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Volume 4

Advances in Mobile Mapping Technology

The growing market penetration of Internet mapping, satellite imaging and personal navigation has opened up great research and business opportunities to geospatial communities. Multi-platform and multi-sensor integrated mapping technology has clearly established a trend towards fast geospatial data acquisition. Sensors can be mounted on various platforms, such as satellites, aircrafts or helicopters, terrestrial vehicles, waterbased vessels, and may even be hand-carried by individuals. Mobile mapping refers to a means of collecting geospatial data using mapping sensors mounted on a mobile platform. Its development was primarily driven by the advances in digital imaging and direct-georeferencing technologies. With the escalating use of telecommunication networks and the increasing availability of low-cost and portable sensors, mobile mapping has become more dynamic, and even pervasive. This book addresses a wide variety of research issues in the mobile mapping community, ranging from system development to sensor integration, imaging algorithms and mobile GIS applications. ***Advances in Mobile Mapping Technology*** will provide researchers and practitioners a good overall view of what is being developed in this topical area.

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Tao & Li

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information from imagery

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Contents

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Foreword

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We are now at the stage where mapping, which is a well established engineering subject, has become increasingly influential to people's lives and business processes. The growing market penetration of internet mapping, satellite imaging and personal navigation has opened up great research and business opportunities to geospatial communities. It has long been recognized that geospatial data is at the heart of any geospatial application. Consequently, collecting and updating map and image information in a timely, accurate fashion has become more important than ever.

Multi-platform and multi-sensor integrated mapping technology has clearly established a trend towards fast geospatial data acquisition. Sensors can be mounted on a variety of platforms, such as satellites, aircraft, helicopters, terrestrial vehicles, water-based vessels, and even people. The increasing use of internet and wireless communication networks and the recent advances in sensor networks further enable us to transfer and process data in a more efficient manner. As a result, mapping has become ***mobile***, and ***dynamic***.

Mobile mapping refers to a means of collecting geospatial data using mapping sensors that are mounted on a mobile platform. The research on mobile mapping dates back to the late 1980s. This process was mainly driven by the need for highway infrastructure mapping and transportation corridor inventories. Cameras, along with navigation and positioning sensors, e.g., the Global Positioning System (GPS), and inertial devices such as inertial measurement unit (IMU), were integrated and mounted on a mobile vehicle for mapping purposes. Objects can be directly measured and mapped from images that have been georeferenced using navigation and positioning sensors. In the early days, the research community had used various terms to characterize this exciting research area. Terms like kinematic surveying, dynamic mapping, vehicle-based mapping, etc., appeared in the scientific literature. In 1997, the first International Symposium on Mobile Mapping Technology was held at the Center for Mapping at The Ohio State University, Columbus, Ohio. Subsequently, the term "Mobile Mapping" became accepted and frequently cited.

The development and advancement of mobile mapping was primarily driven by advances in digital imaging and direct-georeferencing technologies. In the late 1990s, a number of terrestrial vehicle-based mobile mapping systems were in commercial operation. There had been high expectations that these mobile mapping systems would have a large impact on conventional transportation surveying and mapping. However, market acceptance did not reach the expected level due to the following reasons: (1) there was a workflow issue in the deployment of the technology for transportation surveying. Often re-surveying of missing objects by ground crews was required in order to finalize the project that had originally been delivered by the mobile mapping system. Thus, the productivity of such systems was not guaranteed; and (2) the high cost of system acquisition and deployment has to date limited the use of such systems for routine road corridor surveys.

Despite the barriers, we have seen an increasing demand for terrestrial mobile mapping for transportation, telecommunication, emergency response and engineering applications where roadside information is of value. Many customized systems and service models have been developed for a variety of applications. Some companies offer road image services or a pay-per-click pricing model to attract customers. Instead of owning a system or a software package, the customer can purchase the road image data and only pay for the number of objects collected or measured from images.

In general, the evolution of mobile mapping technology can be broken down into three stages:

Photo-Logging
In the 1970's, photo-logging systems were used by many highway transportation departments to monitor pavement performance, signing, maintenance effectiveness, encroachments, etc. These services are usually required at intervals of about two or three years. Often film cameras were used to capture photos through the windshield of a van-type vehicle. An inertial device (e.g., gyroscopes and accelerometers) and a wheel counter were employed to determine the instantaneous positions of the captured photographs. Each photo was stamped with time and geographic position information. These photos were stored mainly as a pictorial record of highway performance.

Due to the poor accuracy of vehicle positioning and the use of only a single camera configuration in these systems, 3-D object measurement functionality was not available. The main drawback of photo-logging is film-based storage and processing. Accessing the photos for engineering, planning, legal or safety activities was time-consuming because film is fragile and film processing is costly.

Video-Logging
With the advent of the GPS as well as video imaging technologies, cumbersome photo-logging systems were replaced by GPS-based video-logging systems. It has been demonstrated by many projects that the GPS-based video-logging systems offer a fast and low-cost approach to highway inventory. The collected video images can be georeferenced with respect to a global coordinate system using continuous GPS navigation and positioning information. The turn-around time of data processing is significantly reduced since no film processing is involved. Furthermore, the digitally georeferenced video data allows for quick retrieval and effective management. The capability of being able to interpret highway video data is also strengthened through the use of image processing software. This approach has become widely accepted by most transportation departments. Visual inventory and feature documentation along road corridors remains the major purpose of these kinds of systems.

Mobile Mapping
The development of terrestrial mobile mapping systems was initiated by two research groups in North America, The Center for Mapping at The Ohio State University, USA and the Department of Geomatics Engineering at The University of Calgary, Canada. Compared to video-logging systems, mobile mapping systems are able to offer full 3-D mapping capabilities that are realized by using advanced multi-sensor integrated data acquisition and processing technology.

A common feature of mobile mapping systems is that more than one camera is mounted on a mobile platform, allowing for stereo imaging and 3-D measurements. Direct georeferencing of digital image sequences is accomplished through the use of navigation and positioning techniques. Multiple positioning sensors, GPS, IMU and dead-reckoning, can be combined for data processing to improve the accuracy and robustness of georeferencing. The ground control required for traditional mapping is thus eliminated. The systems can achieve centimeter accuracy of vehicle positioning and meter or sub-meter 3-D coordinate accuracy of objects measured from the georeferenced image sequences.

In parallel, we have experienced impressive development in airborne sensors, such as large-format digital cameras, laser scanners (or Lidar) and interferometric synthetic aperture radar (IfSAR or InSAR) mapping systems. In the last eight years, spaceborne sensors, in particular, high-resolution commercial imaging satellites (e.g., IKONOS, QuickBird, OrbView-3), have played a significant role in mapping. Also, on the sensor side, the increasing availability of cheap and miniature sensors, both for professional and consumer users and wireless, mobile, and nomadic network access; mobile mapping has become ***pervasive*** and ***ubiquitous***.

The new technological trend in mobile mapping can be characterized by: (1) increasing use of mobile and portable sensors with low-cost, direct georeferencing devices; and (2) collaborative mapping with networked, multi-platform sensors. Given the improved capacities in telecommunication bandwidth and distributed computing power, collaborative data collection is no longer a technical hypothesis. Mapping can be performed using either a sensor network or a network of many sensor networks. Recently we have seen a growing and exciting development in this field; for example, a network of ground stationary sensors, terrestrial mobile mapping systems, airborne systems and even satellite systems can now be fully integrated for multi-level mapping and monitoring. Thanks to real-time telecommunication links, collaboratively collected data can be distributed and accessed through widely available Internet and wireless networks. As a result, data acquisition, processing, transfer and management are controlled in a seamlessly integrated workflow. This indeed represents an exciting framework for smart sensing[1].

On the application side, it is even more exciting to see that mapping is gaining in popularity among consumer users. Thanks to the internet giants, namely Google, Microsoft, and Yahoo, who have used aerial and satellite imagery extensively in their on-line mapping services, mass consumer users are now more appreciative and aware of the value of geospatial data. Recently, A9.com (www.a9.com), a subsidiary of Amazon, released street side images collected using sensors mounted on a moving vehicle. Microsoft has published both airborne oblique images, along with very impressive street-side images, in its windows live local portal in order to enhance local experiences. The ongoing market surge in on-line mapping signals that a new mapping era is emerging; where low-cost, fast and high quality mobile mapping will become much more valuable in serving mass consumer users.

Sponsored by the International Society for Photogrammetry and Remote Sensing, we are pleased to assemble a synthesis of invited papers and research papers into this book format. The research papers represent research results derived from preliminary papers presented at the 4th International Symposium on Mobile Mapping Technology (MMT'2004) held from March 29 to 31, 2004 in Kunming, China.

This book consists of four parts, each with a particular theme. In Part One, termed "Terrestrial and Airborne Mobile Mapping Systems", the focus is placed on system development technology. Schwarz and El-Sheimy provide an overview of the major steps in the development of digital mobile mapping systems in four specific areas: digital imaging, direct geo-referencing, mathematical modeling, and filtering and smoothing. It touches both on the technical challenges and on the achievements in this area. The second paper, co-authored by Talaya et al., describes the development of the GEOVAN system at the Cartographic Institute of Catalonia in Spain, as well as their results, which entailed integrating a dynamic laser scanner with the mobile mapping system. The third paper, contributed by Artese, introduces a low-cost, land-based mobile mapping system termed OrthoRoad. This was developed at the University of Calabria, Italy, for road surveying and mapping. Unlike most stereo imaging systems, Gontran et al. present their research, which focuses on a single camera-based Photobus system, developed at Swiss Federal Institute of Technology in Lausanne (EPFL). Part 1 is concluded with a paper by Grejner-Brzezinska et al., in which the use of airborne multisensor remote sensing systems to support traffic flow parameter estimation was studied. Experimental results from a helicopter test flight using The Ohio State University (OSU) GPS/IMU/CCD prototype system are given.

Part Two is termed "Multi-Sensor Integration" and is comprised of four research papers that collectively discuss a variety of sensor integration techniques. The paper co-authored by Ip et al., examines those parameters that are critical to properly operating a mobile mapping system for different platforms; Sensor placement, sensor synchronization, system calibration and the sensors' initial alignment are discussed in detail. Paletta et al., present an automatic procedure for digital image segmentation whose main goal is the detection of road edges from an image sequence collected by a land-based mobile mapping system. The road edge detection procedure is based on the integration of the extended Kalman filter with the Canny edge detector and the Hough transform. Retscher introduces a scenario for the development of a pedestrian navigation prototype system based on simulated observation data. His study demonstrates that a Kalman filter is suitable for the real-time evaluation of multi-sensor system integration. The paper co-authored by Kealy et al., demonstrates the potential for an integrated system to provide the necessary outputs of position, attitude and visualisation to support augmented reality (AR) applications. A case study

[1] C.V. Tao, The Smart Sensor Web, A Revolutionary Leap in Earth Observation, *GeoWorld*, September 2003

undertaken within the land mobile environment is used to test the performance of the AR prototype as a means of improving a driver's ability to "see" the road and surrounding vehicles despite poor visibility.

Part Three, termed "Image Processing and Object Extraction" and also comprised of four papers, focuses on image-based processing algorithms. Di et al., present a special constrained bundle-adjustment method to support high-precision Mars landing-site mapping. A complete set of constraint equations is derived to model the unique geometric characteristics of the stereo camera system. The proposed method, as well as the developed software, were used in the 1997 Mars Pathfinder (MPF) mission. The paper co-authored by Toth and Grejner-Brzezinska discusses the feasibility of using airborne LiDAR imagery data to support traffic flow parameter estimation, including vehicle count estimates and vehicle classification, and to a lesser extent, velocity estimates. Hu et al., describe an interesting algorithm, based on the constrained Hough transform, which purpose is to extract the grid-type street network automatically. Their results demonstrate the potential power of using LiDAR data for road extraction in dense, urban areas. Dong et al. introduce a semi-automated strategy for extracting highway intersections from pansharpened IKONOS images. The proposed method is based on the multi-scale wavelet transform and on knowledge of road geometry.

In Part Four, termed "Mobile GIS and Distributed GIS", we include two papers, both of which address the use of mobile mapping data in a geospatial information system (GIS) environment. The paper, contributed by Huang et al.,, introduces a location-aware travel guide prototype for pedestrians, with the aid of a mobile GIS. Their experimental results show that the indexing method they had developed has a significant performance improvement over the exhaustive search method. The last paper presented by Zlatanova et al., describes a framework for the use of geo-information in emergency response. The paper concludes that wider utilization of 3D geospatial information is needed for users and decision-makers in the response phase.

The book addresses a wide variety of research issues in the field of mobile mapping, ranging from system development to sensor integration, imaging algorithms and mobile data management. We envision that this book will provide researchers and practitioners a good overall view of what is being enveloped in this topical area.

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