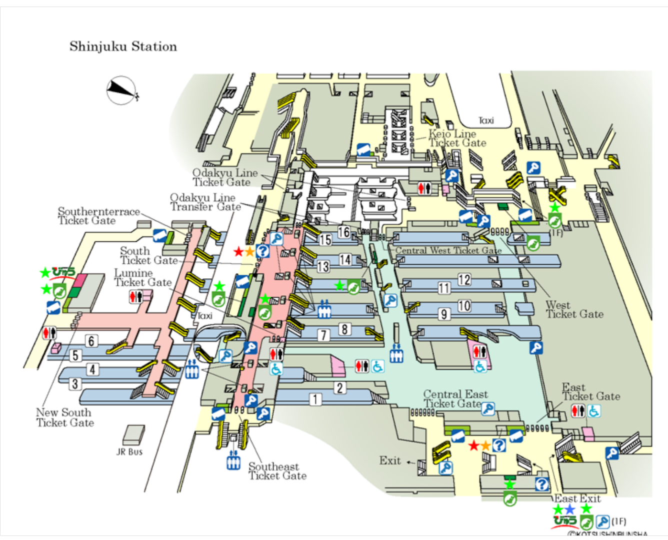
FreeMotion-*Locate*™: ***Position and Attitude Indoors***

Knowing one's position and attitude indoors will enable many new consumer applications. A consumer can use the information to navigate a shopping mall or a subway station. He can also be directed to where in the parking garage he has left his car. Manufacturers can notice that a consumer is near a point of sale and automatically present her with a targeted incentives to spur a purchase. Tourists can recall or look up the subjects in their photographs because the camera taking the picture had geo-tagged the photo with the location of the camera and direction it was pointing. Residents in an automated home can even point to an appliance and control them. Sensor Platforms' FreeMotion-*Locate* library is being developed to address the challenge of tracking indoor positions and attitudes.



High level map of Shinjuku station in Japan. This busiest train station in the world is a multi-level structure that houses 29 tracks of railroad, 6 subway platforms, 8 department stores various shopping arcades and well over 200 exits. Indoor navigation would be sorely needed here.

Physics is Not Enough

Conventional navigation solutions, such as an inertial measurement unit (IMU) in an airplane, combine information from a gyroscope and a compass to determine heading and integrates data from an accelerometer over time to estimate distance. These solutions apply physics and basic mechanics to fuse the sensor data into location and motion estimates. For indoor applications, however, relying on physics alone is not enough.

In Chinese, a compass is literally translated as a "south-pointer." While that is indeed the purpose of a compass, the description is far from truthful. A compass, in reality, is made of a magnetometer that measures the polarity of an ambient magnetic field.

Indoor environments include many localized magnetic field distortions: steel girders, main power lines in a tall building, elevator wells, refrigerators, etc. A small error in attitude estimate due to the influence of any magnetic distortion results in a very large error in location estimates over time.

Furthermore, avionic instruments are well secured to the chassis of an airplane. Any indoor positioning system usable by consumers must be handheld. Consequently, not only do the sensors suffer from environmental distortion, they are affected by voluntary and involuntary movements of the user. These include hand tremors, inadvertent motions of the arm or hand, twists of the torso, and other biomechanical interferences.

The figure below illustrates the situation. It records the acceleration at various frequencies recorded by an accelerometer. The graph on the left shows the result when it is sitting on a desktop and the graph on the right shows when it is held "motionless" by a user. The measurement taken in hand is about 7 times higher and the acceleration profile looks completely different in-hand.

The sharp spikes in the graph on the right are generated by involuntary hand tremors. The lower frequency signals corresponds to other unconcious motions in a "steady" hand. One should note that amplitude of the tremor was recorded above 2.5 m/s^2, over one-fourth the magnitude of Earth's gravity. The accelerations resulting from these movements often overwhelm the signal needed to track travel movements.

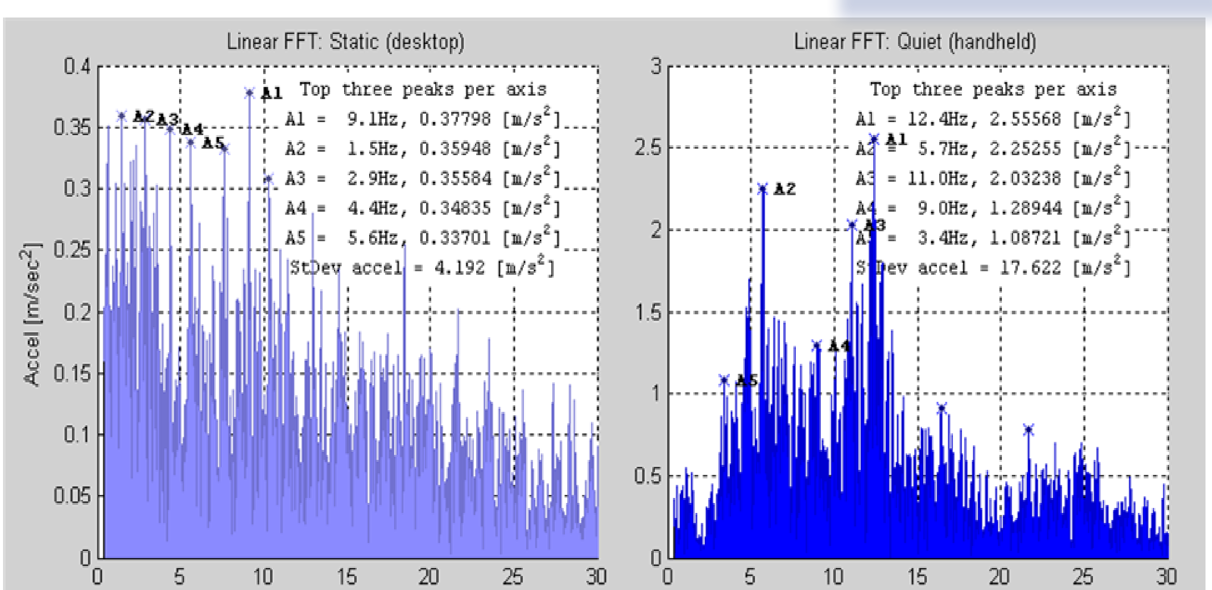
Further complicating the challenge, consumer grade sensors, like micro electro-mechanical system (MEMS) based gyroscopes found in digital cameras and smart phones suffer from large drift errors. Drift refers to the accumulated effects of sensor noises. As gyroscope outputs are integrated over time to estimate attitude, the effects of noise accumulates and causes an unbounded uncertainty for the estimate.

FreeMotion™ as a Foundation

Sensor Platforms' FreeMotion interface technology is successfully deployed in smart remote control interfaces and in infinite reality computer games. FreeMotion takes the artifacts associated with hand motions into account and takes in a set of over-determined data from low cost sensors data to accurately determine attitude changes at 100 times per second.

In the course of developing FreeMotion, Sensor Platforms developed a large, diversified test battery to identify and compensate for the presence of anomalies induced by the user and by changing environments. This allows FreeMotion to contribute accurate attitude determination towards addressing the challenges of indoor navigation and absolute pointing.

Acceleration measured on a device stting on a table (left) and the same device held stationary in hand (right).



References Bound the Errors

Left without an absolute positional reference, estimates using an IMU alone would still have an unbounded uncertainty over time. Consequently, a positioning system indoors cannot rely on sensor data alone for long.

Today, many indoor positioning systems under development rely on prior knowledge of a set of reference beacons. Some research attempts to use the much attenuated GPS signals indoors. Others compile databases of the locations of cell phone towers, WiFi access points and their associated signals to replace GPS as references when satellites become inaccessible.

Estimating positions using a set of reference beacons alone is also inadequate for determining accurate indoor position and attitude. Radio signals from these beacons suffer from multipath and occlusion effects. As a result, they can only provide relatively coarse estimates, typically containing errors much larger than one meter.

Combining Everything

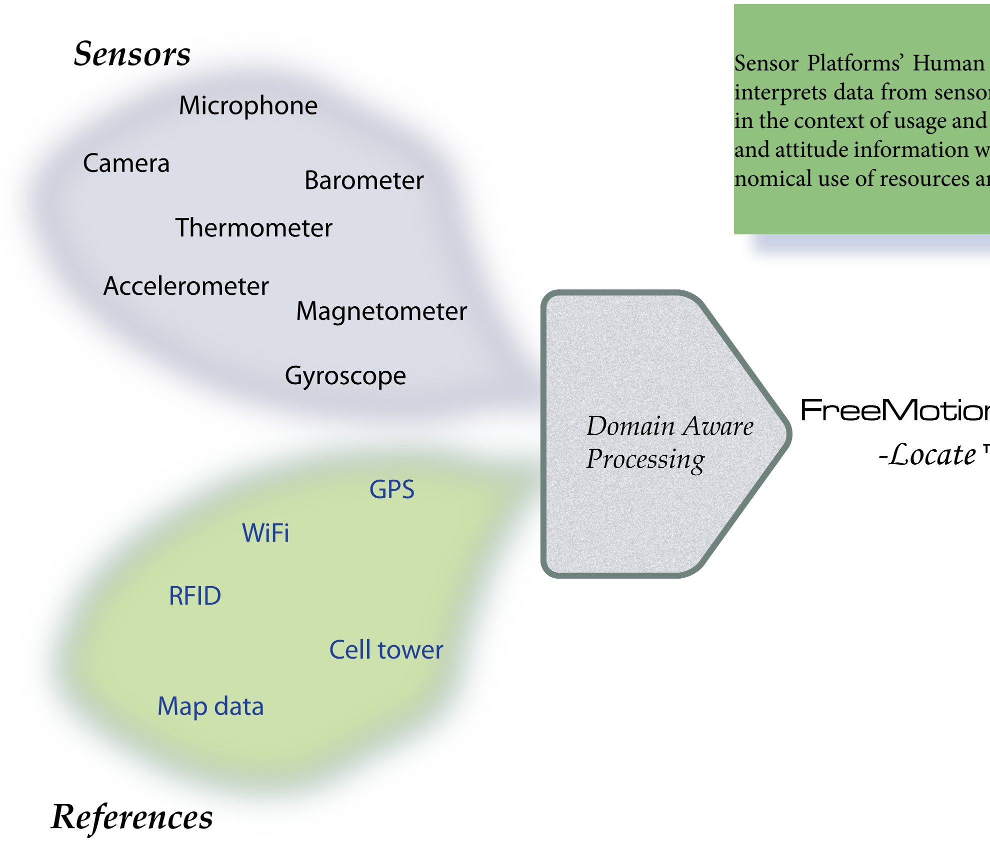
Any system for tracking indoor position and attitude must leverage an intelligent combination of sensor and reference data. Understanding the usage environment and context is helpful in making this potentially large data set more manageable and meaningful.

For example, multipath signals from reference beacons can result in discontinuous positional estimates. Using sensor data and understanding the limits of kinematics, the system can correctly identify that it is experiencing multipath errors and interpret the beacon data accordingly. Similarly, beacon and gyroscope data can help the system identify the type of localized magnetic field distortion so that it can treat magnetometer data differently

Context and Domains

Providing a user's position and the direction he is pointing in a way taht is meaningful to the user requires more than integrating available sensor data. Motion that is meaningul

Sensor Platforms' Human Dynamics Filter interprets data from sensors and references in the context of usage and delivers position and attitude information while making economical use of resources and power.



in one context may be superfluous in another. For example, hand motion in a user interface application might be a meaningful gesture but in the context of handheld inertial navigation, it becomes a distraction that should be ignored.

Furthermore, applications using position and attitude information must work in environments where they need to be mindful of their power and resource consumptions. Noteably, navigation applications running on a smart phone may decide to rely less on databases in the cloud when battery level is low or when wireless data bandwidth is expensive.

Sensor Platforms' FreeMotion-*Locate*™ library is designed to be aware of the domain in which it operates. Applications can call the library with different optimal performance criteria. An intelligent resource manager automatically adjusts the algorithm so that it may intelligently conserve resources.

Sensors and Beacons At Hand

Handheld consumer electronics devices, such as smart phones and digital cameras, include a large number of sensors and beacons that can be used by FreeMotion-*Locate*. These include accelerometers, gyroscopes, magnetometers that provide motion and attitude data. WiFi and cell phone receivers provide ranging data from known signal sources. Cameras scan the environment and use optical cues to augment tracking. Even the microphone and speakers can be used for sonic beaconing. Sensor Platforms continues to create key strategic alliances to make sensor and beaconing data available.