ASSIST: An Advanced Snow Plough and Salt Spreader Based on Innovative Space Based Technologies

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BIOGRAPHY

Antonio Defina received his Communication Engineering degree from Polytechnic of Turin in 2005. He has worked as a researcher on GNSS technologies in the Navigation and Signal Analysis Group at ISMB Torino. Since 2010 he is a member of the Mobile Solution Area and Microsoft Innovation Center of Torino unit as senior firmware architect, hardware design and developer of embedded technologies and applications. His skills covers advanced navigation technologies, GSM and professional communication and embedded systems connected to cloud computing platforms focused on road and smart energy applications, in line with Intelligent System Paradigm. He is involved in several national and international research project (including ASSIST).

Alfredo Favenza is a Senior Researcher at ISMB in Turin. He received his Master of Science in Computer Science in March 2007 from the Università degli Studi di Torino with a thesis on information retrieval conducted in collaboration with Centro Ricerche e Innovazione Tecnologica RAI (CRIT). In May 2007, he joined ISMB where he was principally involved in research activities in the areas of Cloud Computing, Virtualization, Mobile and Web technologies. In 2010, he started his research activity in the area of Navigation technologies developing strong expertise on GNSS Software Defined Radio, Galileo, EGNOS/EDAS Augmentation and RAIM Integrity. Nowadays, Alfredo is a researcher of Mobile Solutions Area of ISMB. He is active on several Regional and European R&D projects, where cloud computing, big data, mobile devices and navigation technologies are combined to generate innovative value-added solutions.

Gianluca Falco (PhD) is a Communication engineer, currently employed at the NavSAS lab of Istituto Superiore Mario Boella (ISMB) in Turin. His interest has been mainly focused on multi-sensors fusion, particularly between GPS and inertial navigation systems, as well as on advanced processing techniques for dual frequency GNSS receiver, advanced tracking loop techniques, GNSS-reflectometry and remote sensing.

Diego Orgiazzi received his Communication Engineering degree from Polytechnic of Turin in 2001. He worked on the Institute contribution to the Galileo System Test Bed (GSTB) V1 phase. In the frame of the GSTB V1 activities, he dealt in the operations of the Experimental Precise Timing Station (E-PTS), hosted by IEN Time and Frequency laboratory.
He participated – as technical support and/or responsible - in a number of research activities funded by National and European institutions (ESA, Galileo Industries, Alenia Spazio IT, Helios UK), including ASSIST.
Moreover, he was involved in the operations of geodetic GPS receivers hosted by the laboratory as well as in the time transfer oriented processing of the data provided by such receivers. Since the end of 2003, he was co-responsible of the permanent geodetic GPS station of the Institute which is joining the International GPS Service (IGS) station. From 2006 he is currently a freelance engineer mainly working for Italian SMEs on R&D projects (especially concerning wireless communication applications).

ABSTRACT

In a densely populated urban environment, heavy snow events during the winter season represent a critical issue for citizens and public administration. In some city and critical areas, is one of the scenarios, which might benefit of smart advanced services able to run in efficient and cost-saving mode. The need to maintain the roads open and safe is still a driver for developing leading-edge navigation services. In such scenarios, the need of having a precise knowledge of snow plough position as well as of road coordinates, boundaries and roadside elements becomes crucial to avoid collisions of the snow plough with hidden road infrastructures during the winter maintenance operations.
In order to face these new challenges and keep up with the need to assure an adequate safety level for workers and citizens, it becomes increasingly important to improve the technology applied to the winter maintenance process.
ASSIST (Advanced Snowplough and salt Spreader based on Innovative Space Technologies) aims to address the aforementioned issues exploiting the capabilities of GNSS and Earth Observations technologies. ASSIST proposes an end-to-end system

that is able to collect and aggregate data from different sources such as Earth Observations, navigation data and road databases.

This paper presents the architectural design, highlighting the role of the space assets (GNSS\INS integration and Earth Observation) and the preliminary results achieved during on field tests performed on a real winter maintenance truck in collaboration with Swedish Transport Administration and Norwegian Public Road Administration.

INTRODUCTION

A good smart-city proves the benefits of ICT–based smart services in time of challenges. During winter the ability to cope with heavy snowfalls in an efficient way, in some city and areas is one of the scenario, which might benefit of smart advanced services able to run in efficient and cost-saving mode [1]. The need to maintain the roads open and safe is still a driver for developing leading-edge navigation services, that might lead to relevant social benefits such as reducing both direct and indirect costs for the community, limiting the environmental impact and increasing the safety on the roads.

The impact of such services is easily understood considering, as an example, that during the recent winter storm of January 2015, that blasted the northeast of the United States, in the city of New York, more than 2500 winter maintenance vehicles were deployed.

In fact, nowadays the most common solutions to guarantee safe road conditions during wintertime are still winter maintenance vehicles armed with salt spreaders and snow ploughs. Many improvements have been done to optimize the salts spreading process leveraging GNSS technologies. Such solutions can be integrated with on-board devices able to offer a good level of accuracy and integrity of positioning which is useful to improve the process of salt spreading and reducing related costs [2].

Nevertheless, the proof-of-concept and early service of these new technological solutions, highlighted new critical limitations of the only GNSS-centered approach, particularly using snow plough on critical road segment where human visibility is very limited. In such scenarios, the need of having a precise knowledge of road coordinates, boundaries and roadside elements (e.g. road signs and bus stops) becomes crucial to avoid collisions of the snow plough with hidden road infrastructures during the winter maintenance operations.

In order to face these new challenges and keep up with the need to assure an adequate safety level for workers and citizens, it becomes increasingly important to further improve the technology applied to the winter maintenance process.

Advanced Snow plough and salt Spreader based on Innovative Space Technologies (ASSIST) was a 12-month Feasibility Study funded by ESA within its IAP (Integrated Application Promotion) ARTES 20 programme [3]. According to an effective user-driven approach, ASSIST aimed to trade off the most efficient solutions for winter road maintenance services, evaluating from a technical and economic perspective the convergence of two space assets:

- **Satellite navigation**, achieving an accurate and robust in-vehicle positioning, by exploiting a tight integration between multi-constellation GNSS receiver and low-costs on-board inertial sensors. Since the target application is automotive, additional features (e.g. detection of static condition, constraints of the vertical velocity and non-holonomic constraints in case of GPS unavailability) have been implemented in the multi-sensors fusion algorithm to improve the performance with respect to a traditional tightly couple technique. Such strategy permits to enhance the robustness of the positioning in limited GPS availability (e.g. heavy foliage, bridge, tunnel);
- **Earth observation**, enabling the extraction of main road attributes (e.g. boundaries, centerline and width) from the very high-resolution satellite image data and the ingestion with road weather forecasting and snow monitoring data.

ASSIST was led by the Istituto Superiore Mario Boella (ISMB) [4] , an Italian research center focused on the innovation of products and processes leveraging on ICT technologies, with specific expertise in satellite navigation, mobile solutions and complex R&D project management. ISMB and its subcontractors (Giletta S.p.A. [5] and Alpha Consult [6] from Italy, GeoVille Information Systems [7] from Austria) all together provided complementary skills and integrated expertise areas, representing the whole value chain for enabling innovation in the winter maintenance process. Of particular importance was the participation of Giletta S.p.A, an Italian company leader in the production of winter road maintenance equipment and part of Bucher Municipal, leading manufacturer of municipal vehicles for street cleaning, snow removal and garbage collection for public and private spaces. In addition, two significant users - the Swedish Transport Administration (STA) and the Norwegian Public Roads Administration (NPRA) - were engaged by ESA since the beginning of the Feasibility Study, providing to the ASSIST partnership a great opportunity for open and fruitful interaction and ensuring an outstanding support to the activities.

The system studied takes advantage of mature, ready-to-market, components as results of the GOLDEN-INFRA [8] and GOLDEN-ICE [9]-[10] projects establishing an innovation roadmap for winter maintenance services. Particularly, GOLDEN-ICE, funded by the EC under the seventh framework program, provides automatic control of the salt spreading process by means of a technique called “Route Replay”: during mission, the truck equipment automatically replicates the settings according to the vehicle position based on a set of manually recorded parameters.

According to the analysis performed by the Consortium about the major operational scenarios, nowadays the road icing control reached a good level of technological evolution (with wide room for improvement) thanks to the automatic replication of the recorded parameters along the path, whereas there are no commercial services for the automatic control of snow ploughs. The operator manages the snow plough manually while driving, often in very harsh condition. ASSIST tried to solve the aforementioned issues and meet the user requirements. The project goal was to investigate the potential and the attractiveness of a suite of innovative "assistance services" in supporting the winter maintenance operations, in order to:

- Reduce the workload for the driver, thereby increasing her/his safety conditions;
- Provide assistance to the driver during the mission, especially in darkness or bad visibility and in large open areas with drifting snow;
- Reduce the environmental impact by spreading the right amount of chemicals in the right place and at the right time;
- Save chemicals and optimize the winter maintenance operations, then reducing costs while improving the safety for the road users;
- Reduce the damages to the road attributes and road surface that may occur with snow ploughing.

ASSIST strategy proposed to build up a high fidelity and updated model of the road to clear collecting information (in particular Earth Observation and Weather Forecasts) acquired by external service providers in a cloud-computing platform (called Winter Service Middleware). The model allows evaluating analytically the geo localized work parameters (both in terms of salt spreading and snow plough control) in order to maximize the effectiveness of the winter maintenance treatment. Such parameters can be applied along the path thanks to an NAV\COM intelligent device mounted on the truck (called On Board Unit (OBU)). The feasibility of this functionality is strongly dependent on a precise, trustable and reliable positioning unit. The most significant steps beyond the state of the art of this approach are:

- The possibility to analytically evaluate the real road condition and compute the best work settings thanks to geo localized layers. Such feature permits to avoid the recording phase based only on the personal experience and feeling of the human operator that is in charge to perform recording;
- The first steps towards completely automatic control of the snow plough not available on the market;
- Further optimization of salt spreading with potential reduction of wasted material.

In this sense, this project features a holistic integrated approach at the crossroads of Energy, ICT and Mobility, that helps to reach all three sides of the triple sustainability triangle in line with objectives of smart-cities, bringing benefits in social, safety and economical terms.

This paper provides a comprehensive picture of the project, focusing on the role of space assets and giving some preliminary results obtained during the Proof of Concept.

In details, the contents of such paper are listed in the following:

- Section I provides an overview of whole System by giving a high-level description of the main blocks that form the ASSIST project;
- Section II highlights the theoretical analysis of the design of a real-time positioning prototype able to achieve accurate and robust navigation information, thanks to a tight GPS/INS integration;
- Section III describes the integration strategy of the Earth Observation and the road weather information, highlighting the description of road mapping through an advanced processing of satellite imagery and the real-time of the status of road conditions through an analysis coming from Earth Observation satellite information;
- Section IV describe the Proof of Concept activities performed in order to evaluate the technical aspects and demonstrate the feasibility and the validity of the ASSIST concept;
- Section V reports the preliminary results achieved for tightly coupled GNSS/INS integration during Proof of Concept activities;
- Section VI describes an example of integration of navigation solution, Earth Observation and road weather information within PoC prototypal system.
- Section VII will draw the conclusion.

I - SYSTEM ARCHITECTURE

ASSIST project is a feasibility study that mainly relies on vehicle enhanced positioning system and the geo localized information (from which the Earth Observation and Weather Forecasts data are the most important ones). Such information are extracted, aggregated and processed by a Winter Service Middleware (WSM) in order to guarantee a robust and trustable snow plough positioning information as well as to allow the winter road maintenance vehicle to have an efficient and fully automatic salt spreading system.

The ASSIST overall system architecture is illustrated in Figure 1.

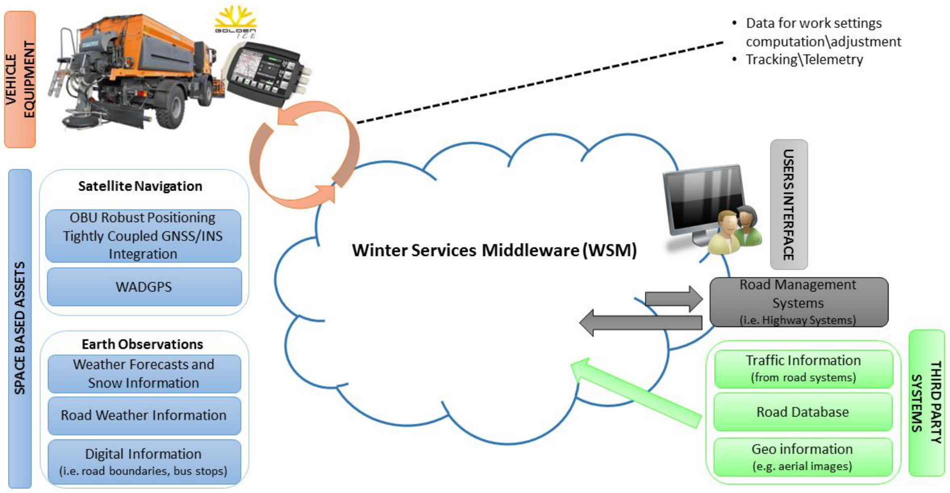


Figure 1: ASSIST System Architecture

The key elements of the ASSIST architecture are listed in the following:

- **Vehicle Equipment**: The apparatus placed on the Winter Maintenance Vehicle (WMV) that controls the winter maintenance operations and supports the operators during missions. The On Board Unit is the “brain” of this subsystem and holds all the logic and data; the power pack that translates electrical stimuli in mechanical actuations and the mechanic equipment and sensors. Figure 2 provides some details about hardware configuration.
- **Winter Service Middleware (WSM)**: The cloud-computing platform that enables the management to supervise the missions, providing support for the advanced system functionalities. A back office system allows communicating with the WMVs on the fields and aggregate data from third party data source to get useful information for mission purposes. Moreover, a web portal is the service’s front end for management;
- **Space Assets and Services**: External source of data and services from space-based assets:
    - **Satellite Navigation**: The improvement in terms of accuracy, reliability and availability of the vehicle’s position covers a key role within ASSIST framework. Satellite navigation technologies goes in direction to solve major issues can affect the vehicle provisioning. ASSIST solution leverages on robust positioning based on tightly coupled GNSS\INS integration and WADGPS augmentation techniques to reach these goals;
    - **Earth Observation and Weather Forecasts**: The availability of road context information (e.g. road geometry indicator, road morphology and road attributes’ position) and road weather information before the missions is crucial for ASSIST strategy. Therefore, the aforementioned space asset is fundamental.

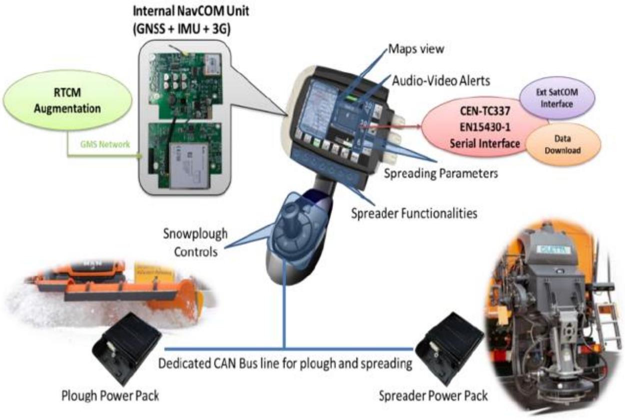


Figure 2: Vehicle equipment hardware components.

- **Third Party Systems:** Additional external data source information that provides aggregated data to foster the quality of the service offered by the cloud platform (e.g. Traffic Information to help the operators during missions, road information to add cartographic information may be useful along the path).

In summary, the strategy proposed by ASSIST project is the integration at WSM level of geo localized information (in particular Earth Observation and Weather Information) comes from external data source on top of OBU’s maps in terms of vector layers that provides a realistic and accurate model of the road at the time of the mission. Such geo-localized information allows computing the correct working settings to automatically apply during the mission. In the project framework, this concept has been resumed in a dedicated definition: ASSIST layers. Figure 3 emphasizes such idea.

The correct adoption of the working settings is strictly dependent on the accuracy and the reliability of the OBU's positioning system that is achieved by a GPS/INS fusion; in this sense, the robust positioning meets the requirements raised for the localization within preliminary analysis.

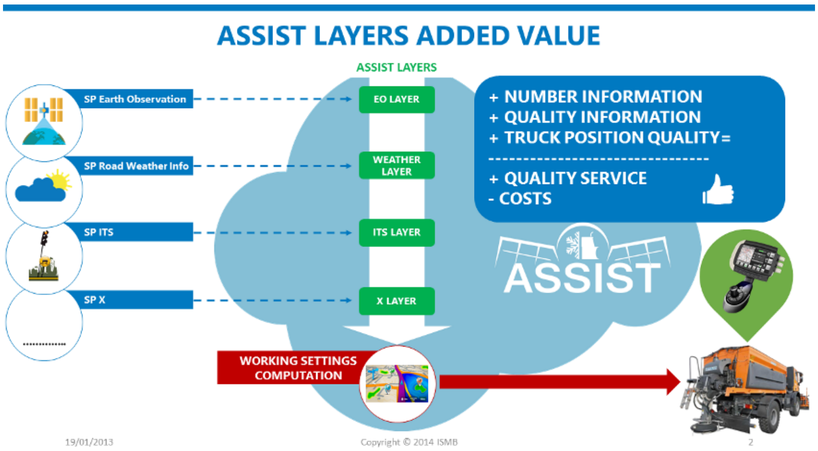


Figure 3: The concept of ASSIST Layers that combined with accurate and reliable truck positioning allows the enhanced automatic control of the overall winter maintenance treatment.

By considering the complexity of the whole system and the nature of feasibility study, the work done during the project activities points out to study in details a theoretical solution. The Consortium developed a preliminary version of a prototypal test bed to show and prove the applicability of the aforementioned architecture as a valuable solution for winter maintenance domain. It has to be remarked that, during ASSIST framework, the Consortium puts an important effort in technical development, as illustrated in the following of this paper.

II - ROBUST POSITIONING BASED ON TIGHTLY COUPLED GNSS/INS INTEGRATION

A tightly-integrated system uses the pseudorange and pseudorange rate information extracted from the GNSS receiver to compute the corrections to be applied to the trajectory estimated by the INS device and to estimate, if necessary, the biases that affect the accelerometers and the gyroscopes.

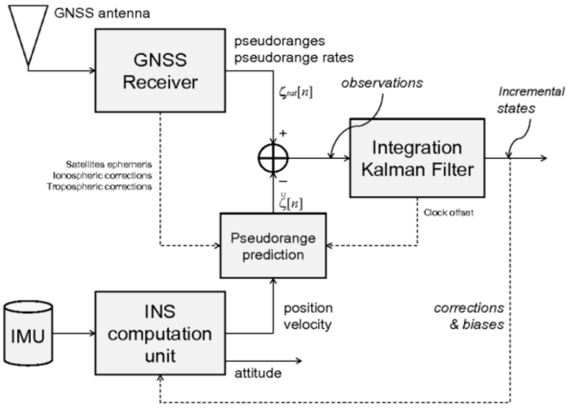


Figure 4: Block scheme for a tightly integrated GNSS/INS system.

Tight integration is based again on the definition of a state-space model of the hybrid system and the application of an EKF to compute the corrections necessary to refine the INS-based trajectory. The architecture of a traditional tight integration can be represented as in Figure 4.

The IMU measurements are used to predict the position, velocity and attitude by means of the navigation equations in the INS block. The INS-predicted trajectory is then employed in the feedback branch to predict the pseudoranges of all visible satellites. The Kalman filter uses the differences in pseudoranges (GNSS-measured minus INS-predicted) as its observations.

The set of the system states (incremental states) has to be firstly identified. The structure considered here is the following at the n^{th} time instant:

$$\Delta x[k]=\left[\Delta p^e[k]^T,\Delta\tau[k],\Delta v^e[k]^T,\Delta v_\tau[k],\Delta\psi^e[k]^T,b_a{}^b[k]^T,b_g{}^b[k]^T\right]\in\Re^{17,1} \quad (1)$$

where the superscripts *e*, *b* indicates *Earth frame* and *body frame* respectively an.

The state vector stores the following components:

- $\Delta p^e[k] \in R^{3,1}$ is the corrections vector to be applied to the nominal body position expressed in the Earth frame;
- $\Delta v^e[k] \in R^{3,1}$ is the corrections vector to be applied to the nominal body velocity;
- $\Delta\psi^e[k] \in R^{3,1}$ is the vector of misalignment angles along each axis;
- $b_a{}^b[k] \in R^{3,1}$ is the vector of the biases of the accelerometers expressed in the body frame;
- $b_g{}^b[k] \in R^{3,1}$ is the vector of the biases of the gyroscopes;
- $\Delta\tau[k]$ is the GPS clock bias of the receiver;
- $\Delta v_\tau[k]$ is the GPS clock drift of the receiver.

The definitions of the transition matrix $\mathbf{A}_k$ and the design matrix $\mathbf{H}_k$ can be found in [12] and are omitted in this paper. Many studies are available in the scientific literature that are based on a GPS/INS integration via a tightly-coupled approach [12]-[14] and [15]-[17]. Therefore, in this paper we add additional constraints to further improve the performance of a traditional tightly-coupled that exhibits poor performance when based on very low cost IMU.

Since the hybridization algorithm is specific for land applications we can consider the vertical velocity close to zero. Thus, the measurements vector will have the following extra element:

$$\mathbf{z}_k = [v_D[k] - 0] \tag{2}$$

where v_D is the vertical velocity obtained through the INS navigation equations. Accordingly, the design matrix will have the additional row as stated in (3):

$$\mathbf{z}_k = [0 \quad 0 \quad 0 \quad R_e^n(3,1) \quad R_e^n(3,2) \quad R_e^n(3,3) \quad 0_{1x11}] \tag{3}$$

where the R_e^n is the attitude direct cosine matrix from ECEF to the NED frame. Such rotation can be easily computed according to (4):

$$R_e^n = \begin{bmatrix} -\sin\varphi \cdot \cos\phi & -\sin\phi & -\cos\varphi \cdot \cos\phi \\ -\sin\varphi \cdot \sin\phi & \cos\phi & -\cos\varphi \cdot \sin\phi \\ \cos\varphi & 0 & -\sin\varphi \end{bmatrix} \tag{4}$$

where φ and ϕ represent the latitude and longitude estimation of the user position.

Moreover, we have improved the performance of the algorithm when a static condition is detected. In fact, when the user does not move for a certain amount of time, it is important to avoid position, velocity and heading from drifting. We have achieved this by monitoring the velocity (as computed through the INS navigation equation) and when it gets lower than a certain threshold (e.g. 1m/s) we assume the vehicle is not moving. The velocity estimate is then set equal to zero and for all the duration of the static condition the heading angle is kept constant.

Eventually, in case of GPS outage, the performance of the tightly-coupled algorithm is further improved by using *Non Holonomic Constraints.* This method is valid for land applications only. According to this concept, the vehicle velocity constraints are derived assuming that the vehicle does not slip, which is a close representation for travel in a constant direction. A second assumption is that the vehicle stays on the ground, i.e. it does not jump off the ground. If both assumptions are true, then the velocity of the vehicle in the direction perpendicular to the movement of the vehicle must be zero. All the mathematical details about such constraints can be found in [14] and when a GPS outage occurs a complementary Kalman filter is used to combine the INS- and constraints-derived velocity measurements to keep the position and velocity errors bounded. In a future version of the system, the team will take into consideration the possibility to include an odometer to achieve better performance in particular in case of GPS unavailability.

III – EARTH OBSERVATION AND WEATHER INFORMATION

The Earth Observation (EO) space assets for ASSIST are essential and are composed of two critical components:

- The static road mapping component for establishment of up-to-date (seasonal) OBU road network database, including the critical information on road boundary, width, additional sealed surfaces (e.g. parking lots, bus stops, etc.) and obstacle data.
- The continuous environmental road condition component, for operationally delivering data on road snow depth and degree of road icing for operator planning and efficient automatic control of salt spreading (i.e. snow amount).

A - Road Mapping

Traditional road network databases, as used car navigation device, do not include the critical road information needed for the management and support of road snow ploughing and de-icing operations. Specifically, such commercially available data miss information on road width (needed for efficient automatic control of salt spreading), road boundary and obstacles (for driver snow plough assistance and collision avoidance) as well as other sealed surfaces to be maintained (such parking lots or sideway areas).

The advent of very high to high resolution optical multispectral satellite imagery, such as SPOT-6 or Pleiades, provides the capacity for the extraction of linear road features needed for the ASSIST OBU. During the feasibility study, the semi-automatic road extraction from very high (VHR) and high resolution (HR) imagery, providing relevant road attributes such as boundaries and width, has been successfully proved. This included the following image processing steps:

- Testing and selection of appropriate VHR/HR satellite imager sources;
- Pre-processing of imagery;
- Geographic correction and rectification (for sub-meter positional accuracy);
- Topographic correction (elimination of shadowing effects);
- Atmospheric correction (elimination of haze, ionosphere effects, water vapour effects)[18], [19];
- Noise reduction through radiometric corrections and image enhancement (filtering sensor noise and enhancing contrast through histogram modifications)[20];
- Road extraction from satellite imagery and post-processing for “clean” vector lines [21], [22].

The quality and the amount of the information that is possible to detect depends on the quality of the images: the Very High Resolution (VHR) images have a better resolution and allow for a road boundary extraction satisfying the accuracy requirements for snow ploughing, but come at approximately three times higher costs.

Figure 5 provides some example of information that is possible to extract from EO.

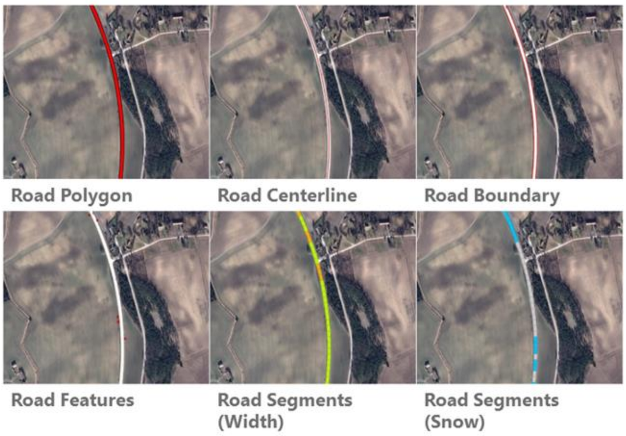


Figure 5: Different types of information available from ASSIST EO.

For the EO based mapping, the study has developed a strategic approach for updating the road network database and proven the cost-benefit of employing very high resolution satellite imagery for detecting changes in road networks as well as mapping of required road boundaries and other sealed surfaces. The EO based road network is a static procedure, required to be updated each year. Moreover, a Geographic Information System (GIS) [23] approach is required to fuse and attribute the mapped road database suitable for winter road maintenance navigation with slope (from digital elevation models) and curvature. Here the extracted road is split into regular segments and attributed with the road characterization. Similarly, the environmental road condition (see next step) is attributed in such way.

B - Environment Road Condition

Here the EO satellite information on snow coverage is one of the critical inputs (apart from weather station data) to improve the accuracy of numerical metrological models, which provide homogenous status and forecast information on snow depth, temperature and expected icing degree [24]. The GIS component attributes the information to the road segments within the OBU, thereby providing road surface focused information.

In the following it is resumed the process. The information provision is a dynamic, fully automated process with an operational (daily) information flow from satellite operators to the EO company (GEOVILLE) extracting the necessary snow extent parameters to the Meteorological providers (National). Such parameters run the specialized numerical weather forecast models, back to the EO Company ingesting and segmenting the now-& forecast data to the road segments and pushing it to the ASSIST layers database. Both the EO road mapping and environmental condition were fused into the ASSIST prototype system component for the end-to-end integration into the OBU.

IV -PROOF OF CONCEPT

An extensive Proof of Concept (PoC) took place in the 2014-2015 winter season aiming to verify the technical feasibility of the proposed solutions and to validate the intended services from a user's perspective, mostly by field test campaign with direct and active involvement of the two engaged administrations (STA and NPRA) and their contractors. Despite the tight schedule and the budget constraints, the ASSIST consortium sets up with a significant investment a complete end-to-end prototypal system. The implementation took advantage of the Giletta S.p.A. commercial solutions properly complemented by ad-hoc implementation. More precisely, the PoC work package included some internal tests carried on in the partner's on-premises areas (in particular in Turin for ISMB) for technical verification and two different on field tests performed with a real winter maintenance truck (equipped ad hoc by Giletta S.p.A.) in Sweden (see Figure 7) and in Norway for user validation. The basic prototypal architecture realized for this purpose is reported in Figure 6.

Figure 6: ASSIST PoC Prototype architecture.

Figure 7: The ASSIST team in front of demonstration truck in Sweden

The huge effort put in place by ASSIST Consortium was mainly focused to analyze some specific topic both from technical and user perspective:

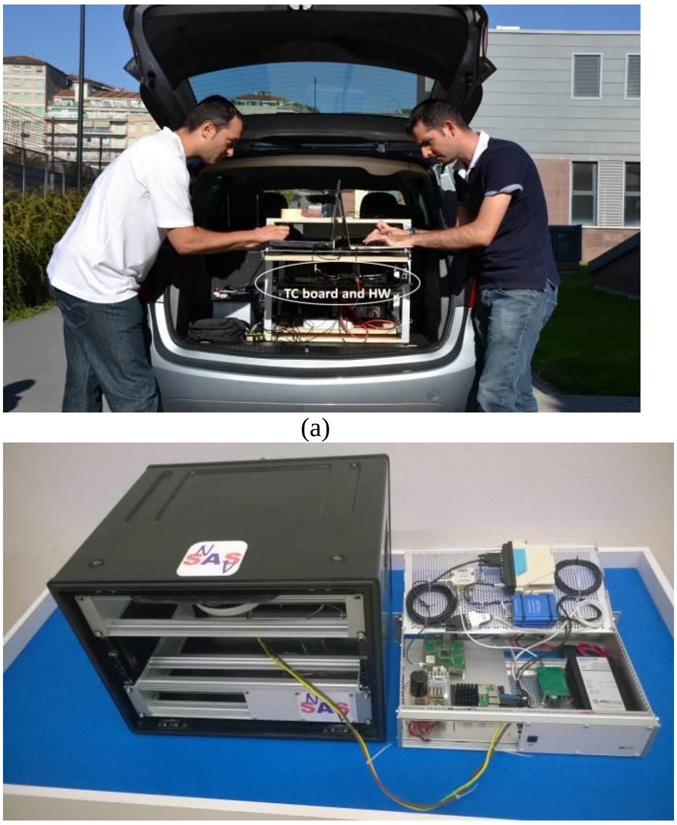
- Automatic snow plough management;
- WSM prototype, in terms of draft cloud computing platform for service provisioning and internet connection with OBU for tracking\telemetry purposes;
- Robust positioning based on tightly coupled GNSS/INS integration;
- Integration of Earth Observation and Weather information within OBU and WSM maps.

Considering the aforementioned list, this paper will reports only the elements related to the space assets domains (robust positioning and Earth Observation\weather forecasts), because the other parts are considered out of scope of this paper from author’s perspective and an interested reader can find useful information in [3].

Moreover, it is important to stress that in the current version of the prototype system, the GNSS augmentation module was not fully integrated yet even if the team has carried out an accurate analysis and a preliminary design to include such part is shown in [11].

IV – GNSS/INS TIGHTLY COUPLED RESULTS

In order to evaluate the performance of the implemented real-time Tightly-Coupled (TC) algorithm, many tests have been carried out. The first set of data has been collected with a car in the city of Turin and its suburban areas. Then, the TC algorithm has been run on the final target vehicle (i.e. snow plough) in Sweden. The two different setups, used to validate the real-time TC technique, are depicted in Figure 8.



(a)

(b)

Figure 8: Set-up used to test the TC algorithm in an urban environment (a) and the set-up used on board of the snowplough (b).

It is important to highlight that in the case of the urban tests two PCs where used to log both the data coming from the TC algorithm (through the RS-232 connection of the custom board) and the one obtained from a GPS mass-market receiver.

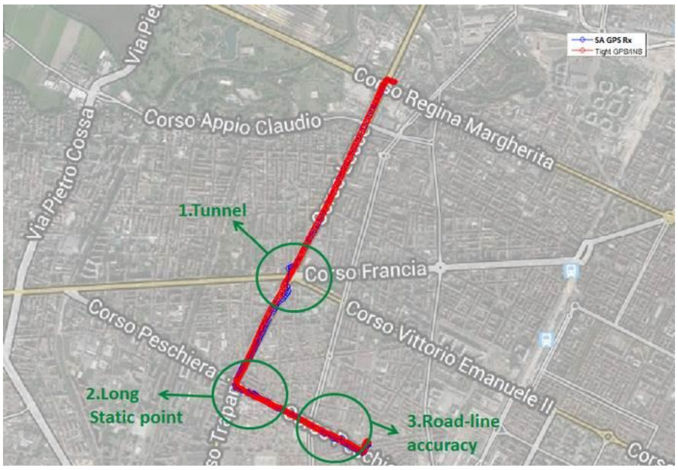


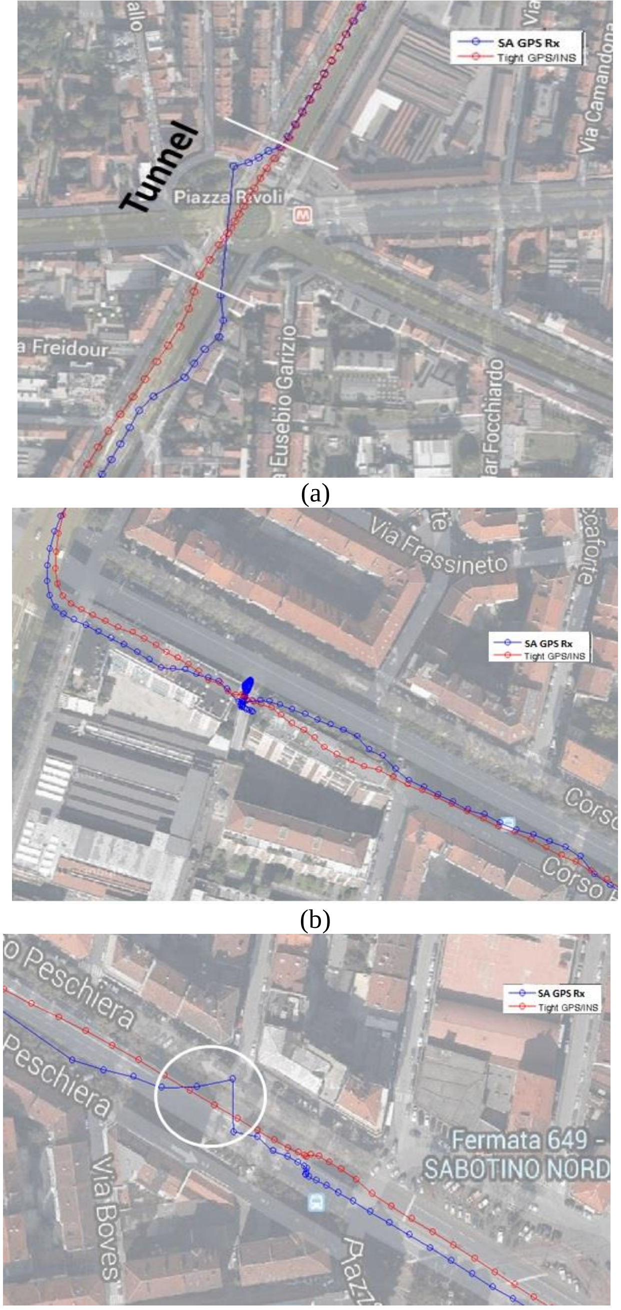
Figure 9: Trajectory in an urban environment. TC output is plotted in red and the Stand-Alone GPS receiver in blue.

On the contrary, in the test run in Sweden, the TC data were logged into the SD card of the board and, in parallel, raw data and PVT estimates from a dual frequency (i.e. L1 and L2) professional receiver and two GPS consumer receivers were simultaneously stored by an Odroid single board computer for comparison. The logging functionality in this case was completely automatic being started at the vehicle engine ignitions and stopped a while after the engine switch off, this in order to avoid interference during the vehicle service.

IV.A - TC Results in an urban environment

The trajectory under investigation is reported in Figure 9 where the TC output is down-sampled to 1Hz for a better comparison with the GPS mass-market receiver. Moreover, the most interesting sections of the path are highlighted and further zoomed in.

These sections include: a complete GPS outage due to a tunnel, a long stop of the car and the drive along a dual lane road to highlight positioning capability at lane level. All these scenarios are plotted in Figure 10.



(a)

(b)

(c)

Figure 10: Critical situation in an urban environment: tunnel(a), static condition(b) and road-lane detection (c).

As it can be appreciated from Figure 10, our implementation of the TC algorithm offers remarkable improvements when the car is driving in challenging urban area with respect to a stand-alone consumer receiver. In fact we can observe how the TC algorithm continues to provide a valid PVT solution when no GPS is available (case a) or when the number of GPS satellite is low (case c). Moreover, the additional constraints that we have included in the current version of the algorithm prevent the PVT solution from drifting when the vehicle is not moving (case b).

In summary, it is possible to evaluate the maximum errors experienced by the TC algorithm solution and the GPS module (i.e. uBlox receiver) in the aforementioned critical area of the test. The results are reported in Table 1.

Table 1: Maximum horizontal errors experienced in critical area (urban environment) in the city of Turin. Comparison between the TC algorithm and SA GPS receiver.

Selected Area (Test Torino 2)	Maximum Error [m]	
	TC Algorithm	SA Mass-market Receiver
Before Tunnel	1	26
Tunnel	3	No position available
After Tunnel	5	30
Long Static Condition	0.2	14
Straight Road Lane	5	17

The TC algorithm gives a remarkable improvement in all the critical area with respect to a stand-alone GNSS module. These results prove once again the benefits of integrating with an INS device when the land vehicle application is deployed into a harsh environment. On the contrary, the improvements given by a TC algorithm are not so significant when the vehicle is operating in an open-sky scenario.

IV.B - TC Results obtained by the target land application

The setup shown in Figure 8.b has been placed on board of a snow plough and several runs have been collected during the month of January and February 2015. Figure 11 shows the snowplough ready for a road maintenance work in Sweden.

Figure 11: The snowplough used to test the TC algorithm in Sweden

The PVT solution obtained from the real-time GPS/INS algorithm has been compared with the one coming from the post-processing of the raw data collected by the dual frequency professional receiver. In this case the Post Processing Kinematic (PPK) technique, relying also on the data of a local geodetic GNSS network (SWEPOS), provided a very accurate estimation of the snowplough position (the errors can be estimate to be less than 10 cm).

A snapshot of the whole trajectory is plotted in Figure 12, where it is possible to see how sometimes the PPK algorithm fails in computing a PVT solution. The reason is due to the fact that sometimes it is unable to fix the ambiguity of the carrier-phase measurements and the position solution is not provided during such time instants. After zooming in, the reason appears quite evident: the GNSS receiver fails in having reliable carrier-phase measures because in those instants the snowplough was driven under some bridges and most of the satellites were not in visibility or with a low C/N_0. It is quite likely the PPK engine had to restart the ambiguity computation (e.g. batch solution) and therefore, it was not able to calculate a highly accurate PVT based on carrier-phase measurements (therefore such solution were discarded).

Eventually, we have also computed the horizontal positional error of the tightly-coupled algorithm with respect to the reference trajectory. In the points where the professional receiver could provide a valid PVT, we have found a difference of less than 5 meters from our version of the GNSS/INS algorithm, with an average value of 1.5 meters.

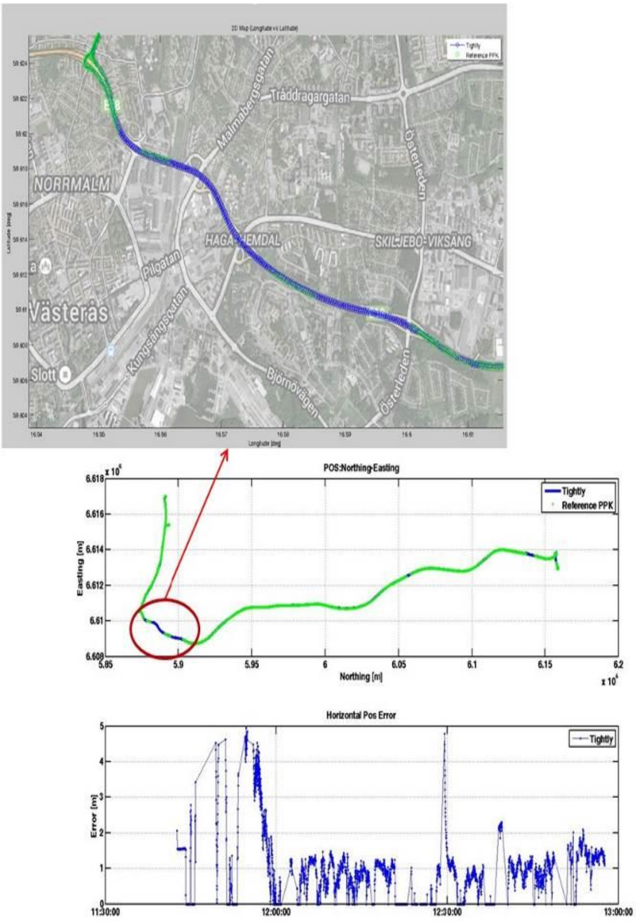


Figure 12: performance comparison between the TC algorithm and the reference trajectory.

In this test, the horizontal error has been computed for the TC algorithm and the mass-market receiver with respect to the reference trajectory. Of course, this estimation is possible only when a valid PPK solution is available.

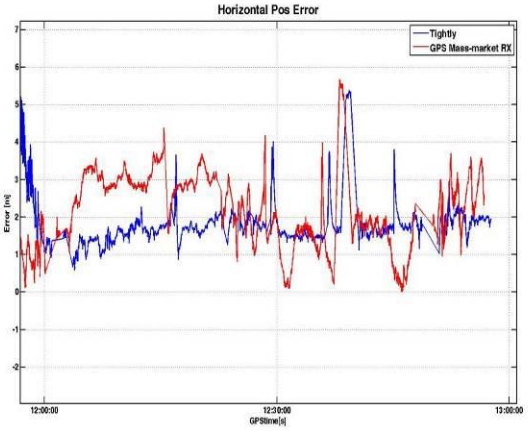


Figure 13: Horizontal error with respect to the reference. TC algorithm error is depicted in blue while GNSS mass-market receiver error is shown in red.

Results are shown in Figure 14: the TC algorithm exhibits an accuracy similar to the one computed by the mass-market receiver.

A more clear understanding can be drawn from the data reported within Table 2.

Table 2: Horizontal error for the Test in Sweden for TC algorithm and a SA Mass-market receiver.

Test Sweden 2: Positional Error [meters]		
Parameter	TC Algorithm	NVS NV08C-CSM
Maximum Error	5.383798	5.66718
Mean Error	1.78986	2.111
Error Variance	0.3467	0.97952

From the results shown in Table 2, the TC provides slightly more accurate PVT estimation than the mass-market receiver, but the differences in the performance are so small to consider both receivers equivalent. Due to the fact the TC algorithm uses only code-based measurements (as the GPS Stand-Alone mass-market receiver) and the data collection was in open-sky scenario, the improvement given by integrating with an INS device cannot be clearly appreciated as in the case of an urban canyon scenario.

Eventually, the Euler angles as computed through the implemented TC algorithm are shown in Figure 14.

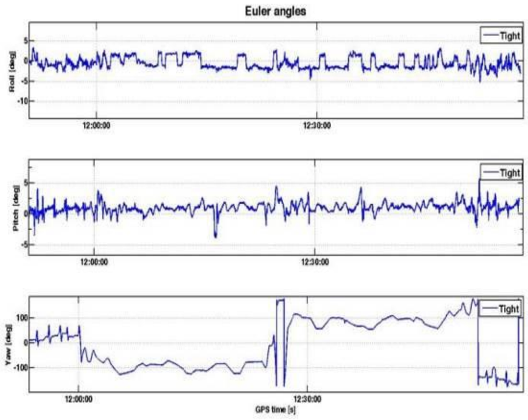


Figure 14: Euler angles as estimated by the TC algorithm.

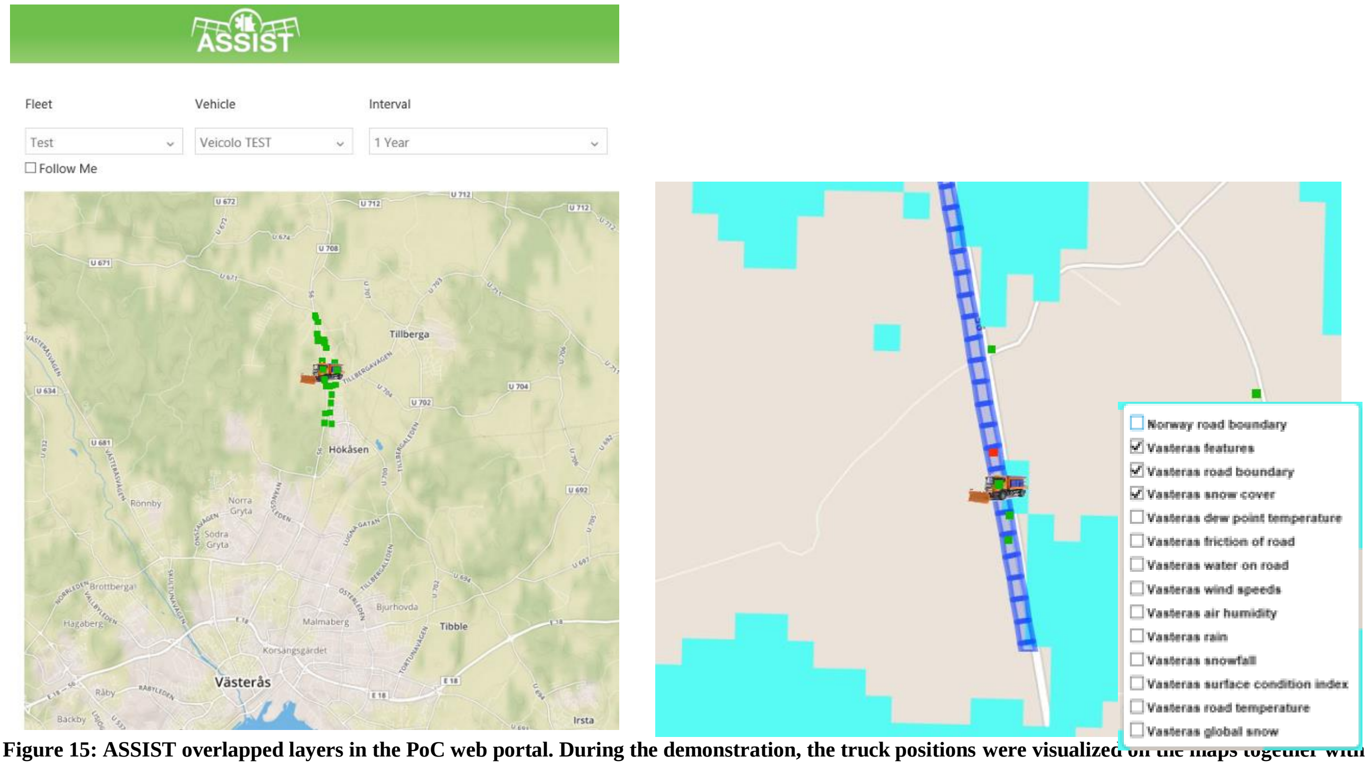
Typically, in case of land applications, the pitch angle varies between -5 to 5 degrees. Such range is verified in Figure 14 and a similar trend can be observed in all the data sets analysed. The roll angle should change of a few degrees only, since no severe tilt can be experienced on board of a land vehicle. In addition, the trend observed in Figure 14 gives a confirmation of this statement. As far as the yaw angle is concerned, it is impossible to have a term of comparison since an additional GNSS/IMU receiver should be required to estimate the accuracy of the heading angle. However, it is possible to say that all the severe variations in the yaw angle correspond to the correct time instant when the vehicle was approaching a big turn, curve or roundabout.

VI - CARTOGRAPHIC INTEGRATION OF EARTH OBSERVATION\WEATHER INFORMATION IN POC

Figure 15 shows an example of integration of ASSIST layers on top of cartography available on the web portal realized for the PoC. During the demonstration running, the OBU provided tracking and telemetry information to the back office system; the information received was visualized on a map (the green dots represents the truck positions with associated work settings). In addition, it was available a checklist box that allows the user to select a required layer of geo localized information (e.g. snow coverage, road boundaries and road features). For instance, the image on the right depicted in Figure 15 shows the information associated to the selected layers:

- The shape of the road according to a discrete model (layer road boundaries): each blue rectangle represents a segment of the road (100 m length) with associated characteristics like road width and slope.
- The azure areas represents the lands that are covered by snow (snow coverage layer);
- The red dots represent the road features (e.g. roundabouts, bus stop) presented on the road.

The layers were acquired by cloud platform by means of standard Web Map Service (WMS). The same set of information was pre-loaded on OBU storage; therefore, during the path the OBU software was able to notify the information according to its real time position (see example in Figure 16) achieved through the GPS/INS tight integration



Fleet: Test
Vehicle: Veicolo TEST
Interval: 1 Year
☐ Follow Me

☐ Norway road boundary
☑ Vasteras features
☑ Vasteras road boundary
☑ Vasteras snow cover
☐ Vasteras dew point temperature
☐ Vasteras friction of road
☐ Vasteras water on road
☐ Vasteras wind speeds
☐ Vasteras air humidity
☐ Vasteras rain
☐ Vasteras snowfall
☐ Vasteras surface condition index
☐ Vasteras road temperature
☐ Vasteras global snow

Figure 15: ASSIST overlapped layers in the PoC web portal. During the demonstration, the truck positions were visualized on the maps together with selected layers.

Figure 16: OBU shows pre-loaded geo localized information along the path according to the position (in this case, the road width and slope).

VII - CONCLUSION

The paper deals with the description of a feasibility study project called ASSIST and funded by the European Space Agency. In this project positioning technologies are associated with precise road information to guide and assist the vehicles operators and snow plough manoeuvres in situations of low visibility, due to either harsh weather conditions or heavy snow falls. This yields to improved treatments for de-icing and snowploughing, increasing also the work safety and to avoid incidents and collisions with hidden road infrastructures. Space assets and related services are the core technologies used to enhance and to renew the winter maintenance process. However, the new baseline of the satellite navigation solution proposed in ASSIST includes full support of the multi-constellation GNSS receiver, support of a GPS/INS tight integration, as well as integration in the OBU of high-resolution road databases. As far as the navigation solution is concerned, the core algorithm is represented by a real-time tightly-coupled technique aimed at fusing the raw data coming from a GPS receiver and a low-cost IMU. The main advantage of using such advanced hybridization algorithm is mainly to enhance the robustness of the navigation solution in case of limited GPS availability whose scenarios are quite common in an urban environment where a snow plough can potentially drive through. Then, the navigation solution computed through a GPS/INS tightly-coupled algorithm is sent to a centralized, cloud-based middleware which is in charge of perform further processing with data collected and aggregated from external source (e.g. road and traffic information, Earth Observations, Road Weather Information, Intelligent Transport System). This approach enables the computation of work settings tailored to the effective service needs. In this paper, the results of the ASSIST "proof of concept" in a real operational scenario are presented. The first test-campaign has been performed in Turin just to test the real-time GPS/INS tight solution and then a pre-commercial prototype including also features coming from Earth Observation and GIS information have been tested on a target application in Sweden relying on the support provided by the Swedish Transport Administration (STA). The performance achieved after the tests on the field are promising and as far as the navigation position is concerned we have obtained a remarkable improvement in terms of accuracy, robustness and availability of the position solution with respect to a GNSS Stand Alone receiver with an improvement of tens of meter in case of urban canyon and poor satellites visibility. Similarly by including the information of Earth Observation and road conditions we are able to provide a map with a high level of information that can both assist the snow plough's driver at any instant and also choose the more proper de-icing salt spreading in real-time and automatically.

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REFERENCES

[1] F. Dominici, A. Defina, M. Pasin, M. Doria, F. Ferrero, and M. Gaido, "Advanced ICT Technologies for costs optimization and innovation of winter maintenance processes in the perspective of Smart-City", in the Proceedings of 14th International Winter Road Congress (AIPCR), Andorra, 02/2014.

[2] "Precision salt spreading demonstrated in Prague", web site: http://egnos-portal.gsa.europa.eu/news/precision-salt-spreading-demonstrated-prague.

[3] "ASSIST – Advanced Snow plough and Salt spreader based on Innovative Space Technologies", web site: https://artes-apps.esa.int/projects/assist-fs.

[4] Istituto Superiore Mario Boella (ISMB), web site: http://www.ismb.it/.

[5] Giletta S.p.A., web site: http://www.buchermunicipal.com /it/node/86907.

[6] Alpha Consult Srl, web site: http://www.alphaconsult.it/.

[7] GeoVille Information Systems Group, web site: http://www.geoville.com/.

[8] "GOLDEN-INFRA project", web site: http://www.mictorino.it/ web/?p=1232.

[9] "GOLDEN-ICE project", http://www.mictorino.it/web/?p=1201.

[10] G. Marucco, F. Dominici, P. Mulassano, A. Defina, K. Charqane, and G. Falco, "An Innovative GPS/EGNOS-based Platform to generate Advanced Solutions in the Winter Service Technology", in the Proceedings of 23rd International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+2010), Portland, Oregon, USA, pp. 1402-1410, 09/2010.

[11] A. Favenza, M. Pasin, G. Marucco and F. Scullino "Challenges and Opportunities of EGNOS/EDAS Augmentation and Integrity Computation in the Cloud", In Proceedings of ION GNSS, 2014, pp. 3343 – 3351.

[12] M. Petovello, "Real-time Integration of a Tactical-Grade IMU and GPS for High-Accuracy Positioning and Navigation," PhD Thesis, Department of Geomatics Engineering, University of Calgary, Canada, UCGE Report No. 20173.

[13] G.Falco, M-C. Cossio and A.Puras, "MULTI-GNSS receivers/IMU system aimed at the design of a heading-constrained Tightly-Coupled algorithm," in the Proceedings of International Conference on Localization and GNSS (ICL-GNSS), Turin, Italy, 25-27 June 2013..

[14] S.Godha, "Performance Evaluation of Low-Cost MEMS-Based IMU Integrated with GPS for Land Vehicle Navigation Application," MSc. Thesis, Dept. of Geomatics Eng., University of Calgary, Calgary, Canada, 2006.

[15] J. Wendel and G.F. Trommer, "Tightly coupled GPS/INS integration for missile applications" Aerospace Science and Technology, 8 (2004), pp. 627–634

[16] Y. Li, J.Wang and C.Rizos , PJ. Mumford and W. Ding, "Low-cost tightlycoupled GPS/INS integration based on a nonlinear Kalman filter design",.In: Proceedings of the U.S. institute of navigation national tech. meeting, pp 958–966, 2006

[17] Y. Yi and D. A. Grejner-Brzezinska, "Tightly-coupled GPS/INS integration using unscented Kalman filter and particle filter," in Proc. ION GNSS, Fort Worth, TX, Sep. 2006, vol. 4, pp. 2182–2191.

[18] D.G. Hadjimitsis, C.R.I. Clayton and A. Retalis, “The use of selected pseudo-invariant targets for the application of atmospheric correction in multi-temporal studies using satellite remotely sensed imagery”, International Journal of Applications and Earth Observations, 11, 192–200, 2009a.

[19] D.G. Hadjimitsis, K. Themistocleous, A. Agapiou and C. Clayton, “ Monitoring Archaeological Site Landscapes in Cyprus using Multi-temporal Atmospheric Corrected Image Data,” International Journal of Architectural Computing, 7, 121–138, 2009b.

[20] A.J. Richards,. “Remote Sensing Digital Image Analysis. An Introduction”, Berlin: Springer-Verlag, 1983.

[21] W. Neuenschwander, P. Fua, G. Szekely, and O. Kubler, ¨ From Ziplock Snakes to VelcroTM Surfaces”, In: Automatic Extraction of Man-Made Objects from Aerial and Space Images, Birkhauser Verlag, Basel, Switzerland, pp. 105–114, 1995.

[22] C.Steger, H. Mayer, and B. Radig, “The Role of Grouping for Road Extraction”, In: Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), Birkhauser Verlag, ¨ Basel, Switzerland, pp. 245–256, 1997.

[23] M.F. Goodchild, “Geographic Information Systems” Journal of Retailing, 67 (1991), pp. 3–15.

[24] B.H. Ramsay, “Interactive multisensor snow and ice mapping system', Proceedings of the 14th International Conference on Interactive and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology, 11-16 January 1998, Phoenix, Arizona: American Meteorological Society. pp. 126-129.