GIMPHI: A NEW INTEGRATION APPROACH FOR EARLY IMPACT ASSESSMENT

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ABSTRACT:

In the early impact assessment, a useful instrument for early mapping and rescue assessment can be the Mobile Mapping System. In this context, the Politecnico di Torino research team has developed a Low Cost System, where only low cost sensors are involved. The system is equipped with webcams, a MEMS IMU and up to three GNSS receivers. The main problem of this low cost system is when some GNSS outages occur. In this case, the IMU can estimate the trajectory and the attitude of the vehicle, adopting particular integration algorithms, such as the loosely or the tightly coupled in order to improve the IMU performance reducing the gyroscope and accelerometer drifts, but only for short periods (<25 s). For this reason, a new approach has been developed integrating the GNSS/IMU trajectory and attitude with the information achieved from web-cameras by means of a photogrammetric process. Using a novel Auto-Adaptive Scale-Invariant Feature Transform (A²SIFT) algorithm, tie points are extracted from sequences of images in every taking and image texture conditions. In order to manage all these sensors, an integrated positioning algorithm (GIMPHI, GNSS/IMU and PHotogrammetry Integration) has been developed by our group. A rigorous weight matrix is used in order to consider the different accuracies of the various observations (GNSS, IMU, images) and to achieve the position and the attitude of the vehicle at each epoch. In this paper a detailed description of this integrated approach is presented; then, the first tests and the achieved results are shown in order to evaluate the goodness of the proposed approach.

1. INTRODUCTION

Nowadays, Mobile Mapping Systems (MMSs) are used to acquire spatial information such as road paths, images and point clouds that can be directly georeferenced using an integrated GNSS/INS system. Thanks to the high performance and the quick time to have final products (geo-information), the use of MMSs will be extended to new application fields.

During the early impact assessment, the availability of a MMS could be of great importance in particular if a quick investigation of all the damages is requested. On the other hand, available MMSs are not flexible enough to be installed on every vehicle model and they are too expensive (more than $2\cdot10^5$ €) to be commonly available in each country.

Luckily, the remarkable technology improvement has increased the role of low cost sensors into the market, especially for navigation application. Today, single frequency receivers are able to achieve with an accuracy of few cms-dms, under particular condition. The new generation of low cost inertial sensor which uses the MEMS technology has been employed in several fields (mobile phone, gaming) even for geomatics application. Then, the digital camera has also submitted a deep improvement, in fact commercial webcam achieves to obtain high definition videos and good images (2-7MPx), with a very low cost and allowing the implementation of the device control.

The Geomatics research group of the Politecnico di Torino has realized a Low Cost Mobile Mapping System (LCMMS), merging the interest about the low cost sensors and the mobile mapping system. This system has been realized with the purpose to have a really suitable MMS, able to be installed on different types of vehicles, cheaper than other systems and, at the same time, efficient and with good performances.

The main problem of this low cost system is when some GNSS outages occur. In this case, the IMU can estimate the trajectory and the attitude of the vehicle, adopting particular integration algorithms, such as the loosely or the tightly coupled and considering both a Kalman filter and Least-squares based integration algorithms, specially calibrated for low cost GNSS and INS data. These methods allow improving the IMU performance because the gyroscope and accelerometer drifts are reduced. Anyway, these results get gradually worse for long GNSS outages (more than 25 s) such as driving in long tunnels or in dense urban areas.

In these conditions, the information achieved by the images (about 5-10 fps) acquired by the system can be used in order to improve the positioning and increase the redundancy of the system. In particular, position and attitude data can be corrected by means of a photogrammetric approach, exploiting the overlap between adjacent images: in fact, each point captured by the webcams is at least visible in 3-4 frames.

The GIMPHI approach (GNSS/IMU and PHotogrammetry Integration) try to improve the navigation solution, integrating the “a priori” solution (GNSS-IMU) with the photogrammetric information extracted by the images.

In order to realize an automated approach it has been necessary to automatically extract points from images. In this context, valuable help is given by Computer Vision and its feature extractor and matchers, such as the SIFT operator. In particular, a modified version of the SIFT operator, the A²SIFT (Lingua et al., 2009), is adopted: in this way the feature extraction from the images and the preliminary matching between homologous points is made possible by means of a feature matching. This process is then refined by the robust Least Median Square (LMS) relative orientation estimation (Lingua et al., 2000): in this way all the blunders of the feature matching are deleted and only correct homologous points are considered. Finally, the

orientation of all the images is computed using some of the homologous points and the preliminary GNSS-IMU information by means of a Bundle Block Adjustment (BBA). The achieved information (GNSS/IMU/image sequences) is integrated in ad hoc software using a rigorous weight matrix in order to consider the different precisions of the various observations (GNSS, IMU, images). In general according to the operative conditions each sensor contributes in a different way to the final solution and this balance between different weights sensors is one of the more critical aspect that must be evaluated.
In this paper, a description of this approach and first performed tests will be presented. The goal of the work is to evaluate the reliability and the effectiveness of the proposed method. Different operative conditions have been considered in order to consider all the operative condition usually faced by the MMSs.
For this purpose, dedicated tests have been carried out, and the results have been compared with the reference dataset with the purpose to evaluate the accuracy of our solutions.

2. DESCRIPTION OF THE LOW COST MOBILE MAPPING SYSTEM

The Geomatics research group of Politecnico di Torino has designed and built a universal system for the Mobile Mapping, called LCMMS (Piras et al. 2008).
This system is made up of a metallic bar that can be used with any vehicle and that can hold up to three GNSS antennas, two low cost inertial sensors (Xbow 700 CA and Xbow 400) and three web-cameras (Logitech Quickcam Pro 9000, with resolution up to 2 Mpixel).

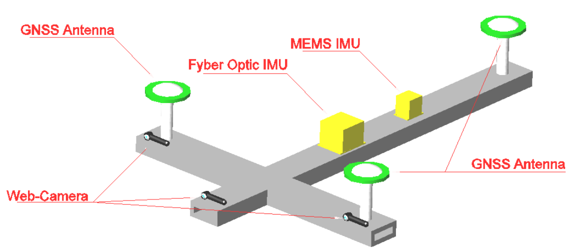

Figure 1. The LCMMS layout

The realized prototype of MMS is composed by low cost sensors with a medium level of accuracy with respect to reduce the cost but not decrease the quality.
It is necessary to pay a special attention about the system calibration procedure, in order to avoid external error. Calibration of the optical lens, definition of the reference frame transformation, synchronization of time devices and integration between sensors has been considered and estimated (Piras et al., 2008).
After the calibration, LCMMS allows to geo-refence the images to the position and attitude of the vehicle at each time without any additional information as described in the following paragraph. In alternatives, all the sensors contribute to define the final solution (GIMPHI approach), as will be described in the next paragraphs.

3. TRADITIONAL MULTI-SENSORS INTEGRATION

A brief description about the traditional integration between GNSS and IMU devices is presented. This solution represents the basis of our systems because it gives a first estimation of position and attitude of the vehicle in each epoch.
Academic or commercial software devoted to realize the GNSS/IMU integration are already available, but only if the INS calibration models (bias, drift of gyros and accelerometers and their variations) are available. Unfortunately, it is very difficult to find a correct individual calibration model of MEMS sensors, but dedicated software which allows the bias and drifts of the low cost IMU to be estimates and applied is necessary.
In particular, the Authors have developed a software where loosely coupled and tightly coupled are implemented. These algorithms and the software have been tested in several cases, obtaining interesting results (De Agostino, 2009).

3.1 Loosely coupled approach

Using three GNSS antennas, it is possible to get, in addition to the positions and the velocity, also the attitude of the vehicle. The last information can be determined into the GNSS process, using double-differenced carrier phase measurements between two of the three receivers to one, assumed as master receiver (Lu, 1995) or, in analogy with the loosely-coupled architecture, directly from the computed positions of the three antennas.
The navigation solution is performed when INS epochs are synchronized with GNSS epochs. This is generally realized using a Kalman filter, and it is especially useful when low-cost inertial sensors are used, which have considerable gyroscope drifts.

3.2 Tightly coupled approach

Tightly coupled approach for GNSS/INS integration is not a new innovation in itself but it has found use in the autonomous vehicle community only recently (George et al., 2005). In this algorithm, GNSS pseudorange observables are fused directly with the INS states (typically, positions and velocities).
With respect to the loosely-coupled solution, in a situation of low GNSS availability (e.g. urban canyons, tree-lined roads) a tightly coupled configuration allows to solve the navigation equations with two visible satellites.
The integration model may also include variables such as GNSS signal propagation delays, accelerometer scale factor errors and system time delays, and the estimated values of these variables may be used for improve the inertial solution performance during GNSS signal outages, and for faster ambiguity reacquisition after GNSS outages (Škaloud, 1999). In addition, a tightly coupled algorithm processes the GNSS signals directly. In a well designed system this increases the chance of optimal solution performance.
In our case, the tightly coupled has to be modified in order to consider a different computational schema. Double differences are available in order to define the position of each antenna and three constrain equations can be included in the mathematical system in order to give more robustness.
This tightly-coupled approach achieves to solve the navigation problem even when only three satellites are tracked. In fact, it is possible define four double difference equations from GNSS data (two for each couple of antennas), other four double difference equations from INS solution and three constrain

distance equations. The value of redundancy is greater than one, then, Least-Square approach or Kalman filter can be applied.

4. GIMPHI: THE NEW APPROACH

In order to increase the redundancy of the MMT and correct the IMU drift, the information collected by images can be used. In particular their orientation parameters have to be estimated, in order to define the position and the attitude of each image during the acquisition. This process can be achieved following several steps. The first step is the extraction and the matching of the feature of interest extracted by the images. Then, the matching process has to be refined by a robust relative orientation and, finally, these data can be used in the orientation itself, by means of a Bundle Block Adjustment. In Figure 2, a scheme of the proposed workflow is presented.

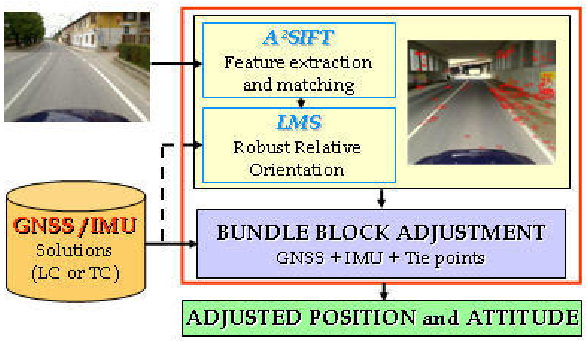

Figure 2. Workflow of the GIMPHI integration approach

4.1 Feature extraction and matching

In order to perform the orientation of the images acquired by the LCMMS, homologous points have to be extracted from adjacent images.
The SIFT operator (Lowe, 2004) is one of the most frequently used in the photogrammetry and computer vision application field. SIFT extracts image features that are invariant to image scaling and rotation and partially invariant to changes in illumination and 3D camera viewpoints (affine transformation). The features (keypoints) are detected in a Difference of Gaussians (DoG) scale space, which represents the difference of Gaussian convolutions of the original image (Figure 3).
A predominant orientation of the radiometric gradients, which assures the invariance to rotations, is assigned to each local maximum of the DoG function. Finally, a “descriptor” is associated to each keypoint. The “descriptor” is a vector of dimension 128 which summarizes the radiometric content of the neighbourhood of the keypoint.
The correspondence between two candidate points is found through the evaluation of the minimum distance between the “descriptors”. A detailed description of the SIFT algorithm can be found in [Lowe, 2004].
The SIFT operator gives different results according to the dynamic range of the images or the texture distribution: some papers (Battiato et al., 2007) have underlined the importance of contrast thresholds of the SIFT in relation to the number of extracted points. This aspect influences the performances of the SIFT detector, especially over areas around roads, such as grasslands, pavements or wooded zones. In these cases, the local dynamic range of the image is quite low and the image can be defined “bad textured”. Therefore, some threshold parameters proposed by [Lowe, 2004] for the removal of low-contrast regions have to be corrected.

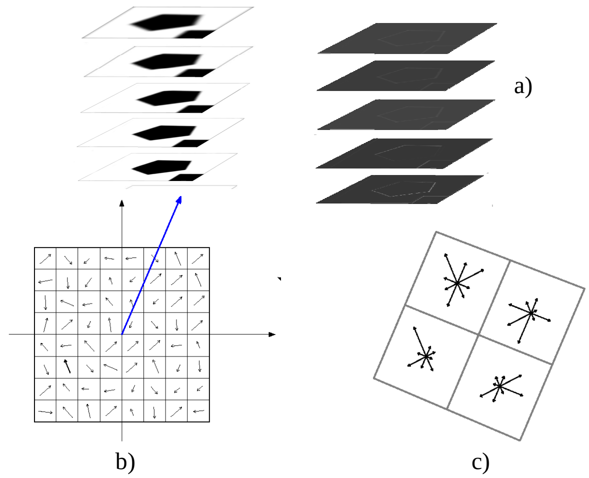

Figure 3. (a) DoG scale space. (b) Predominant orientation of the radiometric gradient. (c) SIFT descriptor

For this reason, a modified version of the SIFT detector has been developed and implemented for this purpose. The Auto-Adaptive SIFT (A^2SIFT) allows the contrast threshold parameters of the SIFT detector to be defined, in relation to the local radiometric content around each feature. Some experimental tests on the MMS have already shown that A^2SIFT (Lingua et al., 2009) allows the feature extraction and matching to be increased, especially on areas with a high rate of repetitive-patterns or bad textures. In this implementation, the original SIFT algorithm was modified in order to fit the contrast threshold according to the texture: in other words, each keypoint has a different threshold according to the texture of the image in its neighbourhood. In order to do this, a coefficient (*Tx_coef*) which is able to define the local texture of the image was implemented. This texture coefficient allows the local radiometric content of the DoG scale around a keypoint to be evaluated: if the texture is good, the *Tx_coef* will be high and vice versa. In this way, it is possible to predict the image areas where the keypoint extraction is more difficult. As a consequence, a lower contrast value $|D(\hat{x})|$ can be used in these areas to extract a higher number of keypoints; vice versa, a higher contrast value $|D(\hat{x})|$ must be adopted in well-textured areas. For a more detailed description of the algorithm refers to [Lingua et al., 2009].
The distribution of the features extracted on the image is a fundamental aspect for the relative orientation and the bundle block adjustment: points that are too close or blank areas can compromise the stability of the relative estimation between images. On the other hand, the number of points alone does not assure the quality of the image orientation. It has been shown that the SIFT operator can match a high number of points on well-textured areas, while it does not allow any points to be

matched on poor textures. The A^2SIFT allowed this problem to be partially solved.

4.2 Matching refinement and robust relative orientation

The feature extraction and matching techniques provide a set of homologous points which are usually affected by outliers and gross errors. Therefore, adjustment techniques must be used to eliminate the inconsistency in the measurements.
For this purpose, the robust estimation of the symmetric relative orientation between the two images has been carried out. In particular the Least Median Square (LMS) (Rousseauw et al., 1987) estimator has been considered. This approach is widely used in photogrammetry (Lingua et al., 2000), especially for the computation of relative orientation between image pairs (in aerial applications) and the estimation of the fundamental matrix in close-range and Computer Vision applications. The algorithm removes outliers by means a two step standard residual analysis according to the rejection threshold *L*. LMS provides good results in data set which can have a number of outlier up the 80%. Nevertheless, it is not an efficient estimator, so it does not supply accurate solutions. Therefore, the unknown parameters must be re-estimated using the Least Square estimator in order to achieve the final results. In order to estimate the orientation parameters, the IMU attitude data are used as approximate values and initialize the LMS algorithm.
The realized LMS algorithm reaches good results when a good point distribution all over the image is assured. Homogenous distribution strength the solution and assure to determine the orientation parameter in a reliable way. On the contrary, bad distribution points (clustered points) determine ambiguous solutions and unreliable parameters. For this reason the image texture and their semantic information are of main significance in the proposed integration approach.
The LMS solution can be influenced by mobile objects (cars, pedestrians, etc.) and can define erroneous parameter solutions; for this reason, a manual deletion of tie points on these objects must be performed. The authors are developing an automatic car recognition algorithm in order to speed up this step of the work.

4.3 Bundle Block Adjustment

The image orientation has been realized by means of a bundle block adjustment: in this step the IMU, the image and the GNSS (if available) information is considered in order to determine the position and the attitude of the vehicle at each epoch.
This algorithm is implemented considering a rigorous weight matrix that considers at each epoch the precision of the different sensors. The weights are achieved considering, on one side the root mean squares of the GNSS-IMU solution and on the other side the residuals of each stereo-pair relative orientation.
In this way, it is possible to consider the performance of the integrated sensors according to different operative conditions, exploiting their information in the best way. In particular, if the GNSS solution is not available, the weight of the GNSS-IMU solution decreases progressively, and the solution is more influenced by the photogrammetric information. On the contrary, when and unreliable relative orientation is reached, the GNSS-INS solution could be not influenced by these information.
Due to the high number of processed images, the Bundle Block Adjustment has a high computational cost. In particular, the high number of extracted points increases the dimension of the normal matrix in the Bundle Block Adjustment. Nevertheless, it has been noticed that a lower number of well distributed points can be sufficient to perform the same process with the same accuracy. For this reason images are divided in 20 regions (see Figure 4) and from each of them a maximum of 2 points are extracted according to their parallax value in the relative orientation: points with minimum residual parallax are chosen. In this way, a maximum of 40 points per image are considered.

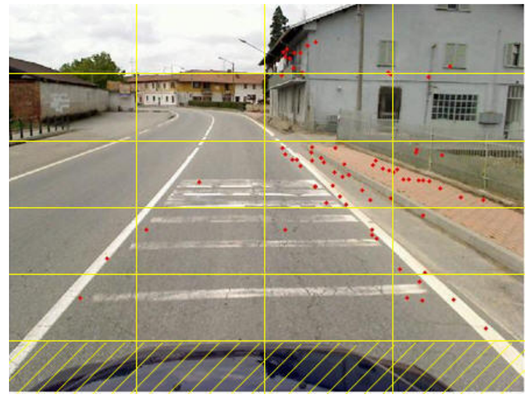

Figure 4. Image region for the points extraction; the lower part of the image has never been considered

5. FIRST EXPERIMENTAL TESTS

The goodness of the GNSS-INS integration and the effective advantages of the proposed approach have been evaluated through several test realized with the LCMMS on the roads of the Piemonte (Italy). In each survey, a large number of images have been acquired: the LCMMS has been able to reach 6-8 fps and, in this way, each surveyed point has been tracked in 4 or 5 different frames (considering a speed vehicle equal to 50km/h and a single camera).
The resolution of the images (960x720 pixels) and the number of available frames, has allowed a bundle block adjustment to be realized, making an along-track orientation of the images (Figure 5).

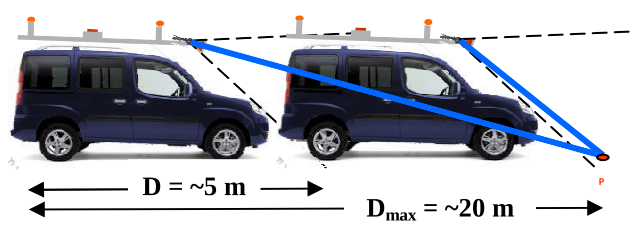

Figure 5. Schema of photogrammetric *along track* image acquisition

The trajectories have been achieved following both the traditional (GNSS+IMU) and the GIMPHI approach. These results have been compared to a reference solution that was achieved by professional MMT system (POS-LV equipped) with decimetric precision (according to their technical specifications). Nevertheless, it is important to notice that the references trajectories have been acquired in a different moment and they did not retrace exactly the same trajectory as the considered data set: the driver has covered a different trajectory according to the external conditions (other cars, pedestrians, etc.). For this reason, only a qualitative comparison can be performed.

The results have shown as the traditional solution (GNSS_IMU) achieves good accuracy results when GNSS information is available (De Agostino et al., 2008). In these conditions, the GIMPHI approach does not improve appreciably the accuracy of the position and attitude determination. In these part, images are poor textured and could hardly improve the final solution.

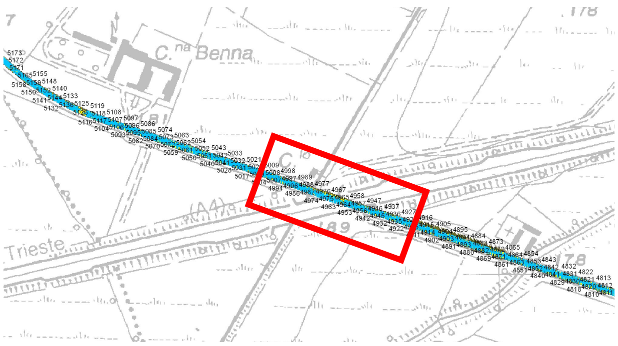

Figure 6: Area of the performed test

In contrast, this new approach seems to give a great improvement during GNSS outages. As an example, a set of data in correspondence to a tunnel can be considered (Figure 6). In particular, the data before, inside, and after the tunnel are processed: the GNSS signal is available before and after the tunnel, in the starting and ending epochs, while in the central part of the data set only IMU and photogrammetric information are available. In this area: about 150 images are available, the tunnel is about 280 m long and the vehicle has taken more than 30 s to cover this distance (an image every 2 m).

In these operative conditions, the A^2SIFT algorithm works very well, in particular it is able to identify several homologous points in bad illumination condition and when the lightness and contrast level change very quickly too (see Figure 7).

Several tests have been performed considering different accuracy in the GNSS-IMU solution. The goal has been the evaluation of the change in the trajectories changing the weight of the image in the joint solution in order to evaluate the effectiveness of the GIMPHI approach.

Figure 7: Example of extracted points in subsequent images in the tunnel test (4960-4961)

The trajectory defined using only GNSS-IMU information reached a good precision (< 20 cm) at the beginning and at the end of the block, completely compatible to the reference solution. Then, a progressively worse solution was obtained in the tunnel, giving more than a meter of difference from the reference solution.

Considering the GIMPHI solution, the trajectory is almost identical to the traditional solution in the first and in the last part of the data set. On the contrary, when GNSS cannot afford any data (any satellite is visible), the photogrammetric approach gives its support reducing the IMU drifts effects. This aspect can be well appreciated in Figure 8. In this figure, the yellow points represent the reference trajectories achieved by POS-LV system; the sky blue points refers to the traditional solution (GNSS+IMU) and the red and green points show the performed trajectory achieved using the GIMPHI approach, considering different weights in bundle block solution: in detail, the green solution gives a greater importance to the photogrammetric information.

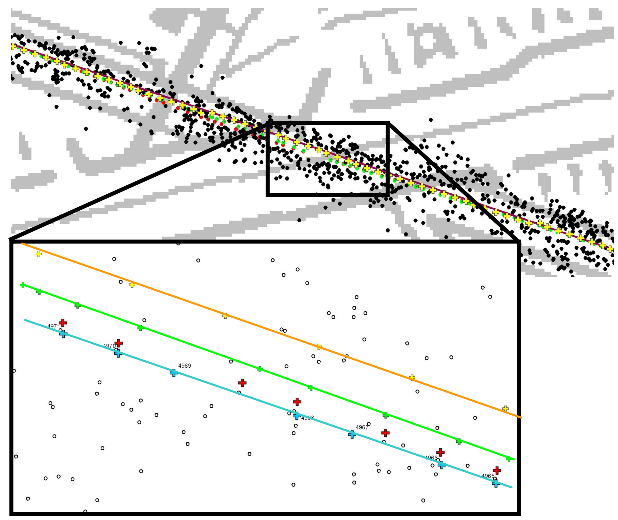

Fig.8: Comparison between reference (yellow), traditional (sky blue) and two GIMPHI (red and green) trajectories

From this example, it can be noticed that the integrated solution allow an improvement in the trajectory to be achieved. In particular, decreasing the accuracy of IMU information along the tunnel, the photogrammetric information became more important in the navigation solution determination. The final error respect to the reference solution can be reduced up to 60% in the middle part of the tunnel (Figure 8).

6. CONCLUSIONS AND FUTURE DEVELOPMENTS

MMSs could be a valid tool for the early impact assessment. These systems provide georeferenced images of the damages in a fast and reliable way. Traditional mobile mapping vehicles cannot be used because the high cost and the low flexibility, limiting their use in the field of impact assessment application.

The proposed low cost vehicle is the good compromise between cost and required accuracy, but they are not “turnkey” solution. It is necessary to study a dedicated procedure of calibrations and particular approach devoted to estimate the solution of navigation (position and attitude), especially when environmental condition not allows to acquire the GNSS data for long time.

The described integration GNSS/IMU achieves to estimate a good vehicle positioning, obtaining decimetre or better precision when a good INS model and GNSS positioning is available. As shown above, in these cases, the photogrammetric approach cannot improve appreciably the solution because of the poor content of the images and the already good position and attitude estimation given by the traditional solution.
The visibility of satellites can quickly change when there are some obstacles (urban canyon, wooded boulevard, tunnels etc), causing fragmentary GNSS solution. In these conditions, the possibility to involve the image measurements allows to limit this problem, increasing the positioning reliability also when the traditional solution is more in difficulty. In this context, the GIMPHI approach has shown to improve the quality of the solution, reducing the IMU drifts up to 60%.
In conclusion, the proposed approach has shown to reach a good reliability, giving encouraging results that can be almost comparable to professional MMT systems in each operative condition. For this reason, the developed LCMMS and the GIMPHI approach could be a suitable solution for the early impact assessment, overcoming the flexibility and the cost limitations.
In the future new tests and developments will be realized in order to improve much more the reliability and the handiness of the system. A further integration of this system with low cost lasers is actually at the study in order to produce point clouds too.

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