Hardware/software integration of a GNSS receiver in RTX with an iMMS slam based system for the insertion of geometric constraints in mixed indoor-outdoor mapping applications

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Abstract

Indoor Mobile Mapping Systems (iMMS) are based on trajectory estimation through the implementation of the SLAM (Simultaneous Localization and Mapping) algorithm. The algorithm has the limitation of requiring the environment being surveyed to have well-varied geometry. Indeed, the SLAM algorithm, by assuming a stable environment, tracks changes in the device's position relative to a landscape of fixed elements and geometries surrounding it. iMMS can operate in outdoor environments and in mixed indoor/outdoor situations. It has been established that SLAM systems are affected by significant geometric drift effects in trajectory estimation. One commonly adopted strategy is to enforce that the surveyed trajectories are closed. Another approach involves introducing constraints in the form of control scans or control points. In particular, control vertices are typically constituted of coordinate points physically measured in the field by the operator, by placing the tip of a measuring pole on them. If in indoor applications, control vertices are generally measured with a total station, in outdoor applications they can also be measured with GNSS measurement campaign. For this reason, it is increasingly necessary to develop easy and accurate integration between iMMS and GNSS receivers to enhance the efficiency of SLAM-based mobile systems in outdoor environments, allowing high-throughput surveys. This article presents the results of such integration, providing guidelines on the most efficient operational methods for introducing these constraints. The contribution details the procedures for hardware design, electronic integration and the development of an application that applies a rigorous cartographic approach, within the compatible limits of the available technologies.

1. Introduction

The GNSS positioning system is commonly used for the position estimation of outdoor mobile mapping systems (MMS) (Viler et al., 2023), increasingly employed in surveying infrastructures, historical centres and more. Such systems are not capable of accurately estimating trajectory travelled by the instrument in the absence of the GNSS signal, except for brief signal loss occurring for examples under bridges or in road tunnels, where positioning is supported by other sensors such as high-performance IMUs (Inertial Measurement Unit) and, if present, a wheel-mounted DMI (Distance Measurement Instrument). Researchers, particularly from the field of robotics, have proposed solutions that can guarantee the positioning of sensing instruments, even in indoor environments in the absence of the GNSS signal. Such systems called iMMS (indoor Mobile Mapping Systems) are based on trajectory estimation determined by implementing an algorithm called SLAM (Simultaneous Localisation And Mapping).

Instrumentation that is based on the SLAM algorithm (Durrant-Whyte and Bailey, 2006) can operate in both outdoor and indoor environments, but has the limitation of requiring the detected environment to be highly varied in geometry. Indeed, the SLAM algorithm is able to estimate the trajectory of the instrument by observing and monitoring the variation of its position with respect to a landscape of features in its surroundings that are assumed stable. Thanks to the fact that SLAM-based systems can also operate in the absence of a GNSS signal, this approach is becoming increasingly popular, particularly in applications requiring the expeditious survey of underground quarries, buildings, and construction sites. In fact, SLAM systems can also be used effectively in outdoor environments, and in particular in areas where the use of GNSS positioning may be critical or non-functional, such as in urban canyons or mixed indoor/outdoor environments. SLAM systems are highly affected by phenomena of geometric drift in trajectory estimation, the value of which depends on the setting parameters of the algorithm, the geometry, characteristics and dimensions of the surveyed environments. For this reason, many SLAM system manufacturers suggest or even impose that during the survey operations the acquisition path is closed in a loop (Hess et al., 2016); other solutions support constraints on trajectory estimation, through the use of control points rather than control scans, georeferenced scans acquired by Terrestrial Laser Scanner (Marotta et al., 2022a). The measurement of the coordinates of control points, in closed environments, is usually carried out using total stations while for outdoor applications the use of GNSS instrumentation is effective.

The use of GNSS for iMMS SLAM-based instrumentation, however, differs substantially from the way it is used in outdoor applications with outdoor mobile mapping instrumentation. In fact, in the case of outdoor mapping instrumentation, trajectory estimation is realised through an integration between GNSS positioning and data from the IMU and DMI sensors (Paijitprapaporn et al., 2021). In contrast, in the iMMS SLAM based instrumentation, trajectory estimation is performed primarily by the SLAM algorithm, and the GNSS provides discrete constraints with variable spatial density, and thus trajectory correction and drift reduction. Therefore, the integration of a mobile mapping system with a GNSS receiver constitutes an efficient and highly productive solution. Moreover, such an approach allows directly geo-referencing of the survey and eventually the framing of a survey within a local reference system, nevertheless taking into account that users of such systems often have only a basic knowledge of cartographic issues.

This paper describes the methods and procedures followed for the hardware design of a measuring head of a SLAM system integrating a GNSS receiver. It also describes the characteristics of the implemented GNSS instrumentation together with the different reference system options that can be used and the relative real-time positioning modes employed. Finally, the workflow for the management of the integrated SLAM GNSS system is detailed, as well as the management of the different ways of using the GNSS data for the insertion of geometric constraints on the survey trajectories, presenting the results of specific tests.

1.1 Literature review

Mobile mapping systems have existed for a considerable period of time, ever since (Thrun et al., 1998) set themselves the goal of creating maps of geometric interior environments with mobile robots, using a probabilistic approach. The formulation of the Simultaneous Localisation and (SLAM) problem, as the question of whether it is possible for a vehicle to move through an unknown environment, and, at the same time, incrementally create a map of the geometries around it that allows its own localisation and trajectory determination, is presented along with key aspects for its solution, by (Dissanayake et al., 2001) and (Durrant-Whyte and Bailey, 2006). The SLAM algorithm makes it possible to determine the position of an instrument, within a three-dimensional environment, with respect to a set of elements in space considered stable.

Since then, the ever-increasing interest from academia and ever-growing presence on the market of novel devices and instrumentation for mobile surveying has made it possible to address the problem of mobile mapping and being able to compare the different solutions available. This has been the work of (Puente et al., 2013): a comparison of the parameters of specific systems was conducted, with particular attention paid for example to accuracy, range, resolution and the purpose of use, and of (Otero et al., 2020), who compared different options of configuration, weight, sensor type and colouring options, in their analysis work.

Light detection and ranging (LiDAR) sensors constitute the core of this type of instrumentation. An explanatory summary of the application framework of these sensors within iMMS instruments and their main modules and components is presented by (Huang, 2021). A low-cost application for dense point cloud acquisition with Velodyne VLP-16 sensor is reported by (Bula et al., 2020). In an extensive literature review on mobile surveying systems that make use of LiDAR sensors, (Di Stefano et al., 2021) take into account the wide range of applications and fields of use, from construction and urban contexts to agriculture, environmental monitoring and architectural cultural heritage, highlighting the considerable flexibility of this type of sensor and instrument.

The increased productivity of iMMSs is to be found in the robustness of the algorithm and the efficiency of the hardware. Then the analysis of final accuracy of the system is one of the most important points for its evaluation. (Tucci et al., 2018) conducted an extensive campaign of field tests, aimed at recognising geometries of diverse indoor and outdoor environments, describing quantitative and qualitative aspects, such as the level of detail or completeness of data, from some commercial mobile systems. Also, (Sammartano and Spanò, 2018) established useful datasets to demonstrate both the accuracy and qualitative information content of a portable mobile mapping system, in environmental and architectural contexts.

The application of SLAM technology and iMMS systems leads highly efficient and precise solutions, even in outdoor contexts (Guivant et al., 2000), where other solutions are not feasible, due to the lack of or possible disturbance to the GNSS signal exploited in typical outdoor mapping devices, and specifically solve the problem of dynamic positioning in mixed outdoor/indoor situations with particular regard to urban canyon situations, as in the cases proposed and analysed by (Treccani et al., 2024), by (Li et al., 2020) and by (Tanduo et al., 2022). Since strong geometric features are essential to operate SLAM-based systems, it is crucial to address the problem of governing the trajectory drifts inherent in the SLAM approach, and geo-referencing the survey. In order to keep such drifts under control, sophisticated algorithms are required, aimed for example at closing loops in the trajectory, as shown by (Hess et al., 2016). In general, however, for all accuracy-based applications, it is strongly recommended to use control points, both in outdoor and indoor applications, which also allow geo-referencing of the model itself. In addition to control points, control scans can also be used. When operating indoor, the coordinates of control points can generally be measured using a total station; when operating outdoor, it is necessary to be able to measure these vertices using GNSS. In (Marotta et al., 2022a), it is documented how control points over the ground (GCPs) can be determined from a GNSS RTK survey, but also terrestrial laser scans can assume the control function, if georeferenced. The GNSS survey in the urban scenario is usually performed at a different time to the mobile mapping, as described also in (Perfetti et al., 2023). Satellite positioning allows the trajectory of an iMMS to be constrained punctually, but remarkable attention has to be paid to the distribution of points in the survey area (Běloch and Pavelka, 2024). In this context, compactness and lightweight characteristics typical for GNSS instruments, together with on-site operational procedures of RTK surveys, could suggest and facilitate as a natural development the integration of the iMMS with a GNSS receiver, thereby enabling their acquisition simultaneously. Indeed, the role of control points is crucial in determining the trajectory generated by the SLAM algorithm, with a beneficial effect in the reduction of drift effects. In (Marotta et al., 2022b), a mountain path was selected as the test-site for an investigation on trajectory drift of different mobile survey solutions. The investigation highlighted the high drift as the most significant drawback of iMMS solutions, if not present control points.

2. Solution development

2.1 Hardware configuration

The study conducted was aimed at integrating a GNSS receiver into the already mature SLAM-based iMMS solution developed by Gexcel srl (Gexcel, 2025a) namingly the Heron MS Twin Color. The GNSS receiver of choice is the multi-frequency and multi-constellation receiver, Trimble Catalyst DA2. The physical characteristics of this receiver, such as its reduced size and lightweight hardware, made it ideal for integration purposes. Moreover, the Catalyst DA2 allows to work in real time kinematic mode, employing the Trimble positioning service, available worldwide.

The current production version of the Heron iMMS employs a pair of multi-beam LiDAR sensors, with 32 channels each with an accuracy of 1-2 cm, one is placed horizontally, featuring a scanning range of 300 m and one is placed inclined at 45 degrees, featuring a scanning range of 120. The measuring head of the system is also equipped with an IMU sensor and an 8K panoramic camera, named MG1, with a 360º field of view.

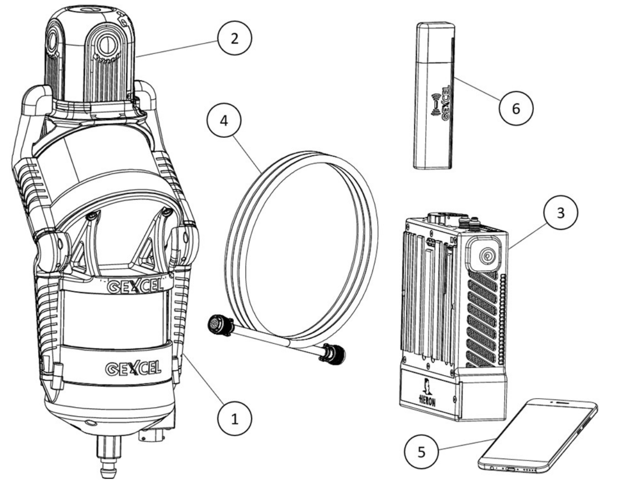

Figure 1. Heron MS Twin Color components: (1) measuring head, (2) 360° panoramic camera, (3) control box, (4) cable, (5) smartphone, (6) internet modem.

The system, represented in its components in Figure 1, is controlled by the operator through a dedicated application installed on a smartphone. At start-up, the app establishes a wi-fi connection with the control unit named control box, connected to the measuring head via cable. Internet connection is granted by the presence of an internet modem. In the upper part of the measuring head, on top of the MG1 camera, there is a fixing 1/4" screw insert which is used as the mount point of the GNSS antenna. At the current stage, the GNSS receiver is connected via Bluetooth directly to the smartphone.

The system power supply is granted by the control box which houses the batteries to power all Heron's regular sensors, i.e., the LiDAR sensors, IMU and camera. The GNSS receiver, instead, is powered independently, granting an autonomy of up to 3 hours. In the development of the solution, particular attention was paid to the design and construction of the battery housing for the GNSS receiver (see Figure 2). The housing was developed in a CAD environment (with Siemens NX software) and realised through 3D printing. The weight of the GNSS receiver is approximately 450 grams, including batteries. Figure 3 shows the system mounted on a pole; alternatively, it is possible to mount the measuring head directly on the backpack.

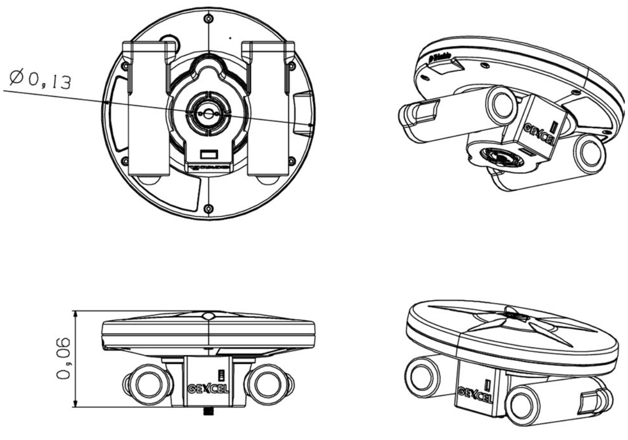

Figura 2. Catalyst DA2 receiver with integrated batteries (measurements in metres), design in a CAD environment.

Figura 3. Heron MS Twin Color integrated system with Catalyst DA2 receiver.

The Catalyst DA2 receiver exploits Trimble Centrepoint RTX, a corrections service for high accuracy point positioning (Precise Point Positioning), without a base station for RTK or a VRS network. The service requires an internet connection, unless one chooses to receive corrections directly via satellite, part of the service itself (Trimble RTX via satellite): differential corrections reaching the Trimble antenna are sent from geostationary (L-band) satellites. The Trimble RTX service approach has the advantage of being independent of a differential correction service based on a network of permanent stations, which is often only available regionally. Moreover, it does not require internet connection for receiving corrections, being able to take advantage of receiving them via satellite, an effective solution in cases where there is no internet network, and also applicable in remote areas. The reference system that Trimble RTX adopts is ITRF2020 (Trimble Geospatial, 2025). Alternatively, with internet connection, it is possible to connect Catalyst DA2 to regional or national services that provide differential corrections, via NTRIP protocol. The performances for RTX via internet and differential corrections through NTRIP protocol are presented also in (Alkan et al., 2020).

2.2 Data acquisition

The integration presented in this paper, combines the efficiency of the SLAM-based mobile system, for fast acquisition even in open/outdoor scenarios, and the possibility of acquiring GNSS measurements to be used as constraints for optimising the trajectory of the mobile system. The GNSS receiver provides positioning with a planimetric and vertical accuracy in the order of 1-2 cm (fixed solution). The minimum convergence time is in the order of a minute, but initialisation can vary: for example, poor network connection can cause convergence to slow down. The performance in terms of accuracy and initialisation time of the GNSS data depends, in addition to the reception of differential corrections, on the environmental conditions of the survey area and the possible presence of multipath due to obstruction by large buildings or trees.

The integrated system (Figure 3), which can be mounted on a backpack or pole, allows simultaneous GNSS positioning and mobile mapping. When the acquisition is performed in backpack mode, the system records the position of the antenna while the operator is moving, on the other hand, when the acquisition is performed in pole mode, the operator acquires the position of points of interest on the ground. The coordinates are saved in

geographic format (Latitude, Longitude, Ellipsoid elevation) in the reference system dependent on the source of differential corrections: Trimble RTX uses ITRF2020; if the receiver operates in RTK mode with NTRIP protocol, the reference system depends on the corrections service, from a network of permanent stations.
The saved coordinates refer to the antenna's attachment point with respect to Heron's measuring head, at the bottom of the antenna. The antenna is integral with the mobile system, thus the offset between the origin of Heron's internal reference system and the point to which recorded coordinates by GNSS receiver refers to, is known. In the case of using the system mounted on a measuring pole, it is necessary to measure the instrumental height of the pole, up to the point of attachment with Heron's measuring head, which is also known in the internal reference system. This integration solution has the advantage of being able to perform GNSS acquisition in tilted and off-axis mode, without necessarily ensuring that the antenna is vertical to the point on the ground. When the acquisition is performed in pole mode, recording individual points of interest, GCPs constraints are applied between the coordinates of the ground points known in the instrument's reference system as a function of trajectory estimation, and those measured by the GNSS receiver, projected on the ground from the effective point of registration. The measurement operation is shown in Figure 4.

Figure 4. Acquisition of ground control points, with the integrated system mounted on a pole.

Data capture is controlled from a smartphone, via the Heron Live application. Figure 5 displays views of the dedicated smartphone app showing the user capture interface. Live positioning data such as coordinates, accuracy level and number of satellites are displayed to the user. Moreover, it is possible to enter the control point coordinates in the local reference system, useful for example for the calibration procedure (see 2.2.3).

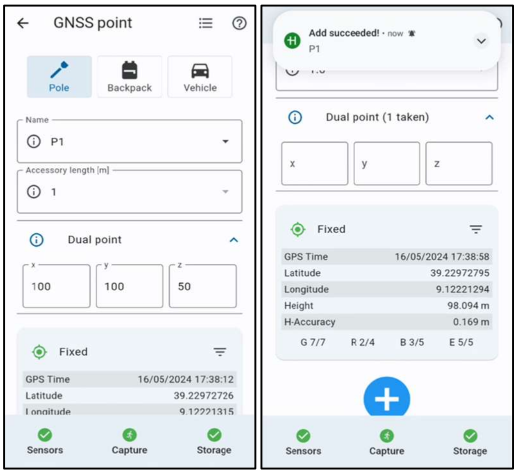

Figure 5. Heron Live application user interface for data capture.

In order for the processing software to handle the coordinates of the GNSS points as constraints for the trajectory estimated by the SLAM algorithm, they must be transformed into a linear (Cartesian) format. The geodetic coordinates are projected onto a local tangent plane to the ellipsoid, passing through a point of origin, corresponding to the first GNSS point acquired, thus defining a 3D Cartesian coordinate system. The georeferencing of the survey is found by calculating the rigid transformation that brings the points from the local Cartesian coordinate system, to the UTM map plane, but without the resulting cloud being deformed in all its points according to the map projection. It is therefore good practice to locate the first GNSS point in an area that is barycentric with respect to the overall survey area.
Depending on the type of GNSS point to be acquired, three fieldwork scenarios can be identified.

2.2.1 Backpack antenna positioning: If the area of interest has no known coordinate points, it is possible to operate by recording GNSS points without the need to measure points on the ground. In this case, the system is mounted directly on the backpack, the operator has the option of moving around to capture the mobile system data and simultaneously acquire GNSS points. The coordinates of the acquired points, however, make it possible to constrain the trajectory and at the same time to geo-reference the three-dimensional model obtained, within the reference system adopted. The constraint occurs between the coordinates of antenna attachment point to the measuring head, known from the GNSS acquisition, and the ones known with respect to the internal reference system.

2.2.2 Physical points measurement: If the area of interest has no known coordinate points, but for the operator it is nevertheless of interest to measure certain physical points on the ground, such as artefacts or on architectural elements, it is possible to mount the instrument on a measuring pole. During the mobile acquisition, the operator stops at these, placing the tip of the pole on them, and records the positioning data. The constraint of the trajectory and the georeferencing of the cloud are thus performed during data processing: the three-dimensional model is framed in the GNSS measurement reference system. Acquisition in correspondence of points in the ground can also be performed in a tilted position.

2.2.3 On-site calibration: This may be the case at a construction site, mine or quarry, where a local topographic network of points is already available, or in an urban or outdoor environment where a number of ground control points are known. Following this workflow, the instrument is mounted on the pole. The points on the ground must be distributed within the area chosen for the trajectory path. The operator during the acquisition stops with the system mounted on the pole at the control points, known in the local reference system. The instrument acquires the geographical coordinates, and at the same time the local coordinates of the known point can be inserted in the control application and associated. This operation, repeated for known points in the local system, allows the calibration of the survey in the topographic local system: among the points on which the operator has positioned himself with the instrument mounted on the pole, a minimum number of 3 can be chosen (in post-processing) as double points to determine the roto-translation, for the framing of the points in the known local reference system.

2.3 Data post-processing

The mobile survey data processing procedure, described here with reference to the Heron Desktop software, developed by Gexcel (Gexcel, 2025b), is divided into 3 phases: Odometer, Map Creation and Global Optimization.
In the first step, the trajectory solution is obtained by the SLAM algorithm, which uses the LiDAR and IMU sensors data as inputs.
During the Map Creation phase, the trajectory obtained in the previous step is subdivided into local maps, with the aim of rendering the entire point cloud associated with the trajectory as the result of linking neighbouring or consecutive scans (maps), connected via matches, using cloud-to-cloud registration. In the final phase known as Global Optimisation, it is possible to operate on these links, in particular by inserting new ones manually, or automatically, in order to, for example, close loops, optimising the final calculation (Figure 6).

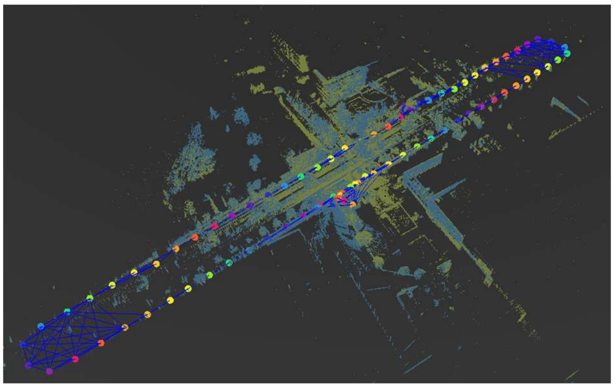

Figure 6. Global Optimisation example, in Heron Desktop software.

Once a first Global Optimization has been completed, it is possible to proceed with a second one, in which the points acquired with the GNSS receiver integrated in the system, can be inserted. To this end, the software automatically imports the list of GNSS points associated with the trajectory being processed: the geographical coordinates and the UTM zone are displayed, together with the planimetric and vertical positioning accuracy values, provided by the receiver for each point acquired, and the indication of the Coordinate Reference System. In the case of differential corrections provided via Trimble RTX service, even if via satellite, the list of points is directly imported, otherwise, if corrections are provided in RTK via NTRIP protocol, before importing the points, the user is asked to indicate the Reference System, to properly frame the coordinates of the acquired points, known according to the specific network used (Figure 7). From the list it is also possible to deselect an unwanted point, for example one with sub-optimal accuracy: the type of solution, such as fixed, floating or autonomous, is also indicated. The constraint points are imported, and a second and final optimization of the constraint matches can be run.

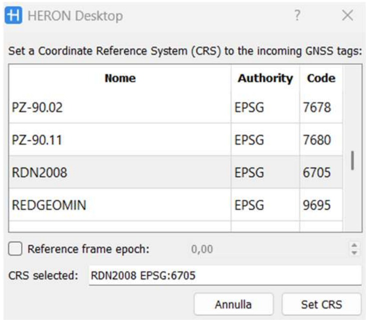

Figure 7. GNSS points importing in Heron Desktop: Reference system choice (NTRIP mode).

The final cloud is then exported to Reconstructor, developd by Gexcel, 2025c). It is possible to read the point cloud in geographical coordinates (dependent on the reference system adopted) or UTM, where these are only relative to the display of the cloud but without it being deformed at all its points according to the cartographic projection. In fact, the cloud is rigidly rotated in a UTM reference system with (ellipsoid) elevation, from the reference system defined from the plane tangent to the ellipsoid, with origin on the first point acquired. Figure 8 provides a schematic representation of the data processing flow in Heron Desktop.

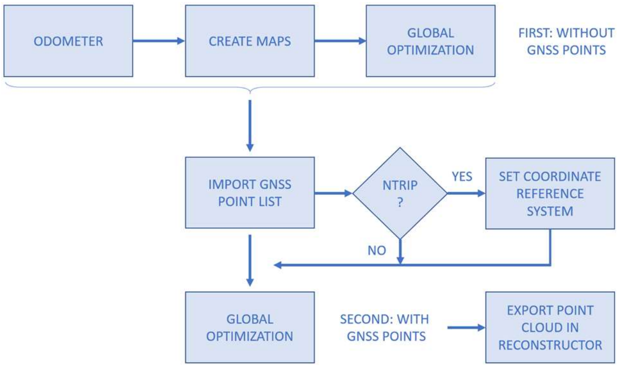

Figura 8. Heron Desktop data elaboration workflow.

In the case of workflow with on-site calibration, the only difference to the GNSS point list import phase is that the local coordinates (with respect to the known topographic reference system) are also given for the calibration points acquired during the survey.

3. Results

A first test of the integrated system was carried out in the field, in an outdoor urban/roadside environment (Figure 9) in order to evaluate the performance improvements of the proposed solution with respect to the production version of the Heron iMMS. This setting was chosen since such survey conditions are not ideal for a typical SLAM-based mobile system, due to the lack of diversified geometries, nonetheless, GNSS positioning could yet be operated successfully. The test took place in an urban street about 500 metres long, the survey was carried out starting from a central point on the road, moving to one end of road, then changing sides and travelling the entire length in the opposite direction before returning to the starting point, closing the route. The acquisition was carried out connecting the receiver to a network of permanent stations, with NTRIP protocol, specifically that of the interregional service valid for Northern Italy, SPIN3 GNSS. The mode of use followed the workflow previously described, for the measurement of physical points on the ground. The system was mounted on a pole, and GNSS measurements were made at road artefacts (manholes, kerbs, detectable elements on the road pavement). The objective of the test is to measure the degree of correction of trajectory drifts, following the inclusion of the GNSS constraints. During the route, one point was acquired approximately every 10 metres, later in processing, points with a precision level higher than 10 cm (horizontal) were excluded. In a specific area of the route, the obstruction to the reception of the signal caused by the presence of a pedestrian overpass led to difficulties in the initialisation of the positioning, resulting in the lack of constraint points.

Figure 9. Surveyed road with GNSS control points

During the data processing phase, it was thus possible to identify 4 trajectories, starting from the same test survey, by selecting different sets of GNSS points. The trajectories considered were: one without the inclusion of any constraint point, one with the maximum number of GNSS constraint points (38), then other two trajectories obtained progressively reducing the number of constraints, 13 and 5. Then, the non-optimized path have been aligned with a best fit alignment through ICP, to the point cloud with 38 control points: this step was necessary to frame the non-optimized solution to the same reference system of the others. On the left of Figure 10, it is shown the comparison between the non-optimized point cloud and the one with the maximum number of constraints, set as reference for the considered comparisons. This comparison shows the curvature effect of the trajectory not including control points, highlighting the drift accumulation at the borders of the travelled path.

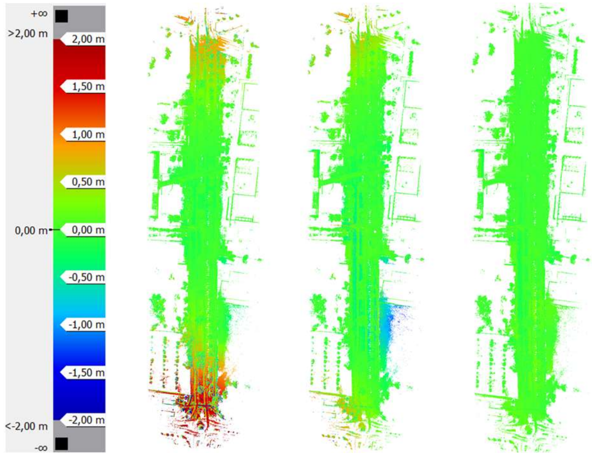

Figure 10. Accuracy of measurements performed with different number of constraints

In the centre of Figure 10, the difference between the point cloud obtained from the trajectory with 6 GNSS points and that without GNSS points, set as the reference one, is reported, while on the right of Figure 10 it is the case of the comparison between the cloud obtained from the trajectory with 13 GNSS points and that without GNSS points. The insertion of the points acquired with the integrated system is beneficial for the reduction of the curvature effect due to the accumulation of drift, particularly at the ends of the road. Decreasing the number of control points, it appears that the solution diverges from the optimal one, with a dense distribution of 38 points over the surveyed area, just in the borders, for the case of the minimum number of 5. In Figure 11, a vertical section obtained at one of the extremities of the survey area, in correspondence of P38, parallel to the main axis of the road, is reported, with particular attention to the distances between the point clouds obtained with the different amount of GNSS control points.

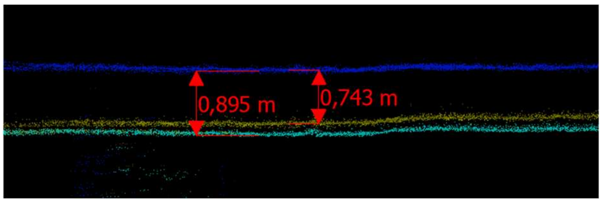

Figure 10. Portion of vertical section of the road. Blue: point cloud without GNSS points; Yellow: 40 GNSS points; Light Blue: 5 GNSS points

POINT	#38 GNNS CP	#13 GNNS CP	#5 GNNS CP
P01	0.026	0.071	0.426
P02	0.046	0.028	0.407
P03	0.016	0.061	0.408
P04	0.035	0.124	0.204
P05	0.004	0.009	0.281
P06	0.013	0.023	0.132
P07	0.037	0.124	0.090
P08	0.003	0.025	0.059
P09	0.033	0.063	0.137
P10	0.062	0.017	0.005
P11	0.006	0.005	0.003
P12	0.052	0.109	0.134
P13	0.015	0.065	0.084
P14	0.019	0.068	0.128
P15	0.027	0.040	0.088
P16	0.018	0.013	0.149
P17	0.047	0.210	0.326
P18	0.025	0.007	0.116
P19	0.029	0.087	0.130
P20	0.027	0.058	0.049
P21	0.008	0.005	0.005
P22	0.011	0.053	0.087
P23	0.010	0.078	0.105
P24	0.017	0.012	0.004
P25	0.018	0.088	0.349
P26	0.018	0.066	0.368
P27	0.010	0.007	0.462
P28	0.012	0.140	0.585
P29	0.028	0.221	0.654
P30	0.046	0.028	0.847
P31	0.055	0.252	0.245
P32	0.039	0.174	0.205
P33	0.022	0.115	0.248
P34	0.008	0.099	0.086
P35	0.005	0.009	0.260
P36	0.018	0.027	0.007
P37	0.030	0.159	0.472
P38	0.020	0.094	0.316

Table 1. 3D distances in metres

In Table 1, the differences between the point clouds are reported from a quantitative point of view, considering the 3D distance between the coordinates of points after the optimization with respect to the measured ones. In the cases of the reduced number of control points (13 and 5 vs 38), for points that are not used as constraints (check points), 3D distances are not in the order of the GNSS precision. Green values refer to control points.

4. Conclusion and future works

The purpose of the work discussed can be traced back to the results of the tests presented: the integrated system between an indoor mobile mapping system, based on SLAM, and a GNSS receiver, allows the application areas of the mobile mapping system to be extended to outdoor environments, or possibly mixed outdoor indoor conditions. The inclusion of GNSS points in the acquisition phase, and therefore in the data post-processing phase, enables the addition of constraints to the trajectory, with the aim of reducing the effects of drift that it accumulates, especially in environments without diversified geometries. It is thus suggested to avoid poor distribution with few GNSS control points, as shown for the case presented with just 5 GNSS points used. The development of presented solution starts from hardware design choices, in particular regarding the choice of a proper GNSS receiver and its integration with the Heron mobile system. The advantages of the Catalyst receiver, apart from its compactness and lightness, also lie in its flexibility of use thanks to the RTX system, which facilitates the reception of differential corrections on a large scale and also in conditions of absence of internet connection, to which the RTK method is limited to.
An extension of the survey tests is planned, especially with regard to use of the system in a context where there is a known local reference system to support the survey, following the on-site calibration procedure.

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