Accurate Satellite Based Vehicle Positioning with Low-Cost Components

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Traffic Safety and Automated Vehicles

FFI Fordonsstrategisk Forskning och Innovation
VINNOVA Energimyndigheten TRAFIKVERKET FKG VOLVO SCANIA VOLVO

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FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness.

Currently there are five collaboration programs: Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.
For more information: www.vinnova.se/ffi

1 Executive Summary

The long term goal of the work has been to realize highly accurate satellite based vehicle positioning based on low cost components. The project has been focused on evaluating if a RTK-GNSS-system based on a low cost single channel GNSS receiver, paired with the existing SWEPOS land based survey stations, can reach a positioning accuracy of ±30 cm in a heavy duty vehicle. The performance level has been evaluated during on-road driving at 80 km/h. The measurements have been conducted on highway E4 south of Södertälje.

To achieve the goals a vehicle model, method for connection to the CAN network in the heavy duty vehicle, and a communications solution for exchanging data with SWEPOS have been developed. All these activities were carried out in accordance with the project plan. However, fine-tuning and final operationalization of the complete system proved to be significantly more resource intensive than planned. The final result with regard to GNSS positioning precision was very good. Future work is however required on the vehicle model and inertial navigation based dead reckoning solution. Particularly the movements of the vehicle cab, which were not modelled in this project, proved troublesome. Improvements are also possible from using better sensors in the inertial navigation. The targets in this area are still seen as realistic to achieve with the given bill of material limitations, but will require additional work in close collaboration between vehicle and positioning experts.

The end result for the positioning was better than ±5 cm with continuous satellite reception. This was significantly better than the target of ±30 cm. The target accuracy could be achieved as long as GNSS reception was not lost for more than 45 m at a time. A requirement to handle GNSS outages up to 120 m while driving at 80 km /h was identified during the project. This robustness is believed to enable reliable operation of the system under real world highway conditions. The gap between 45 m and 120 m is a topic for future work, but should be possible to solve.

2 Background

During the last few year there has been a rapid development of vehicle safety and assistance systems. Examples of such systems include lane departure warning, lane keep assist, automatic emergency braking and automatic discovery of animals on the roadway. The aim of these systems is to decrease the number of accidents and contribute to the societal goal that no one should die or be seriously injured in traffic. There is still a long way to go in order to reach this goal, but with coordinated action in industry and society we will hopefully get there

A few years back, when low cost gyros, accelerometers, and odometers entered the market, the development of anti-lock brake systems and electronic stability control leapt forwards. The development of vehicle safety systems currently relies heavily on information from digital maps and radar. What the enabling technology for the next major breakthrough will be is still unknown.

One very promising technology to emerge recently is centimeter level positioning carried out with low cost GNSS receivers and inertial navigation sensors. Flowscape is a small Swedish high tech company, started in 2011 based on knowledge from e.g. Ericsson. During the last few years they have worked together with a major global corporation to develop a system that uses this technology for positioning and control of mobile robots. Centimeter level GNSS positioning has a long history in the survey engineering field. The equipment has traditionally been rather expensive, with positioning systems costing several hundred thousand Swedish crowns. What is unique with the patent pending technology developed by Flowscape is that it can achieve the same level of precision for a few hundred crowns.

If this technology can be made sufficiently robust there are a large number of interesting applications that may increase traffic safety. One example is to improve the detection of lane placement for the vehicle. If the driver falls asleep or suffers sudden illness the vehicle may automatically stop at the side of the road. With robust detection of lane placement it would also be possible to make better systems to prevent roll-over incidents at highway exits, since the system would then be able to determine that the driver has entered the exit lane. Additionally today's electronic stability and braking systems could also be improved with access to more accurate movement and positioning information.

In addition to the uses in safety related systems accurate positioning will also play an important part in the development of autonomous vehicles. According to a report from IHS there will be 54 highly autonomous vehicles in the world by 2035. The first prototypes are already available, but IHS estimate that they will not reach series production until 2025.

3 Project Realization

The project has been carried out as a cooperation between engineers from Scania and Flowscape. Two Master of Science thesis projects have also been completed. One of the thesis projects focused on making a literature survey on technologies for positioning of autonomous vehicles and lane departure warning and assistance systems. This also included a survey on the reliability of these technologies, with a special focus on the use of RTK-GNSS. In a practical part of the thesis work the student developed software for reading sensor data from the on-board sensors of a Scania truck, through the vehicle communications network. Software for obtaining GNSS reference data from SWEPOS was also developed.

In the other thesis project the student developed a vehicle model that was used to predict the vehicle motion based on dead reckoning, while the GNSS signal was obscured by e.g. bridges or road signs. The complete positioning system is based on the combination of accurate GNSS positioning and the vehicle motion predictions from the model. In addition to this the thesis work also included the design of a reference measurement setup based on a high-cost GNSS positioning system. This measurement setup made it possible to verify the positioning accuracy of the project system.

In parallel to the thesis work engineers at Flowscape integrated both the vehicle network drivers and the vehicle model into the pre-existing mobile robot positioning system.

Finally, the complete system was verified by comparison of the generated positioning information from the developed system and the reference setup, while the host heavy duty vehicle was driving on the highway. The tests were carried out on the highway between Södertälje and Nyköping. The chosen test segment of the road contained no tunnels, but a number of road signs, bridges and natural object obscuring the GNSS signal.

4 Objective

The project has contributed to increased competitiveness for the Swedish automotive industry through combining a small research focused company with technological excellence in the positioning field with a large vehicle manufacturer. The evaluated technology has been shown to work well in a heavy duty vehicle setting, even though some challenges still remain. The developed positioning system can benefit not only Scania but also a number of other companies in the vehicle and robotics sectors.

A finished product based on the investigated technology has significant potential to improve vehicle safety through increased performance in a number of safety systems e.g. automatic emergency brake and electronic stability control. Very accurate position and velocity information also enable new safety systems that require knowledge of the current lane and in-lane position. This is important for the increasingly advanced driver assistance systems of the future.

The project goal, as stated in the application, was to be able to verify a positioning accuracy better than ±30 cm while driving on a highway. This has been achieved, as has been shown by comparison with a significantly more costly reference positioning system.

5 Results and Deliverables

The aim of the project was to realize accurate satellite based vehicle positioning using low cost components. To achieve this, and to evaluate an application that could benefit from such a system, a number of activities have been performed. A main project delivery is the evaluation of the positioning accuracy achieved with the developed inertial sensor aided GNSS system.

5.1 GNSS Precision

The positioning results are very good, with a horizontal accuracy of few cm. The achieved accuracy is significantly better than the stated target accuracy level as long as the GNSS signal is not blocked for too long a time by e.g. a bridge. During GNSS signal outages the system relies on the inertial navigation component, which is still not sufficiently accurate to handle long satellite signal gaps. The test results show that the system is able to handle satellite signal gaps of up to 44 m without losing the position lock. To fully cope with underpasses 120 meter signal gaps need to be handled. The results of the verification measurements are shown in Figures 1 and 2.

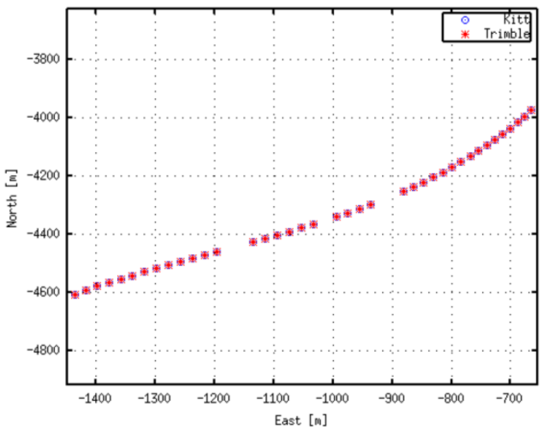

Figure 1 Measurement from the divided highway between Södertälje and Järna. Satellite coverage is partially missing. Kitt is the developed system, Trimble is the reference system.

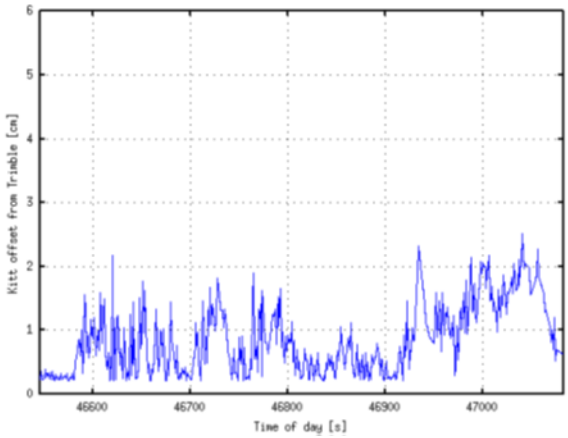

Figure 2 Measurement from the divided highway between Södertälje and Järna. The position difference in the horizontal plane between the developed system and the reference system is shown.

5.2 Vehicle Model

A mathematical vehicle model was developed and tuned in several steps using real-world data collected from the test vehicle. The model and its implementation were tested, and the predictions were found to be a good match for the chassis movements of the vehicle. However, the vehicle cab movements caused problems. The cab movements relative to the vehicle are currently not modelled, and the real-world tests indicate that they significantly affect the performance, since several of the sensors in the prototype system are located in or on the cab [Enberg, 2015].

5.3 Hardware

A significant objective for the project was to determine if a low-cost hardware platform is sufficient. A sensor, radio, and computation unit was constructed. It consisted of an ARM9 CPU, 3D gyro, 3D accelerometer, 3D magnetometer, Ethernet interface, CAN interface, dual USB ports, and a single channel GNSS receiver. The unit cost in larger volumes is expected to be < 300 SEK, which is within the target range. In addition to the developed hardware a commercial 3G/4G modem, and as a backup a cell phone, were used to establish a link to the SWEPOS service. The development of the hardware followed the project plan without major deviations.

5.4 Lane keeping

One part of the project was to investigate how the positioning system can be used for a lane departure warning application (LDW). This was carried out through the development of an addition to the system that visualizes where in the lane the vehicle is currently situated. If the vehicle is about to leave the current lane a warning is issued. Lane maps for the system were generated based on data from previous trips. The LDW system works well as long as the positioning system maintains a position lock [Holmström, 2015].

6 Dissemination and Publications

6.1 Knowledge and Results Dissemination

How has/will the project result be used and communicated?	Mark with X	Comment
Increase the knowledge in the subject area	X	The literature surveys in the thesis projects have increased the knowledge within both Scania and Flowscape.
Be carried on into other advanced technical development projects	X	The reference system used to verity the positioning accuracy can be used by both Scania and Flowscape in future development work.
Be carried on into product development projects	X	The software that has been developed within the project can be integrated as new modules in existing Flowscape control systems. Drivers for vehicle communications network access and downloading of GNSS reference data from SWEPOS are needed in other applications as well. Examples include control systems for agricultural tractors and construction machinery. The developed vehicle model is a good supplement to the robot model that was previously available. The project results make up contributions to new products, but are not individually marketable.
Introduced into the market		
Used in investigations/regulations/ licensing/political decisions		

Large scale implementation of the technologies developed within the project pre-supposes two external changes. GNSS receivers operating with more than one carrier frequency need to reach the mass market, and real-time correction delivery systems such as SWEPOS need to evolve to efficiently handle a significantly larger number of concurrent users. Both these changes are seen as likely, since the economic gains from significantly increased positioning accuracy are large. The U.S: Commerce Department estimates that large scale civil deployment of a second frequency in the GPS system (denoted L2C) could generate USB 5,8 billion in economic productivity benefits through the year 2030 (http://www.gps.gov/systems/gps/modernization/civilsignals/).

Increased awareness of L2C may in turn increase interest in the results of this project. Expansion of the SWEPOS business model to include products for a larger audience would also likely increase interest in the project results.

6.2 Publications

Holmström, Jonathan, 2015. *Lane departure warning using low-cost satellite-aided positioning technology on modern highways.* Master of Science Thesis MMK 2015:78 MDA 503, KTH Industrial Engineering and Management, Stockholm

Enberg, David, 2015. *Performance Evaluation of Short Time Dead Reckoning.* Master of Science Thesis LiTH-ISY-EX--15/4826—SE, Reglerteknik, Tekniska högskolan vid Linköpings universitet, Linköping.

7 Conclusions and Future Research

The combination of a low cost GNSS receiver, sensors for inertial navigation, and correction information from fixed reference stations is very promising. The technology is not quite ready for mass deployment, but the development is progressing rapidly. Now is an excellent opportunity to gather early experience and expertise in the field.

GNSS receivers that can handle dual carrier frequencies are required in order to bring the initialization time for the system down to acceptable levels. These receivers will likely be available from a number of suppliers, at reasonable prices, within only a few years.

Improved modelling of the vehicle and handling of the inertial sensor data is required in order to cope with longer GNSS outages. This work will to an extent need to be carried out separately for each type of vehicle. Since heavy duty vehicles can differ significantly between e.g. busses, distribution trucks, and long haulage trucks, it would be of interest to evaluate the limits of how general a vehicle model can be and still produce the required level of accuracy.

8 Participating Parties and Contact Persons

Participants at Flowscape have been David Enberg (MSc thesis worker), Jonathan Holmström (MSc thesis worker), Peter Reigo (CEO, project leader, and GNSS expert), Isak Tjernberg (expert on inertial navigation systems and robotics), Jakob Almqvist (expert on satellite based positioning systems) and Tommy Palm (electronics hardware designer and project leader).

At Scania the main participants have been Per Sahlholm (project leader, expert on digital maps for vehicle applications) and Pär Degerman (expert on connected services for vehicles).

8.1 Contact Persons

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