Investigation of collision warning possibilities by means of GNSS receivers of Android smartphones

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Abstract
Using of raw GNSS measurements in Android smartphones for precise mutual positioning of vehicles on a road is considered in the paper. Field experiments with two moving vehicles and pedestrian were conducted. 15 kinds of general maneuvers were provided (overtaking, turn, oncoming traffic, etc.). Smartphone measurements were logged and post-processed to get mutual positioning estimations during maneuvering. Smartphone estimations were compared with precision GNSS receivers measurements.

Keywords: GNSS, Android, relative positioning, mutual trajectory, collision warning, vehicles, connected cars

Introduction
Road safety and its enhancement is one of the most important topics of Intelligent Transportations Systems paradigm. There are plethora of approaches being investigated and offered. Most of them are based on additional on-board sensors, besides that the most sophisticated are based on inter-vehicle communication and sharing of measurements [1]. Others are based on substantial modification of road infrastructure.

Necessity of additional hardware implementaton (sensors, computers, communication equipment) is the main obstacle for new road safety and driver assist technologies scaling. At the same time almost every driver, at least in large cities, already has and uses a smartphone most of which are Androids. Unfortunately, general smartphones didn’t provide enough accuracy for collision warning purpose.

There were attempts to adjust smartphones for precise positioning task, but they required specific hardware and/or low-level firmware modification [2, 3]. Also smartphones could be very suitable for inter-vehicle communication needed for example for RINEX (Receiver INdependent Exchange format) sharing to provide precise GNSS (Global Navigation Satellite Systems, such as GLONASS, GPS, Beidou, Galileo and augmentations like QZSS, SDCM, etc.) positioning in differential modes [4].

In the middle of 2016 Google announced new generation of Android operating system, 7.0 Nougah which allowed access to raw GNSS measurements. That provided potential adaptation of smartphones for application requires precise positioning but deep investigating of smartphones' features regarding to the topic is necessary.

One of the first papers on the subject was [5], and authors demonstrated very promising results: decimeter-level positioning uncertainty and cm/sec-level velocity uncertainty obtained with smartphone’s in-built GNSS receiver. Number of other researches were conducted with different models of Android smartphones [6 – 10] which showed sub-meter accuracy even without sophisticated filtering as well as main challenges were identified: poor performance of antenna and battery economy (so called duty cycles).

In [11, 12] an integration of raw GNNNS measurements with raw inertial measurements were implemented on smartphones: sub-meter uncertainty and ability of operationing with incomplete GNSS satellite constellation were demonstrated.

In [13, 14] opportunities of two-band GNSS receiver of smartphone were investigated and PPP (Precise Piont Positioning) mode with cm-level uncertainty was demonstrated as well as reflectometry.
Up to now (August 2019) 53 models smartphones of 13 brands allow access to raw GNSS measurements. 17 of them provide carrier phase measurements and 8 of them have two-band GNSS receivers [15]. So, market share of such smartphones grows and one could expect 60..80% share within 2023..2025 at least in most of high-income regions.

There is an opportunity of collision warning by sharing raw GNSS measurements between neighboring driver’s smartphones (connected car concept), its processing (sort of RTK, Real-Time Kinematics, with mobile baseline) and prediction of mutual trajectories. For fast scaling this processing is to be performed as plug-in software for leading mobile apps for drivers. However, the above mentioned reseaches mostly were provided in ideal environment (static mode, clear sky) and no one in relative mode between moving objects with sky shielded with metall roof as is is in general use case of smartphone assisting to a driver.

In this paper we present some early results of research we’re conducting regarding to usage of smartphones for collision warning of vehicles.

**Methodology**

Two vehicles (Hyundai Solaris and Audi Q3) were equipped with smartphones (both were Samsung Galaxy S8 with Exynos 8895V chipset) being tested and fixed on driver’s panels as it usually done. Both vehicles also were equipped with reference navigation-grade GNSS receivers (NV08C RTK-M) with external two-band antennas (Fig. 1).

![Figure 1. Placement of smartphone and antenna of reference GNSS receiver on one of the testing vehicle.](image)

Besides that, a third reference GNSS receiver was placed static near test road to be binded to absolute ECEF coordinate frame.

Both smartphones and both mobile reference receivers and static reference receiver wrote raw GNSS measurements in RINEX log files. Smartphones logged with help of Geo++ Rinex Logger free mobile app. Reference GNSS receivers logged with customized proprietary software.

There was series of experiments with 15 different trajectories of pair of vehicles and 4 different trajectories of vehicle and pedestrian (Fig. 2a, 2b), pedestrian was equipped with the same kit: Samsung Galaxy S8 and Navis NV08C RTK-M with external antenna. Vehicles moved with speed up to 40 km/h.

![Figure 2a. Kinds of maneuvers (pair vehicles) were tested.](image)
Figure 2b. Kinds of maneuvers (vehicle and pedestrian) were tested.

Experiments were conducted in July 2019 at private road in suburb of Moscow (Fig. 3)

Figure 3. Testing area: road with two turns.

After series of experiments was conducted the written log-files were processed with open-source RTKlib software. Results are presented in the next section.

Models and algorithms

To estimate the base vector the Least Square Method is used. The illustration of the mutual positioning is shown on fig. 4.

Measurements in considered model are differences of pseudoranges:

\[ \Delta \hat{r} = [\Delta \hat{r}_1, \ldots, \Delta \hat{r}_N]^T, \]
\[ \Delta r_j = R_{j2} - R_{j1}. \]  

Relation between measurement and base vector:

\[ \Delta r_j = (\hat{e}_{j1}, \hat{b}) = e_{j1}^x b_x + e_{j1}^y b_y + e_{j1}^z b_z. \]  

System of equations:
\[ \Delta \hat{r} = f(b) = \begin{cases} \Delta r_1 = e_{111} b_x + e_{112} b_y + e_{113} b_z \\ \vdots \\ \Delta r_N = e_{N11} b_x + e_{N12} b_y + e_{N13} b_z \end{cases}, \] (4)

where \( N \) is amount of visible satellites.

The design matrix can be written as:

\[ \Delta \frac{\partial f(b)}{\partial b_0} = H(b) = \begin{bmatrix} e_{111} & e_{112} & \cdots & e_{113} \\ \vdots & \vdots & \ddots & \vdots \\ e_{N11} & e_{N12} & \cdots & e_{N13} \end{bmatrix}. \] (5)

For estimation the iteration algorithm is used:

\[ b = b + (H^T W^{-1} H)^{-1} H^T W^{-1} \mathbf{p} \] (6)

where \( W \) is covariance matrix of observations.

The effect of a pseudodelay smoothing filter by pseudophase measurements was also investigated. The filter algorithm is described below:

The measurement model:

\[ y_k = C x_k + n_k \] (7)

where \( k = 0, 1, 2, \ldots \) is discrete time; \( n \) is vector of discrete white gaussian observation noise with independent components.

The state vector includes pseudodelay, rate of change of pseudodelay and pseudophase:

\[ x_k = [\tau \dot{\tau} \phi]^T. \] (8)

Matrix \( C \):

\[ C = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}. \] (9)

Dynamic model:

\[ x_k = F x_{k-1} + G \gamma_{k-1}. \] (10)

where \( \gamma \) is discrete white gaussian dynamic noise.

Matrices \( F \) and \( G \):

\[ F = \begin{pmatrix} 1 & T & 0 \\ 0 & 1 & 0 \\ 0 & T/\lambda & 1 \end{pmatrix}, \quad G = \begin{pmatrix} 0 \\ T/\lambda \\ 0 \end{pmatrix}. \] (11)

where \( T \) is discrete time’s period; \( \lambda \) is GNSS’s wavelength.

**Experiments**

Figures 5-7 show sample results from 15 ongoing experiments. Table 1 shows the values of the errors calculated relative to the reference trajectory. Comparisons are made between estimates obtained using smartphones in stand alone mode (stand alone), estimates obtained in relative mode without smoothing pseudo-ranges (without smoothing), and estimates obtained using a filter that smooths pseudo-ranges (with smoothing). Consider three paths:

1. Riding cars one after another and turning (fig. 5)
2. Overtaking of one car by another (fig. 6)
3. Passage of one car past standing (fig. 7)
Figure 5. Baseline estimations for path 1.

Figure 6. Baseline estimations for path 1.

Figure 7. Baseline estimations for path 3.
Table 1. Experiment results

| Path number | Stand alone | Without smoothing | With smoothing |
|-------------|-------------|-------------------|---------------|
| 1           | 11.2        | 8.83              | 3.39          |
| 2           | 6.15        | 5.44              | 2.48          |
| 3           | 17.1        | 10.5              | 4.3           |

The stand alone solution for two smartphones provided the highest error of baseline estimation, and the smallest error was provided in the mutual navigation mode with smoothing pseudorange using measurements of the pseudophase, it is on average 3 times less than that achieved in stand alone mode and 2 times less than that achieved in mutual mode without smoothing.

Discussion
Experiments show that access to raw GNSS measurements in driver’s smartphone and its joint processing provides opportunity to track mutual trajectories of vehicles with much less uncertainty than general usage of smartphone. In some cases its quality is enough for direct collision warning. But there are a lot of cases with high uncertainty of estimation of mutual trajectories which is not enough for reliable collision warning. However there are potential fields of improving reliability of trajectory estimation and prediction: trajectory filtering, integration with smartphone’s in-built inertial sensors, wireless integration with on-board sensors (speedometer, steering angle), matching with 3D-map of city and duty cycle turning off.

Trajectory filtering is based on knowledge of regularity of vehicle’s trajectory and provide effective smoothing. Integration with inertial sensors allows to narrow effective bandwidth of trajectory smoothing filter to further reduce noise error of mutual positioning simultaneously reducing dynamic error. Integration with on-board sensors allows fast and reliable adaptation of trajectory filter getting moments of static modes and steer’s turns. Matching with 3D-map allows to implement software mask to cut some damaged signals. Turning off the duty cycle provide much better quality of tracking pseudoranges and carriers’ pseudophases; using smartphone in vehicle could be easily conducted with external power supply, so duty cycle is not necessary for in-car driver assist use case.

Implementing the noted features we’re going to provide sub-meter uncertainty of mutual inter-vehicle trajectory tracking and collision warning with high reliability enough for practical implementation.

Conclusion
Smartphone is a powerful tool for a wide variety of activities. Recent years modern Android smartphones obtained possibility of precision GNSS positioning. Given wide spreading among people and new opportunities smartphones could improve road safety by warning drivers about probable danger of collision.

Experiments showed that in ideal conditions the best smartphones provide sub-decimeter uncertainty. But real-life conditions limit uncertainty to level of about 1..3 meter. Experiments with vehicles and pedestrian showed that direct processing of raw GNSS measurements from smartphones don’t provide reliable enough warning.

However there are additional opportunities for improving of collision warning reliability using access to raw GNSS measurements, their sharing and joint processing.

Our future work in focused on trajectory filtering, integration with smartphone’s in-built inertial sensors, wireless integration with on-board sensors (speedometer, steering angle), matching with 3D-map of city and duty cycle turning off.

First results using smartphones are promising and we’re going to investigate efficiency of more complex processing for collision warning.

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