FOREWORD

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In the fall of 1996, I was asked if I was interested in learning about and working with data using laser technology for mapping. The opportunity to experience new technology has always been of interest to me, so saying yes was easy, and I began a pursuit to understand everything about Light Detection and Ranging (lidar), the instrumentation, and the data characteristics. Six months later I was fully involved with a prototype lidar system full of technical challenges, which lasted about a year.

My first lidar epiphany occurred in the summer of 1997 when I draped color-coded, multiple-return lidar points onto a digital stereo pair of steep terrain, forested-covered terrain in Oregon on a softcopy workstation. I could "see" that the lidar had penetrated into the forest and "mapped" the structure of the trees and also the ground that I could not see on the stereo pair. I realized that this lidar technology would rapidly change the way the geospatial community approaches mapping the surface(s) on the Earth. That fall, I sat in on the first ASPRS Lidar Workshop.

The following year the instrumentation was stabilizing and the development of reliable direct georeferencing technology added confidence to the data collection process. The practitioners' focus shifted to software development, handling/processing "huge" data sets, and trying to quantify lidar map products in the context of existing map standards. Just about the time the software and computer processing time was acceptable, the vendors would introduce new lidar systems with increased hertz rate and even larger files. Even with these issues, lidar was creating quite a lot of interest in the mapping community, and resulted in (in fact, still is) exciting times. At the 1998 ASPRS Fall Conference, I taught my first Lidar Workshop.

Fast forward to 2012, lidar has become an accepted, often preferred, technology for mapping solutions. Enacting the technology, the mapping community throughout the world acquires, processes, validates, fuses with other sensor data, experiments, and archives the data (in a format standard), and visualizes the Earth and its features like never before. Lidar has its own vocabulary, definitions, and acronyms. Furthermore, there are new types of lidars being developed, and finally we have standards and metadata templates

The need for this Manual was recognized in 2010 during the Annual Spring Conference by ASPRS Executive Director, Jim Plasker, and ASPRS Communications Director/Associate Executive Director, Kim Tilley. The amount of interest in lidar technology and applications at the ASPRS conferences and the workshop attendance indicated that a manual was required. Within the ASPRS organization the Lidar Committee had been very active in organizing technical sessions and developing the ASPRS LAS Standard. In 2011, the ASPRS Lidar Division was created to establish the presence of lidar with photogrammetry, remote sensing, and GIS technologies. ASPRS is the leading professional association supporting lidar science and technology.

Because of my experience with lidar as a practitioner, teacher, and consultant, I was asked to become the editor for the ASPRS *Manual of Airborne Topographic Lidar*. For the content, I called upon technical experts to contribute to the individual chapters. From the onset of this project, I recognized that a reference book was needed for general use to document how this technology developed especially within the past 15 years, and introduce new sensors and applications. Additionally, I felt the need to emphasize "best practices" and real-world solutions for the user community. Also, since quality control and quality assurance are so critical to a successful data collection, processing, and validation, the reader will find several

subchapters to support QA/QC throughout the Manual. The arrangement of the content was designed to first review the basics, describe the approach for flight planning, completion of the collection, data processing, and product development. The authors responded well with figures, diagrams, and tables for visualization and ease of understanding.

Operationally, airborne lidar is fundamentally different from photogrammetry or surveying: all of the data collection, control, ground support, postprocessing, and QA/QC results in a "point cloud" which is "classified" and processed into product(s). The driving value of the point cloud is that it is natively 3D, georeferenced, and in the correct coordinate space. When necessary, other technologies (photogrammetry, breaklines, image fusion, lidargrammetry, static lidar, mobile mapping data) are introduced to generate specialized products. If required, lidar data can be processed very quickly.

The following summarizes the contents for each chapter:

- Chapter 1 (Introduction) is an overview of lidar technology, historical events leading to current technologies, and a list of Commonly Used Lidar Terms.

- Chapter 2 (An Overview of ALS Technology) begins with a detailed description of Operating Principals starting with the Electromagnetic Spectrum describing how lidar works with light followed by a summary of Laser Emissions, Absorption and Reflectance. The Features of a Laser Beam details the characteristics of a laser pulse, pulse frequency, beam divergence, and target interaction.

  The Key Elements of ALS Technology is a basic overview of laser and lidar history, technology, various scan patterns, and how lidar systems work.

  In Chapter 2 several types of lidar systems are described:
  · Fiber Optic Lidar Scanners and Applications
  · Full Waveform Lidar including key applications and processing
  · Flash Imaging Lidar – a detailed description, operational procedures, and applications
  · Geiger Mode Lidar – technology description, operations, and applications

- Chapter 3 (Enabling Technologies) is a thorough description of direct georeferencing (DG) as it relates to lidar: overview of GNSS positioning, sources of error, flight planning considerations, processing of DG data and quality control/quality assurance. The Ground Segment section addresses base stations and causes of error.

- Chapter 4 (Airborne Installation and Integration of ALS Systems) begins with a in-depth review of Rotary Wing Platforms based on many years of work to achieve engineering grade lidar data products and imagery; every aspect of low-altitude collection and processing is described in detail.

  The Fixed Wing Platform section covers typical installations of current systems and calibration procedures.

- Chapter 5 (Guidelines for Lidar Data Collection) is a comprehensive summary of "Best Practices" starting with mission planning, in-flight calibration, mapping various types of terrain types, and guidelines for pilots.

- Chapter 6 (Data Processing) begins with a suggested work flow (step-by-step) once the lidar data is collected in the field to delivery of the final product. Preprocessing and Post-processing and handling specific feature types are also discussed.

- Chapter 7 (Status of Lidar Industry Support Systems) starts with a sampling of the latest lidar system technologies available as of June 2012.

  The Lidar Data Management section is a review of the general management of lidar data acquisition through data delivery. Several figures illustrate the data flow and suggested organizational approach as well as best practices. This section ends with an extensive, detailed description of the LAS 1.4 Standard.

- Chapter 8 (Lidar Data and Complimentary Technologies) covers Lidargrammetry with excellent graphics illustrating workflow. Combined Photogrammetric and Lidar Mapping Processes is a comparison of strengths and weaknesses of each technology. Lidar/Image Combinations explains the process to achieve desired co-registration. The Quality Control section focuses on contours, 3D modeling, and urban applications.

- Chapter 9 (Accuracy Standards and Guidelines) address all of the factors that can affect lidar data quality.

  The section on Metadata Requirements is from the USGS-NGP Lidar Base Specification and is a suggested template for a Lidar-Specific Metadata Tags document.

  The Existing Standards and Guidelines section is the core section of the USGS Lidar Base Specification Version 1.0. which contains Conversion Factors, Acronym List, Glossary, and all operational aspects of the Base Specification. A specific section on QA/QC Reporting finishes this chapter.

- Chapter 10 (Applications) is a series of practical lidar applications:

  <u>Digital Elevation Models</u> describes six commonly derived products and definitions of surface interpolation methods, hydro-flattening, use of breaklines, hydro-enforcement, and lidar intensity data. This section contains many color figures illustrating the lidar data products and various terrain treatments.

  <u>Forestry</u> discusses the interaction of lidar pulses with forest vegetation cover, mapping the bare earth, measurement principals, and point density.

  <u>Corridor Mapping</u> is an overview of two examples: Transmission Line lidar mapping and software for vegetation management, and hazard identification; and Transportation Engineering which addresses DOT applications with airborne, static, and mobile mapping lidar data.

  <u>Flood-Prone Area Mapping</u> presents a case study for using lidar for FEMA Floodplain Assessment and Surface Water Modeling.

  <u>Building Extraction and Reconstruction</u> from Lidar Point Clouds describes the current state of reliably classifying and extracting buildings and roof vertices.

  <u>Airport Surveying</u> with lidar is described for a variety of applications in the context of the most current FAA Advisory Circulars with several specific examples.

Coastal Applications are described for coastal management, wetlands and habitat, storm damage, shoreline extraction, with an explanation of the USGS Experimental Advanced Airborne Research Lidar (EAARL) program.

Hydrologic Applications is a literature review for water resources and hydrological issues.

Natural Hazards addresses the constantly changing, dynamic environment of the Earth and recurring hazards with several applications for earth

- Appendix A (Geoid Height Models and Vertical Datums) focuses on geoid/datum applications specifically for lidar work and the models available, including USGG2009 and GEOID09.

- Appendix B (QC Process for Data Users) describes post-mission procedures for evaluating the quality of the final lidar data product. It was taken from and upcoming ASPRS Guideline being developed in conjunction with the USGS.

- Appendix C (Lidar Metadata) is a metadata example document extracted from the USGS Lidar Base Specification Version 1.0

- Appendix D (Acronyms) is a compilation of the acronyms used in the Manual.

I sincerely thank all of the contributing authors for their professional input, technical knowledge, experiences, and time spent writing and reviewing: all of which was volunteered. Several authors made significant contributions which are listed at the end of each chapter; the reader will recognize the author frequency of Jamie Young, Chris Parrish, Qassim Abdullah, and Karl Heidemann. The primary lidar system providers, Leica Geosystems, Optech, Riegl, and Trimble, generously provided information and graphics.

I appreciate the continued support from ASPRS, especially Kim Tilley to gently push me towards the "finish line" and Matthew Austin for his excellent graphic skills and layout for the entire book. I also recognize the love, support, and patience from my wife and life partner, Linda, who has been so understanding during this project and all the other projects during the last 36 years.

Finally, I would like to express my gratitude to all of my ASPRS colleagues for the past 40 years of professional involvement, technology applications, friendship, and collective progress towards our mutual interests. Often we have been "many in body with lots of ideas, but always of one mind" for the advancement and betterment of our profession. I also appreciate my students; I am the benefactor of their efforts and learn so much from them.

Lidar is basically about light, time, and knowing something about where you are. Be there.

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