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Cooperative GNSS positioning aided by road-features measurements

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ABSTRACT

Cooperation between road users through V2X communication is a way to improve GNSS localization accuracy. When vehicles localization systems involve standalone GNSS receivers, the resulting accuracy can be affected by satellite-specific errors of several meters. This paper studies how road-features like lane marking detected by on-board cameras can be exploited to reduce absolute position errors of cooperative vehicles sharing information in real-time in a network. The algorithms considered in this work are based on a error bounded set membership strategy. In every vehicle, a set membership algorithm computes the absolute position and an estimation of the satellite-specific errors by using raw GNSS pseudoranges, lane boundary measurements and a 2D georeferenced road map which provides absolute geometric constraints. As lane-boundary measurements provide essentially cross-track corrections in the position estimation process, cooperation enables the vehicles to improve their own estimates thanks to the different orientation of the roads. Set-membership methods are very efficient to solve this problem since they do not involve any independence hypothesis of the errors and so, the same information can be used several times in the computation. Such class of algorithm provides a novel approach to improve position accuracy for connected vehicles guaranteeing the integrity of the computed solution which is pivoting for automated automotive systems requiring guaranteed safety-critical solutions. Results from simulations and real experiments show that sharing position corrections reduces significantly satellite-specific GNSS errors effects in both cross-track and along-track components. Moreover, it is shown that lane-boundary measurements help reducing estimation errors for all the networked vehicles even those which are not equipped with an embedded perception system.

1. Introduction

Automated driving in city centres has the potential to reduce casualties and traffic jams (Alonso et al., 2011; Santa et al., 2010; Choi, 2015). Driving in high density traffic and different roadway infrastructures is a big challenge for automated vehicles and requires the vehicle's pose and speed to be accurately determined. Standard GNSS positioning (or standalone receiver positioning) is widely used in autonomous navigation but is not enough accurate, particularly in urban areas because of the reduced visibility of the satellites. GNSS positioning alone in constrained environments lacks of integrity even with

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multi-constellation receivers mixing GPS, Glonass or Galileo systems. A solution is to complement this technology with other absolute sensor measures from the vehicles in a data fusion approach. Indeed, a single sensor cannot provide the required level of performance, as autonomous vehicles need not only accurate positioning but also some guaranty on the quality of the computed solution. An new interesting solution is coming from V2X communication. Indeed, the data fusion of multiple sources between vehicles data enables a vehicle to determine its position more accurately and with more confidence as it merges its own sensor data with data shared by other vehicles.

In this paper, we present a new absolute positioning algorithm called Lane Boundary Cooperative Augmented Set-membership GNSS Positioning *LB-CASGP*. This method uses shared GNSS corrections among connected vehicles (inter-vehicles) and fuses local information (intra-vehicle) from GNSS, digital maps and lane boundary detection. The solver relies on a bounded-error algorithm to improve estimation accuracy while keeping a high level of integrity. This approach guarantees with respect to a chosen integrity risk that the real vehicle position is included in the estimated set-membership domain, even if the equations are highly non-linear and even if the same information is reused several times in the computation.

The research described in this paper makes the following contributions to existing literature. The proposed *LB-CASGP* uses V2V/V2I communications to share GNSS differential corrections to all networked vehicles, when subjected to the same satellite-specific GNSS biases (ionosphere, troposphere, satellite clock). The algorithm generates differential corrections using data from connected vehicles, thus eliminating the need to have stationary receivers at known locations. The sharing of GNSS differential corrections for the position estimation, in a set-membership algorithm rather than in a classical iterative least square, is another contribution of this paper.

The *LB-CASGP* algorithm guarantees integrity by assuring that the position, obtained after applying the cooperative corrections, is inside a guaranteed risk integrity zone computed using a non-cooperative Lane Boundary Augmented Set-membership GNSS Positioning (*LB-ASGP*). The zone computed using *LB-ASGP* is constrained by geo-referenced lane boundary measurements and GNSS pseudoranges. The sensor fusion approach exploits lane boundary measurements to improve cross-track vehicle positioning. The along-track positioning error is also improved when using *LB-CASGP* and sharing cross-track errors among networked vehicles. The algorithm only requires a small size database of the infrastructure road network as lane boundaries are described solely by "point-slope" data. The wireless communication bandwidth is quite small as the data to be transferred is only composed by two *floating numbers* per vehicle. Most of the existing data models used in absolute positioning studies consider often more complex databases and transmit full constellation layout and all satellites pseudoranges.

Simulations and real experiments were conducted to test the performance of the *LB-CASGP* algorithm, both in terms of accuracy and integrity. This algorithm has been implemented with low cost sensors and extensive comparative tests have been performed to evaluate its performance in comparison with the Set-membership GNSS Positioning algorithm (*SGP*) proposed in Drevelle and Bonnifait (2009).

2. Related work

Augmenting GNSS localization with other sensory information to improve the positioning accuracy is common in the context of intelligent vehicles (Toledo-Moreo and Zamora-Izquierdo, 2010; Sun et al., 2015). In Drawil and Basir (2010), N.M. Drawil developed a V2V communication assisted localization. This localization technique takes advantage of the fact that GNSS receivers operating in close proximity and observing the same constellation of satellites have strongly correlated errors. These errors are largely canceled when a relative positioning system is taken into consideration. Woo et al. (2001) used V2V, GNSS and the distance among vehicles given by a vision and/or ranging sensor to compute the relative positioning of the vehicle. Although many current relative vehicle positioning methods are sufficient for platooning, their performance is not high enough to implement autonomous driving. GNSS accuracy is often enhanced by using carrier phase measurements (RTKGPS) and real-time corrections (Williams et al., 2012). Challita et al. (2009) used V2V communications, RTKGPS and a vehicle to vehicle ranging system (vision-based ranging system) for absolute positioning. Although this configuration is more performant, the RTKGPS system employed is expensive and therefore not available for massive vehicle distribution.

An algorithm to detect multi-lane marks, including driving lane marks and adjacent lane marks is presented in Hur et al. (2013). This algorithm is able to detect multi-lane marks successfully in the absence of parallelism, thus enabling the algorithm to manage various non-parallel lane situations, such as are found at intersections, in splitting lanes, and in merging lanes. An approach taken for outdoor absolute positioning is presented in Rife and Xiao (2010) and Rife (2012), where vehicles determine their positions in a cooperative way, by fusing their own sensor data with data shared by other users via a common communication network. These papers present cooperative navigation algorithms to increase the accuracy of vehicle positioning via the sensor information sharing through a V2V network. In Rife and Xiao (2010) the algorithm generates GNSS differential corrections from a set of GNSS equipped vehicles by fusing GNSS measurements with a camera-based lane-boundary sensor. The results show that it is possible to generate an error-free differential correction that estimates the projection into the ground plane of the satellite-specific GNSS biases (ionosphere, troposphere, satellite clock) experienced by all collaborators in a local area. The benefits of the proposed method are more noticeable when the density of users is high. In Rife (2012), an algorithm for differential GNSS corrections with no stationary reference receiver is proposed. The algorithm generates differential corrections using data from moving vehicles, thus eliminating the need for an infrastructure of station-