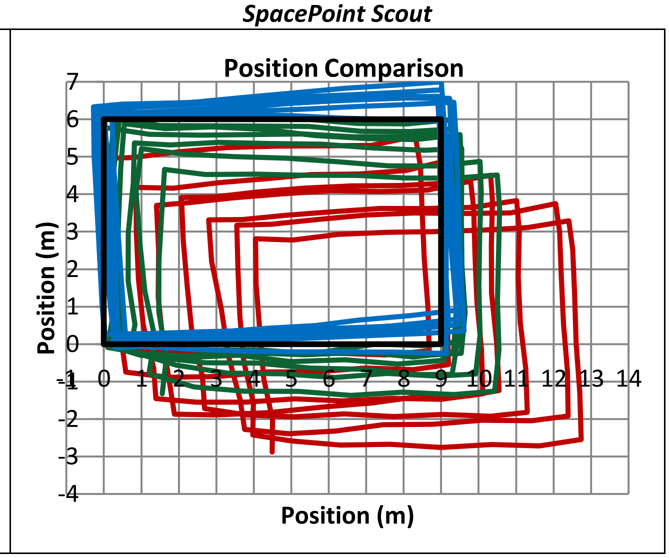


Figure 4: 210m Walk with SpacePoint Scout and SpacePoint API

Figure 5: Position Tracking Comparison

The approximately two percent drift that was observed using the MicroStrain 3DM-GX3-25, shown in Table 1, is fairly typical of previous results using SCIPT in an indoor environment with moderate magnetic conditions. The drift is typically less outdoors, where there are very few local magnetic distortions, and can be significantly higher in harsh magnetic environments. The primary cause of the drift is incorrect heading estimation resulting from local magnetic distortions. These effects can be clearly seen in *Figure 2*. Despite the fact that the accelerometers and angular rate sensors in the MicroStrain sensor are of superior sensitivity to those in the SpacePoint Scout, a 62% reduction in drift is observed when using the SpacePoint Scout. This improvement can be explained largely by better heading estimation made possible by the higher sensitivity and accuracy of the PNI RM3000 geomagnetic sensors in the SpacePoint Scout. The improved heading is evident when comparing *Figure 2* with *Figure 3*.

Even better performance is observed with the addition of the SpacePoint API data fusion algorithm with a reduction in drift of 85% compared with the MicroStrain 3DM-GX3-25. Again the reduction in drift can be explained largely by improved heading estimation. Looking at the results in *Figure 4* it is apparent that the effect of local magnetic distortions has been largely eliminated by the SpacePoint API. The sides of the walk, which had significant variation in heading in *Figures 2 and 3*, are almost completely consistent in *Figure 4*.

The results of this study demonstrate that the SpacePoint Scout is highly effective for use in inertial position tracking, outperforming IMUs that cost as much as twenty times more. This improved performance is due in a large part to the high sensitivity of the PNI RM3000 geomagnetic sensors and SpacePoint API data fusion algorithms. Combined these features provide highly reliable heading information, even in indoor environments.