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THE MAIN IMAGING ISSUES IN THE REALM OF MMS

As principais Questões Referentes às Imagens no Contexto dos SMM

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ABSTRACT

Mobile mapping is a method of acquisition of geo-referenced images that uses a moving platform in which sensors and other devices are set on board. Although the mobile mapping systems (MMS) were built to map roads they were extended to streets, railroads, waterways, environmental areas, and recently entered the buildings, concerning the land-based domain. More recently, MMS concepts were successfully implemented in unmanned aerial vehicles to fly safely. Mobile mapping technology requires measuring, processing and analysis of distinct data types: time, phase, range, force, angular rate, and distance, that provide position, velocity, and attitude (PVA) of one or more image sensors (cameras and LIDAR), which lead to geo-referenced images. The article brings a brief description, evolution, and technologic advances of the method and it also shows the main application branches. The mobile devices, the growing image sensor resolution, the low cost inertial sensors, and the computer performance of the 64-bit processors indicate that this methodology has potential for new applications. These new possibilities demand portability, mobility, and accessibility to sites where PVA have to be estimated by non satellite navigation methods. Image sensors, namely digital cameras and lidar devices, effectively materialize the process of visualization, measurement, recognition, and mapping 3D objects.

Keywords: Mobile Mapping System, Active and Passive Imaging, 3D Modeling, Visualization of Geospatial Data, Production of Geo-information.

RESUMO

O mapeamento móvel é um método de aquisição de imagens georreferenciadas que usa uma plataforma móvel, na qual sensores e outros dispositivos são embarcados. Embora os sistemas móveis de mapeamento (SMM) tenham sido construídos originalmente para mapear rodovias, eles foram estendidos para ruas, ferrovias, hidrovias e áreas de interesse ambiental, e recentemente adentraram edifícios, considerado o âmbito terrestre. Mais recentemente, o conceito de SMM foi implementado nos veículos aéreos não tripulados para voar com êxito e segurança. A tecnologia do mapeamento móvel requer medições, processamento e análises de distintos tipos de dados: tempo, fase, extensão (distância), força específica, variação da velocidade angular, que proporcionam posição, velocidade e atitude (PVA) de um ou mais sensores de imagem (câmeras e lidar), que levam às imagens georreferenciadas. O artigo traz uma breve descrição, evolução e avanços tecnológicos do método e também apresenta os principais ramos de aplicação. Os dispositivos móveis, a crescente resolução do sensor de imagem, os sensores inerciais de baixo custo, e o desempenho dos computadores de 64 bits indicam que esta metodologia tem potencial para novas aplicações. Estas novas possibilidades demandam portabilidade, mobilidade e acessibilidade a lugares onde PVA tem que ser estimadas por métodos que não se baseiam em satélites. Sensores de imagens, a saber câmeras digitais e sistemas lidar, efetivamente materializam o processo de visualização, medição, reconhecimento e mapeamento de objetos tridimensionais.

Palavras chaves: Sistema Móvel de Mapeamento, Imageamento Ativo e Passivo, Modelagem 3D, Visualização de Dados Geoespaciais, Produção da Geoinformação.

1. THE MOBILE MAPPING SYSTEMS CONCEPT

Mobile mapping systems (MMS) were introduced to the mapping and geospatial communities in the nineties. Its technology appeared when digital video cameras and navigation sensors were embarked and integrated on a moving vehicle. The vehicle´s trajectory and the exterior orientation parameters (EOP) of the cameras with respect to a fix reference system is determined from the data acquired by the navigation sensors, such as GPS (Global Positioning System) and INS (Inertial Navigation System). Bossler et al. (1991) built the first MMS when they mounted one GPS receiver and a pair of video cameras on the roof of a van to specifically map roads (Fig. 1).

Currently there are dozens of MMS built with distinct configuration of sensors. The general concept of a MMS is characterizes by a moving platform that carries a GNSS (Global Navigation Satellite System) receiver and its respective antenna, inertial measurement unit – IMU, digital video cameras (charge coupled device – CCD, and complementary metal-oxide semiconductor – CMOS) and LIDAR (light detection and ranging, i.e. lidar in this article). There also are auxiliary sensors (odometer, barometer and magnetometer), that are related to a simple navigation method by estimation named dead reckoning - DR.

Fig. 1 - GPSVan in 1991 (NOVAK, 1995).

In the beginning the mobile platform was a self-propelled land vehicle (car, truck, tractor or motorcycle). The necessity and creativity took MMS onto trains, boats and pedestrians, so that wherever the human presence is possible equipped with positioning and imaging sensors we are making mobile mapping (Fig. 2).

This technology is also set to aircrafts with the purpose of determining the spatial orientation of light sensors (cameras and lidar) – method known as direct geo-referencing (DGR). Unmanned aerial vehicles (UAV) and terrestrial robots are technological machines that integrate different types of sensors for mapping purposes and many other applications. Figure 3 illustrates the DGR in land-based mobile case: the coordinates of P with respect to an external referential system (ERS) are determined after processing the position and orientation data of the cameras which are given by inertial and satellite navigation data.

The definition of MMS according to two exponential researchers which observed the very beginning of this technology enriches this introduction: “Mobile mapping systems can be defined as moving platforms which integrates a set of imaging sensors and a position and orientation system (POS) for the collection of geo-spatial information” (HABIB et al, 2011), and “A mobile

Fig. 2 - Special applications: left - KUKKO et al, 2010) right - GONÇALVES et al, 2009.

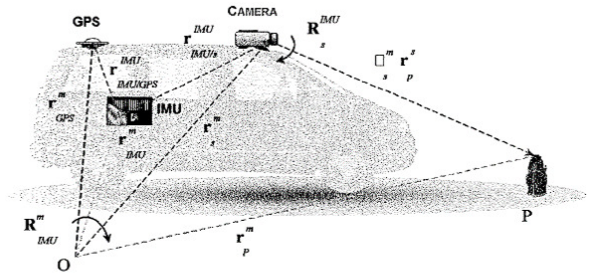

Fig. 3 - Connections of referential systems of the mobile mapping sensors (ELLUM; EL-SHEIMY, 2002).

mapping system can be defined as a kinematic platform, upon which multiple sensors have been integrated and synchronized to a common time base, to provide three-dimensional near-continuous and automatic positioning of both the platform and simultaneously collected geo-spatial data" (GREJNER-BRZEZINSKA, 2001).

The acclaimed advantages of mobile mapping are speed, safety and the ability to map places that are difficult to access using stationary equipment. MMS are capable of fast unlimited acquisition of geospatial data with required detail and accuracy. The richness of details is emblazoned in megapixels of image sequences, which is already more than enough for visual analysis. The resolution, however, tends to grow, so it demands more of the digital processing techniques. The storage is already possible in terabytes. These images are geo-referenced either in real time and post processing. For mapping and visualization purposes, post processed data generate spatial information that meet the requirements of (sub)metric accuracy according to the GNSS/INS/DR integration settings.

The visual and manual methods do not offer the range of possibilities that digital methods do at any stage of the production process of geographical information acquisition, storage, retrieval, processing, analysis and use. Within and between different sectors of an organization geo-information electronic flow offers advantages and it practically is a requirement to be up to date with the technological paradigm given by the informational level of today society. The mobile mapping can be inserted in the areas in which the geo-information is part of the production process that depends on the intensive use of the road system, for example. The steps of operational management, planning, design, emergency response, safety oversight, management, analysis and decision making are enhanced with this type of visual geographic information that can be integrated into geographic information systems.

This brief review approaches the main components and applications of the mobile mapping technology (MMT) and it brings the relevant scientific and technologic issues mainly related to imaging sensors and data. Processing imaging data to derive or extract geospatial information still has issues and problems to be overcome so they can be fully used to complete the goals of MMS.

2. THE MAIN MMS DATA ACQUISITION COMPONENTS

MMS are composed of three principle types of sensors: originally the Global Positioning System (GPS) receivers, then Global Navigation Satellite System (GNSS); an Inertial Navigation System (INS), based on Inertial Measurement Units (IMU); and imaging sensors, initially digital video cameras, then lidar devices were added. We can introduce a fourth type of auxiliary sensors such as odometers, magnetometers, and barometers. Each type of sensor is in fact a subsystem that functions independently of each other.

2.1 Positioning and Navigation

Most of the contemporary terrestrial MMS use tactical or navigation grade IMU (COLOMINA; PARES, 2012) to determine the approximated angular exterior orientation parameters of matrix (camera) images. Navigation grade IMU, usually integrated with GNSS receivers, are also used to determine the projection center coordinates, particularly when the satellites signals are not received properly by the moving antenna for instance in urban corridors or when passing through tunnels. The high costs associated to these superior systems restrict them to the big companies and the main government agencies and consequently their services and products are expensive to a common user.

Researchers have promoted the use of low-cost attitude and heading reference system (AHRS) and/or low-cost IMU to satisfy the demands of certain photogrammetric applications. Low cost devices are suitable for constructing small low-cost photogrammetric-based MMS. This brings these systems to the common application world that means to the needs of the great majority of users. Two low-cost devices, providing information about image attitude and heading, were tested recently and we mention them as examples (KOLECKI; KURAS, 2011). The first one was a calibrated camera equipped with GPS, an electronic compass and a level indicator. The second device was a unit with AHRS, comprising 3 MEMS (micro-electro-mechanical systems) gyros, 3 MEMS accelerometers and 3 magnetometers; a calibrated SLR (Single Lens Reflex) camera completed the system.

2.2 Image Sensors

As one of the basic sensors of the original MMS prototype (BOSSLER et al, 1991), digital cameras are still taking the major role to acquire road and ground images for stereo measurements, fusion with laser point clouds, texture extraction for 3D modeling, ortho-image generation, and site scene view. Mounted on a roof of a vehicle, initially a pair of cameras pointed forward to acquire frontal images of a road (Fig. 1). A variant of such arrangement had the axes pitched to the road pavement. Then several cameras were mounted to all directions – front, rear, and side views – so that a panoramic coverture of the scene can be made (Fig. 4).

Over the last decade, the omni-directional cameras have been added to many MMS to collect panoramic images. These cameras can record much visual information of the real environment in one image since it covers a field view angle of 360° in azimuth direction and 180° in zenith direction. Algorithms correct the severe geometric distortions of panoramic images so that 3D close range photogrammetry can be fused with 3D laser point clouds.

Fig. 4 - All direction MMS (PASCO, 2013).

2.3 Auxiliary Sensors

Odometers, magnetometers and barometers in fact are not mandatory to be part of a MMS. The covered distances measured by odometers and the heading directions sensed by magnetometers may give linear and angular information of a body system along the track. The pressure variation is transformed into elevation variation of the same body system. These auxiliary devices are low cost sensors that may complete a MMS for the purpose of helping trajectory control and analysis.

3. MMS METHODOLOGY

DGR is a primary factor for the total orientation of digital images. Both the camera and sensor LIDAR have their own internal reference systems. These must be completely oriented (reference center position and the coordinate axes attitude) with respect to an ERS. In open areas with wide visibility of the sky, the satellite signals reach the antennas of the GNSS receivers that continuously (1 Hz) save the three dimensional geocentric coordinates. In urban environments, notably where buildings are concentrated, multi-paths deteriorate significantly the quality of the coordinate estimates.

The solution found was the insertion of inertial navigation technology in the system. An IMU is an instrument with built-in accelerometers and gyroscopes arranged over the three coordinate axes that effectively measure the changes in the state of inertia of a rigid body. The accelerometers measure the specific force and the gyros sense changes in angular velocity, both at frequencies of up 400 Hz. The fundamental system of inertial navigation is formed by three differential equations: the first derivative of position with respect to time (w.r.t.t.) equaled the speed; the first derivative of speed w.r.t.t. matched to an expression of the specific force and angular velocity variation; the first derivative of the rigid body rotation matrix w.r.t. the ECEF (Earth Centered, Earth Fixed), considering the angular velocity variation (SCHWARZ; WEI, 1995).

The numerical solution is the Kalman filter (KF) to integrate GNSS and inertial data into a single solution (prediction, filtering and smoothing) for each time interval, resulting in PVA (position, velocity and attitude). This solution can be weak (loosely) or strong (tightly), as the observations (specific force and angular speed variation) are processed separately or together in the filter (LIMA, 2005).

PVA is a solution for navigation. Position (P) and attitude (A) are enough when it comes to mapping,. Essentially, KF is an algorithm for real-time solutions. A post-processed KF solution is sufficient for mapping. There are variations like the EKF (Extended Kalman Filter) that includes differential equations with calibration parameters of inertial sensors (accelerometers and gyroscopes): trend (bias), drift, scale factor (linear and nonlinear), axes misalignment, and noise (SANTANA, 2011).

The integration of the navigation sensors among themselves and also with the image sensors requires synchronization, that is, the measurements must have the same time basis. Easy to understand but difficult to implement, it needs synchronization systems. The integrated solution requires that all sensors must have their respective centers referenced to a common referential system, which can be expressed by distance vectors between them. Colomina; Pares (2012), among others, offer more details of the methodology.

Such set of distinct sensors rise the costs to build a system. Low cost sensors are an alternative way to build low cost land-based MMS (LBMMS) which can make them available to a growing number of users at an affordable cost. MEMS have appeared in the last decade to provide devices to sense the inertial observations at reasonable prices so that instead of only one device the researchers have been preconizing an assemble of redundant MEMS (COLOMINA et al, 2004).

In MMS the image sensors must have their EOP completely known so we can compute 3D coordinates for a spatial feature from the image measurements. EOP of image sensors are determined by the KF algorithm with the integrated navigation data. The image based modeling of an object has been defined as a complete process that starts with image acquisition and ends with an interactive 3D virtual model. The photogrammetric approach to create 3D models involves image pre-processing, camera calibration, orientation of images network, image scanning for point detection, surface measurement and point triangulation, blunder detection and statistical filtering, mesh generation and texturing, visualization and analysis (JAZAYERE; FRASER (2008).

For high accuracy of 3D objects reconstruction operators are required as a preliminary step in the surface measurement process to find the features that serve as suitable points when matching across multiple images. Operators are the algorithms which detect the features of interest in an image, such as corners, edges or regions. (ZAWIESKA, 2012)

4. APPLICATIONS OF MMS

When it comes to visualize a scene or a local of public interest and to evaluate a tri-dimensional object from the measurements made on close range images, either for the purpose of recognition or mapping, we are in the realm of MMT applications. Professional applications are found among situational awareness, inventory of public areas, real estate valuation, assessment of permits and inspecting security risks.

Detection and 3D localization of various objects imaged by digital cameras of a MMS has become an efficient tool in mapping applications especially to construct large scale visual street-level image database. Small or huge databases have been demanded either by local users or by the internet giants. Both need visual and geo-referenced spatial data to support their needs and decisions.

The notable improvements on performance and the lower costs of high resolution digital cameras and GNSS/IMU devices have gradually caused MMS to become one of the most important technologies for mapping highway and railway networks, generating and updating road navigation data and constructing urban 3D models. The growing interest on MMS has been motivated by the high demand for a fast and cost-effective 3D data acquisition method. Cost-effectiveness (time and money) has been provided by technological developments in navigation, digital imaging sensors and laser scanners, especially when one considers the elapsed time to acquire data, particularly road and/or street geo-referenced images.

Considering MMS earlier times, most applications were for ways and their surroundings, where the mobile platform can get around, such as streets, roads, railroads, and waterways. Recently, passages, corridors and indoor environments have been covered by humans and robots carrying a portable MMS to acquire data for topographic mapping and three-dimensional visualization. The path was dominantly along the track linear (EL-SHEIMY, 2009). The mobile technology has been extended to environmental applications related to a surface coverage, such as beaches, water bodies and forests, for example, including their surrounding morphology, and fluvial bathymetry (KUKKO et al., 2010); the snow cover, obviously in regions where the amount of snow is significant; monitoring coastal areas after storms to check erosion and possible morphological changes in the dunes (GONÇALVES et al., 2009); and verification of firebreaks in the reforested areas. Urban and rural areas damaged by earthquakes are also retrieved, either in emergency or in reconstruction tasks, with the support of mobile mapping (SHAO et al., 2009). Fig. 2 and Fig. 5 illustrate some of these applications.

However, the dominant applications are demanded in transport routes and their surroundings for the following purposes: topographic mapping and cadastral inventory (assets), utilities (water, sanitation, energy, data and voice communications), support the engineering projects (transport, urban infrastructure and railway station, security, surveillance and monitoring of construction works – as built, among others), architecture and urbanism (thermal and acoustic comfort, aesthetics) and environment. Geometric modeling and mapping of highways (KARAMANOU et al., 2010) and railways (WU et al., 2009), based on the determination of the central axis, tunnels, overpasses, bridges etc., safety and signaling equipment, total visualization, panoramic and vertical (FANG et al., 2009), are contributions to supervise, monitor and manage the entire infrastructure of a road and train network.

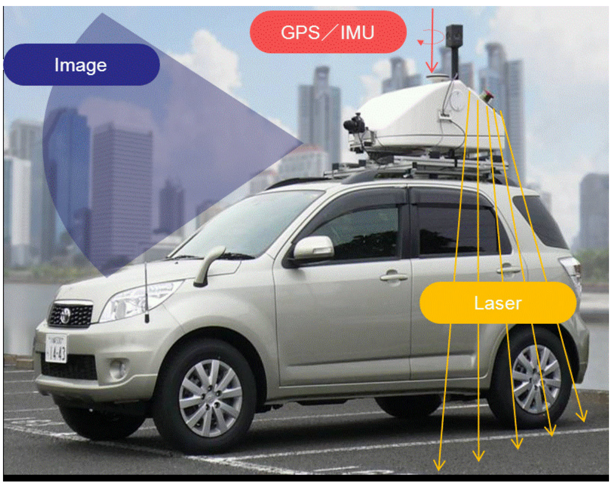

Fig. 5 - MMS used to assess Sendai tsunami damage (SPARPOINTGROUP, 2013).

In the last two decades, the applications have grown from the center line and the road boundary lines using processing methods of image sequences (BOSSLER; TOTH, 1996) for the mapping of highways and research on autonomous vehicle navigation to the latest uses in the fields of virtual reality, 3D visualization, 3D modeling of urban environment and its roads and railways scenario (SCHALL et al., 2010). The demand for 3D models is continuously increasing in fields as cultural heritage, computer graphics, robotics and many others. The number and types of 3D features are highly dependent on the use of the 3D models and can vary in terms of accuracy and time for their creation.

Both computer vision and photogrammetric communities have approached the reconstruction problems by using different methods to solve the same tasks, such as camera calibration, orientation, object reconstruction and modeling. Although the terminology which is used for addressing a particular task in both disciplines is sometimes diverse, on the other hand, the integration of methods and algorithms coming from them can be used to improve both. For instance, the development of the feature extraction and image measurement process is central to the automation procedure for high accuracy point cloud generation in multi image networks. Robust orientation is a prerequisite for 3D point determination and surface measurement and modeling within a single software system. A multi-image matching of close-range photographs for automation of 3D photorealistic reconstruction in virtual city modeling is another has been practiced.

As an example that MMS is already a mature technology a commercial system was tested on highway and streets (SUKUP; SUKUP, 2010). Where traditionally single points were selected and measured, the MMT registers massive amounts of detailed points. The MMS, equipped only with laser scanners, collected countless points which document interest areas. Combined with spherical images, a virtual reality of the surrounding scene was constructed – an achievement difficult to realize for a person in the field, especially in streets during rush hours. The acquired data was rich in information which was extracted conveniently in the office – either visually or with programs designed for specific purposes. Terrestrial lidar and photogrammetric techniques are effective methods of acquiring environmental data and of integrating them in digital products. These techniques have shown effectiveness when the area of interest is limited.

The results demonstrate that fast and extensive applications of lidar techniques using mobile mapping vehicles can be done in a short time (a day of surveying for 6 km of road) to obtain a set of geospatial information to effectively describe roads and their surroundings (buildings, rock faces, etc.). The use of several low cost sensors allowed the acquisition of a large number of observations (positions, attitudes, etc.). Combining these measurements, the required accuracy could be achieved. Lidar data can be geo-referenced directly, showing the presence of several useful three-dimensional data regarding rock faces (DE AGOSTINO et al 2012).

There are many potential and possible applications. Millions of vehicles carrying people and cargo move daily so that traffic security is an issue of the highest importance. Unfortunately road accidents do happen. A road accident is an event in traffic routes with some damage to people and/or property. MMS can effectively contribute to road safety (CHAVES, 2012; SILVA et al 2012). From road accident reports on major highways of the Brazilian country (BRASIL, 2011a; 2011b), it is possible to build a geographic information system (GIS) which of course will have three-dimensional geometric and statistical data, geographic accidents snippets, and the scene and cartographic visualization. The safety conditions of a road can be analyzed considering its accesses and crosses, interferences and supporting areas, and the pavement quality and traffic signalizing. All these features can be mapped and monitored to help traffic managers to make decisions for comfort and safety of users.

Considering the high numbers of road accidents in Brazil, this technologic application tends to have significant educational and social benefit. Five key variables can be analyzed individually or together: the road geometry (WANG et al., 2007), the pavement conditions, the driver, vehicle and environmental conditions, namely rain, sun, wind, dust, smoke, temperature etc. (FERRAZ et al., 2008). Figure 6 shows an example of streets and their corresponding pavement conditions for visualizations purpose.

Other potential use of this technology regards on the regulatory framework of the Brazilian electricity sector which requires that all assets of the electric power utilities must be registered in a regulatory geographic information system regulatory, the so-called SIG-R (ANEEL, 2012). It is speculated whether the assets along the urban and rural roads and highways can be surveyed and identified with the use of vehicular and pedestrian mobile mapping (Fig. 7). Google Street View images are not good enough for accuracy metric purposes. However, they excel for visualization which is their main purpose and this helps a lot for planning for instance (CRUZ, 2012).

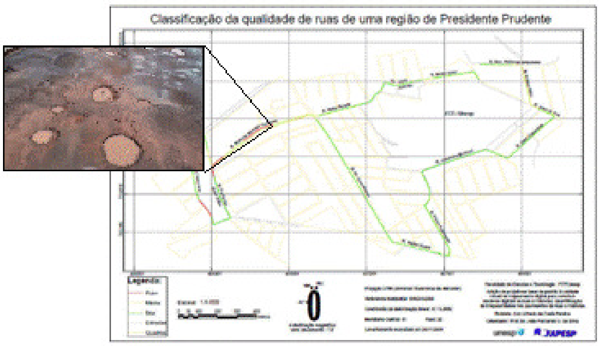

Fig. 6 - Street map (reduced) and the pavement condition for visualization purpose (PEREIRA et al., 2010).

5. RELEVANT IMAGING ISSUES IN MMS

Although MMT has reached a status to support commercial MMS ready to produce reliable spatial information, there still are issues that challenge the researchers. They are related to new low cost sensors, multi-sensor calibration, calibration and use of range cameras, epipolar geometry and feature extraction from panoramic images, lidar and photogrammetric point clouds, image-based navigation, automated reconstruction, integration of the distinct phases of the whole MMS process, integration of UAV data to LBMMS for civilian applications, road and urban image database, visualization of the 3D geo-referenced information, and so forth. Some of them are discussed below.

5.1 Calibration

Every measuring system needs to be periodically calibrated. Individual cameras either non metric or photogrammetric have been calibrated especially with analytic methods since the strongest contribution made by Duane Brown (BROWN, 1971). Other methods based on orthogonal polynomials have been used (TANG et al, 2012). One or more cameras can have their internal and relative orientation parameters (ROP) estimated by a self-calibration procedure based on a bundle block adjustment (BBA) with additional parameters.

Particularly, in the realm of MMT, pairs of cameras are set up together with other sensors as already described. Then multi-sensor calibration methods have been researched in the last decade either for traditional matrix cameras or the panoramic cameras (CANNELLE et al, 2012). Left alone, the sensors would all record independent measurements in separate reference frames that would be of no use for real mapping. Hence the need for a multi-sensor calibration, defined here as the process of determining the translational and rotational offsets between the sensors, to bring all sensor data into the same reference frame.

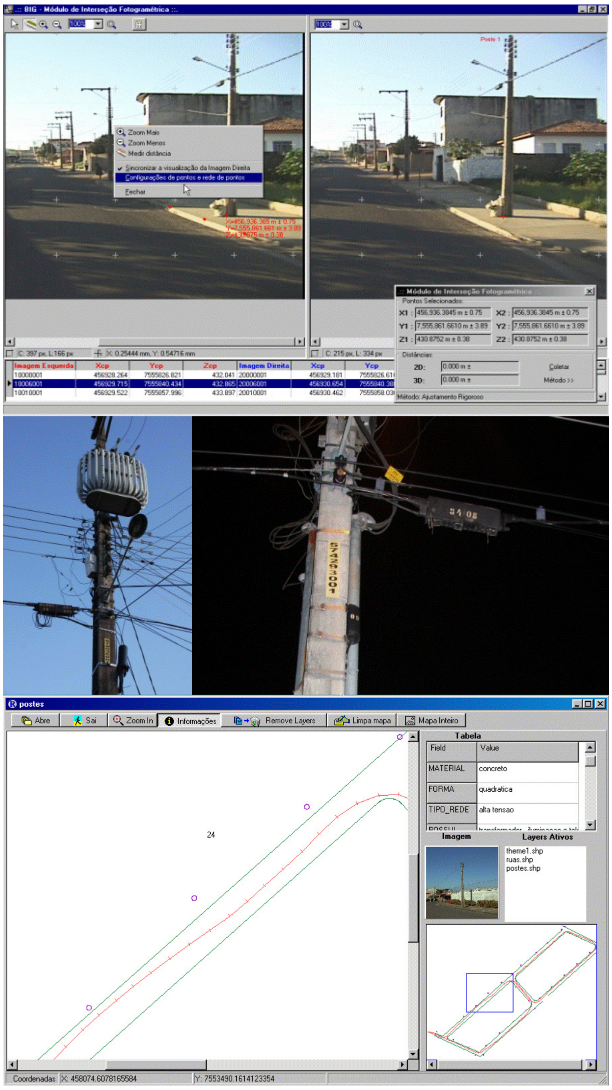

Fig. 7 - Up: photogrammetric intersection to determine the topographic position and the height of an electricity pole (OLIVEIRA et al., 2003). Middle: images of electricity poles, day and night, with details of assets (CRUZ, 2012). Low: Map of light-poles in urban streets (SANTOS et al., 2003).

Crawford (2012) recommends that the inter-relationships among the sensors should be determined in two steps through the use of contemporary surveying and photogrammetric techniques. First, the position of all sensors will be precisely surveyed to determine with high accuracy the position of the sensor where data is recorded. Since the positions of these sensors are measured in the same coordinate system, they can be related to a common sensor, the INS in this case, through translation and rotation with respect to the data recording point of the INS and the INS body axes.

Secondly, photogrammetric techniques can be applied to determine the translational offsets needed to relate the surveyed center of each camera to the camera perspective center and the rotational offsets needed to relate the camera frame to the INS body frame. Additionally, the estimation of the ROP among the cameras, i.e., the inter-camera geometric relationship (lever-arm offsets and boresight angles among the cameras) can be computed for each pair of stereo cameras (front, side, back), allowing for the creation of a stereo model by the extraction of three-dimensional information from the overlapping fields of view of these cameras. In determining sensor inter-relationships it is important to retain a high accuracy standard on the survey, as all relationships are determined based on the initial survey results of the sensors and ground control points. Failure to maintain a high accuracy will directly result in an incorrect alignment and orientation between sensors.

This, in turn, can result in the extraction of incorrect geo-spatial and navigation information if image-to-image matching is used for navigation. It is, therefore, important to ensure that the highest level of accuracy is obtained, which is accomplished through choosing an appropriate level of precision, following good surveying practices, and performing checks on measurements to detect and remove errors.

Camera resection is a major source of errors entering into the measurement process. Errors could enter this step during the selection of ground control points in each image. Therefore, the best results are only obtainable if the center of a rivet fixed on a wall is visible when recording the pixel coordinates of that point. Furthermore, the best measurements can only be made if the rivet is fully visible in the image, which requires more than a small portion protruding from a wall to be seen.

A final consideration with selecting control points relates to the pixel size, as this will determine the smallest discernible measurement in the image. The pixel size in all images is small enough to represent all rivets as multiple pixels but the center of the rivet may not necessarily be the center pixel representing the object. For instance, the method used to measure the pixel coordinates of a selected point can be based on the upper left corner of the pixel and so be able to determine pixel position on a sub-pixel precision level. Such precision has made possible a more accurate determination of the rivet centers and helped to ensure a high accuracy standard for determining the inter-relationships between the cameras and INS.

Habib et al (2011), however, introduces a method to allow for a single-step estimation of two sets of ROP, i.e. the ROP among the cameras (when GNSS/INS is not available) or the ROP among the cameras and the IMU body frame. The author claims that experimental results using simulated data have demonstrated that the proposed single-step procedure provides improved results in the precision of the estimated ROP as well as in the object space reconstruction when compared to the two-step procedure. The reason is that the single procedure provides more accurate results for the ROPs among the cameras due to the fact that the relative orientation constraint is explicitly enforced.

There have also been development of methods to calibrate magnetometers, digital compass, AHRS, barometers etc. The results prove the usefulness of the low cost auxiliary devices or sensors for constructing a small hand-held MMS. Their measurements can be treated as approximations in the photogrammetric BBA. The main issues commonly referred are: misalignment of compass and lens optical axis, ferromagnetic effect, compass bore-sight calibration.

5.2 Feature Extraction

Feature extraction has been a long time issue in image processing and particularly in photogrammetry. Poles, trees, buildings, and all visible street and road environment such as road lines and traffic signs, for instance, have deserved the attention of the research community.

Automatic traffic sign recognition from an equipped mobile platform has been a challenging issue for both intelligent transportation and municipal database collection. Many authors have already published on this subject for automatic detection, recognition and localization of traffic signs (VETTORE; EL-SHEIMY, 2007). However, there still are several inevitable problems coherent to all the recognition methods completely relying on passive chromatic or grayscale images.

5.3 Panoramic Cameras

Two interesting problems related to panoramic camera and images are the camera calibration itself and the automation of the panoramic epipolar image generation for 3D modeling and mapping by stereoscopic viewing. The panoramic images are captured by panoramic cameras mounted on the top of a vehicle at certain small intervals, 2 m for instance, along the streets in urban environment. As usual onboard GNSS/IMU, speedometer and post sequence image analysis technology such as BBA provide high accuracy position and attitude data for these panoramic images and laser data. This integrated approach makes possible the construction of the epipolar geometric relationship between any two adjacent panoramic images and then the panoramic epipolar images could be generated.

Chen et al (2012) worked with several projection plans to produce panoramic epipolar images. Sphere, cylinder and flat planes were selected as the image epipolar planes. The effective parts – middle parts of base line's two sides – of the flat plane was selected and used for epipolar image generation. They selected two cubic planes along the base line as basic projection planes for panoramic epipolar image generation. The generated panoramic epipolar images are vertical parallax free and were used for stereo viewing and image matching in 3D retrieval.

5.4 Range cameras

A range camera system solves an old problem with new technology. The system comprises a standard digital camera and a so-called range camera. The range camera is a digital camera whose pixels (light-detector cells) can measure the time of flight (TOF) of the light from the pixel to the object than back to the same pixel. Then the pixel-object distance (d), i.e. the range, is estimated based on $d = c \cdot t$ where c is the velocity of the light and t the time interval (PMD, 2012).

In fact there are two types of images: the range image and the intensity image. The intensity images are red-green-blue (RGB) images. The colored range images are produced based on hypsometric colors. In current affordable technology the range limit is around 6 to 8 m.

Shabazi et al (2012) presented an algorithm to detect, recognize and localize traffic signs by fusing the shape, color and object information from both range and intensity images. A self-calibration method based on integrated BBA via joint setup with the digital camera was applied for the TOF camera calibration. As the result, they demonstrated an improvement in root mean square (RMS) of range error and in RMS of coordinates residuals for TOF camera, over that achieved with basic calibration. Conventional photogrammetric techniques based on controlled network adjustment are utilized for platform calibration.

As a distinction from all the conventional MMS, thanks to the TOF range camera, the developed system is able to extract the 3D coordinates of objects in milliseconds and only from a single image. Combining the shape, color and object-based observation and regarding the distinguishing characters of traffic signs, the algorithm is capable of reliably detecting and recognizing the traffic signs and overcoming the issues regarding illumination, disorientation, scaling and partial occlusion.

5.5 Clouds of points

Automatic 3D point cloud registration is a main issue in computer vision and photogrammetry. The most commonly adopted solution is the well-known ICP (Iterative Closest Point) algorithm. This standard approach performs a registration of two overlapping point clouds by iteratively estimating the transformation parameters, and assuming that good a priori alignment is provided. A large body of literature has proposed many variations of this algorithm in order to improve each step of the process. The ICP algorithm can be improved by using geometrical features which optimally describe the neighborhood of each 3D point. The knowledge of the optimal neighborhood of each 3D point can improve the speed and the accuracy of each of these steps (GRESSIN et al, 2012).

The geometrical features are the basis. These low-level attributes describe the shape of the neighborhood of each 3D point, computed by combining the eigenvalues of the local structure tensor. Furthermore, they allow retrieving the optimal size for analyzing the neighborhood as well as the privileged local dimension (linear, planar, or volumetric). Several variations of each step of the ICP process are proposed and analyzed by introducing these features. These variations are then compared on real datasets, as well with the original algorithm in order to retrieve the most efficient algorithm for the whole process.

The method can successfully be applied to various 3D lidar point clouds both from terrestrial and MMS. The method takes into account both the neighborhood shape and the confidence level of the shape estimate, which allowed the improvement of two of the four steps of the method. Since the computation of the interest features only requires the knowledge of the position of the 3D points, the method has been tested for various lidar datasets. Satisfactory results have been obtained for terrestrial static and mobile mapping system datasets, both in terms of accuracy and speed.

The geometric features should allow speeding up the matching step by introducing a distance function. The neighborhood analysis of a point should not be reduced to its supposed optimal scale since, in reality, several scales of interest exist. Multi-scale features have to be designed (GRESSIN et al, 2012). These features of interest may be used in order to ûnd key points in the 3D point cloud that would allow compute a ûrst coarse registration when this step is mandatory.

5.6 Integrated software

This will pave the way for a change of paradigm: the mobile mapping for 3D modeling (GREJNER-BRZEZINSKA, 2004). Whether in the field of mobile mapping or in mobile 3D modeling, it is critical that the process of extraction, classification and recognition of features of interest is automated to a level such that it tends to be considered autonomous. The volume of geometric data, semantic and pictorial is so big that it will require a system with a high degree of automation of tasks and shared interactive decision to construct three-dimensional models, urban and rural. Currently there is no single software package available that allows for each of those steps to be executed within the same environment.

5.7 Small low cost sensors

Low cost MMS have been mounted by researchers focusing on applications demanding fast response for visual analysis and rapid mapping. Despite apparent neglecting on accuracy the data acquired by low cost systems enable 1:1000 road mapping (SILVA et al, 2003).

Low-cost technology enables the mounting of small systems with sensor redundancy (WAEGLI et al., 2008). A modular arrangement can integrate a GNSS receiver and antennae, an IMU, and a digital video-camera. Two modules enable to acquire stereo-images so it is possible to estimate the EOP of the cameras by the least square method (LSM) based on redundant data. Three modules give redundancy of stereoscopic pairs and spatial object coordinates. The emergence of low cost small size sensors with low power consumption has challenged the geospatial community to investigate solutions that match or approach the costly high performance systems. The prices relationship is of 1:10 to 1:20.

The CCD and CMOS cameras give megapixel resolution, notebooks processing at GHz rate, storage media with terabytes of data, the potent and versatile smart-phones and tablets, long range 3G network for voice and data communication, all these are options to acquire imagery and to process data with portable and reasonable cost equipment (AKCA; GRUEN, 2009) plus low cost lidar and decreasing cost radar technologies will favor the diversity and the redundancy of sensors and data. The micro electro-mechanical system (MEMS) of reduced size, weight, cost, and energy consumption with or without GNSS integrated receivers are the basic boards for a low cost navigation devices. Combining all these technologies will be possible the acquisition and real time processing of images taken by mobile devices.

The integration of IMU/MEMS devices with GNSS and cameras can be made by microcontrollers (Fig. 8), such as the Arduino platform (SCHMIDT, 2011), whose main characteristic is its open hardware and free software. This allows their exploitation by users without deep knowledge in electronics. However, the algorithmic and mathematical modeling continues to require that the PVA solution is estimated, filtered and smoothed.

Special applications such as very narrow tunnels in archaeological sites (INSTITUTE OF GEOMATICS, 2012) can be surveyed with an integrated hand held low cost system with a high sensibility camera for low light or dark environments. Such system has potential to integrate the LBMMT either by car or pedestrian to a GIS oriented to a location based services (WU et al., 2009).

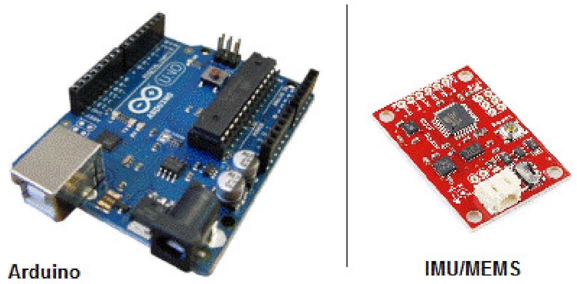

Fig. 8 - Open-source electronic prototyping board Arduino (left) and inertial sensor board (right).

5.8 Temporal analysis

Uma característica das análises que se baseiam em imagens é a temporalidade. As imagens são repositórios de informações múltiplas que se acumulam e facilitam a análise evolutiva do tema de interesse. As imagens terrestres georreferenciadas oferecem esta possibilidade. Ruas, rodovias, ferrovias, áreas de parques, praças, praias, enfim, quaisquer espaços de interesse público aos quais se possa chegar e transitar com uma unidade móvel de levantamento integrado, são passíveis de mapeamento pontual ou momentâneo tanto quanto o acompanhamento do processo histórico de ocupação e desenvolvimento. Da mesma forma, o interior dos edifícios pode ser explorado para fins específicos.

If images are taken along the time, i.e., in distinct epochs of the same places, temporal analysis can be done. These images constitute multiple and accumulated information repositories that facilitate the evolutionary analysis of subject of interest. Terrestrial geo-referenced images offer this possibility. Urban ways, highways, railroads, parks, plazas, beaches, etc., every place of public interest to where a LBMMS can be driven or walked through, i.e., by car or on foot, is a local liable to be surveyed and mapped once and repeated in distinct epochs so the historical development process can be known. Similarly, the interior of the buildings can be surveyed for specific purposes.

5.9 Image-based navigation

The interest of researchers to integrate the navigation methods based on INS to image or vision sensors has grown lately (RANDENIYA et al., 2008; ROUZAUD; SKALOUD, 2011). A yet more challenging method of navigation has also been investigated based only on MMS image-to-image navigation. Here, feature matching from successive image pairs will be used to determine the changes in attitude of the MMS platform and sensor. This information will be combined with the odometer readings between successive images as an alternative method of determining the sensor attitude and position in unfriendly areas for satellite observations.

There also is an even more radical intent of navigating solely by images (GIACHETTI et al., 1998; SILVA et al., 2007; VETH, 2011). The aim is not to exclude or compete with the referred instrumental navigation methods. The intention is to take advantage of the technological advancement of computational processing power and build a methodology that integrates the existing methods of navigation and positioning of platforms and sensors.

Vehicle speed estimation (BARBOSA et al., 2007) and road traffic state are challenges for traffic engineering due to the infrastructure of sensors and control devices along a road. A solution is tested by an inverse modeling algorithm to reconstruct the traffic state (speed field) on highways from GPS observations and images taken by mobile phones onboard of vehicles (WORK et al., 2008). Inevitably, there is traffic captured by the image pairs around the moving platform. Most mapping applications focus on stationary objects and the surrounding flow is seen as noise. To assess the quality of the static data (assets, for instance), it is necessary that the movement detection of surrounding traffic should be automated and this must be treated differently for the traffic estimation (SUN et al., 2009).

Li; Sclaroff (2007) published a solution based on a stereo-pair, optical flow, and correspondence. Silva et al. (2007) e Barbosa (2007) oriented images using only image processing and photogrammetric techniques without any external sensor. The method is based on the vehicle speed estimated from the computed dense optical flow and BBA.

Randenyia et al. (2008) calibrated an integrated inertial and visual system. Such integration is a passive technique suited to indoor environment. The authors adapted it to the outdoors so the pose estimation is acceptable even without the GPS signals. Veth (2011) synthesized the techniques and the advances in navigation based on images. He classified them in optical flow and in feature tracking. Both use the apparent motion of image pieces along the frame sequence to determine the relative camera motion.

Considering a sequence of images taken by one camera, three basic steps are required to automate the image orientation process: to select regions in the images to extract features, to match these features in two or more images of the sequence, and to estimate the EOP of the camera. Video images (frames) are transformed into still images (frames) before the steps.

Lemes Neto (2013) studies and researches this method for a pair of images or stereo-images as it follows: every 1/30s still frame of a sequence is captured and it receives an identifier. E1, E2, ..., Ek are for the frames made by the camera at left and D1, D2, …, Dk are the same for the camera at right, both respectively for the instants t1, t2, … tk as the cameras are sync operated (Fig. 9).

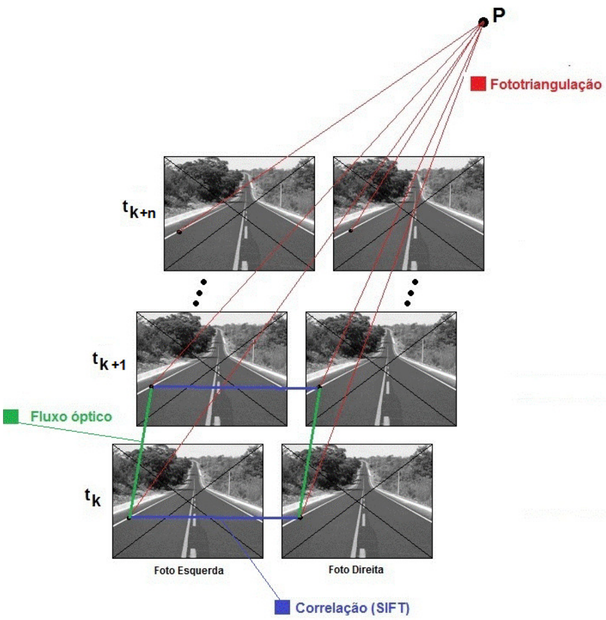

Fig. 9 - Sync stereo pairs sequences at regular time intervals.

The frames are filtered by the difference of Gaussians (DoG) to extract and enhance features. These are submitted to optical flow techniques to correspond them along the sequence. The left and right sequences are treated separately. Given the feature correspondence between t1 and t2, t2 and t3, …, tk and tk+1 frames, the photocoordinates are determined automatically. Then E1 and D1, E2 and D2, …, Ek and Dk pairs are processed to correspond the homologous features based on the scale invariant feature transform – the so-called SIFT algorithm (LOWE, 1999).

Fig. 9 shows the E and D sequences so it is possible to see common features along and side tracks, where image points have their photo-coordinates determined from optical flow (along the track) and from SIFT algorithm (lateral or stereo-pair). It means that at least four frames (Ek-1, Dk-1, Ek, Dk) are involved so a small BBA can be used to estimate the EOP of the images (cameras). Of course, the first pair must have its external orientation fully know. And then the process is repeated for the next block with four frames (Ek, Dk, Ek+1, Dk+1). Blocks with six frames will also be investigated. Lemes Neto (2013) takes part of his research on Barbosa et al (2007) and Silva et al (2007).

5.10 Combined methodologies

UAV technology is becoming useful to solve problems in many civilian applications. Navigational and mapping technologies have been integrated in land-based, aerial, and orbital domains. UAV was benefitted from LBMMS concepts which were extended to aerial systems. UAV can fly remote controlled or autonomously. Both contain all the equipment that a LBMMS has: GNSS receivers, INS/IMU sensors, auxiliary sensors, active and passive image sensors plus the aeronautical equipment such as motor, rotor, wings, flight stabilizing and controlling devices, and other appliances such as batteries and so on. Of course, all items must have the lightest weight possible for operational reasons.

Considering the wings, there are two types of UAV: rotor wing and fixed-wing. Based on few studies, rotor wing units are more stable and are able to capture images easily and it also allows remote control over any environment and urban mapping (TAHAR et al, 2012). For photogrammetric purposes a consumer digital camera can be used for imagery acquisition and it can be mounted vertically in a rotary-wing UAV. The acquired images can be processed using photogrammetric software to produce orthophoto and digital elevation model (DEM). Both are very common photogrammetric products for large scale terrain mapping. An experimental photogrammetric process assessed the accuracy as root mean square errors (rmse): +-2mm, +-1mm, +-220mm for coordinates x, y and z respectively (TAHAR; AHMAD, 2012). No surprise when altimetry still remains a very challenging issue in aerial photogrammetry!

UAV is suitable for various applications in small area projects, and also for project planning that has limited budget and time constraint. This technology can be adopted in photogrammetry work which requires updating geospatial information within a short time. It has been successfully applied to farming, surveillance, environmental monitoring and study, fire disaster, flood monitoring, to monitor and to support the decision process around mountainous urban areas and roads crossing mountains that are prone to landslide, and aerial terrain mapping.

Accuracy assessment of the photogrammetric process has been analyzed using the RMSE, slope angle analysis and slope aspect analysis so that rotor wing UAV images can be used in slope angle analysis or production of slope map.

In the short future this technology will be expanded to larger areas in order to increase the project planning process based on pre-analysis considering the accuracy and the costs of the aerial photogrammetric mapping. Besides that LBMMS and UAV, which mean terrestrial and aerial images taken in and over linear features such as roads, rivers, power lines etc and in and over areas, will certainly increase the potentiality of both technologies for the production of related geographic information.

6. CONCLUSION

The whole mobile mapping process involves as macro steps the acquisition, the processing, the analysis, and the storage of huge volumes of geospatial data. The execution of each step is performed according to technologic options or variants. We observed the evolution of MMS from a minimum set of sensors (GPS, INS, cameras) to a superabundant set of sensors [GNSS, INS(IMU), cameras, lidar]. The computational and information technology offer the conditions for real time or post-processing for each process step. For mapping purposes post-processing is enough.

An entirely overall solution to integrate all process steps is a relevant target. Navigational, positioning and imaging sensors and data integrated at hardware and software level will mark a new era in MMS history.

Although they are general purpose devices, smart-phones and tablets can be specialized to specific applications. Either at streets, roads, railways or in buildings or at public interest places, the mobile devices applications will contribute to disseminate MMT and the production of the geo-referenced information. This is of great interest to many potential users that demand low cost MMS.

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