Introduction to the *PE&RS* Special Issue on Advances in Terrestrial Lidar Techniques and Applications

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Since the appearance of the first commercial light detection and ranging (lidar) system over 20 years ago, the geomatics community has witnessed profound changes in how three-dimensional (3D) range data are acquired and the uses to which it can be applied. Airborne lidar (or airborne laser scanning , ALS) systems lead the way into the world of directly obtained point clouds (in contrast to photogrammetrically obtained point clouds that required a substantial amount of post processing) through the integration of three components of technology: laser scanners, inertial measurement units (IMU), and global navigation satellite system (GNSS) receivers. The net result was an exciting technology that proceeded to revolutionize the collection of terrain related point clouds. Shortly thereafter, terrestrial lidar (alternatively called terrestrial laser scanning, TLS) systems appeared and began a similar revolution in the way ground-based point clouds were acquired.

While airborne lidar systems predominately belong in the realm of government and large corporate institutions due to their higher infrastructure costs, terrestrial lidar systems are within the reach of a much broader range of practitioners. There is a terrestrial lidar system for nearly everyone. Systems range from simple stationary scanners best represented by the second-hand market (e.g., CYRAX 2500), to newer, faster, and more flexible panoramic scanners, and mobile laser scanning (MLS) systems (e.g., Riegl VMX-450). Currently, the fundamental directions of technological changes are in the speed of point acquisition. In 2001 the CYRAX 2500 a data rate of 1,000 points per second; in 2011 time of flight scanners achieve over 100,000 points per second and phase-based, and mobile scanners can generate over 1,000,000 points per second (Riegl VMX-450). Secondary to this are reduction in size, increase in range, and more flexibility in data control. TLS has adopted several ALS technologies such as Position and Orientation System (POS) platforms and waveform digitizing to create truly universal instruments. The result is that terrestrial lidar systems are now being seen on our roads, railways and waterways; there is now almost nowhere safe from the touch of a laser dot.

Today, the impact of terrestrial lidar can be seen in many areas of our day-to-day life, and it is not only traditional scanning instruments that are changing the way 3D data is being captured. There are laser cameras, stripe scanners, white-light scanners, and a multitude of hybrid technologies that are turning objects of all sorts into point clouds. One day, in the not too distant future, you will be selecting options for your new car which include autonomous navigation - which scanner do you want?

Hardware is only a part of the TLS scene, of course. Software is equally important, and so are the applications and operational techniques. And, what use would all the technology be if the quality of the XYZs were in doubt? Managing the various point cloud processing tasks is a significant issue, and it is not just a matter of computational and display speed. With the size of point cloud databases growing into the terabyte range, more efficient data structures are required to search neighborhoods for the appropriate points to be processed and displayed, and tools relating to simple concepts such as hidden point removal are now more necessary than ever before. What about data standards? How long will it be before we can easily exchange our point clouds? System calibration (particularly for mobile systems), automatic registration and georeferencing (particularly for static terrestrial scanners), blunder detection, data mining, modeling and texture mapping are all areas that receive attention from the research and professional communities alike. Hardware and software vendors do a good job of making their products user friendly, often to the point of removing the need for expertise. Fortunately, there is still a long way to go before the processing of complex point clouds into 3D models becomes a push-button affair, but, as you will see, that day is slowly dawning. In addition to our spatial world, we can see scanning of one type or another applied in entertainment and in gaming consoles. What this means is that, as users and developers of scanning technology, we should not sit on our hands and wait for clients to come to us; we need to be creative and proactive in pushing the boundaries of development and application.

Given the rapid and wide-spread adoption of terrestrial lidar the time is ripe for an expose of the current trends in this domain. It is in this environment that *Photogrammetric Engineering & Remote Sensing* brings to you this Special Issue on Advances in Terrestrial Lidar Techniques and Applications. Within the pages of this issue you will find eight articles that cover a wide range of topics. Of course, it is impossible to cover every possible aspect of TLS with such a small number of papers, so the eight we have chosen are ones that should appeal to a wide range of readers of this journal. The topics cover scanner calibration, point cloud management, data structures, feature extraction, mobile scanning, deformation monitoring, forestry, fluvial topography, heritage recording, and biomass estimation. We trust you will see beyond the specific topics and perceive where variations of the reported algorithms and methodologies might be applied in other areas so providing inspiration for the next Special Issue on this topic.

The first pair of papers (Ruther *et al*. and Wu *et al*.) is classified as conventional applications. These two, relating to heritage recording and deformation respectively, highlight two similar but contrasting applications of TLS to what used to be considered as mainstream surveying or photogrammetric tasks. In the case of heritage recording, there are still gaps between the practitioners' and the clients' expectations and understanding; between the ease of scanning and the difficulty of processing and managing data sets that easily exceed billions of points, and between the claimed performance of software and the reality of working with it. These issues, and more, are dealt with from the point of view of a group with in-depth experience for undertaking many projects of both large and small scale, throughout Africa. In contrast, deformation surveys do not necessarily require large volumes of data, but the results of such surveys are none the less significant to the client. Key to the success of using point clouds for deformation studies is in exploiting point clouds that cover the entire object thus allowing the whole structure to be monitored rather than specific segments or points. Under this premise automatically extracting deformations rather than objects is paramount, a solution is presented.

Mobile laser scanning has very quickly become widely adopted technology. Asset managers appreciate the benefits of having dense 3D point clouds, rather than 2D imagery or line drawings. While the 3D nature of a point cloud provides valuable information, the spectral data is also very useful. One use of such data is the accurate identification and location of road markings: a task that is important for many reasons. Asset managers need to know what is on their pavement surfaces and the condition. Map and navigation suppliers need to know what restrictions apply to various sections of roadway; and autonomous navigation systems will need to know and understand the current status of a lane, a turn, or an access restriction compared to the information stored in its database. An automated method for the extraction of road markings is presented by Yang *et al*. But how useful would such a method be if the point cloud itself was in the wrong place? As with ALS systems, the calibration of mobile lidar systems is critical to the accuracy of the data they generate. Glennie reports on the calibration and assessment of one of the newer mobile scanners, i.e., one that is capable of generating 1.3 million points per second.

Environmental issues are facing us every day. Air pollution, noise pollution, global warming, vegetation decimation, the health of our streams and waterways, all affect the quality of our lives. In another parallel to our airborne lidar cousins, terrestrial lidar systems are now being applied to the measurement of biomass. Can terrestrial point clouds complement airborne point clouds to allow more accurate estimations of biomass? How can TLS data be used to estimate tree biomass? How can the complexity of a stream be represented? Two groups of researchers (Ku *et al*. and Resop) tackle these problems and show us new ways of looking at tress and streams respectively.

It could be argued that each of the six papers already mentioned simply represent data modeling problems, but we know this is not true. There is a purpose behind each of them that is driven by a need for spatial data in a particular domain. However, where would these applications be if it was not for those of us that enjoy looking for ways to make a better mouse trap? With the ability to generate vast volumes of point clouds that seemingly outstrip the pace at which our computers can efficiently process them, managing that data efficiently and effectively is imperative. It is interesting that the last two papers (Gong *et al*. and Schilling *et al*.) also are related to trees. One presents a novel tree structure for the organization of point cloud data and the other presents a novel data structure to represent a tree. The presented algorithms allow the large point cloud data sets to be managed efficiently and automatically and to create meaningful representations of the objects with which we expect to work. Is that not why we collect so much data in the first place?

The impetus for this Special Issue grew out of an ISPRS sponsored event: Terrestrial Lidar 2010 which was held in Zhengzhou, Henan, China in October 2010. The event was exciting because many of the papers presented belonged to the young students of the TLS discipline. Their work was innovative and interesting, and encouraged us to propose this Special Issue in order to highlight the work of the new scholars in this field. The majority of the papers presented here represent the work of such younger scholars drawn from across the world. We are encouraged to see that the comparatively new technology of TLS that has a vanguard of bright, young people leading the way: exactly what we need to ensure that TLS stays at the forefront of spatial data capture.

Of course no issue of a journal would be possible without the efforts of the reviewers. Our gratitude goes to those who poured over the manuscripts and provided the critical feedback to us and to the authors necessary for successful publication. Their efforts were especially helpful to and appreciated by our younger authors. Special thanks go to Dr. Haiyan Guan for her assistance in handling the peer-review process. Finally, we wish to thank the Editor-in-Chief, Professor Russ Congalton and the Manuscript Coordinator, Ms. Jeanie Congalton for their patience and guidance.

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