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Improving the Accuracy of GPS

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Abstract: We analyze typical positioning errors of the GPS system and present an approach to improve the accuracy of position information obtained from standard GPS receivers. Based on a basic movement model, we pre-calculate a position estimate and compare it with the position delivered by the GPS receiver. This approach is validated by means of simulations and real world measurements and shows a reduction of the positioning errors of ten percent.

1 Introduction

The *Global Positioning System* (GPS) is the most relevant technology to identify the position in outdoor scenarios [1,2]. An alternative European technology (*GALILEO* [3]) is expected to be operational in a few years. GPS is used for the navigation of planes and ships, land surveys and to analyze changes of the earth's crust, but it is also available in daily life through mobile phones, PDAs or car navigation systems. A direct line of sight to GPS satellites and a positioning error of fifteen meters or more are the major disadvantages of this system.

Figure 1 depicts the changes of position data that were recorded by a stationary GPS receiver. More than 6000 data sets were stored within a few hours during a slightly cloudy day on the roof of a building. These values are plotted in a diagram [4] and show a maximum positioning error of fifteen meters.

Differential GPS (DGPS) [5,6] improves the accuracy of positions significantly, and hence the expected positioning error drops below five meters. A reference station on the surface of the earth analyzes the GPS signals and transmits correction information, which is used by DGPS receivers to adjust the measurements. Compared to standard GPS receivers, DGPS systems are more expensive and larger due to additional antennas.

The goal of this paper is to present an approach to improve the position information with standard GPS receivers. The idea is to identify and filter single positioning errors and improve the position information by interpolating the current position with previous position values.

This paper is structured as follows. In the following Section, typical positioning errors of a GPS system are analyzed. In Section 3, values for the accuracy of position are derived from the GPS receiver, which define the weights for the interpolation. This approach is validated in Section 4 with several simulations and real world measurements. The paper finishes with a conclusion and an outlook.

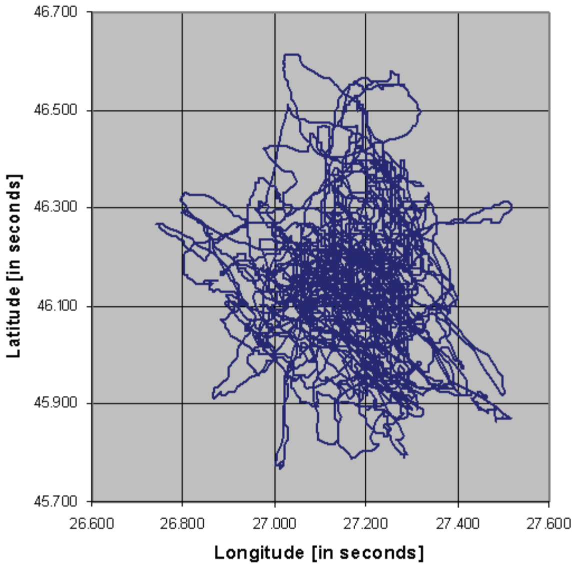

Figure 1: Position information of a stationary GPS receiver

2 Positioning Errors

In this section, we analyze the typical positioning errors of GPS systems. These errors may be caused by satellites, the atmosphere, the GPS receiver or the environment where the GPS receiver is located [7,8].

Satellite orbits: Although the satellite obits are usually very precise, small changes are possible due to the gravity of the sun and moon. Temporary errors caused by the orbit may generate positioning errors of several meters.

Inaccurate calculation based on satellite positions: It is much harder to determine a precise position if the available satellites are close to each other. Very small calculation or measurement errors can lead to significant positioning errors.

Changes in the atmosphere: The velocity of propagation of the GPS signal is reduced in the ionosphere and troposphere. Solar wind influences the ionosphere and can cause positioning errors up to 5 meters. Current weather conditions and the amount of water in the troposphere generate additional errors.

Quality of GPS receivers: The constructions of the antennas, the quality of the components and the algorithms which calculate the position have a great impact on the accuracy of the position.

Errors based on timers: Even very small differences of the timers in the satellites or the receivers may cause positioning errors of several meters.

Assumption of a wrong altitude: If only three satellites are in range of a GPS receiver it determines its position with the 2D position-fix approach which assumes a fixed altitude. Especially in mountain regions, the assumption of the altitude is problematic and may cause positioning errors of several hundred meters. The 3D position-fix approach is used if data from at least four satellites is available.

Reflection of GPS signals: The GPS signals can be reflected from the environment (e.g., buildings) and the distance between the satellites and the GPS receiver increases compared to a direct line of sight. An error of several meters may occur.

If different positioning errors are aggregated a deviation from the correct position of fifteen meters or more is possible. The recorded positions in Figure 1 of the stationary GPS receiver confirm this deviation. DGPS reduces the effects of the ionosphere, the changes of the orbits and timer errors, so that the positioning error is usually reduced to less than five meters.

3 Approach

Usually, GPS receivers provide the position information (longitude, latitude, altitude) in a standardized format [9,10]. This format may contain additional information like date, time, available satellites, the technology (GPS or DGPS), as well as a value called *dilution of precision* (DOP) which measures the accuracy of the position. The DOP value makes a prediction about the expected positioning error [11]. With a probability of 95 percent the real position is within a certain range (based on the DOP value) of the GPS position.

We assume a high correlation of the position, direction and speed of the GPS receiver within a short time interval. An *estimated position* is calculated based on a linear regression model from the previous position values. We compare the position of the GPS receiver (*GPS position*) with the estimated position, weight both positions based on the current accuracy (DOP) and get a final *interpolated position*.

The weights for the estimated and GPS position are based on the quality measurement values. If the DOP indicates very precise position information the GPS position is weighted by 75 percent, and it drops to 25 percent for low values. Additionally, we reject the estimated values if the distance between the GPS and estimated position exceeds a predefined threshold. This rejection usually corresponds with significant changes of the direction or speed of the GPS receivers.

The quality of the interpolated values is significantly influenced by the number of changes in direction or speed. A major factor is the current speed because even a slight modification of the direction has a large impact on the absolute position of fast moving GPS receivers. Latest GPS receivers calculate position information twice or even four times a second and hence make our interpolation approach applicable for higher velocities.

In our approach, the current direction and speed is estimated from previous positions. The algorithm adapts much faster if only two values are used for the estimation. On the other hand, if a constant speed and direction is expected additional values will increase the accuracy. In our implementation, the number of selected positions (2-5) depends on the refresh rate and speed of the GPS receiver.

4 Experimental Results

We have conducted a large number of simulations and measured positions in real world scenarios to evaluate our proposed algorithm. We assume that very fast changes of the direction are not possible (a change of direction within on second should not exceed 60 degrees). The simulated GPS positions are influenced based on given DOP values.

In our simulation, we analyzed the effect of the interpolation with the standard GPS approach first and assume a deviation of fifteen meters or less [12]. In low-speed scenarios (less than 50 km/h), the interpolation improved the accuracy of the position by 0.45 meters on the average (more than ten percent), but the accuracy gain drops with increasing speed. In high-speed scenarios (75-120 km/h or faster) the advantage of the interpolation is reversed to a disadvantage: the interpolation reduces the accuracy and the data should not be interpolated anymore.

A different probability distribution is used to analyze the behavior for DGPS. In this case, the positioning error is usually below 5 meters, even slight direction changes may cause obvious positioning errors and only a very low speed is advantageous.

If no valid GPS signal is available (e.g., in tunnels or between high buildings) the interpolation is mandatory.

We validated our simulation results in real world measurements and used the following setup: Ten points were marked in a distance of 5 meters on a straight line of an open field. Three additional measuring points with a distance of five meters and an angle of 30 degrees were tagged, followed by ten additional points on a straight line. The weather condition was fine which caused low DOP values between two and three (high quality). Twelve runs were performed and analyzed with a standard GPS receiver. The position could be improved in more than 90 percent, and the average positioning error decreases by 0.7 meters for each measurement point. These results show that our simulation model and the simulation results are valid.

5 Conclusion and Outlook

Especially in scenarios with low speed and standard GPS receivers the interpolation of the position improves the accuracy of the position significantly. This advantage drops with higher speed and more precise GPS receivers. On the other hand, if the GPS device provides data more often than once per second the interpolation is even applicable for higher velocities.
The interpolation is quite useful in tunnels and other places without direct line of sight to satellites. This approach provides position information until the next data record is available. The relevance of the interpolated value should also increase if the quality of the position accuracy decreases significantly. With very low additional computational costs an up to ten percent improvement of the accuracy is possible.

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