iTRANSIT

Public report

Project within Effektiva och uppkopplade transportsystem

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Content

1. Summary

The iTRANSIT project has been running from September 2015 to December 2017. The partners were Volvo Car Corporation, ÅF, AstaZero, Chalmers University of Technology, and SP Technical Research Institute of Sweden (now RISE Research Institutes of Sweden). The overall goal of the iTRANSIT project has been to support development and test of intelligent transport systems (ITS) where road users and vehicles are connected. An example of a complex intersection scenario of this kind can be seen in Figure 1 below.

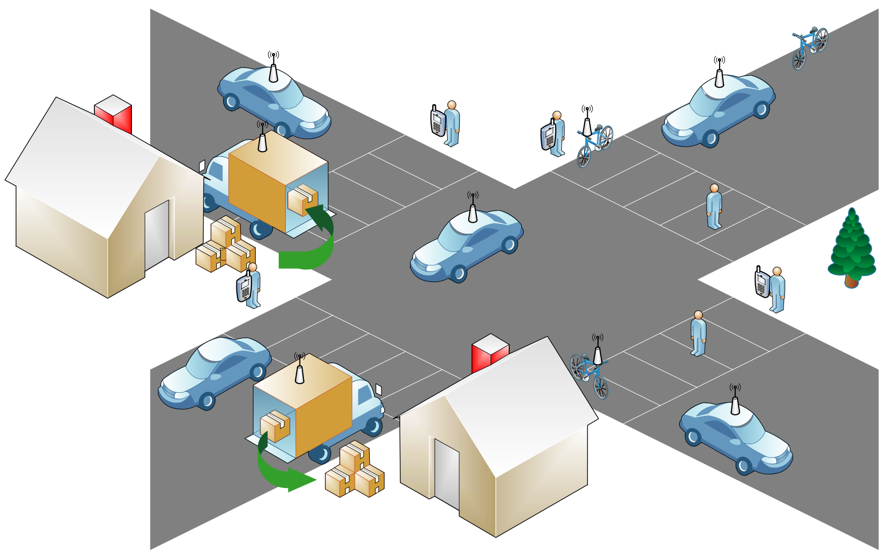


Figure 1. Complex ITS intersection scenario

To facilitate such scenarios, a few essential components are needed. Each connected object must have a safe ITS station having the most fundamental services: positioning and time (POTI), cooperative awareness basic service (CABS), local dynamic map (LDM), and a management service (MGMT). For connected vehicles, a vehicle data provider (VDP) service may also be present.

The project has been organized into work packages that have focused on different areas and domains to be analysed and experimented upon. The results have then been aggregated into a demonstration work package where actual physical tests have been performed to validate results.

In the project one focus area has been on the development (process) of safe CABS and LDM services according to the international safety standard for road vehicles: ISO 26262.

Another important component that has been analysed implemented and validated is a central ITS traffic management server which aggregates information from vehicles into a unified Global Dynamic Map (GDM). The central server supervises operational situations and gives recommendations to the road users. In the server different object motion and reachability algorithms have been tested to perform object collision detection and object collision avoidance amd mitigation strategies.

Affordable, accurate and reliable positioning system is imperative in an ITS and the project has evaluated several approaches augmented with real time kinetic (RTK). The results have been very promising and partly used in another industrial project, DRIWS (Digital Runway Incursion Warning System) to solve an EU directive about safety at airports.

Accurate maps are also an important part of an ITS and the AstaZero test track has been laser scanned partly into a point cloud map. Tools have been developed to process this accurate map into other map formats, e.g. OpenDrive (an open source format for road topologies).

2. Sammanfattning på svenska

Projekt iTRANSIT har utförts under perioden September 2015 till December 2017. Partners har varit RISE, Volvo Car Cooperation, ÅF, AstaZero, och Chalmers Tekniska Högskola. Det övergripande målet med projektet har varit att titta på de standarder som ETSI har levererat till EU för att implementera ett Intelligent Transport System. Där kommunicerar trafikobjekt med varandra via ITS-stationer enligt standardiserade protokoll och meddelande objekt. Projektet har införskaffat kommersiella ITS-system som har varit öppna och anpassningsbara för att utprova, implementera och analysera samt validera koncept och forskningshypotser.
Några viktiga få essentiella komponenter och tjänster behövs i ett intelligent transport system: positionering och tid (POTI), kooperativ informationsdelning (CABS), en informationslagringsenhet (LDM) och ett management system (MGMT). I fordon finns det en Vehicle Data Provider (VDP) brygga mellan fordonets interna informationskällor och ITS stationen.

Projektet har organiserats i ett antal arbetspaket där fokus har varit olika domäner som har analyserats och genomfört praktiska experiment. Resultaten har sedan sammanfogats i ett arbetspaket för demonstrering där resultat har validerats praktiskt på testbädd AstaZero.

Ett stort focus har varit att utvärdera hur standarden för funktionssäkerhet för vägfordon (ISO 26262) kan anpassas och användas i sin informativa del om ett ”Safety Element out of Context (SEooC)” för att utveckla komponenter (semi)formellt för högsta säkerhet.

iTRANSIT har tagit ett centraliserat perspektiv på att analysera operationella trafiksituationer och aggregerat informationen från fordons lokala ITS stationer/LDM till en global informationslagringsenhet (Global Dynamic Map – GDM). I den centrala servern har olika algoritmer för objektrörelser och deras framtida potentiella positioner analyserats för att genomföra antikollisions-beteenden och riskminimerings-strategier.

Ekonomiskt tillgängliga positioneringssystem som är både tillförlitliga och korrekta är en annan viktig komponent och projektet har analsyerat flera olika systemlösningar med kommersiella system till en bråkdel av kostnaden för referensmätningssystem. Genom att använda korrigeringssignaler från en basstation så har precisionen visat sig vara lika bra som de avancerade och dyra systemen. En validering av detta har varit att viss information från projektet har använts i ett kommersiellt system för att monitorera fordon på flygplatser enligt en EU förordning (DRIWS via Luftfartsverket och Saab Combitech).

Kartformat över väg och transportnätet är också en viktig aspekt. Asta Zero har delvis laserskannats till ett detaljerat punktmolnsformat. Projektet har utvecklat verktyg och metoder för att analysera ett sådant punktmoln och tranformerat informationen till öppna format såsom OpenDrive och därmed reducerat kartinformationen till en bråkdel av punktmolnets storlek.

3. Background

Communication between road users, particularly from one vehicle to another and between vehicles and infrastructure, will facilitate their cooperation and result in more efficient transport systems. An infrastructure that can collect and fuse the positions and sensor data from many traffic actors in real time will á priori have a better awareness of traffic situations, and is envisioned to provide better traffic management than any of the individual road users. The resulting intelligent traffic management system will result in higher throughput of vehicles, improved traffic safety, and reduced environmental impact. The research questions here are not restricted to system development and architectures, but also ITS affordability and co-operability with existing vehicle systems.

In February 2014 CEN and ETSI announced that they have delivered the first set of standards of the intelligent transport system (ITS), as requested by the European Commission in 2009[1]. These standards define the ITS communication architecture [1] including message formats [2] [3] as well as the information storage of ITS applications: the local dynamic map (LDM) [4]. The main goal of an ITS is to collect and distribute information. The information can be positions, speeds, and accelerations of vehicles and other moving objects as well as environmental information such as: road temperature, precipitation, and accidents. Mobile and stationary ITS stations will act as information sources and sinks. Mobile ITS stations can either be personal or vehicle ITS systems, and stationary can be central or roadside ITS systems, see Figure 2. GNSS is commonly used to get positioning data which could be improved by the use of digital maps. In GNSS-denied areas on-board sensors such as odometer and accelerometers could be used for odometry (dead-reckoning).

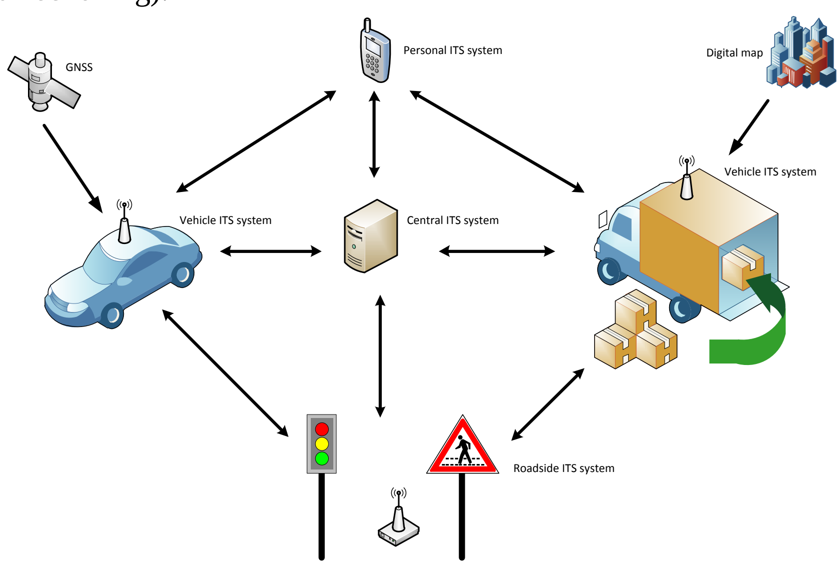


Figure 2. Overall ITS architecture with possible components.

[1]http://europa.eu/rapid/press-release_IP-14-141_en.htm

The LDMs are the key components of ITS-equipped actors, but the quality of the stored information depends heavily on the quality of positioning systems and communication links. Moreover, there is a risk that different traffic actors equipped with different implementations of local ITS applications may treat the same actual situation in unexpectedly different ways. This may result in compromised safety. In an efficient traffic management system it is vital to be able to aggregate LDMs of all relevant actors to a global dynamic map (GDM) from which strategic and tactical traffic management decisions can be made. Recent research results provide solutions for information aggregation from an individual vehicle perspective [5] [6]. This is a complementary approach that, in addition to solving the task in a centralistic manner as we do, allows some parts of the solution to be found in a distributed manner. Further advantages of a centralistic traffic management system are possibilities for more powerful computational resources and more storage memory than available in the vehicles, which enables management of more complex/fast developing situations with shorter delays as well as storage and processing of high-resolution digital maps. We believe that both approaches are important and we propose to start from the more cost efficient centralistic approach and take the completely (and more complex) decentralized approach only when needed.

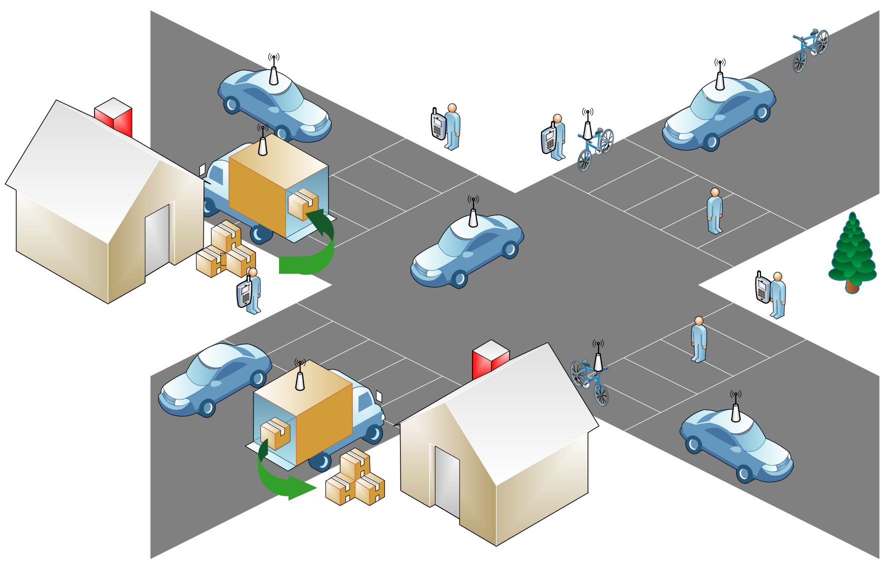


Figure 3. Complex traffic scenario.

For successful large-scale deployment of ITS-systems, it is imperative to have affordable and yet high fidelity positioning technologies. 50-100 kSEK state-of-the-art RTK-based GNSS solutions are not viable. Positioning performance of built-in GPS receivers in smart phones has been shown to be insufficient for most ITS use due to antenna limitations (problems with multi-paths) [7]. There exist ground-based positioning systems [8], but they are still unaffordable and have limited coverage area which are dependent on the number and spacing between the anchors used for triangulation. Low-cost open RTK-based GNSS solutions are emerging on the market.
However, their static and dynamic performances are still questionable and need investigation. On the other hand, their performance might be sufficient, if their output

positioning data is fused and filtered in a clever way[2]. One of the iTRANSIT objectives is to improve existing RTK-based positioning technologies so that ITS station could become affordable as well as using effective way to integrate this online information with the area laser-scanned point cloud.

The provision of high fidelity information to traffic management systems (TMSs) facilitates the prediction of prospective traffic behavior and the detection of possible risks. An ITS system could then relay the needed action to harmonize traffic and mitigate risk, such as speed advices and risk warnings. In fact, by leveraging on the TMS ability to coordinate, we allow existing (vehicular) active safety systems to enhance their performance, while aiming for affordable costs, simpler prototyping, verification, and deployment.

[2] http://mitpress.mit.edu/books/probabilistic-robotics

4. Purpose, research questions and method

Some of the key research questions of this project include:

1. How can data fusion and smart filtering be used to get affordable and yet high fidelity positioning systems?
2. Is there an affordable LDM aggregation and GDM dissemination in a scalable and timely manner?
3. How detailed can we represent the roads and the environment, e.g. maps based on laser-scanned point clouds, and yet be able to transmit them in the ITS network while meeting the safety requirements? The answer to this question must be counterbalanced with the following one: What is the achieved level of performance with respect to communication and processing costs as well as precision and validity?
4. Given the above system performance, to what extent can we leverage on the proposed centralistic approach when (partially) planning vehicle trajectories? For example, can the multidimensional problem of finding safe (stop) trajectories for all involved actors be found by the intelligent traffic management system?

The methods used to answer the questions above have been:

1. State of the art survey.
   Reading existing standards.
   Market survey for suitable test objects.
   Identification of area of improvement.
   Theoretical analysis of different filtering and aggregation algorithms.
   Improving the algorithms.
   Implementing them in the test objects.
   Running statistical experiments to gather data.
   Analyzing the result.
   Using the results for position and time component (POTI) in an ITS station
2. Survey of the ETIS ITS standards.
   Survey of existing safety standards.
   Market survey for suitable test objects.
   Conducting several master thesis of different approaches for object motion estimations, collision predictions, and collision avoidance.
   Specifying parts of the ETIS standards for the Local Dynamic Map (LDM) and Cooperative Awareness Basic Services (CABS) in accordance to the safety standards and the identified suitable algorithms.
   Conducting experiential setups with implemented ITS stations in real test vehicles at test bed Asta Zero.
   Demonstrated 2 key scenarios for collision avoidance and sensor fusion at AstaZero for public.
3. Test site Asta Zero has been laser scanned partly into a huge detailed point cloud format.
   Developed algorithms and tools for point cloud analysis to identify objects as road edges, walls etc.
   Developed algorithms and tools for transforming point cloud representation into a more

compact open source format, OpenDrive that has been used in conjunction with the POTI system.

4. The fourth research question has been researched by using combinations of the research results from above and investigations of a centralistic sensor fusion approach, which have been analyzed in several master theses.
   The results have then been aggregated into two key scenario tests which have been performed at test site AstaZero using real vehicles and R/C cars in scale 1/6.
   The research question has shown to be complex and depends on several system design choices and parameters.
   Some more theoretical analysis have been initiated to be used as baseline for further research projects but there are no conclusions yet to be delivered from that research..

5. Objective

The purpose of iTRANSIT is to provide technical enablers that are affordable for perspective ITS applications and services in the areas: safety, comfort, and traffic management, to name a few. iTRANSIT exploitation includes also allowing AstaZero to work towards having its first open ITS infrastructure and by that we facilitate a broader spectrum of test services in the future, and strengthened international competitiveness. Note that AstaZero has been highlighted as a key innovation environment and test bed for ITS by Trafikverket [9]. Additionally, ITS services are necessary conditions for automatic driving.

The importance and potential of the ITS area should not be underestimated, and it is underlined by the interest and research started by traditional information and communication technology stakeholders such as Ericsson, IBM, Google, and Apple, among others. It is extremely important to realize that ITS systems are information centric which will cause a paradigm shift within the transport sector. New business models and services will emerge. It is vital that Sweden is in the forefront with ITS as we once were with nation-wide expansion and employment of Internet.

The participating companies: SP, AstaZero, Volvo Cars Corporation, Chalmers, and ÅF have in several cases worked together in national and international research projects. However, the departments and personnel involved in this project mostly represent a new constellation. This is a typical project where state-of-the-art academic research will be accessible for industry by the aid of a research institute.

This project, when approved, fitted very well to the two sub-programme objectives: “5.1. New vehicle concepts” and “9. The intelligent transport system” [10];
in particular the project results will be an enabler for “The vehicles as sources and sinks of information and diagnostic probes of the transport system”, but also as part of a robust communication solution where LDM and GDM are kept synchronized and consistent efficiently and reliably. However, implicitly the project results will additionally enable better traffic management, logistics, real-time optimal routes, and support for automated driving.

According to the strategic roadmap (FFI) for effective and connected vehicles [11], the co-modal transport systems shall be established in 2020. In particular all vehicles should be connected and the information shall be transferred in real-time. Probe vehicle data shall be structurally collected and utilized to provide e.g. information on the current traffic situation. Additionally, systematic functional requirements on the interaction between vehicles and the infrastructure are mentioned. All these statements are perfectly in line with the objectives of the iTRANSIT project.

6. Results and deliverables

6.1 Safe ITS Station

SPs main work has been in work package 2 - ITS Stations. Main task has been to address safety standard ISO 262626 and specially its informative part 10 to evaluate how to develop safety related components - POTI, CABS, LDM - in an assumed safety context without explicitly specify an whole ITS station as an ISO 26262 item. This has resulted in a delivery D2.2b Software SEooC, CABS and LDM.

Instead of targeting a mobile phone application a reference ITS prototype design, as described in “D2.1 ITS station prototype”, was implemented with an explicit 4G modem, a Raspberry PI and an ITS station evaluation kit. This setup is much more suited for experiments in the projects and for real demonstrations outside of the project.
Delivery D2.3 ITS station Evaluation Report presents experimental and analytic results.

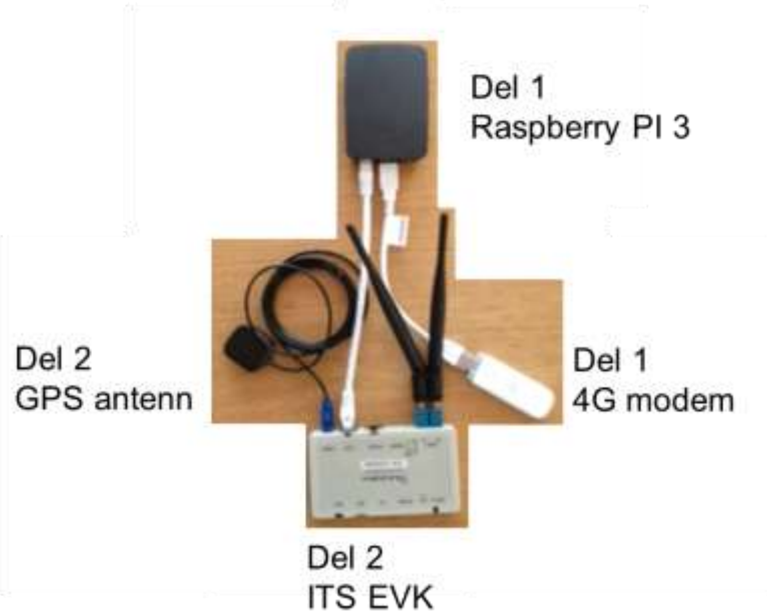


Figure 4. ITS prototype setup

Cooperative Awareness Basic Service

The project developed a formal parser for ASN.1 (abstract syntax notation1), a format heavily used in telecom standards by ETSI. All ITS standards specify the data messages in this format. The goal was to assert that formal tools are viable to use in a commercial approach in all domains and design phases. An external professional ASN.1 compiler was also used in conjunction in the project to transform ASN.1 into C code.
The project modified some messages protocol in ETSI ASN.1 standards to attribute the messages with performance indicators. Delivery D2.1 ITS Station Prototype describes this.

Two test cars at testbed AstaZero where each equipped with a reference design of the projects ITS-station. Messages for position and timing where produced in the POTI component implemented in the Raspberry unit and sent to the CABS component to be assembled into an ITS Cooperative Awareness Message (CAM).
The Cooperative Awareness Message packet where then delivered to the ITS station, over UDP and Ethernet cable, which in turn broadcasted the CAM according to standard G5. Upon reception of the messages in the other vehicle by its ITS station the CAM was transferred to the Raspberry unit for re-transmitting the same message over 4G back to the initial car. In this setup the project could use both 4G cellular techniques and ITS G5 WiFi techniques to send CAM and measure performances in each technique.

Local Dynamic Map

As part of delivery “D2.2a. ITS station”, a LDM component was semi-formally specified and implemented in C code. The code was augmented for semi-formal post processing and verification.

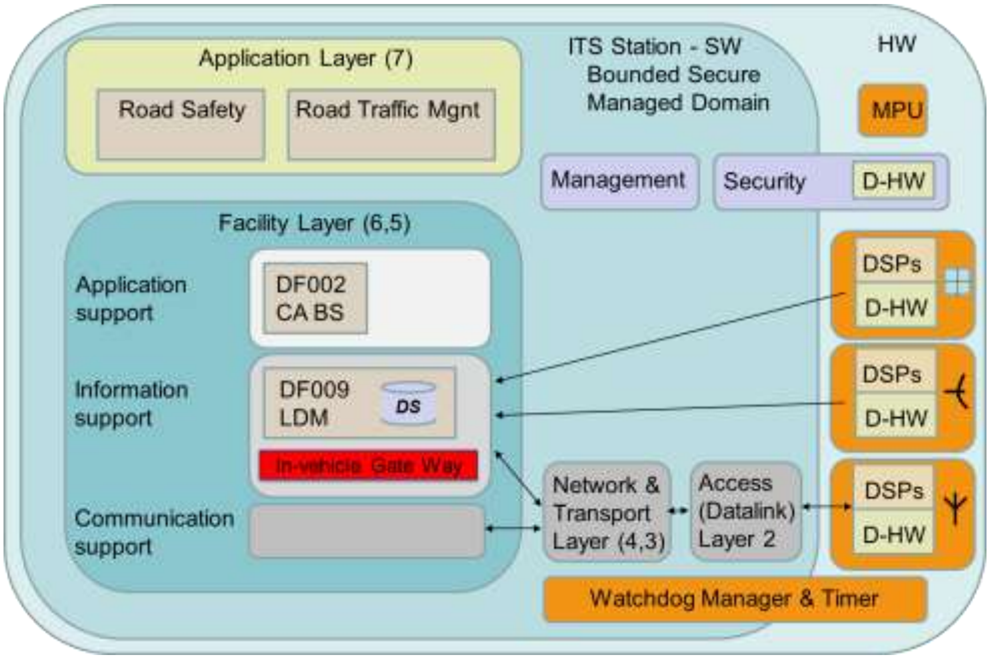


Figure 5. CABS and LDM component in an ITS

The LDM was used in both the ITS stations at vehicles but also as a Global Dynamic Map (GDM) at a server implementation. At the server side a command interface was implemented using TELNET protocol. Managers for vehicles and two different browsers were implemented, one for Carmenta's map server and one for HiQ's 3D browser GREIT.

In this setup both real cars and virtual cars could be connected to the server and displayed in real time at any web platform and also in VR googles.

Figure 6. An ITS station with a screen view from the LDM.

Figure 7. ITS station as a road side unit communicating with a test vehicle at AstaZero

Figure 6 and 7 shows the ITS station in two different modes: as a vehicle unit and as road side unit (RSU).

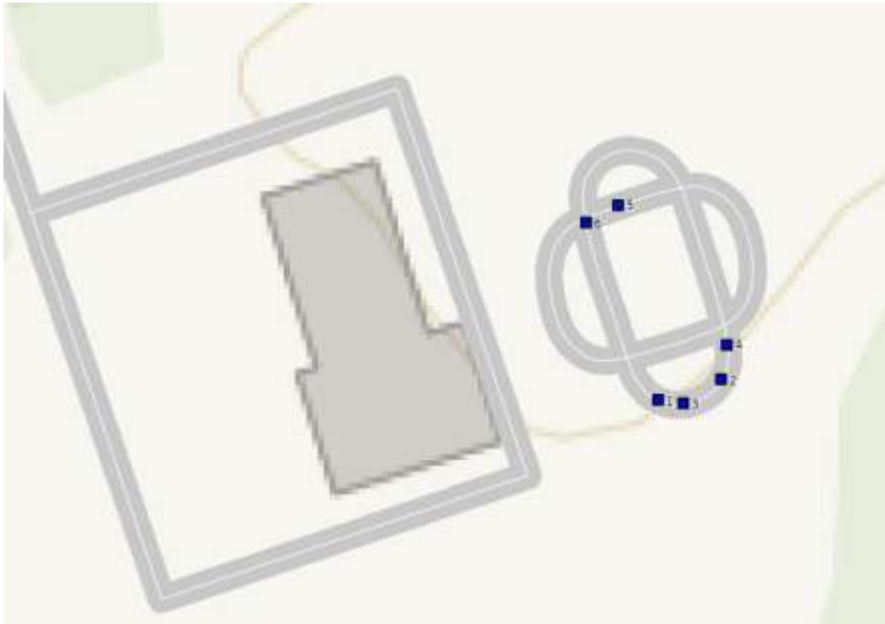


Figure 8. Snapchot from a webbrowser showing a virtual road at AstaZero with real and virtual cars.

Carmenta's map server was running at Amazon Web Services and connected to a LDM component imbedded in a traffic server as a Global Dynamic Map (GDM). One of the blue dots in Figure 8 is a real car and the others are virtual cars interleaved in the scenario.

Positioning and Time

The POTI component has been designed and implemented in a Raspberry unit. It has been used in two configurations, one as part of the ITS station and used in a real car and in the other configuration as a freestanding component to be used for experiential setup and measurements in a more easy way using remote controlled (R/C) car scale 1/6.

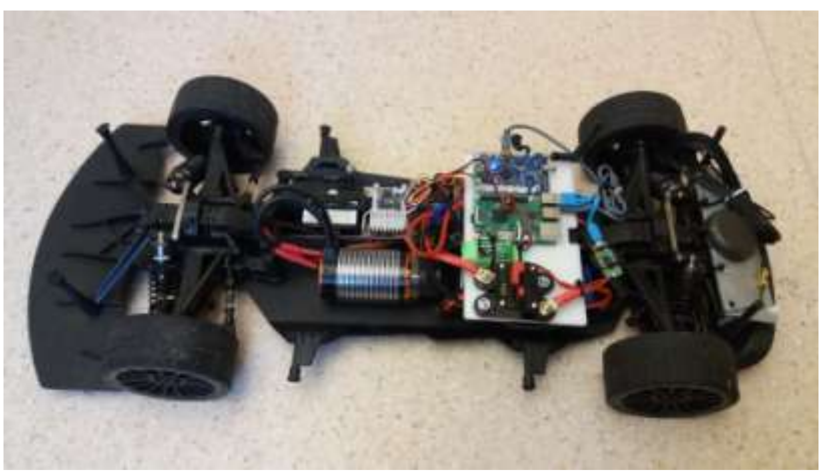


Figure 9. iTRANSIT R/C car scale 1/6 with POTI and communication equipment.

The R/C car has been using a Real Time Kinetic server at AstaZero as an augmented information source and the positioning accuracy has been measured at different locations at AstaZero with very good performance.

Results

- Three main component of an ITS station have been designed and implemented as open source:
  Positioning & Timing POTI, Cooperative Awareness Basic Service (CABS) and Local Dynamic Map (LDM).
- The LDM has been semi-formally specified and the code has been augmented for formal verification. Only message format has been formally checked but the specification is anticipated to be used by other projects for formal verification.
- The ITS messages which are specified in formal notation ASN.1 has been processed by a formal parser implemented in the functional language Haskell for validation.
- The LDM has been connected to HiQ's GREIT 3D visualizer (based on game engine Unity) and also to Carmenta's map server running on Amazon Web Services.
  In this configuration the LDM could be browsed in real time from any number of mobile devices equipped with ordinary web browsers.
- The positioning systems has been measured and validated by placing them on the mentioned R/C car scale 1/6 but also by using real cars.

6.2 Central Traffic Management Server

A Central Traffic Management server was developed in Simulink by Volvo Car Corporation. The server takes measurement data, called LDMs (Local Dynamic Maps), from a number of actors; for example cars, radio-controlled (R/C) cars and road side units. This data is then fused in the server to a GMD (Global Dynamic Map) with the global position of all actors. The data is logged using Simulink's built in logging capabilities and visualized both online and offline.

The scenario is defined in a traffic manager that also makes sure that all actors are connected to the server. The scenario can be either a predefined scenario or a dynamic scenario based on the state of another actor. From these scenarios, trajectories are generated for each actor that define their global position and velocity as a function of time. A master thesis has also investigated monitoring the scenario and rerouting vehicles if a collision is possible.

Additionally, wrappers to a number of different actors have been developed so that the objects can be controlled from Simulink and/or that their state can be read. A motion controller has been developed for following a trajectory without knowing the object's dynamic properties. Using models from VCC's traffic simulator, virtual actors have been implemented that can be run alongside real actors in the same test scenario. A concept for injecting these objects into the sensor fusion of DriveMe cars is implemented that makes them visible to the sensor fusion even though they are not physical objects.

The server is built up of the Fusion Server, the Traffic Manager and the Trajectory Planner. The Fusion Server takes the LDMs (Local Dynamic Maps) from the actors and fuses them into a common GDM (Global Dynamic Map). The Traffic Manager defines the scenario events that the actors should follow and overviews the test to ensure safety, e.g. to avoid possible collisions. The last module is the Trajectory Planner which takes the scenario events and transforms them into a continuous, global, trajectory which is then sent to the actors.

The Steer by Server architecture and the components of the iTRANIST server are summarized in Figure 10 and Figure 11. Further details can be found in the deliverables 3.2 and 3.5.

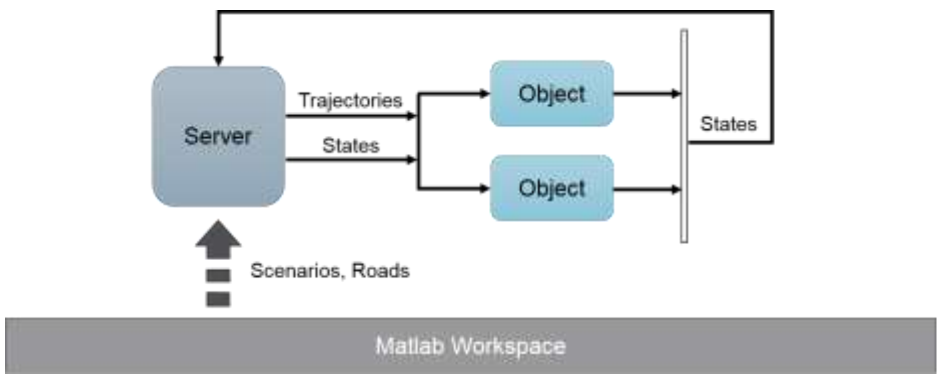


Figure 10. Architecture of the Steer by Server setup

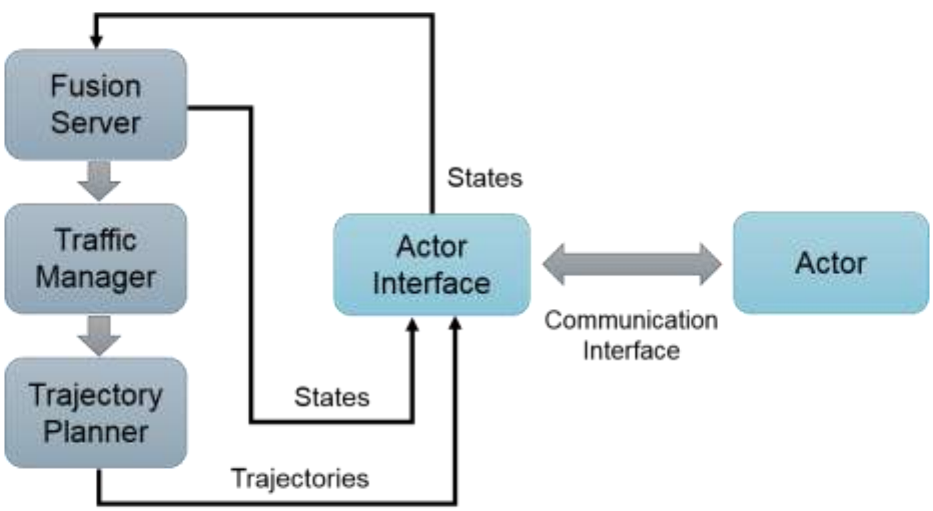


Figure 11. Components of the iTRANSIT traffic management server (TMS).

Fusion

The goal with the fusion server is to produce a more accurate and coherent view of all dynamic objects in the environment seen by the active actors. This is done by fusing data from the LDMs that each active actor sends to the fusion server, which then combines them into a GDM. A LDM contains state estimates and covariance matrices for the ego states as well as for all objects it can detect with its sensors.

A first implementation of the fusion algorithm was developed as a Master thesis project at Chalmers University of Technology (Johnny Ngu & Ronakorn Soponpunth, 2016, see §7.3) and is described in Delivery 3.1. The algorithm was developed in C++ and used an Information Filter (a variation of a Kalman Filter). This work was continued at Volvo Cars where the fusion server was implemented in Simulink and connected to the iTRANSIT server. A Constant Acceleration model was used to model the movement of the objects and rollback was used to deal with out-of-sequence data.

During the spring of 2017, another Master thesis (Alexander Berg, Andreas Käll, 2017, see §7.3) extended and improved the fusion model. A more accurate motion model was used to better mimic the motion of a vehicle, in this case a nonlinear coordinated turn (CT) model. This algorithm associate tracks in the LDMs with the server tracks with higher accuracy. The implementation was also done in Simulink. The wireless communication between the actors and the fusion server was modelled as a random delay where each LDM was delayed differently according to a normal distribution such that it's more common for the packets to have small delays.

Traffic Management

The traffic management service that has been implemented in the iTRANSIT server was discussed in the Master thesis "Centralized collision avoidance system for automated vehicles" (Andreas Hahlin, Anton Olsson, 2017, see §7.3).

The purpose of the system is to ensure that the ego vehicles are not at risk of colliding with the target vehicle at any given time. This is achieved utilizing Reachability Analysis (RA) on the target vehicle in order to predict its reachable sets up to some prediction horizon H_x in time and then applying Model Predictive Control (MPC) on the ego vehicles in order to avoid these sets. The current implementation is designed for lateral control of the ego vehicles and assumes that their trajectories are parallel with the global x-axis. Lateral control could be relatively easily included with moderate alteration to the system, though it has not been tested in this project.

The system starts by separating the ego vehicles from the target vehicle by using predefined tags. These definitions are included in the scenario description.

The current information (pose) of target vehicle is passed to the RA algorithm to formulate its reachable sets, up to the time horizon. The remaining desired trajectories of the ego vehicles are then compared individually to that reachable set in order to find future collision risks. In those cases the MPC algorithm solves for new safe paths for the ego vehicles, replacing the original desired trajectories, that then get passed on to the actor. Further details can be found in deliverable 3.5, "Development and validation of the iTRANSIT fusion server".

Logging

Logging is a mandatory component for development of new systems, without which e.g. evaluation, verification, fault identification cannot be performed. In this project logging has been done mainly on two levels; the ITS application level and reference level. VCC handled the ITS application level and AstaZero the reference level.

The ITS server developed by VCC was implemented in Simulink and connected to the SPAS (Simulation Platform for Active Safety) simulation environment. The logging of all data is done naturally in Simulink as Matlab variables. The logged information includes:

- **Ego vehicle pose:** own position, velocity, and heading as detected by onboard sensors (e.g., GPS, inertial sensors, odometry), together with uncertainties.
- **Local dynamic map (LDM):** position, velocity, and heading of other objects detected by each vehicle, and relative uncertainties.
- **Global dynamic map (GDM):** position, velocity, and heading of all objects after track fusion by the server, and relative uncertainties.

All the logged information can be displayed by SPAS own bird's eye viewer, as shown in fig 12.

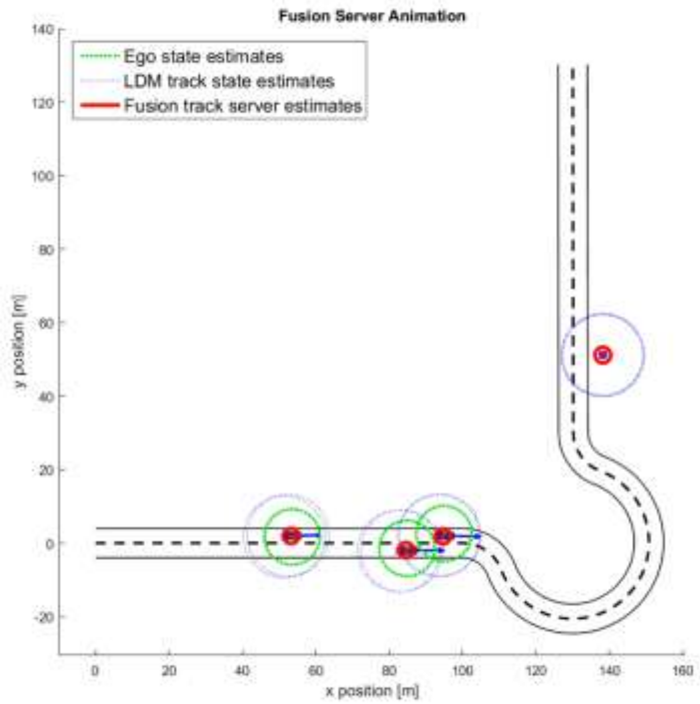


Figure 12. Visualization of the iTRANSIT fusion server simulation in SPAS bird's eye viewer. Circles show uncertainties of object position estimates from Ego, LDM , and GDM

On the reference level AstaZero provided state of the art technology for accurate and reliable vehicle dynamics measurements. This technology was used to calibrate and evaluate POTI [WP4 D4.1 and D4.2], and for test vehicles used in test scenarios and demos. Another component the project touched upon was ITS enabled traffic lights.

For more details concerning logging please see deliverable D3.4 Logging infrastructure. The document was written in collaboration between AstaZero and VCC.

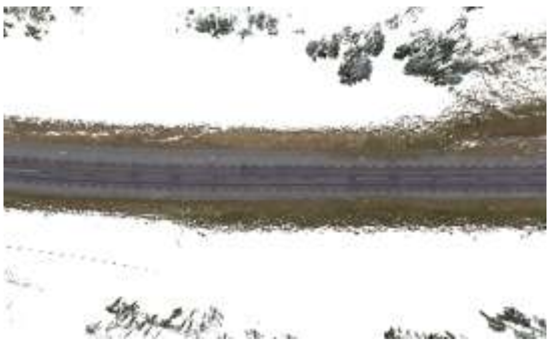
6.3 Digital Map

Map Extraction from Point Cloud to Binary Format

ÅFs main work in this project has been to develop methods for automatic generation of a 3D-map from a point cloud. The work is described in the report “D4.4.1 ÅF Map Generation Report”. The resulting 3D-map of AstaZero is part of the delivery, “D4.4.2 AstaZero 3D-map” (please ask the project for a copy).

Pointcloud → Software → 3D-map, i.e. a list of geometrical shapes with known coordinates

Figure 13. Tool chain



Pointcloud

3D-map with road markings

Map Extraction from Point Cloud to OpenDrive Format

ÅF has developed an application to generate an OpenDrive map (see www.opendrive.org) from the raw 3D-map format. The resulting OpenDrive map of the rural road part of AstaZero is part of the delivery and is stored in the file “D4.4.3 AstaZero OpenDrive map (rural road)”. The methods used to create the OpenDrive map from the raw 3D-map is described in Appendix B of the “D4.4.1 ÅF Map Generation Report”

3D-map, i.e. a list of geometrical shapes with known coordinates → Software → OpenDrive-map

Figure 14. Map format and tool chain.

6.4 Positioning

Affordable RTK GPS and Sensor Fusion with IMU

Connected to an RTK base station, affordable RTK receivers promise sub-decimeter performance. Since the automotive industry is cost-sensitive, affordable components are essential for market penetration. In this project, affordable RTK receivers, the assembly of low-cost RTK GPS receiver prototypes were proposed. The static and dynamic evaluation of the proposed porotypes was provided. The evaluated receivers were compared with a state-of-the-art RTK GPS system which additionally employs an IMU to reach sufficient performance. To get repeatable and accurate results, a test vehicle with a steering robot was used on the AstaZero proving ground. This part of the report briefly presents our porotype and its evaluation environment as well as gives a summary of these results.

The developed prototype.

In Figure 15, we present a sketch of system architecture that we used for evaluations, and in Figure 16, we present a unit that we have built in our lab (which does not include the OXTS GPS and the RTK base station).

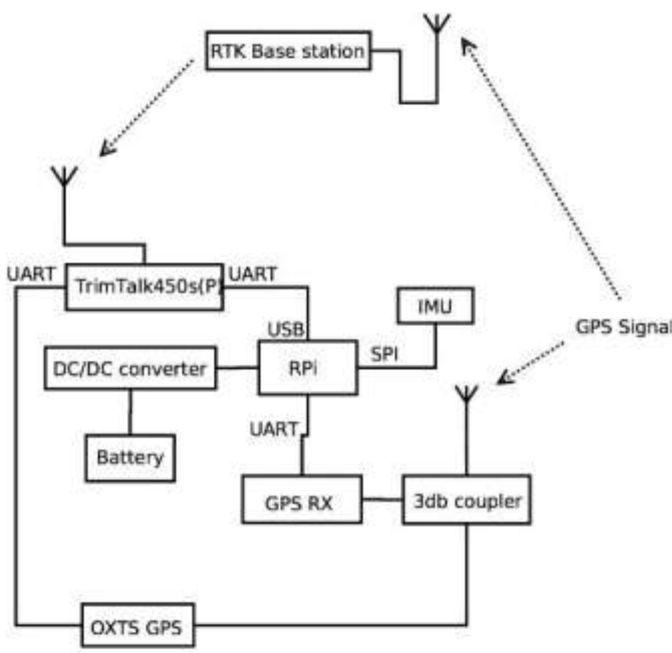


Figure 15. Model of the System

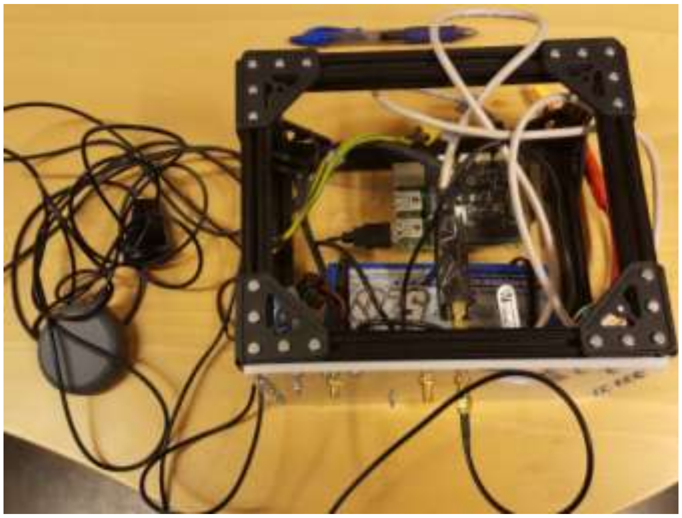


Figure 16. The Built Unit

Static Measurements.

A phenomenon that was observed was that position is fairly inaccurate in the beginning of the measurements. We observed that the measurement error subsides after about 10 minutes. The system performances are significantly better after the system acquires a fixed position. We can also observed that the performances are compromised by the long cable and the signal splitter.

Dynamic measurements.

Broadly speaking, the receivers are very sensitive and quick to detect changes. However, finding the correct absolute position to start from takes a little more time; typical around 10 minutes. The RTK GNSS technology has exceptional precision and decent accuracy. The accuracy improves given enough time to acquire a fixed position.

We have observed that the studied RTK modules have much better performance than standard GPS systems, and have a performance which is not far from expensive RTK GPS. The measured static performance has a standard deviation of less than one meter and typically less than half meters. In dynamic measurements, the cheap RTK GPS modules performed well with a precision of 20 cm under some conditions.

Examples.

The benefit of using RTK correction is best illustrated using a figure. In Figure 3, GPS tracks with (green) and without (yellow) RTK correction is presented. It is quite clear how much the precision is improved by employing RTK correction data.

Judging from their performance and their price trend, these affordable RTK receivers will find their way into many new applications. It is probable that many ITS actors will get one eventually, regardless if they move on land (roads), on sea, or in the air.

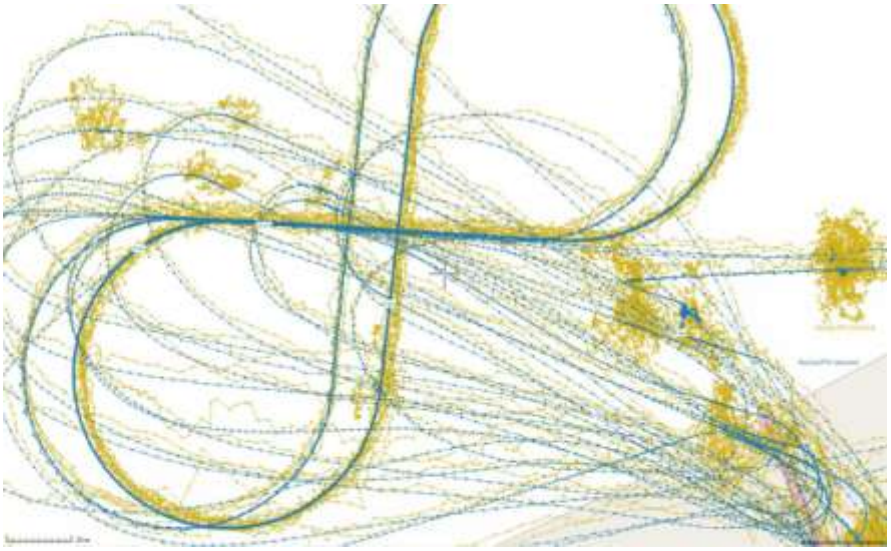


Figure 17. GPS track with (green) and without (yellow) RTK correction.

Camera- and Lidar-Based Positioning

In order to fully utilize the potential of a high-definition 3D-map, the vehicle needs to know its exact position in the map. Today's GPS is not good enough and hence methods need to be developed to increase positioning accuracy. ÅF has explored a concept where data from multiple sensors (GPS, camera, Lidar, IMU and odometer), as well as the map itself, are fused to give a higher accuracy. This work is described in the report "D4.5 Multi sensor fusion and 3D-map matching Report".

Furthermore, a paper describing a pure Lidar-based position algorithm was started but had to be discontinued due to a lack of reference data for verification. The data that was available had quality issues that couldn't be resolved within the scope of the project.

6.5 Demonstrators and Demonstrations

During the project a number of demonstrations have been performed on the test track at AstaZero. Here AstaZero as a project partner was an active part of planning, preparing, coordinating and executing the demonstrations. In total, three demonstrations have been conducted, in all of which AstaZero took an active part, preparing the track for demonstration, providing track time, test engineers, vehicles and technology such as reference systems. Demonstrations were held for an FFI conference on 14/7-2016, as well as on AstaZero Researcher's days 18/10-2016 and 17/10-2017. The demonstration on 17/10-2017 was considered the final demo for the iTRANSIT project.

The demonstration conducted during the FFI conference involved a radio controlled (R/C) autonomous car following a predefined internally known path. The position of the car was visualized together with the path in real-time on a computer. See Figure 4 which shows a picture of the autonomous car in the middle of following the path on the high speed area (HSA) at the AstaZero track.

Figure 18. Picture taken of the autonomous radio controlled car during demonstration at the FFI conference on the 14th of July 2016. The car is following a predetermined path on the High Speed Area (HSA) at the AstaZero track.

During the first of the two Researcher's Day, the same demonstration as July 14th was performed but on a different track environment. The iTRANSIT final demo was performed during the Researcher's Day October 16, 2017. This demo consisted of two parts. The first was sensor fusion which was as shown as a video, more details in §6.2. The second part was an intersection scenario at AstaZero's city environment.

For the intersection scenarios two vehicles where used, one real car (V2) and one small RC-car (V1), see Figure 19 below. Here V1 adapted speed to let V2 pass the intersection first.

The final demo was organised as follows. VCC handled the TMS server, SP (RISE) handled the RC-car and AstaZero acted as project manager, and also provided test track, reference equipment and the real car.

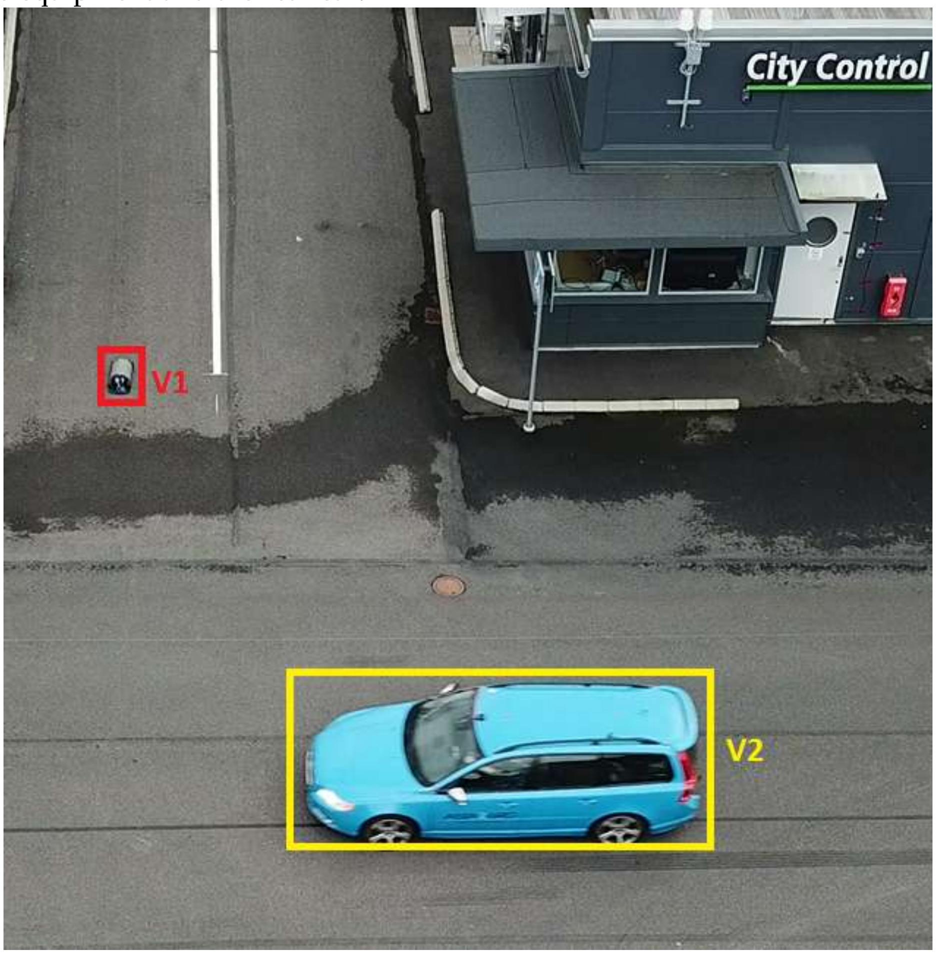


Figure 19. Picture from the final demonstration. Car V2 was a real car and car V1 was an autonomous RC-car. Position of V2 was shared with V1 such that V1 could autonomously yield to V2 in the intersection.

7. Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Fulfilled	Comment
Increase knowledge in the field	X	VCC is using the results in their DriveMe project
Be passed on to other advanced technological development projects	X	Results have been applicable to support design of a commercial safety application at Swedish airports to handle an EU directive (DRIWS - LFV)
Be passed on to product development projects	X	Carmenta AB has been using the results in developing their Traffic Watch ™ product. A C-ITS traffic management system.
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions		

1.	Transportforum, 2016
2.	AstaZero Researchers Day, 10 May, 2016
3.	AstaZero Researchers Day, 18 October, 2016
4.	Transportforum, 2017

7.2 Publications

1.	M. Skoglund, T. Petig, B. Vedder, H. Eriksson, and E.M. Schiller, "Static and dynamic performance evaluation of low-cost RTK GPS receivers", in Proceedings of 2016 IEEE Intelligent Vehicles Symposium (IV), Gothenburg, Sweden, June 19-22, 2016
2.	Olaf Landsiedel, Thomas Petig, Elad Michael Schiller, "DecTDMA: A Decentralized-TDMA - With Link Quality Estimation for WSNs". 18th International Symposium Stabilization, Safety, and Security of Distributed Systems, SSS 2016, pages 231-247, 2016.
3.	Shlomi Dolev, Chryssis Georgiou, Ioannis Marcoullis, Elad Michael Schiller: Self-stabilizing Reconfiguration. Networked Systems - 5th International Conference, NETYS, pages 51-68, 2017
4.	Vladimir Savic, Elad Michael Schiller, Marina Papatriantafilou: Distributed Algorithm for Collision Avoidance at Road Intersections in the Presence of Communication Failures. IEEE Intelligent Vehicles Symposium, IV 2017
5.	H. Eriksson and A. Söderberg," Remote Sensing and Functional Safety in ITS" in Proceedings of 12th ITS European Congress, 2017

7.3 Master Theses

1.	Damian Dziadak, Suriya Prasanna Bhubalan, ”Autonomous Filming of test cars”, Chalmers, 2016
2.	Matthias Pernerstorfer, Rajesh Thangaswamy, “Visualization of tests for future active safety and selfdriving cars”, Chalmers, 2016
3.	Johnny Ngu, Ronakorn Soponpunth, “Fusing data from multiple vehicles into a common picture”, Chalmers, 2016
4.	Marko Cotra, Michael Leue, “Lidar-based Methods for Tracking and Identication” , Chalmers, 2016
5.	Herman Fransson and Gustav Ehrenborg, “ Sensor fusion based indoor positioning with iBeacons” , Chalmers, 2016
6.	Henning Phan, “ Towards Wireless Communication with Bounded Delay” , Chalmers, 2016
7.	Anton Olsson, Andreas Hahlin, “Centralized Collision Avoidance System”, Chalmers, 2017
8.	Andreas Käll, Alexander Berg, “Track-to-track Fusion for Multi-target Tracking Using Asynchronous and Delayed Data”, Chalmers, 2017
9.	Gustav Hjelmare, Albin Karlsson, “Updating and improving accuracy of dynamic maps using iterative autonomous vehicle measurements”, Chalmers, 2017
10.	David Gardtman and Albin Casparsson, “ Cooperative Positioning of Vehicles with Consensus”, Chalmers, 2017
11.	Albin Pålsson and Markus Smedberg, “ Evaluation of ROS as a development platform for automated guided vehicles”, Chalmers, 2017

7.4 Student Projects

Projects in project courses.

1.	Shervin Shojaee, Omid Fassihi, “Dynamic model of RC car”, Chalmers, 2016
2.	Erik Thiel, Ulf Fäldt, “Trajectory compression”, Chalmers, 2016
3.	Alicia Gil Martin, Fanny Sandblom, Filip Slottner Seholm, Kevin Hoogendijk, Lars Niklasson, Nils Andrén, “Predictive Control for Articulated Autonomous Vehicles”, Chalmers, 2017

Summer jobs.

1.	Martin Ekerstedt, “RC car development in SPAS”, 2017
2.	Cheerudeep Chintha, “Track-to-track Fusion for Multi-target with Real Data”, 2016

7.5 Reference Group

- Carmenta AB
  Carmenta provides powerful traffic management system for connected vehicles, their TrafficWatch™ acts as an invisible traffic network supervisor, constantly working to ensure the safety of autonomous and connected vehicles**.**
  Carmenta has been supporting the project by allowing the project to use their map services over Amazon Web Service, where ITS station data from iTRANSIT has been sending data to the central server to which the Carmenta's Map Web Server has been connected to, allowing any number of web based traffic watch application to visualize the GMD in real time.

7.6 Exploitation

Results, techniques and components developed in iTRANSIT have been used in:

- CHRONOS (Positioning, ITS, RC Car) FFI project
  CHRONOS will evaluate the OpenDrive-map that ÅF has developed within iTransit. The algorithms for object motion estimation and collision avoidance will be used and parts of the server implementation will be reused.

- HIFI RADAR Target (RC Car) FFI project
  The RC car equipped with the iTRANSIT positioning and communication system is currently used as a carrier for the radar in the HiFi Radar Target FFI Project The projects aims at characterizing and modeling the radar signature of real cars and soft targets used in automotive testing.

- COPPLAR (Higher level MAP API) FFI project
  ÅF will continue to build on the mapping technologies developed in iTransit. A higher level API will be developed to facilitate e.g. path planning for autonomous vehicles. Some, or all, testing in COPPLAR will be done at AstaZero.

- ATLAS (Map extraction from point cloud, rapid turn-around time) FFI project (not started yet)
  ÅF will continue to develop the mapping technologies from iTransit. The purpose is to achieve faster turn-around times when creating maps for new traffic scenarios at AstaZero. Also the process of adding new types of map objects (e.g. traffic islands, speed bumps, zebra crossings etc) shall be improved.

- NGEA (RC Car) FFI project
  The RC car equipped with the iTRANSIT positioning system and communication system.

- Intelligent cykelhjälm (Positioning) Skyltfonden project
  The positing system and algorithms developed by SP (RISE) and Chalmers will be used.

- DRIWS – Digital Runway Warning System
  An EU directive mandates that airports needed to implement red stop lights at entrances to the landing/take off strip by end of 2017 for improved safety.
  By using some of the positioning results from iTRANSIT Luftfartsverket, Swedavia and Saab Combitech took the approach to develop virtual stop lights in airport maintenance vehicles using affordable and reliable positioning techniques.

8. Conclusions and future research

Project iTRANSIT have in structured way analysed different perspectives for an intelligent traffic management system and cooperated closely with industry.

Concrete results have been used by;

- VCC in their DriveMe project.
- Anticollision warning systems (Digital Runway Incursion Warning System – DRIWS) for airports have been developed in record time using some results from the project.
- Carmenta AB has been supporting the project with their products which then have been further devolped and they are now developing a commercial multi modal C-ITS product - TrafficWatch (TM).
- ÅF has used the results in further projects.
- RISE will use the results in future research project about C-ITS and autonomous systems.

Results shows that a centralistic approach with sensor aggregation and fusion for decision making may be appropriate for some simpler operational situations and scenarios, such as the project was using and demonstrated, successfully. But there is no conclusive result that shows that a centralized approach is to prefer to a decentralised.
Demonstrators were showing some difficulties with information synchronisations in real time and this area needs more research.

ITS is getting more and more attention as the car industry has promised to equip cars with communication capabilities according to ETIS ITS standards by 2019-2020. At the same time telecom operators and telecom system companies are also paying more attention to the ITS area. iTRANSIT hypothesis was that ETSI standards would apply and be used as specified. However resent activities at AstaZero in collaboration with Ericsson in FFI project CHRONOS reveals that there is now an effort to make 5G to support safety applications in ITS with a platform2platform technique. Probably a hybrid solution with both car2car communication together with platform2platform will be both a technically viable solution but also a commercially a good approach allowing sensor fusion and data mining techniques to be applied at base stations as a half centralised, edge computing, approach.
This needs much more attention and research than iTRANSIT has conducted.

iTRANSIT has successfully showed that GNSS positioning system can be built in an affordable way but GNNS solutions are vulnerable for signal disturbance and more reliable solutions are needed to assert always reliable position information.
This area is now getting a lot of attention from the industry and since iTRANSIT started there are now companies that delivers GNNS chip with sensor fusion capabilities using odometry. The demand for continued research in this area is still needed for advanced sensor fusion algorithms.

9. Participating parties and contact persons

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[2] ETSI, "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service ," ETSI EN 302 637-2 V1.3.1, 2014.

[3] ETSI, "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specification of Decentralized Environmental Notification Basic Service," ETSI EN 302 637-3 V1.2.1, 2014.

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