New frontiers of Geomatics: some applications at the Politecnico di Torino

DEQUAL Sergio, Professor, Politecnico di Torino, Italy, sergio.dequal@polito.it
BENDEA Horea Iosif , Professor, Politecnico di Torino, Italy, iosif.bendea@polito.it
DE AGOSTINO Mattia, Ph.D. student, Politecnico di Torino, Italy, mattia.deagostino@polito.it
MARENCHINO Davide, Ph.D., Politecnico di Torino, Italy, davide.marechino@polito.it
NEX Francesco, Ph.D. student, Politecnico di Torino, Italy, francesco.nex@polito.it
PIRAS Marco, Ph. D., Politecnico di Torino, Italy, marco.piras@polito.it

Abstract: *What are the new Geomatics application fields? Who are the possible end users? This contribution will attempt to describe the state of art and the effective capability of research in the Geomatics field, paying particular attention to land surveying and built heritage issues. The research carried out in recent years by the Geomatics group at the Politecnico di Torino will be described, with respect to the technologies, algorithms and software that have been developed, concerning GNSS satellite positioning systems, inertial navigation systems (INS), digital photogrammetry, laser scanning, SAR and remote sensing. This research has been applied in several fields, ranging from the survey of natural and urban environments, to the modelling of archaeological finds. Some of these applications, e.g. Mobile Mapping Systems (MMS) and the Unmanned Aerial Vehicles (UAV) will be outlined in this paper.*

Keywords: *GNSS, INS, Mobile Mapping Systems, Unmanned Aerial Vehicles, Features Extraction, Solid True Orthophotos, LIDAR and Photogrammetry Integration*

1. Introduction

The word “Geomatics” originates from the fusion of two words “Geodesy” and “Informatics”. This science is therefore directed to the study of the land and the environment using informatics instruments together with modern technologies. A large number of subjects belong to Geomatics research fields: in addition to traditional Topography, it is necessary to also consider GNSS (Global Navigation Satellite System) and INS (Inertial Navigation System) positioning systems, digital photogrammetry, laser scanning, SAR and remote sensing.
But, what are the new Geomatics application fields and who are the possible end users?

A research group has been set up at the Politecnico di Torino which is composed of professors, technicians, assistant researchers and PhD students and which works in the Geomatics fields and has many years of experience on this topic. The group carriers out research at the Land, Environment and Geo-Engineering Department (DITAG) where several Geomatics laboratories are available. The group’s research activities concern several application fields, ranging from the survey of natural and urban environments to the modelling of archaeological finds.

The research carried out in recent years by this group will be described in the following pages, with respect to the technologies, algorithms and software that have been developed, with the aim of describing the state of art and the effective capacity of the research in the Geomatics field, paying particular attention to land surveying and built heritage issues, in addition to the common end-user applications.

2. GNSS Satellite Positioning

The experimental real time network control centre of the Piedmont Region GNSS Reference Stations (RS) has been in use at the DITAG Department at the Politecnico di Torino since 1994 (Fig. 1 (a)).
The GNSS network is composed of 15 RS, all of which are located in the Piedmont Area or nearby; such a network ensures total signal coverage over the entire Region.

(a)


(b)

Fig. 1. (a) GNSS Test Network of the Politecnico di Torino. (b) PND sensors that can improve position accuracy using the network differential corrections

Each GPS reference station is computed once a year in the IGS05 reference system through a global network adjustment. The control centre receives the observation data from each RS in real time through an Internet connection according to the RTCM protocol. The network management software (SpiderNET® from Leica Geosystems) can compute and distribute different services, both for real-time and post-processing applications. In particular, it is possible to generate a differential positioning correction which is computed using the entire network or a single network station, both for static and kinematic applications and for different qualities of receivers. Each user who wants to make a differential GPS positioning can easily communicate with the control centre and also improve the accuracy of the positioning using low-cost receivers (i.e. Personal Network Devices - PNDs).

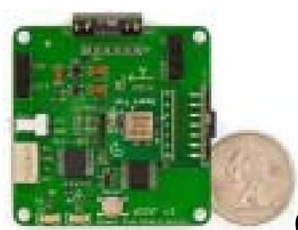
Table 1. Different accuracies in stand-alone and differential modes

Receiver Type	Observation Type	Stand-Alone	Differential mode
Mass-market Receiver	GPS L1 Pseudorange	15 – 20 m	4 – 5 m
Single Frequency Receiver	Full GPS L1	3 – 5 m	< 1 m

Geodetic Multi-Constellation Receiver	GPS L1+L2 (+L5) GLONASS Compass / Galileo	1 – 2 m	~ 1 cm (NRTK)

3. The Inertial Positioning

An Inertial Navigation System (INS) determines the position, velocity and attitude of a moving platform (aerial or terrestrial) through a processing of the accelerations and angular velocity measurements of an Inertial Measurement Unit (IMU), which consists of two orthogonal sensor triads, one with three accelerometers and the other with three gyros. Inertial positioning is therefore based on the simple principle that differences in position are determined by a double integration of acceleration, as a function of time, in a well-defined and stable coordinate frame, with an obtainable precision that can vary from centimeters to meters according to the type of application, the constructive technology and the entity of the contained errors inside the output signal.
In recent years, the construction technologies of civilian used inertial sensors can be divided into fiber-optic/laser/mechanical sensors (i.e. Fiber Optic Gyros, Ring Laser Gyros and Surface Acoustic Wave accelerometers) and solid-state Micro-Electro-Mechanical Sensors (MEMS). MEMS devices offer potentially significant cost, size, and weight advantages, which have resulted in a proliferation of the applications where such devices can be used in systems. Although there are many conventional military applications, there are also several newer applications that will emerge with the low cost and very small size that are inherent of such sensors, particularly at the lower performance end of the spectrum. In fact, MEMS sensors are also used in different application-fields, such as, for example, in digital cameras, mobile phones and videogame controllers.


(a)

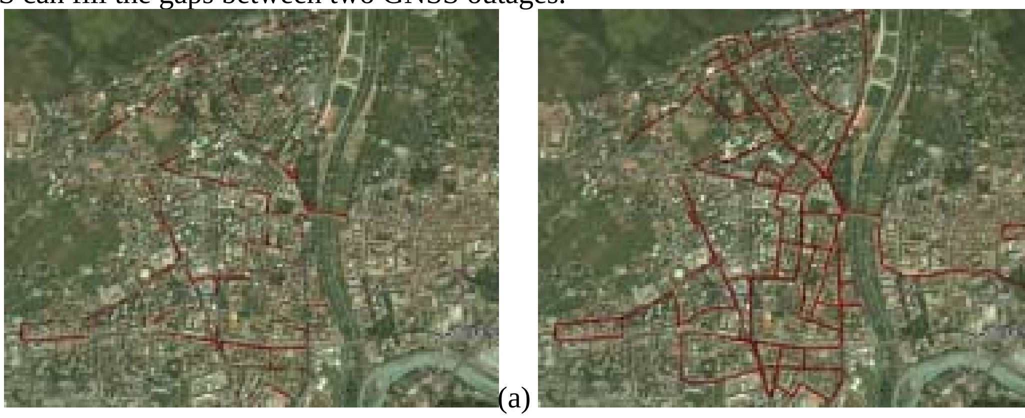

(b)


(c)

Fig. 2. (a) MEMS sensor with two bi-dimensional accelerometers and one gyro. (b-c) Examples of MEMS-based technologies: the Apple iPhone® and the Nintendo Wii®
(source: from the web)

Apart from the common applications, inertial sensors can also be used in different Geomatics fields. In fact, in the last few years, the search for this kind of solution in different environments (i.e. forestry roads, town centres and tunnels) has frequently looked at the use of inertial technology. The relatively low signal-to-noise ratio of the MEMS sensor measurement (especially for gyros) does not ensure an accurate computation of the attitude angles, which are necessary to give a precise determination of the position and attitude during motion and the evaluation of the parameters during navigation.

This aspect has allowed our research group to investigate different GNSS/INS integration algorithms within low cost devices. The complementary nature of GNSS and INS is well known. In fact, GNSS provides, in differential mode, absolute positions with decimetric or centimetric precision, but the GNSS signal is not always available, for example in the presence of tree-lined roads and urban canyons. On the other hand, inertial sensors provide a seamless solution at a high sampling rate (over 100 Hz), but with an accuracy that decreases in time due to the accumulation of systematic and accidental errors of which accelerometers and gyroscopes are affected. Therefore, GNSS can limit and correct INS long term errors, and INS can fill the gaps between two GNSS outages.



(a) (b)

Fig. 3. (a) GPS solution and (b) GPS/INS solution in the centre of Bolzano (Italy)

In order to evaluate the reliability of our GNSS/INS positioning system, and more generally of the low-cost GNSS/INS positioning, some tests have been performed in different environments, in the presence of obstacles that reduce the GNSS signal power. These tests were carried out in a non-urban environment near Biella and Morozzo (Piedmont, Italy), under open-sky conditions using up to three GNSS receivers and up to two MEMS sensors, at different velocities.

The following figure shows the trend of the three-dimensional error, in terms of GNSS cycle slip length, for a low-cost MEMS-based system, both for Kalman filtered and Kalman smoothed solutions. The first solution indicates the accuracy obtainable in real-time, while the smoothed solution is particularly recommended for post-processing applications. The thick lines indicate~~s~~ the average error over the GNSS outage, while the two pairs of dashed lines show the standard deviation of the solution.

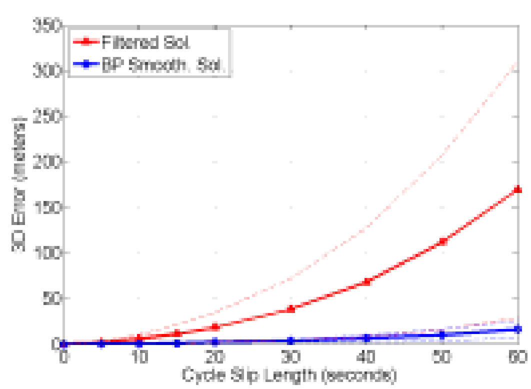


Fig. 4. 3D position error during the GNSS outages

4. The Multi-Sensor Systems

In recent years, multi-sensor navigation systems have undergone a remarkable development, both in aerial and terrestrial applications. These applications have taken advantage of the development and the modernization of satellite positioning technologies, such as network RTK positioning, and of the development of more efficient algorithms devoted to integrating different sensors both in real time and in post-processing.
The Geomatics research group at the Politecnico di Torino has designed and built a universal system for Mobile Mapping, called *LCMMS* (Low Cost Mobile Mapping System) with the aim of reducing the assembly and maintenance costs of the system. This system is made up of a metallic bar that can be used with any vehicle and which can hold up to three GNSS antennas and up to two inertial sensors. In addition, three high-resolution webcams (Logitech Quickcam Pro 9000, with a resolution of up to 2 Mpixel) are installed to detect the road details (i.e. lane markings and traffic signs). In order to produce a more accurate solution, all the level-arms between the sensors have been defined with a millimetric accuracy, and all the cameras have been calibrated both in static and in kinematic conditions.

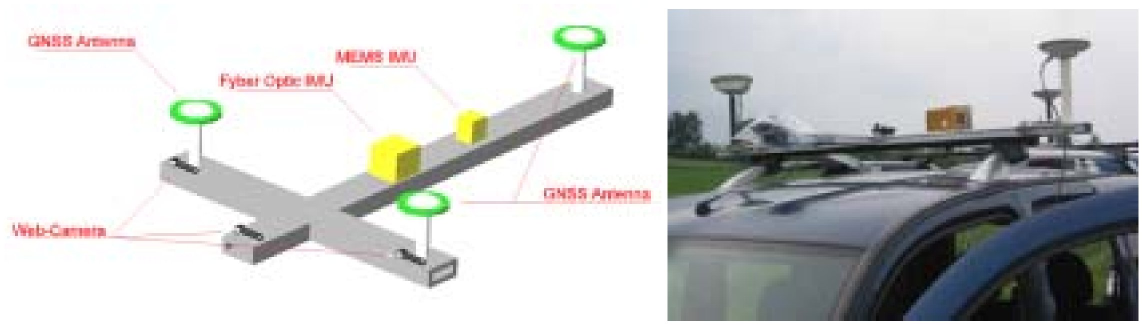


Fig. 5. The *LCMMS* layout

In alternative to MMV, it is possible to use an aerial system (AVS) that allows georeferencing metric and radiometric information to be acquired through different integrated sensors. The word "UAV" (Unmanned Aerial Vehicle) is well known in the research community, and in the last few years it has also become more and more used in everyday language. Scientific reviews, newspapers and magazines have published many articles about the potentiality and the applications of these systems, and surfing the Internet it is possible to consult almost three million websites related to this word. Many types of UAVs exist, each with different capabilities to respond to different user needs.
The Geomatics research group at the Politecnico di Torino, in cooperation with the ITHACA (Information Technology for Humanitarian Assistance, Cooperation and Action) association and the Department of Aerospace Engineering (DIASP) at the Politecnico di Torino, have developed a mini-UAV devoted to emergency management in the case of environmental disasters. ITHACA conducts an intense operational and research activity in the field of Geomatics for the analysis, evaluation and mitigation of damage caused by natural or anthropic catastrophes. Since 2006, ITHACA has been involved in many initiatives, in cooperation with the WFP (World Food Programme), the largest United Nations operational agency. Currently, the association produces basic and thematic maps for the monitoring and the assessment of areas subject to catastrophic events, mainly exploiting remote sensing techniques. Nevertheless, satellite images are usually unable to quickly acquire data relative to a catastrophic event, therefore in situ visits have to be foreseen, in order to acquire the data

required to plan emergency and food aid interventions. To this purpose a UAV, called "Pelican", has been developed. "Pelican" is a low-cost mini-UAV equipped with photogrammetric sensors which is capable of autonomous navigation (GPS/IMU) and automatic digital image acquisition (characterized by a suitable geometric and radiometric quality). The platform is easily transportable on normal aircraft and can be autonomously used in the field by a couple of operators. Currently, three different versions of the "Pelican" UAV have been manufactured: prototype version (Fig. 6), built in wood and two carbon fibre versions (Fig. 7).

The aeronautical specifications of the platform (

Table 2), the availability of a navigation system for autonomous flight (autopilot with GPS/IMU- GCS), and the features of the payload installed onboard (RICOH GR, a high resolution digital camera), allow the system to be employed for photogrammetric surveys. The UAV can follow flight tracks in a completely automatic way (excluding take-off and landing), according to flight plan specifications. Therefore, the "Pelican" UAV is able to perform photogrammetric surveys in remote and disaster-affected areas, where it is not possible to carry out traditional photogrammetric flights.

Fig. 6. ITHACA UAV 01 prototype

Table 2. Technical features of the ITHACA UAV
(based on the MH2000 UAV developed by the Politecnico di Torino – DIASP)

PROPULTION	DC (prototype/C.F.)	ICE (prototype/C.F.)
Wing span (m)	2	2
Wing surface (m^2)	2.1	2.1
Length (fuselage, m)	1.75	1.75
Width (fuselage, m)	1.43	1.43
Weight (body, g)	7500/8150	7500/8150
Fuel weight (g)	-	1000/1000
Payload capacity (g)	2500/2000	1500/1000
MTOW (g)	10000/10150	10000/10150
Flight envelope@sea level (m/s)	10-20	10-20
Cruise Altitude (m)	120	120
Cruise speed (m/s)	15	15
Optimum range limit	15 Km	25 Km
Optimum endurance limit (min)	30@15m/s	60@15m/s

(a)

(b)

Fig. 7. (a) ITHACA UAV - Carbon fibre, ICE engine version. (b) Carbon fibre, DC engine version

5. Digital Photogrammetry

The DITAG research team has developed a methodology for the photogrammetric processing of images acquired by the “Pelican” UAV . An automatic procedure for the stereoscopic acquisition of digital images has been carried out; furthermore, algorithms for the digital image processing, devoted to the production of Digital Surface Models (DSM) and Solid True Ortho-Photos (STOP) have been implemented and tested. First, a procedure for the analysis of the image acquisition phase was developed. Validation of the stereoscopic coverage and detection of shooting problems was carried out, according to the flight plan specifications. An in-depth research on the techniques developed in photogrammetry and Computer Vision communities was then performed, in order to define the state of the art in the automation of the digital image process. Hence, algorithms related to digital image pre-processing, automatic feature extraction and matching, automatic DSM generation and orthophoto production were implemented and tested.

The enhancement of the radiometric features of the raw images has been performed with a Wallis filter, with the aim of improving the dynamic range and the edge contrast of the image. The automatic extraction of homologous pairs for the generation of tie points was then performed by means of a technique that is widely used in Computer Vision applications, called Scale Invariant Feature Transformation (SIFT). SIFT is an image matching technique which allows the detection and matching of regions that do not vary under different geometric and radiometric transformations (illumination, scale, rotation, weak 3D viewpoint change). The algorithm was tested on aerial, close-range images and frames acquired by the “Pelican” UAV (Fig. 8).

Fig. 8. Features extracted by SIFT on a stereopair of the archeological ruins at Benevagienna (599 points)

The availability of the row attitude data supplied by the GPS/IMU sensors allowed the suitability of the Direct Georeferencing approach to be evaluated, in order to perform the aerial triangulation process. The Direct Georeferencing technique exploits the flight attitude data measured by the GPS/IMU system for the assessment of the external orientation parameters. This method is very useful for the photogrammetric processing of the images acquired by the "Pelican" UAV in remote or damaged areas, where in-situ topographical survey operations might not be possible. The suitability of the row attitude data provided by the "Pelican" navigation system is related to the accuracy of the GPS or DGPS. Experimental tests have shown the good accuracy of DGPS, which assures the estimation of the approximate unknowns of the aerial triangulation.
The DSM generation was performed implementing a robust and reliable technique. The method, called Multi-Image Geometrical Constraint Cross-Correlation (MIGC3), exploits a multi-image and auto-adaptive approach for the image matching. It was developed by the ETH research team in Zurich as part of a project focused on DSM generation from linear array images. In this work the aforementioned algorithm was adapted to process close-range frame images, such as those acquired by the "Pelican" UAV. However raw DSMs produced with image correlation techniques are usually affected by gross errors, due to geometric and radiometric distortions of the stereoscopic pairs. A method for automatic blunder detection has therefore been developed and implemented. The algorithm is called Self-tuning Standard deviation Median Filter (S2MF) and can detect gross errors using a robust and auto-adaptive approach. The final product of the photogrammetric process is the Solid True Orthophoto (STOP). STOP supplies not only the geometric and radiometric information of a classical orthophoto, but also the altimetric data provided by the DSM. An efficient and user-friendly web-based tool for STOP production and visualization has been developed by the Geomatics research group at the Politecnico di Torino. It can be installed in low-cost notebooks and it allows the investigated areas to be examined by means of measurements of 3D points, distances, areas and volumes. Therefore, STOP can be suitable for the rapid assessment of natural and manmade hazards in remote areas, according to the goal of the Early Impact project headed by ITHACA.

The photogrammetric procedure has been tested on aerial images acquired by using the "Pelican" UAV over the archaeological site of Benevagienna (Italy). Two photogrammetric flights, at about 100 m of altitude (GSD = 0.04 m), allowed the STOP of the theatre and amphitheatre ruins (Fig. 9) to be produced at a 1:500 nominal scale. The experimental results confirm the suitability of the UAV technology for the quick production of maps for emergency management applications, in accordance with the goals of the ITHACA association.

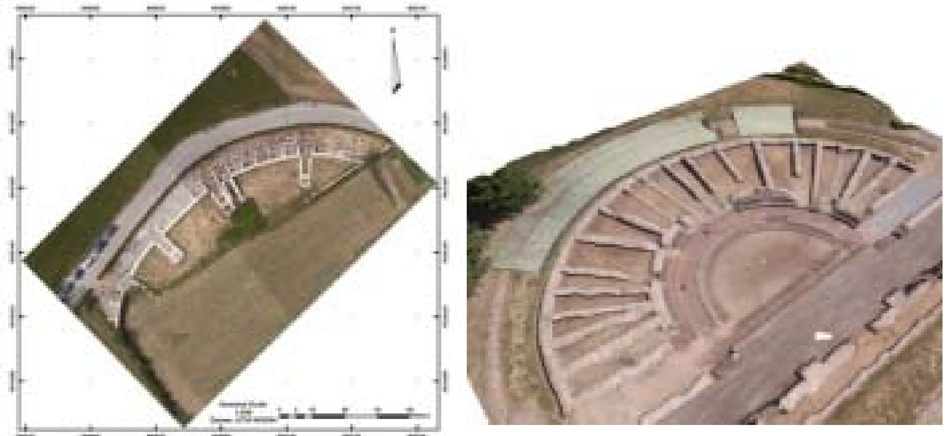


Fig. 9. The STOPs of the amphitheatre and theatre area (left) and the 3D model (right)

6. LIDAR and Photogrammetry integration for the Architectural Survey

In recent years, LIDAR and image matching techniques have achieved good results in many applications, because of their speed and accuracy in point cloud generation. Nevertheless, neither technique assures complete and reliable results, especially in complex applications such as architectural and cultural heritage surveys: laser scanning techniques have non-negligible drawbacks due to the impossibility of directly obtaining radiometric information and the exact position of the object breaklines; on the other hand, image matching techniques cannot assure that a point cloud is achieved without blunders in all conditions and are not able to guarantee good results in bad-textured areas. Furthermore, once the point cloud has been acquired, several automated and manual interventions have to be applied in order to segment, classify and model the surveyed points. These problems have limited the improvement of these instruments in architectural surveying. Several authors have already suggested how to overcome these problems through a combined use of LIDAR data and image information to obtain highly versatile systems and new application potential. In this way, new integration solutions between photogrammetry and LIDAR techniques have been investigated. Several papers have considered this integration as a possibility of sharing the point clouds generated by these two kinds of instruments. Only a few papers have described this integration considering it as a sharing of radiometric and ranging information. These works, however, only consider single images and the extraction of information is performed manually; a complete and automatic integration between laser scanner acquisitions and multi-image matching techniques has never been implemented. On the basis of these works, a new integration approach has been proposed by the Research Group at the Politecnico di Torino. In this approach, LIDAR and photogrammetric techniques continuously share information in order to complete point cloud information and extract building breaklines in the space and to ease the segmentation and the modelling. In order to do this, multi-image matching techniques and point cloud segmentation have been merged; these techniques work independently and the shared information is used as feedback to perform matching and segmentation algorithms in a more reliable way. The proposed algorithm can be divided into several steps, according to the workflow shown in Fig. 10.

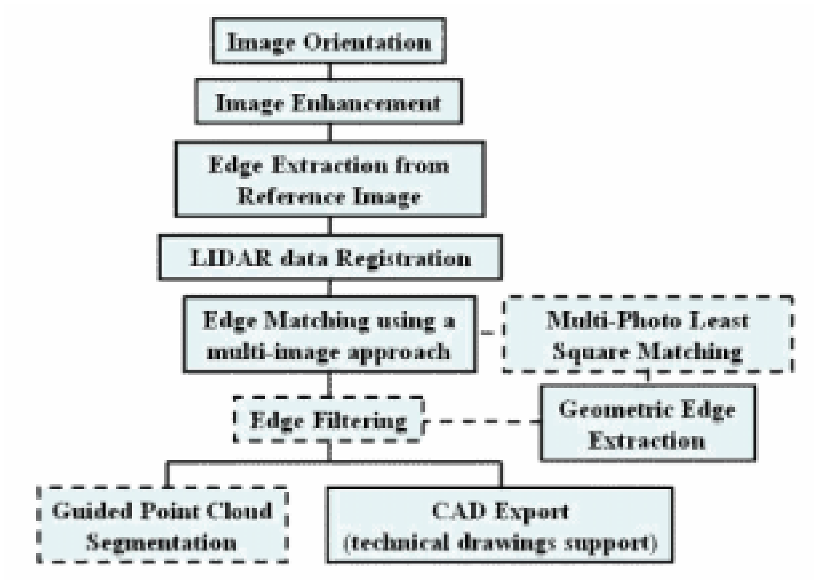


Fig. 10. Algorithm scheme (dashed blocks are under development)

The algorithm has been completely implemented in a *Matlab* code: the computation time was not assessed during the performed tests. The algorithm is still being studied; most of the steps have been fully implemented, but some still have to be improved and they will be tested in more detail in the next few months (see Fig. 10).

An example of the achieved results was produced in a test which was performed on the calibration field in the Photogrammetry Laboratory at the Politecnico di Torino. This test was performed using a *Riegl LMS-420* laser scanner for the point acquisition and a *Canon EOS-5D* camera for the image acquisition: it was performed in order to evaluate the geometric accuracy in the edge extraction and the reliability of the algorithm in the presence of a repetitive patterns. A 0.030 gon scan resolution point cloud and 5 images were considered in the multi-image matching algorithm. The point of view of the reference image was approximately the same as the scan position in order to have the same occluded areas in the LIDAR and image acquisitions. The other 4 images were acquired on both sides of the reference one and at different heights; the taking distance was on average 7 m and the base from the reference image to the other images was between 1.2 and 2 m.

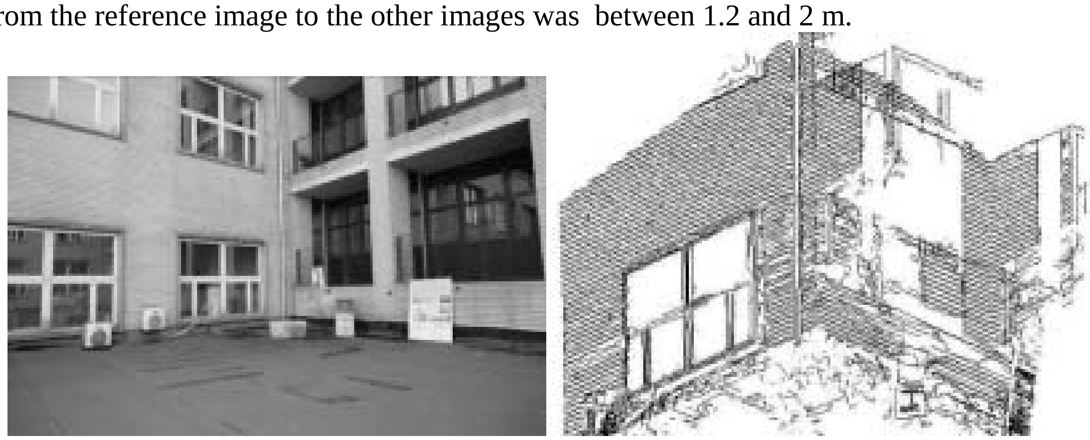


Fig. 11. Reference image (left) and matched edges exported in 3D CAD (right)

The images were taken in an unusual convergent position in order to guarantee a good configuration in the matching process.
In general, the achieved results have shown that the percentage of mismatches is low; furthermore the mismatches were concentrated in correspondence to the basements. The mismatches on glass, due to glass reflection, were avoided, by ignoring the windows in all the images. Some elements of the façade, such as the banister, were not completely represented, because of their small dimensions and their repetitive pattern. The edges in correspondence to the repetitive patterns on the walls were almost completely matched, while the percentage decreased slightly for the window frames, because of the proximity of the window areas. Nevertheless, the completeness of the extracted edges is high: the percentage of matched edges, on the façade, was approximately 92%.
Finally, a comparison between the manual photogrammetric plotting (using 2 images acquired by a *Rollei 6008* in normal conditions) and the matched edges was made in order to compare the achieved accuracy. The test results show that the edges have been extracted with centimetre accuracy. The extracted edges can give preliminary data for the graphic drawing of the survey; in addition, the LIDAR point cloud can be segmented using a region growing algorithm and by constraining the segmentation process from crossing the geometric edges. In other words, the edges represent the boundaries of each element of the façade.

Conclusions

In this contribution, the Geomatics research activities developed at the Politecnico di Torino have been generally described, in particular the main attention was focused on the possible integration of sensors. The novel frontier is the integrated use of different sensors which acquire three-dimensional data in order to obtain a more complete spatial information, overcoming the limits of each technique of acquisition.
Nowadays, Geomatics principle are commonly used in different fields (i.e. agriculture, civil service); the purpose of Geomatics research is also to realize systems, algorithms and software which are able to increase the number of users, to improve the interest of people who needs to acquire spatial information and to consider the contribute of the new technologies.

The Geomatics research group is working on the use of low cost sensors (i.e. digital camera, IMU, GNSS single frequency) into integrated mobile mapping systems, developing dedicated hardware and software.

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