# Mobile Mapping Systems – The New Trend in Mapping and GIS Applications

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## 1. Introduction

Mobile Mapping Systems (MMS) have become an emerging trend in mapping applications because they allow a task-oriented implementation of geodetic concepts at the measurement level (Schwarz and El-Sheimy, 1996). Examples of such systems can be found in airborne remote sensing (Cosandier et. al., 1994), airborne gravimetry (Wei and Schwarz, 1995), airborne laser scanning (Wagner, 1995), and mobile mapping vans and trains (El-Sheimy et. al., 1995), and (Blaho and Toth, 1995). All of these systems have a common feature in that the sensors necessary to solve a specific problem are mounted on a common platform. By synchronizing the data streams accurately, the solution of a specific problem is possible by using data from one integrated measurement process only. The post-mission integration of results from a number of disjointed measurement processes and the unavoidable errors inherent in such a process are avoided. This results in greater conceptual clarity, task-oriented system design and data flow optimisation, and also offers in most cases the potential for a real-time solution, which is becoming more important in many applications.

The trend towards MMS in Geomatics is fuelled by the demand for fast and cost-effective data acquisition, and by technological developments, which satisfy this demand. Two developments are especially important in this context: Digital imaging and precise navigation. Digital imaging sensors considerably reduce the data processing effort by eliminating the digitising step. They also open the way towards new and flexible designs of the processing chain, making ample use of mathematical software tools readily available. In the form of digital frame cameras, they are inexpensive enough to make redundancy a major design tool. In the form of pushbroom scanners, they provide additional layers of information, not available from optical cameras.

Precise navigation has developed to a point where it can provide the solution of the exterior orientation problem without the use of Ground Control Points (GCPs) or block adjustment procedures; for details of the principle, see Schwarz (1995); for results and practical considerations see Cannon (1991) and Skaloud et. al. (1994). Since results are available in a digital form, data fusion with the imaging data is easy and real-time applications are possible in principle. Operational flexibility is greatly enhanced in all cases where a block structure is not needed. Costs are considerably reduced, especially in areas where little or no ground control is available. Current accuracy is sufficient for many mapping applications; see for instance Schwarz (1995). The potential to solve even high-accuracy cadastral applications certainly exists.

Combining these two developments, the concept of the georeferenced image as the basic photogrammetric unit emerges. This means that each image is stamped with its georeferencing parameters, namely three positions and three orientations, and can be combined with any other georeferenced image of the same scene by using geometric constraints, such as epipolar geometry or object-space matching. This is a qualitatively new step because the georeferencing parameters for each image are obtained in a direct way by independent measurement. This is conceptually different from the notion that a block of connected images and sufficient ground control is needed to solve the georeferencing problem. The direct method, in contrast, does not require connectivity information within a block of images to solve the georeferencing problem, and thus offers much greater flexibility. It is especially intriguing to consider its use for mapping applications which use digital frame cameras, pushbroom scanners, or laser scanners as imaging components.

In this article, the concept of mobile mapping will be illustrated. The mathematical formulation of the mobile mapping system will yield to the main system component and consequently the main data flow in these systems. To highlight the importance of mobile mapping systems, two dedicated examples have been selected with different mapping sensors, platforms, and applications. Finally, an outlook for the future of these system's sensors, applications, and theories is considered.

## 2. Concept of mobile mapping

The idea of mobile mapping is simple and straightforward and is based on simple vector algebra as in shown equation 1:

$$\begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} = R_{(t)}^{sys} \cdot \left[ R^{ms} \left( \overline{ms\_m} \right) + \begin{pmatrix} \Delta X^{ms} \\ \Delta Y^{ms} \\ \Delta Z^{ms} \end{pmatrix} \right] + \begin{pmatrix} X_{(t)}^{sys} \\ Y_{(t)}^{sys} \\ Z_{(t)}^{sys} \end{pmatrix} \qquad (1)$$

The left hand side represents the 3D ***unknown*** coordinate of point (i). Two rotation matrices are involved; the first is the

***time-dependant*** system attitude rotation matrix $R^{sys}_{(t)}$ at an instant (t), which represents the system (as represents by the navigation sensor coordinate frame) orientation relative to the mapping frame. The second rotation matrix is the mapping sensor delta rotation ***constant*** (in most cases) $R^{ms}$ matrix as a function of boresight angles between the mapping sensor and the navigation sensor. The $X_{(t)}^{sys}, Y_{(t)}^{sys}, and\ Z_{(t)}^{sys}$ represent the ***time-dependant*** system position. Additionally, $\Delta X^{ms}, \Delta Y^{ms}, and\ \Delta Z^{ms}$ are ***constant*** (in most cases) lever arm components of the mapping sensor with respect to the navigation coordinate frame. Finally, $\overline{ms\_m}$ is a mapping sensor measurement vector for point (i)-scaled if required (e.g. camera-based system). The system of equations is solved to obtain the 3D coordinates of the point under consideration. There are two distinct examples of applying mapping equations in optical mapping (e.g. frame cameras) sensors and range mapping sensor (e.g. Laser). In the case of a range mapping sensors, the system of equations is balanced, with no redundancy available. In the case of an optical mapping sensor, the system of equation is underdetermined, as there is one added scale factor. In this case, more observations are added from different images.

## 3. Mobile Mapping System Component

Regardless of the mobile mapping system platform, application, or capabilities, its component is divided into three major classes: navigation, mapping, and control components. The function of the navigation component is to continuously provide an accurate full trajectory description, from which the exterior orientation of the sensor can be derived based on time. Depending on the application and the required accuracy, the navigation component can have a GPS receiver in addition to one of the following sensors:

- Full **I**nertial **M**easurement **U**nit (IMU), sensitive to 6 degrees of motion freedom
- Odometer
- Inclinometer
- Any other navigation aid sensor

The mapping component of a mobile mapping sensor can vary widely from simple tools to very complicated devices. The mapping sensor can simply be a voice recorder with descriptive annotations for the surrounding objects. For accurate applications, the mapping sensor can be, but not limited to color digital camera(s), infrared camera, laser scanner, and **S**ynthetic **A**perture **R**adar (**SAR**). The function of the mapping sensor is to determine the relative location of objects to its local coordinate frame.

The control component steers the data logging to a local hard drive while keeping all the data steams into one time frame. By considering the high data rates for both navigation and mapping data, the control component becomes critical and one of the key factors for an efficient mobile mapping system. Robust hardware and software has to be provided for successful data logging.

## 4. Work Flow

The production cycle of a mobile mapping system has been shaped into a standard procedure. Apart from the system calibration, once the data has been logged successfully, it has to be transferred to a computational server, where processing can take place. The processing starts with navigation data integration. The integration of all navigation sensors is based on some optimal estimation techniques (e.g. Kalman filter). The output is a six-degree trajectory description with high frequency in addition to time tags. Based on the output of this process, the mapping sensor data is georeferenced (i.e. tagged with its position and orientation with respect to a certain mapping frame). Figure 1 summarizes the whole mobile mapping system (based on cameras) survey life cycle. At this point, three critical points have to be stressed which are synchronization, sensor calibration, and total system calibration.

Time synchronization is achieved based on a GPS **p**ulse **p**er **s**econd (**PPS**) signal. All the collected data is tagged with GPS time when they take place. The importance of time synchronization becomes more pronounced in applications with high speed/dynamics. Individual navigation sensor calibration is used in optimal data integration. Mapping sensor calibration is critical in mobile mapping as it will result in bad object space reconstruction. Finally, the spatial relationship between the navigation and the mapping sensor has to be accurately estimated. This relation can be described by 3D translation vector (lever arm) and three rotation angles (boresight angles). These parameters can be estimated in a so-called total system calibration procedure.

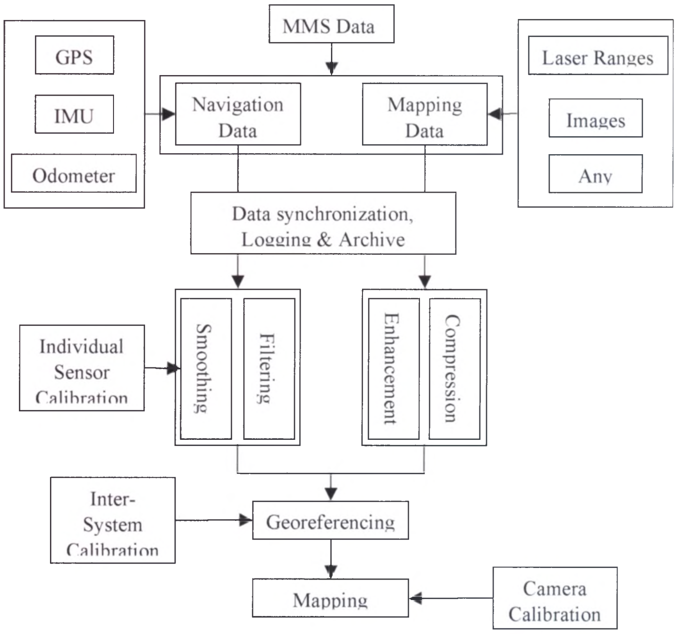

**Figure 1: Overview of Mapping Procedures in Mobile Mapping Systems**

## 5. VISAT – An Example of Land Based Mobile Mapping Systems

In the context of mobile mapping systems, there are numerous examples of operation systems in North America, Europe, and Japan. Among those systems, the VISAT (**V**ideo,

**I**nertial, and **SAT**ellite GPS) mobile mapping system was chosen to demonstrate the capabilities of such systems and how much they can provide. VISAT, developed at the University of Calgary in the early 1990s, was one of the first terrestrial MMS. Recently, an improved version – shown in Figure 2 – was developed (AMS Inc., 2006). The system's data acquisition components include a strapdown INS system, a dual frequency GPS receiver, 8 colour digital cameras, and an integrated DMI hookup on the speed sensor of the vehicle, and the VISAT™ system controller. The function of each component can be subdivided into primary and secondary tasks. In terms of primary functions, the camera cluster provides up to a 330° panoramic field of view, which in most cases is the perspective center of one of the cameras. The DMI provides the van traveling distance to trigger the cameras at constant intervals. The data-logging program, VISAT™ Log, allows for different camera configurations and different image recording distances or triggers the camera by time if necessary (both can be changed in real-time). In terms of secondary functions, the camera cluster provides redundancy, i.e. more than two images of the same object. The DMI data can be used to update the INS data if the GPS signal is blocked for periods longer than the INS bridging level required to fix the GPS integer ambiguities. Using VISAT™, mapping accuracies of 0.1 - 0.3 m for object distance of 50m from the van can be achieved in urban or highway environments while operating at speeds of up to 110 km per hour.

**Figure 2: VISAT™ Van 2006**

VISAT Station is one of the dedicated software that is designed to view, analyze, measure, and transfer data to GIS platforms. The VISAT Station environment permits user-friendly viewing of the imagery. It is fully integrated with ArcGIS. Through the VISAT station, both geometrical features and attributes of the measured objects can be transferred to a GIS platform for further analysis and processing. Moreover, the VISAT station is a server-based application, which enables many user terminals to access the same image database and perform parallel processing.

The VISAT Station User Interface The VISAT Station Object Editor Window

**Figure 3 – The VISAT Station Software**

To check the system absolute accuracy, some well-defined Ground Control Points (GCP) along one of the test runs were used for comparison. Figure 4 shows the difference between the GCP coordinates and the coordinates obtained from the VISAT system. They are obtained by deriving GPS-based coordinates from the VISAT system and transforming them to 3TM coordinates. These coordinates were then compared to the completely independent GCP coordinates. The GCPs were about 10-30 m away from the van.

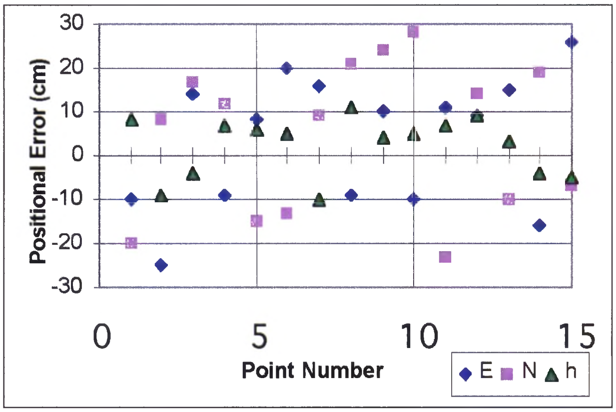

**Figure 4: The VISAT Absolute Accuracy**

The figure indicates that an RMS of 0.3 m in the horizontal and a few centimeters in height are achievable for distances up to 25 m under normal conditions. For more details about the absolute accuracy of the VISAT system, see El-Sheimy, 1996.

## 6. Real-Time Airborne Mapping System for Forest Fire Fighting (F3) System

The system presented in the previous section typically works in post-mission mode of operation. In this mode of operation, the data is collected in the vehicle (van, airplane, or ship) and processed off-site in order to extract the information of interest. Due to the post-mission mode of operation, very high accuracy in position ($\leq$ 0.1 m "RMSE") and attitude ($\approx$ 0.02 degrees "RMSE") can be achieved. This is accomplished by using the precise GPS carrier phase in Differential mode (DGPS: uses two GPS receivers; one in static mode over a known control point and the second on the vehicle) and by tightly coupling DGPS and INS data through Kalman filtering.

In many remote sensing applications, however, there is no need for real-time processing of the data and therefore post-mission mode of operation is adequate. In many emerging remote sensing applications, specifically forest fire fighting, the requirement for real-time mapping is more important than the highest possible accuracy. One of the main problems in combating forest fires is monitoring the time history of the fire. Understanding the size, location, and speed of advance of the fire front is critical to optimal allocation of fire fighting resources and maintaining the safety of the fire crew. Investigation of major wild-land fire accidents involving loss of life often indicates that the crews became imperiled because of insufficient or untimely information about the location and speed of the advance of the fire. An example of these systems is the Forest Fire Fighting (F3) System developed by the University of Calgary.

The F3 system integrates imaging sensors (Thermal Infrared "TIR" Cameras) with real time navigation technologies (Wide Area Differential GPS "WADGPS" and low cost INS). The system is very useful in reporting the exact situation of fires, assisting the forest fire departments in accurately assessing the fire and precisely directing water-bombers and fire-fighting crews. The use of infrared/thermal infrared cameras, which sense the heat emitted in the form of infrared radiation, will enable early detection and location of forest fires in reduced visibility due to haze, smoke or darkness. Apart from assisting in fire fighting, the proposed system will have other uses as well. One of the most labor-intensive jobs firefighters have is "mopping up" and patrol. When a fire has been contained and suppressed, there is a possibility of smoldering fires underneath the surface flaring up days after the fire has been put out. Even though it is an arduous task, patrolling and mopping the perimeter fire lines for days after the fire has been put out is essential to ensure the fire is totally out. Through its infrared capabilities that can detect smoldering fires underneath the surface, the proposed system will facilitate the mop-up and patrol process by directing the ground fire fighters to the areas of active heat emission, saving not only time and effort but also protecting the lives of the ground fire fighters. Figure 5 shows the main components of the F3 system.

1. Signal Synchronization Board
2. AHARS – Attitude and Heading Reference System
3. Infrared Video Camera
4. WADGPS Receiver
5. Thermal Camera
6. Inertial System
7. Data Logger

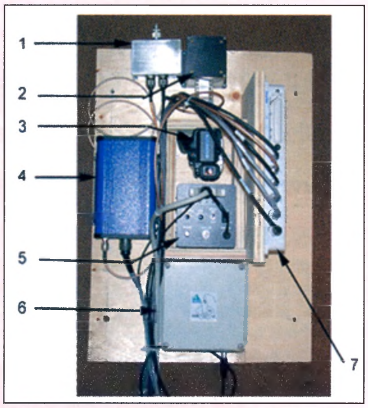

**Figure 5: Hardware of the F$^3$ System**

To determine 3-D coordinates of the fire from the images, the position vector (3 parameters per image) and direction/orientation (3 parameters per image) of the camera at exposure times are needed for a pair of images. These parameters will be obtained from the WAGPS and INS data. After the georeferencing process, the images can be used for feature extraction using photogrammetric intersection techniques. As a first step, image processing techniques will be applied to the TIR images. The purpose of the image processing is to identify, isolate, and track the hotspots and fires in real-time. Different filtering techniques, such as thresholding, morphological, texture and variance filtering are used for identifying and isolating hotspots and fires from the rest of the image.

Once the hotspots and fires are identified within the video sequence, they must be tracked from frame to frame to accurately position them. The goal is to track the hotspot across as long as possible to give the space intersection calculation as wide an angle as possible (see Figure 6). Following the 3D coordinate computation of the hotspots and fires, this information will be sent to the Web server using one of the satellite communication techniques, e.g. the European Space Agency REMSAT (Real-time Emergency Management via Satellite).

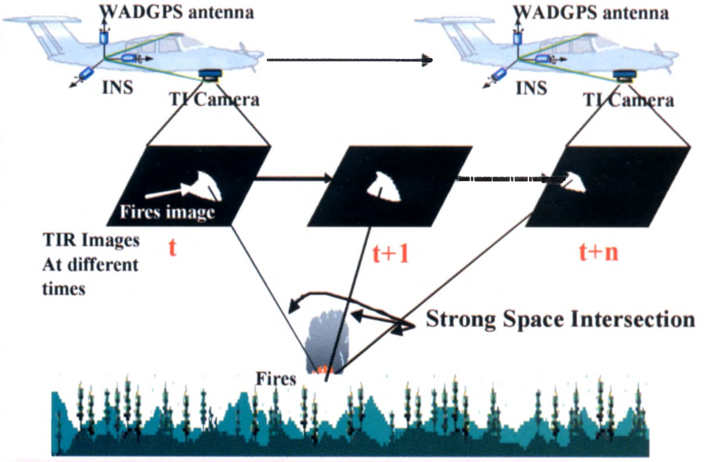

**Figure 6: Principles of the Operation of the F$^3$ System**

## 7. Future Trends in MMS

While MMS are already invaluable tools in the construction of GIS for urban development, and highway and rail surveys, their future seems bright for many other applications. Research is currently being done on a variety of applications and on methods to streamline the post processing of the large amounts of data captured by these systems. These areas include the use of MMS in a real time forest fire fighting system and backpack systems to be used for areas not reachable by land-based MMS.

Automated feature extraction is one of the many topics that are currently being researched in hopes of improving the post processing that is required when dealing with the large number of images captured by MMS. Though MMS can gather a large amount of versatile information, the processing still involves a fair bit of human interaction. Automated feature extraction is a process that is fundamentally trying to mimic the pattern of reasoning that occurs in a human brain to allow the identification of simple objects. Researchers hope to refine the current semi-automatic methods to a more automated system. Feature extraction is based on the grouping of like patterns until something can be identified as potentially an object of interest. The current methods are quite unreliable and still require a large amount of human interaction to verify the automated selections. Automation has many difficulties that first must be overcome. Many objects possess similar geometric and radiometric signatures while being quite different. An extended project for automatic extraction and updating GIS data bases has been initiated by Mobile Multi-Sensor Systems (MMSS) Research Group at the University of Calgary in cooperation with Absolute

Mapping Technologies Inc. The project collectively gathers computer vision, photogrammetry, and navigation experts. The initial step of this project has taken place successfully, where a robust framework for automatic lane line extraction from VISAT mobile mapping sequence image database, has been established. The results were quite encouraging with a minimum amount of human interaction.

## 8. Summary and Conclusions

In this article, we have demonstrated that Mobile mapping systems are ever-growing industrial resources with a lot of potential to facilitate mapping applications of all kinds. Advances in navigation and computing technology are allowing the collection of more accurate results at higher speeds, improving the cost effectiveness of the use of an MMS over more traditional methods. Two different examples of mobile mapping systems were given. These two examples are quite different considering the navigation/mapping sensor used, field of application, and results time availability. Past examples such as VISAT provide a solid foundation for future developments to build on. In combination with the stable and powerful GIS systems that are now available, MMS may be one of the best competitive tools for future spatial data collection.

Mobile mapping has opened new avenues for both researchers and industry visionaries. We are sure that in the future we will witness a tremendous evolution in all aspects of mobile mapping systems including, hardware, applications, and data fusion/automation.

## Acknowledgment

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## Sites to See

### National Oceanic & Atmospheric Administration (NOAA)

**http://celebrating200years.noaa.gov/**

In 1807, President Thomas Jefferson founded the U. S. Coast and Geodetic Survey to provide nautical charts to the maritime community for safe passage into American ports and along the extensive U. S. coastline. The weather bureau was founded in 1870 and the U.S. Commission of Fish and Fisheries one year later. These three agencies were brought together in 1970 with the establishment of NOAA. This Website is dedicated to the 200th anniversary of the founding of the Coast and Geodetic Survey and it contains links to several anniversary celebrations as well as links to many interesting stories and historical resources.