

Utility of Sensor Fusion of GPS and Motion Sensor in Android Devices In GPS-Deprived Environment

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Abstract

These days most of android devices are equipped with GPS sensors and motion sensors (accelerometer, magnetometer and gyroscope sensors). GPS uses network known GNSS satellite positions to calculate any position and it is accurate to meter level. This means gps antennae needs a clear view of sky. In GPS deprived conditions like urban settlements and indoors (inside airports, hotels, malls) it doesn't give position effectively. Median horizontal error in static outdoor environment is around 5.0 to 8.5 m. In dense and crowded areas with more buildings it is even worse. On other hand, in same device, Compass provides orientation, gyroscope provides direction of motion and accelerometer provides speed. Using these devices can track its position with reference to itself, also known as Inertial Navigation System (INS). These computations can be made continuously, autonomously and independent of external factors. But small errors in observations accumulate on longer observation period giving large error. Combining these two methods i.e. GPS acquisition as external source of position and INS system as internal source of position computation, to derive a more accurate estimate of user's position. error accumulation from INS can be limited using gps observations. And INS can complement in GPS deprived condition. A Kalman filter is implemented to predict user's position using motion sensors and laws of motion and gps observations is used to access accuracy and provide better estimate of user's position.

Keywords: GPS, INS, Kalman, Sensor, Android

1. INTRODUCTION

use of Global Positioning System (GPS) signals to deliver location-based services has been widely implemented by smart phones, especially android and iOS devices. Companies like MapQuest, teleatlas, navteq and mapbox have already been exploiting services like Google Maps, Apple Maps, Nokia Maps and many more. potential of extending usability of these services to larger ground level users depends largely upon how accurately position can be captured. Localized service delivery with users in center is new marketing strategy.

Global Positioning System (GPS) is a space-based navigation system that provides location and time information in all weather conditions, anywhere on or near Earth where there is an unobstructed line of sight to four or more GPS satellites. [1] system provides critical capabilities to military, civil, and commercial users around world. However, position accuracy is limited by several error sources and varies from centimeter to meter level depending on conditions. [2]. performance of GPS is degraded in urban and indoor environments due to poor geometry, weak satellite signal reception, fading and severe multipath. This limits availability and accuracy of GPS solution especially in indoor environments. [2]

Non-GPS positioning techniques [3], can provide accurate short-term navigation solutions, such as Inertial Navigation Systems and Attitude and Heading Reference System [4]. However, such systems have unrestrained positioning errors in absence of coordinate updates from other information sources such as GPS or other wireless measurements. As other alternatives, terrestrial wireless positioning methods can also be used to determine user location. These methods use radio frequency signals to determine position of user. Examples are use of broadcast single carrier systems such as Amplitude Modulated (AM) and Frequency Modulated (FM) radio signals, cellular communication systems, or broadcast multicarrier systems for positioning applications.

One class of solutions is known as hybrid positioning system. Such systems integrate other methods in order to enhance availability and robustness of positioning solutions [5]. In other words, non-GPS technologies can be employed as augmentation or back-up in GPS-denied environments.

1.1 GPS AND ACCURACY

GPS receivers use geometric trilateration to calculate current location using signal messages from different satellites. A GPS message contains information about time when message was sent, precise orbital information, health of system and information about orbits of other satellites. Receivers calculate transfer time of each message and compute distance to satellite. Distances to satellites together with satellites' locations are used to calculate position of receiver. Highly accurate latitude, longitude and altitude information can be determined, however, line of sight (LOS) is required for functioning. This leads to an inability to use these systems in an indoor environment where LOS is blocked by walls and roofs. For any GPS to function properly antennae needs a clear view of sky. Smart phone users tend to be in urban settlements and indoors, where sky is not visible. Unfortunately, GPS accuracies of smart phones have not been studied nearly as thoroughly as typical GPS receivers. During static outdoor testing, positions provided by mobile phones revealed a median horizontal error of between 5.0 and 8.5 m. Horizontal errors during static indoor testing were larger compared to outdoors. Testing under various conditions revealed frequent possibility of very large errors. Maximum horizontal error in outdoor testing is 30 meters and in indoor testing is 100 meters.[6]

1.2 INERTIAL NAVIGATION SYSTEM

An inertial navigation system (INS) is a navigation aid that uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate via dead reckoning position, orientation, and velocity (direction and speed of movement) of a moving object without need for external references. [7] It is used on ships, aircraft, submarines, guided missiles, and space-crafts. INS is initially provided with its position and velocity from another source (a human operator, a GPS satellite receiver, etc.) accompanied with initial orientation, and thereafter computes its own updated position and velocity by integrating information received from motion sensors. Advantage of an INS is that it requires no external references in order to determine its position, orientation, or velocity once it has been initialized. An INS can detect a change in its geographic position (a move east or north, for example), a change in its velocity (speed and direction of movement), and a change in its orientation (rotation about an axis). It does this by measuring linear acceleration and angular velocity applied to system. Since it requires no external reference (after initialization), it is immune to jamming and deception.

All inertial navigation systems suffer from integration drift: small errors in measurement of acceleration and angular velocity are integrated into progressively larger errors in velocity, which are compounded into still greater errors in position. Since new position is calculated from previous calculated position and measured acceleration and angular velocity, these errors accumulate roughly proportional to time since initial position was input. Therefore, position must be periodically corrected by input from some other type of navigation system. By tracking both current angular velocity and current linear acceleration measured relative to moving system, it is possible to determine linear acceleration. Inertial navigation is usually used to supplement other navigation systems, providing a higher degree of accuracy than is possible with use of any single system.

1.3 KALMAN FILTER

Kalman filtering, also known as linear quadratic estimation (LQE), is an algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those based on a single measurement alone. Kalman filters also are one of main topics in field of robotic motion planning and control, and they are sometimes included in trajectory optimization. Algorithm works in a two-step process. In prediction step, Kalman filter produces estimates of current state variables, along with their uncertainties. Once outcome of next measurement (necessarily corrupted with some amount of error,

Model:

$$x_k = Ax_{k-1} + Bu_k$$

$$z_k = Cx_{k-1} + v_k$$

Predict:

$$\hat{x}_k = A\hat{x}_{k-1} + Bu_k$$

$$P_k = AP_{k-1}A^T$$

Update:

$$G_k = P_k C^T (C P_k C^T + R)^{-1}$$

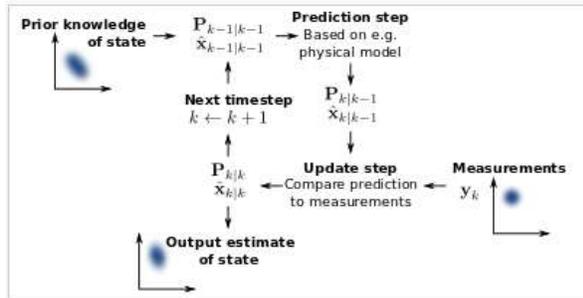
$$\hat{x}_k = \hat{x}_k + G_k (z_k - C\hat{x}_k)$$

$$P_k = (I - G_k C) P_k$$

including random noise) is observed, these estimates are updated using a weighted average, with more weight being given to estimates with higher certainty. Algorithm is recursive. It can run in real time, using only present input measurements and previously calculated state and its uncertainty matrix; no additional past information is required.

Kalman filter can be written as a single equation; however, it is most often conceptualized as two distinct phases: "Predict" and "Update". Predict phase uses state estimate from previous time step to produce an estimate of state at current time step. This predicted state estimate is also known as a priori state estimate because, although it is an estimate of state at current time step, it does not include observation information from current time step. In update phase, current a priori prediction is combined with current observation information to refine state estimate. This improved estimate is termed a posteriori state estimate.

Typically, two phases alternate, with prediction advancing state until next scheduled observation, and update incorporating observation. However, this is not necessary; if an observation is unavailable for some reason, update may be skipped and multiple prediction steps performed. Likewise, if multiple independent observations are available at same time, multiple update steps may be performed (typically with different observation matrices H_k). [8]



The Kalman filter keeps track of the estimated state of the system and the variance or uncertainty of the estimate. The estimate is updated using a state transition model and measurements. $\hat{x}_{k|k-1}$ denotes the estimate of the system's state at time step k before the k -th measurement y_k has been taken into account; $P_{k|k-1}$ is the corresponding uncertainty.

state of filter is represented by two variables:

$\hat{x}_{k|k}$, a posteriori state estimate at time k given observations up to and including at time k ;

$P_{k|k}$, a posteriori error covariance matrix (a measure of estimated accuracy of state estimate).

Figure 1: Kalman Filter Algorithm

k	0	1	2	3	4	5	6	7	8	9
x_k	1000	750	563	422	316	237	178	133	100	75
z_k	1384	658	405	631	574	214	172	416	288	381
p_k	1									
\hat{x}_k	1384									
g_k										

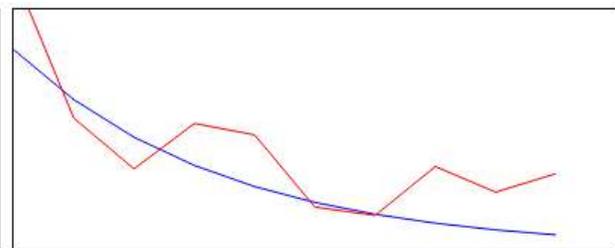


Figure 2: Blue – Original Signal, Red – Noisy signal,

k	0	1	2	3	4	5	6	7	8	9
x_k	1000	750	563	422	316	237	178	133	100	75
z_k	1384	658	405	631	574	214	172	416	288	381
p_k	1	0.562	0.316	0.178	0.1	0.056	0.032	0.018	0.01	0.006
\hat{x}_k	1384	1038	778	584	438	328	246	185	138	104
g_k		0.001	0.001	0	0	0	0	0	0	0

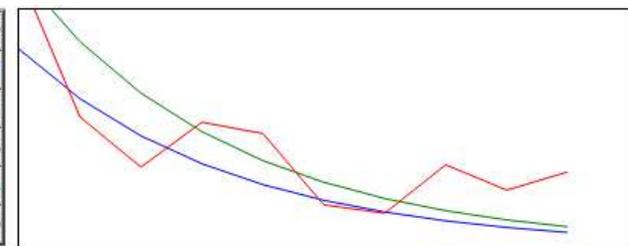


Figure 3: Blue – Original Signal, Red – Noisy signal, Green – smooth version

2. IMPLEMENTATION

2.1 EXPERIMENT DESIGN

To analyze performance of algorithm, motion sensor and GPS position data were collected from android devices in indoor and outdoor environment of Land Management Training Center, Dhulikhel. selected location is a three storied building with huge interior space. Sensor data were collected using "Sensor Steam GPS + IMU" android app available in Google play store. This app sends A Stream containing Sensor-Values in CSV- Format by WLAN to a Client and/or a Stream to a SD-Card. It can be started and stopped on demand and Sensor-Update frequency can be adjusted.

2.2 OBSERVATION AND COMPUTATION

All devices were held in static position in roof of building for accurate GPS position acquisition, then experimenter would walk down inside building and come out to open sky where GPS could gain fully function. Then a complete round of premise was made which was through open space and trees covered areas. Open space gives good GPS accuracy

but covered areas reduce accuracy. Sensor data was to be calculated every second. figure below shows data collected from HUAWEI device.

Data and Observation from android device

timestamp	gps	easting	northing	accelerometer	x	y	orientation	x	y	z
1467528475	1	9522455.035	3201110.468	3	-0.201	2.72	81	241.812	-16.062	-1.031
1467528476	1	9522455.035	3201110.468	3	-0.172	2.614	81	243.5	-15.688	-0.734
1467528477	1	9522455.035	3201110.468	3	-0.575	2.72				
1467528478	1	9522455.035	3201110.468	3	-0.421	2.519	81	241.453	-14.656	-2.375
1467528479	1	9522455.035	3201110.468	3	0.23	2.509	81	226.203	-16.328	2.234
1467528480	1	9522455.035	3201110.468	3	0.393	2.413	81	175.016	-11.812	3.578

Computation was done using python with help of pyKalman module (<https://pykalman.github.io/>). results of data are shown below:

Predict Phase										update			
Ae	An	ue	un	dt	de	dn	e	n	p	g	ek	nk	pk
-2.3025	-1.461997878	0	0	1	-0.53279	2.906915403	9522454.502	3201113	1	0.166667	9522455	3201110	
-2.2626	-1.320289794	-2.30247	-1.462	1	-2.38847	-0.154997878	9522452.647	3201110	0.833333	0.142857	9522453	3201110	0.833333
-0.575	2.72	-4.56508	-2.78229	1	-4.85258	-1.422287672	9522450.182	3201109	0.714286	0.125	9522451	3201109	0.625
-2.0116	-1.573595548	-5.14008	-0.06229	1	-5.35058	1.197212328	9522449.684	3201112	0.625	0.111111	9522450	3201112	0.555556
-1.9702	-1.570479215	-7.15165	-1.63588	1	-7.03665	-0.38138322	9522447.998	3201110	0.555556	0.1	9522449	3201110	0.5
-0.1819	-2.438019318	-9.12182	-3.20636	1	-8.92532	-1.999862435	9522446.11	3201108	0.5	0.090909	9522447	3201108	0.454545
1.8288	-3.218743832	-9.3037	-5.64438	1	-10.1752	-4.011381754	9522443.746	3201104	0.454545	0.083333	9522445	3201104	0.416667
-0.1194	-3.40799247	-7.4749	-8.86313	1	-7.4319	-7.158625586	9522445.599	3201098	0.416667	0.076923	9522446	3201098	0.384615

3. RESULTS

Resulting coordinates of prediction phase, update phase and gps observation phase are plotted using QGIS.

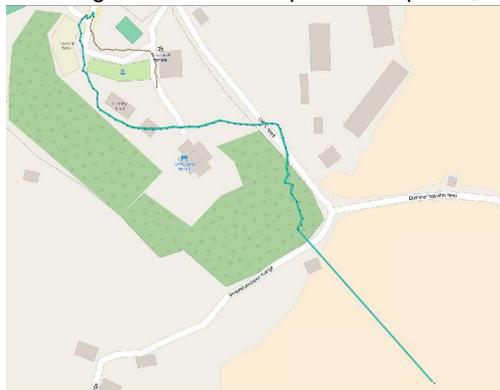


Figure 4: Map of prediction, update and observation phases overlapped Figure 5: Magnified view of starting section

figure shows that prediction and estimations are way off observed points. GPS observations should have mapped along white path but due to errors in GPS line is not coincident. In figure below, it is seen that motion sensor reads in direction opposite to direction of movement form first reading onwards. And it tends to come back to track which is result of filter. But it again diverges because motion sensor readings are not optimal.

In last part; in blue line (at green forest area). line shoots out to brown field area. This is because, at this stage, covered-up forest area started due to which gps could not lock onto coordinates. Since there were no observations, filter took previous measurement and kept up going in last known direction. Without GPS observations there was no way to check its accuracy.

4. CHALLENGES

4.1 ERROR ACCUMULATION

To calculate position from acceleration requires a double integration. If accelerometer readings are off even a little, calculated speed will be off. This makes position even further. Next reading may also be off slightly and get another slightly incorrect speed which calculates a distance. Now this already incorrect position is applied on previously incorrect position to get a new position, that will now be even further off.

4.2 ESTIMATED POSITION USING INS SENSORS

Linear acceleration calculated by Android was not perfect, alternative was to try to calculate linear acceleration using gyro and accelerometer. It was found that main issue here is to get rid of gravity component. To begin with, initial orientation angles are needed; this can be calculated calibrating device completely at rest measuring gravity in each axis. Next, exact orientation angles are needed; this can be obtained from integrating gyro.

5. CONCLUSION AND RECOMMENDATION

main objectives were: research of area; examine level of accuracy that can be achieved in positioning by using available sensors in an Android device, and research of possible applications of technology.

results showed that sensor fusion positioning technique was not able to achieve acceptable accuracy due to challenges listed above. Further research and improvement are required to improve accuracy. amount of research in field shows that this type of navigation technique has various potential application areas, such as shopping malls, large hotels, museums, etc. There are a number of different aspects of further developing this project. most significant is to increase accuracy of position estimation. That can be approached in various ways:

1. Improve linear acceleration calculation by using rotation matrix calculations;
2. Implement a model with Kalman filter to integrate information from various sensors.
3. Kalman filter's recursive nature of error estimation can be used to improve accuracy of position estimation. With increased computational power on handheld devices, a propagation-based technique could be implemented to determine position of device using wireless network.

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