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, water-based 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.

Dr. C. Vincent Tao is Director of Microsoft Virtual Earth Business Unit. Prior to joining Microsoft, he was Canada Research Chair in Geomatics, Professor and the Director of the GeoICT Lab at York University in Toronto, Canada. C. Vincent Tao was the Conference Chair of MMT'2004. He is currently serving as Chair for the ISPRS WG III/3 (2004-2008). His research interest ranges from on-line mapping, 3D web, local search, Lidar and image based feature extraction and 3D modeling.

Dr. Jonathan Li is Associate Professor at the Department of Geography, University of Waterloo, Canada. From 2001-2006, he was Assistant/Associate Professor and the Director of GeoVELab at Ryerson University in Toronto. Jonathan Li was the Conference Secretary of MMT’2004, and is currently serving as Co-Chair for the ISPRS WG IV/8 (2004-2008). His research interests include remote sensing, 3D urban modeling, intelligent object extraction from imagery, spatial data integration for disaster management, and WebGIS.
Advances in Mobile Mapping Technology

Edited by

C. Vincent Tao
Microsoft Corporation, Redmond, USA and York University, Toronto, Canada

Jonathan Li
University of Waterloo, Waterloo, Canada
Contents

Acknowledgements vii
Contributors ix
Foreword: Advances in mobile mapping technology xi
C.V. Tao and J. Li

Part 1. Terrestrial and airborne mobile mapping systems 1

Digital mobile mapping systems – state of the art and future trends 3
K.P. Schwarz and N. El-Sheimy

GEOVAN: The mobile mapping system from the Cartographic Institute of Catalonia 19
J. Talaya, E. Bosch, R. Alamús, A. Serra and A. Baron

ORTHOROAD: A low cost mobile mapping system for road mapping 31
G. Artese

A mobile mapping system for road data capture via a single camera 43
H. Gontran, J. Skaloud and P.-Y. Gilliéron

Airborne remote sensing supporting traffic flow estimation 51
D.A. Grejner-Brzezinska, C.K. Toth and E. Paska

Part 2. Multi-sensor integration 61

Performance analysis of integrated IMU/DGPS systems for mobile mapping systems 63
A.W.L. Ip, N. El-Sheimy and M.M.R. Mostafa

Appearance based positioning in urban environments using Kalman filtering 79
L. Paletta, R. Wack, G. Paar, G. Ogris and C. Le Gal

Multi-sensor systems for pedestrian navigation and guidance services 89
G. Retscher

Integrated technologies for augmented reality applications 95
A. Kealy and S. Scott-Young

Part 3. Image processing and object extraction 107

Constrained bundle adjustment of panoramic stereo images for Mars landing site mapping 109
K. Di, F. Xu and R. Li

Vehicle classification from LiDAR data to support traffic flow estimates 119
C.K. Toth and D.A. Grejner-Brzezinska
Acknowledgements

The editors would like to acknowledge the contributors and reviewers for giving their time generously to the preparation of this volume. The advice and counsel of Paul Aplin, ISPRS Book Series editor (2004–2008) is extremely valuable to improve the quality of this book. Assistance from Maxim Shoshany, former ISPRS Book Series editor was much appreciated. Special thanks go to the following review panel members for the selection and review of the papers published in this volume of the ISPRS Book Series: Rifaat Abdalla, Costas Armenakis, Michael A. Chapman, Dongmei Chen, Isabelle Couloigner, Kaichang Di, Jianya Gong, Cameron Ellum, Naser El-Sheimy, Wayne Forsythe, Dorota Grejner-Brzezinska, Ayman Habib, Boxin Hu, Xiangyun Hu, Yong Hu, Bo Huang, Andrew Hunter, Zhizhong Kang, Allison Kealey, Rongxing Li, Songnian Li, Xiaopeng Li, Yu Li, Hans-Gerd Maas, Mohamed Mostafa, Marcelo C. Santos, Jie Shan, Gunho Sohn, Charles Toth, Jianguo Wang, Jinling Wang, Shengrui Wang, Demin Xiong, Xuedong Yang, Robin Zhang, Yun Zhang, Detang Zhong, and Sisi Zlatanova.
Contributors

Ramon Alamús, Cartographic Institute of Catalonia, Parc de Montjuïc 08038, Barcelona, Spain, E-mail: ralamus@icc.es

Giuseppe Artese, Department of Land Planning, University of Calabria, Cosenza, Italy, E-mail: g.arte@unical.it

Anna Baron, Cartographic Institute of Catalonia, Parc de Montjuïc 08038, Barcelona, Spain, E-mail: abaron@icc.es

Ernest Bosch, Cartographic Institute of Catalonia, Parc de Montjuïc 08038, Barcelona, Spain, E-mail: ebosch@icc.es

Michael A. Chapman, Department of Civil Engineering, Ryerson University, 350 Victoria Street, Toronto, Ontario M5B 2K3, Canada, E-mail: mchapman@ryerson.ca

Kaichang Di, Mapping and GIS Laboratory, Department of Civil & Environmental Engineering and Geodetic Science, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Avenue, Columbus, OH 43210-1275, USA, E-mail: di.2@osu.edu

Haibin Dong, GeoVELab, Department of Civil Engineering, Ryerson University, 350 Victoria Street, Toronto, Ontario M5B 2K3, Canada, E-mail: haibindong@yahoo.com

Naser El-Sheimy, Mobile Multi-Sensor Research Group, Department of Geomatics Engineering, University of Calgary, 2500 University Drive NW, Calgary, Alberta, T2N 1N4, Canada, E-mail: elsheimy@ucalgary.ca

Christophe Le Gal, INRIA Rhône-Alpes, 655 Av. de l’Europe, 38330 Montbonnot-St. Martin, France, E-mail: Christophe.Le-Gal@imag.fr

Pierre-Yves Gilliéron, Geodetic Engineering Lab, Swiss Federal Institute of Technology, Bâtiment GC, Station 18, CH-1015 Lausanne, Switzerland, E-mail: pierre-yves.gillieron@epfl.ch

Hervé Gontran, Geodetic Engineering Lab, Swiss Federal Institute of Technology, Bâtiment GC, Station 18, CH-1015 Lausanne, Switzerland, E-mail: herve@topobox.org

Dorota Grejner-Brzezinska, Department of Civil & Environmental Engineering & Geodetic Science, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Avenue, Columbus, OH 43210, USA, E-mail: dorota@cfm.ohio-state.edu

Daniel Holweg, Department of Graphic Information Systems, Fraunhofer Institute for Computer Graphics, Fraunhoferstr. 5, 64283 Darmstadt, Germany E-mail: daniel.holweg@igd.fraunhofer.de

Xiangyun Hu, Leica Geosystems Geospatial Imaging, LLC, 5051 Peachtree Corners Circle, Norcross, GA 30092, USA, E-mail: xiangyun.hu@gmail.com

Yong Hu, GeoICT Lab, Department of Earth and Space Science and Engineering, York University, 4700 Keele Street, Toronto, Ontario, M3J 1P3, Canada, E-mail: yhu22130@gmail.com

Bo Huang, Department of Geography and Resource Management, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China, E-mail: bohuang@cuhk.edu.hk

Alan W. L. Ip, Applanix Corporation, 85 Leek Crescent, Richmond Hill, Ontario L4B 3B3, Canada, E-mail: AIp@applanix.com.

Allison Kealy, Department of Geomatics, The University of Melbourne, Melbourne, Victoria 3010, Australia, Email: akealy@unimelb.edu.au

Jonathan Li, Department of Geography, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2L 3G1, Canada, E-mail: Junli@uwwaterloo.ca
Foreword

C. Vincent Tao  
*Microsoft Corporation, USA and York University, Canada*

Jonathan Li  
*University of Waterloo, Canada*

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.

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.
About the editors

C. Vincent Tao
Director of Microsoft Virtual Earth Business Unit. Prior to joining Microsoft, he was Founder of GeoTango International Corporation, acquired by Microsoft, and Canada Research Chair in Geomatics, Professor and the Director of the GeoICT Lab at York University in Toronto, Canada. He was the Conference Chair of MMT’2004. He is currently serving as Chair for the ISPRS WG I/3 (2004–2008), Multiplatform sensing and sensor networks, and Chair of ASPRS Softcopy Photogrammetry Committee.

Jonathan Li
Associate Professor, Department of Geography at the University of Waterloo, Waterloo, Ontario, Canada. Prior to joining the University of Waterloo, he was Associate Professor and the Director of GeoVELab at Ryerson University in Toronto, Canada. He was the Conference Secretary of MMT’2004. He is currently serving as Co-Chair for the ISPRS WG IV/8 (2004–2008), Spatial data integration for emergency services.