GPS POSITIONING AND GROUNG-TRUTH REFERENCE POINTS GENERATION

Mussa Bshara [1], *Umut Orguner*[2], *Fredrik Gustafsson* [2] *and Leo Van Biesen* [3]
[1] Higher Institute For Applied Sciences and Technology, Damascus, Syria
[2] Linkping University, 581 83, Linkoping, Sweden
[3] Vrije Universiteit Brussel, Brussels, Belgium
E-mail (1) mussa.bshara@hiast.edu.sy
E-mail (2) (umut, Fredrik)@isy.liu.se
E-mail (3) lvbiesen@vub.ac.be

Abstract – The global positioning system (GPS) is a Global Navigation Satellite System (GNSS) uses a constellation of between 24 and 32 Medium Earth Orbit satellites that transmit precise microwave signals, which enable GPS receivers to determine their current location, the time, and their velocity [1]. Initially, the GPS was developed for military applications, but very quickly became the most used technology in positioning even for end-user applications run by individuals with no technical skills. GPS reading are used also as reference points for many positioning techniques such as the techniques that depend on the transmitted electromagnetic signal to determine the position of the transmitter or the receiver, due to their superior accuracy comparing to such techniques. But how accurate are those readings, and how to obtain accurate reference points starting from raw GPS observations even when they are corrupted with errors.

In this paper, a practical study about GPS positioning is provided. Generating the *ground-truth* reference points depending on GPS observations is also provided and discussed in details.

Keywords (not more than four).

1. INTRODUCTION

The availability of GPS and its ease of use were the driving forces behind its penetration almost in all location-dependent applications, especially in navigation and Location Based Services (LBS). Somehow, it has been believed that GPS can be used as (absolute) reference for all types of spatial measurements. This is actually not true and GPS position fixes need further processing to obtain the *ground-truth* reference points for spatial measurements.

Since its introduction, the GPS has undergone several improvements to obtain higher accuracy, such as Differential GPS (DGPS) that uses two receivers to correct the various inaccuracies in the GPS system. The two used receivers are one with fixed and known location known as reference station, and the other one is the one that makes positioning measurements. This system is known as differential GPS (DGPS). It provides high positioning accuracy enabling the users -in addition to navigation- to position objects on a very precise scale. DGPS involves cooperation of the two mentioned receivers. In the early days reference stations were established and used by private companies who had big projects demanding high positioning accuracy. But now, corrections can be available for free from some public agencies, such as the United States Coast Guard and other international agencies who are establishing reference stations. Some other solutions used in addition to the transmitted coded signal by the satellites, the carrier signal to improve the accuracy, however this solution is useful only in case of static and low speed moving targets. Dual-frequency carrier phase receivers can eliminate most of the ionospheric errors and can lead to high positioning accuracy. This solution is still limited to military only, and specialized scientific equipment that are capable of using this solution.

A number of augmentations to the Global Positioning System are available, to aid providing better accuracy, reliability, availability or any other improvement to GPS performance [2]. Such augmentations include the Nationwide Differential GPS System (NDGPS), the Wide Area Augmentation System (WAAS), the Continuously Operating Reference Station (CORS), the Global Differential GPS (GDGPS), the International GNSS Service (IGS) and the European Geostationary Navigation Overlay Service (EGNOS). Despite the improvement in accuracy due to the mentioned systems, but still the traditional GPS receivers are used the most, and their observations still need further processing to obtain high accuracy reference points.

2. GPS ACCURACY AND PRECISION

GPS uses trilateration to determine a position by using the distance to three points (satellites). For more precise position evaluation, four or more satellites are used. Using information (messages) received from the visible satellites, a GPS receiver is able to determine the satellite positions and time sent. The x, y, and z components of position and the time sent are designated as $[X_{i,} Y_i \ Z_i \ t_i]$ where the subscript i is the satellite number. Assuming that the messages travel from the satellite to GPS receiver at speed light c, the distance between the receiver and each of the serving (visible) satellites can be computed and the position can be fixed.

Due to the high speed of the light, an extremely accurate clock has to be used in the receivers. Otherwise, it is difficult to measure accurately the required times to compute the distances to the satellites, and the system will suffer from low positioning accuracy. The accurate clocks are expensive and not suitable for mass market; therefore, the solution is to correct the GPS receiver's clock. The fourth satellite plays an important role in clock correction and it is very important to use at least four satellites to obtain accurate positioning. In addition to clock error, GPS suffers from:

- **Ephemeris error:** Any deviations caused by natural atmospheric phenomenon, are known as ephemeris errors. The gravity influence of the sun, moon and earth -in addition to other influences like solar radiation and eclipses- introduce deviation in satellite's orbit. Tracking the satellites positions is needed to deal with this error [3].
- **Satellite geometry:** Trilateration performs better and gives precise results if the reference points (the satellites) are spread and not situated in one side. That is why the GPS performs badly near the rising and high buildings where some satellites can be blocked and only satellites seen from one side can be used (in addition to multipath effect on the received signal from satellites). the geometric strength of satellite configuration on GPS accuracy is expressed in GDOP values (Geometric Dilution Of Precision). The GDOP amplifies the error; e.g. a GDOP value of 50 with a 6 meters accurate device will produce an error of 300 meters; at this level of GDOP, measurements should be discarded. To study the effect of satellite geometry, measurements have been conducted during different day times (in the morning, midday and in the afternoon). The area has been chosen to have high building on one side and on the other side is an open area. Note that when the satellites were seen from all directions, the GPS readings were correct, and when the satellites were only seen from one side, the committed error by the GPS receiver was very big comparing to the first case. The buildings don't necessarily block the satellites from a certain side all the time; this depends on how the satellites are moving and which satellites can be seen at a certain time. The results are depicted in Figure [1]. Figure [2] shows the error Cumulative Distribution Function (CDF) for the points which have been affected by satellite geometry. The error for 67% of the points is less or equal to 57 m and less or equal to 72 m for 95% of the points which is largely higher than the used GPS operational error (≈ 3 m) as shown in Figure [3]. However, error of about 5 m is noticed in other places. Thus, the operational accuracy is considered to be between 3 and 5 meters.
- **Atmospheric effects:** The effects of the troposphere and ionosphere are known as atmospheric effects. The GPS signals passing through the mentioned layers encounter refraction effects including ray bending and propagation delays; because propagation velocity in the ionosphere and troposphere is lower than in outer space.
- **Multipath propagation:** This error depends on the propagation environment. It takes the highest values in urban environments near high buildings and other elevations. The reflections on objects cause the GPS signals to arrive with an extra delay. The resulting error typically lies in the range of a meter depending on the environment.

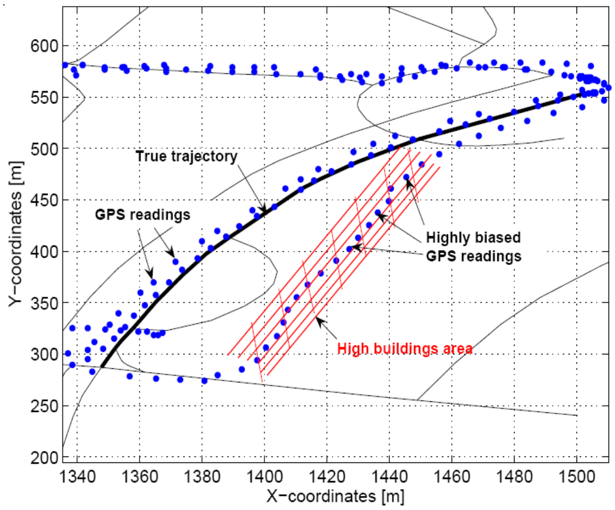

Fig. 1. The effect of satellite geometry. Note how the GPS readings were shifted (biased) when some satellites were blocked by the high buildings. The correct GPS readings and the biased ones were obtained by separate drives and during different day times.

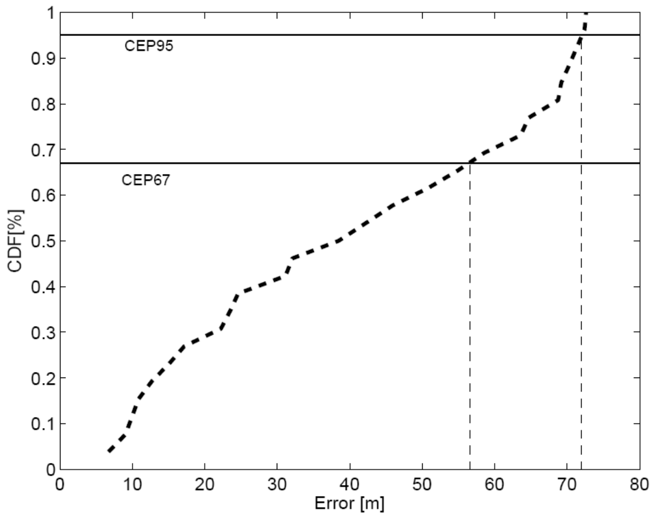

Fig. 2. The error CDF for high GDOP points.

3. GROUNG-TRUTH REFERENCE POINT

Ground-truth reference points are very important to develop and evaluate any positioning system. All the obtained values (coordinates) need to be compared to reference points to know how much the estimated values are close to the truth. For example, the estimated position needs to be compared to the true one to compute the estimation accuracy. The biased or not accurate reference points will

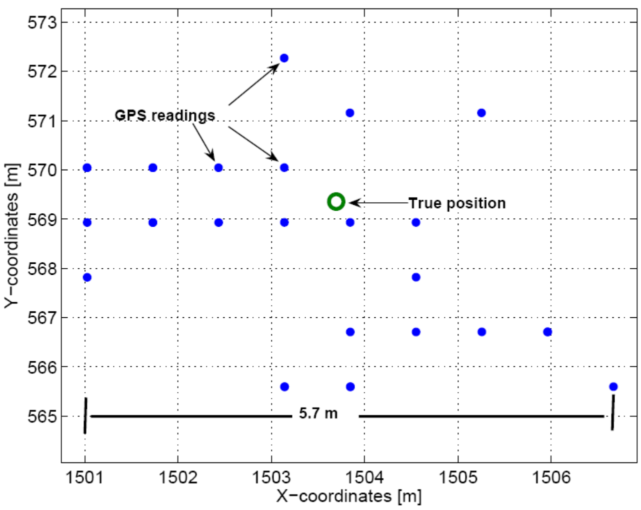

Fig. 3. The used GPS accuracy and precision in the best case. The measurements are obtained in an open area where 4 or more satellites can be seen.

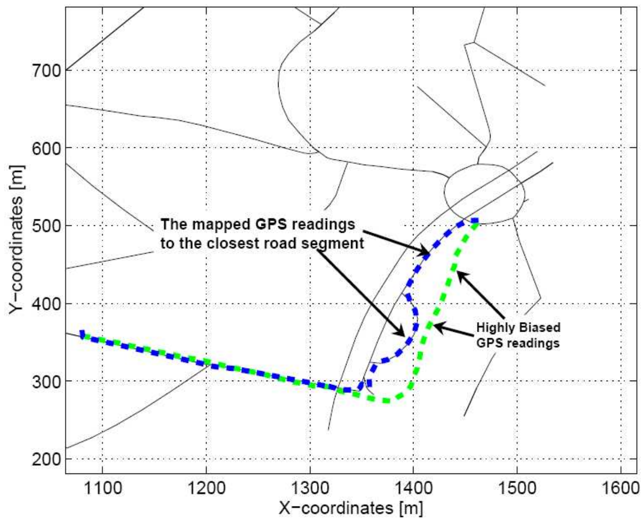

Fig. 4. GPS readings correction using mapping to the closest road segment.

introduce a systematic error to the positioning system under development; and our judgment regarding the said system will be not accurate.
In this study, and knowing that the user is using the public road network (all the measurements are taken using a car in Brussels capitol city). The reference points are obtained by processing the GPS observations using two ways:

1. *Mapping to the closest road segment:* Knowing that the user is using the public road network, all the points that lie outside the road (off-road points) were mapped to the closest road segment. This approach performed well in most of the cases. But two main drawbacks can be observed:

   - The on-road errors can't be corrected: The true position could be after or behind the estimated one (by GPS receiver); or in the case of having close road segments to each other (or the GPS readings were corrupted with big errors), some points could fall on wrong road segments. In the two mentioned cases the points will be considered as correct ones and no action will be taken to correct them.
   - Some off-road points could be mapped to a wrong road segment: This happens when big errors are committed by the GPS receiver, or in case of having very dense road network. In this case, the closest road segment could be not the right one, and therefore, the points will be mapped to a wrong road segment (the closest segment). Figure 4 depicts this case.

2. *Using Particle filters:* To overcome the aforementioned drawbacks, a Particle filter was used to correct the GPS readings and to produce the ground-truth reference points. The particle filter was used with road information obtained from the public road network maps.

The implemented PF is called on-road filter, because it makes use of map database information. The used approach here, considers a single reduced-order on-road motion model with a bootstrap filter. The particles will be spread only on road segments (on-road particles), no particles will be found outside road segments (off-road particles). The road information appears in the motion model and has been emphasized by using the letter r in the state model which is denoted by X_k^r, and is given as $X_k^r = [p_k^r, v_k^r, i_k^r]$ where the scalar variables p_k^r, v_k^r denote the position and speed values of the target on the road segment i_k^r.The following model is used for the dynamics of X_k^r. The measurement model uses GPS readings. At a single time instant t_k, the measurement vector is of the form:

$$y_{t_k} = [y_1 \quad y_2]^T \tag{1}$$

where, y_1 and y_2 are the target instant coordinates. The likelihood value $p(y_{t_k} / x_{t_k})$ is calculated using the GPS readings as given algorithm 1.

The best results were obtained when the particle filter was used to correct the GPS readings; because of its ability to correct the on-road errors in the two mentioned cases: 1) the points are misplaced on the right road segment (before or after the right position), 2) the points are placed on a wrong road segment. By using its motion model, the particle filter can adjust the points to the right place and discover the points that are positioned on a wrong road segment and place them again on the right one as shown in Figure [6].

Algorithm 1: Calculation of $p(y_{t_k} / x_{t_k})$

3. Calculate the difference between each particle's coordinates and the GPS reading's coordinates, such as

$$d_j^x = y_x - p_x^j \tag{2a}$$

$$d_j^y = y_y - p_y^j \tag{2b}$$

where y_x denotes the measurement x coordinate, y_y denotes the measurement y coordinate, p_x^j and p_y^j are the particle j (x,y) coordinates respectively.

4. $p(y_{t_k} / x_{t_k})$ is a multivariate normal probability distribution of the differences given the covariance matrix:

$$\begin{pmatrix} \sigma^2 & 0 \\ 0 & \sigma^2 \end{pmatrix}$$

where σ is the standard deviation of the GPS readings. Its value is usually selected equal (or slightly bigger) than the operational accuracy.

One of the most difficult situations is the one depicted in Figure 4. In such situation, using the mapping method will always position the points on the wrong segment (the closest). The particle filter usually, will position the points on the right road segment (depending on the motion model). But in this case, there is a junction between the two segments (the right one and the wrong one) and the target can be on both (the target can use any of the two segments); in such situation we distinguish between two cases:

1. One of the two segments is not available: Not permitted to go on this segment due to road direction or any other reasons. In this case the problem is solved and the right segment will be picked up depending on road information.
2. The two segments are available: In this case there is possibility one out of two to pick up the right segment. Attention has to be paid to the covariance matrix when implementing the particle filter, because if we consider the GPS operational error (which was found to be about 5 m), the closest segment will be picked up (the wrong one in this case); see Figure 4. Therefore, we have to consider the cases when the worst accuracy is obtained by GPS receiver, and assume higher error values than the operational one. That it is: we have to consider the GDOP error values.

4. THE ON-ROAD PARTICLE FILTER IMPLEMENTATION

The on-road particle filter is developed for users (targets) that move exclusively on roads [4]. This filter utilizes a "one-dimensional" dynamic model since all particles must be located on a road. The on-road dynamics depicted in Figure 5 model the distance of the target

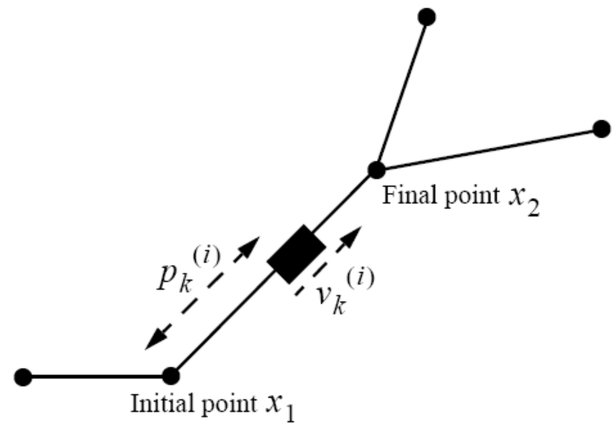

Fig. 5. The on-road state of the target.

from the initial state value (this can be modified to model the distance from the last time instance). Each particle has to remember which road it is located on and the last point it passed by. It is also necessary to remember its direction on the said road. In order to be able to obtain the target's global coordinates (the coordinates in X and Y), Two state models are needed. One for the one-dimensional dynamic model and is given in a simplified form by equation 3. The other state vector is a two-dimensional model given by the equation 4.

$$X = [p \quad v]^T \tag{3}$$

Where, p is the distance from the initial point, and v is the speed of the target.

$$X = [x \;\; y \;\; v_x \quad v_y]^T \tag{4}$$

Where, (x; y) is the global coordinates (the Cartesian coordinates), and $(v_x \quad v_y)$ is the speed of the target on x and y respectively. The dimension of a model is referred in terms of the position. Hence, for the one-dimensional model the distance p from the initial point on the road is considered to be the position of the target, whereas for the two-dimensional model the position is given by the (x, y)-coordinates. The conversion between the two position types is feasible and has to be implemented with the implementation of the particle filter, i.e., from a given ((x, y)-coordinates), the nearest road state should be possible to obtain. Also, from a given road state and a path (a sequence of point indices), the global state should be possible to obtain.

4.1. Motion models

The motion model for the global particle filter (uses the global (x,y) coordinates) is given by:

$$\begin{bmatrix} p_{k+1}^x \\ p_{k+1}^y \\ v_{k+1}^x \\ v_{k+1}^y \end{bmatrix} = \begin{bmatrix} 1 & 0 & T & 0 \\ 0 & 1 & 0 & T \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} p_k^x \\ p_k^y \\ v_k^x \\ v_k^y \end{bmatrix} + \begin{bmatrix} \frac{T^2}{2} & 0 \\ 0 & \frac{T^2}{2} \\ T & 0 \\ 0 & T \end{bmatrix} w_{k+1}^{off} \tag{5}$$

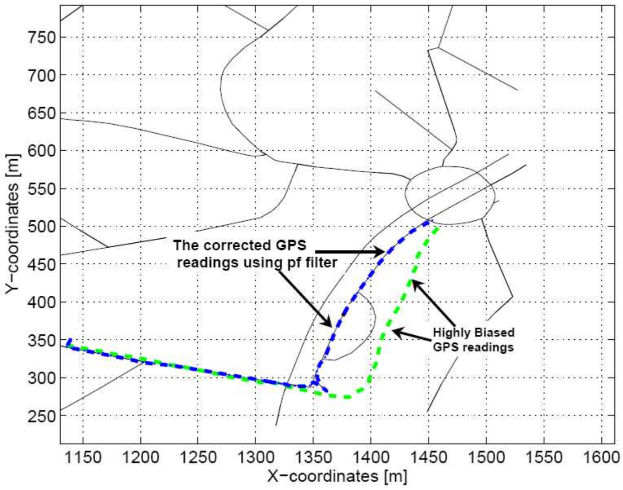

Fig. 6. Using the Particle Filter to correct GPS readings.

where w_{k+1}^{off} is a white Gaussian noise with zero mean, T is the difference between consecutive time stamps of the measurements. p^x, p^y are the (x,y) coordinates and v^x, $v^\wedge y$are the velocity components on x and y coordinates respectively. The motion model for the on-road particle filter is given by:

$$\begin{bmatrix} p_{k+1}^{on} \\ v_{k+1}^{on} \end{bmatrix} = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix} \begin{bmatrix} p_{k}^{on} \\ v_{k}^{on} \end{bmatrix} + \begin{bmatrix} \frac{T^2}{2} \\ T \end{bmatrix} w_{k+1}^{on} \qquad (6)$$

The continuous process noise w_{k+1}^{on} is a scalar white Gaussian noise with zero mean. The notation on is used to indicate the on-road model, and off is used to indicate the off-road model where no map information is used. p and v are the position and the velocity on the road respectively.

4.1. The on-road particle filter algorithm

Algorithm 2: On-road particle filter

1. Initialize the particles
   • set initial on-road coordinates.
   • set initial indices of start and ending points of the road segments that the particles are on.

2. Time update
   • For each measurement
   – For each particle
   * Predict the on-road coordinates of the particle.
   – Find all the possible road segments that the particle can go.
   – Select one possible road segment from the list of road candidates randomly.
   – Find new road coordinates, start and end point indices, and global coordinates of the particle.
   – Calculate the likelihood of the particle using the global coordinates of the particle.

3. Measurement update
   • Resample from the normalized likelihoods.

4. Repeat from step 2 for the next time step.

5. CONCLUSIONS

This paper discussed positioning using the current GPS receivers from practical point of view. GPS readings were collected in an urban environment using different day times and weather conditions to evaluate the actual error committed when the current GPS receivers are used and their actual operational accuracy. It is found that the most affective error source (regardless the cases when no GPS signal is received, such as inside the tunnels) is the satellite geometry when some satellites seen from a certain angle (or side) are blocked (by high risings for example). This is actually the main reason of the low performance of GPS receivers inside narrow streets and beside high buildings in urban environments.

Correcting GPS readings or obtaining the *ground-truth* points is performed by mapping the GPS readings to the closest road segment. This method is found to perform well in most cases but it has drawbacks especially in dense road network where some points could be mapped to wrong road segment or some points could originally fall at wrong road segment where no correction will be done in this case. To avoid these problems, a new GPS readings correction approach is introduced depending on particle filter. A particle filter is used to obtain the *ground-truth* points from the raw GPS readings. This approach is proved to give the best results. Practical implementation hints were given for better particle filter implementation.

Dr. Mussa Bshara is currently with the Department of Communication Engineering at HIAST (Higher Institute For Applied Sciences and Technology), Damascus, Syria. He has been with the Department of Fundamental Electricity and Instrumentation, Vrije Universiteit Brussel, Brussels, Belgium up to July 2010
Tel: +963 (0)11 512.26.03
Fax: +963 (0)11 223.77.10
E-mail: mussa.bshara@hiast.edu.sy.

Dr. Umut Orguner is with the Department of Electrical Engineering, Linkoping University, 581 83, Linkoping, Sweden.
Tel: +46 (0)13 281 338
Fax: +46 (0)13 139 282
E-mail: umut@isy.liu.se

Prof.dr. Fredrik Gustafsson is with the Department of Electrical Engineering, Linkoping University, 581 83, Linkoping, Sweden.
Tel: +46 13-282706
Fax: +46 13-282622
E-mail: fredrik @isy.liu.se

Prof. dr. ir. Leo Van Biesen is with the Department of Fundamental Electricity and Instrumentation, Vrije Universiteit Brussel, Brussels, Belgium.
Tel +32 (0)2 629.29.43
Fax: +32 (0)2 629.28.50
E-mail: lvbiesen@vub.ac.be

REFERENCES

[1] Prof. D.r. ir. Leo Van Biesen, "Applied Electricity, in Dutch: Toegepaste Electriciteit, ," VRIJE UNIVERSITEIT BRUSSEL, Course for the 2nd Bacholor in Engineering programme.

[2] Global positioning system. [Online]. Available: http://www.gps.gov.

[3] N. Deblauwe, "GSM-based Positioning: Techniques and Application," Ph.D. dissertation, VUB University, 2008.

[4] M. Bshara, U. Orguner, F. Gustafsson, and L. V. Biesen, "Fingerprinting localization in wireless networks based on received signal strength measurements: A case study on WiMAX networks," IEEE Transactions on Vehicular Technology, vol. 59, no. 1, pp. 283–294, Jan. 2010.