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State of the Art in Laser Scanning

JUHA HYYPPÄ, Masala

ABSTRACT

Laser scanning (LS) has dramatically developed since the first commercial Airborne Laser Scanner in 1994. Since then Terrestrial Laser Scanning (TLS) and Mobile Terrestrial Laser Scanning (MLS) have shown new possibilities for modelling of the built and non-built environment. Due to the rapid development of LS in various forms of new applications and methodologies, some new possibilities of LS are demonstrated in the following using the latest works done at the Finnish Geodetic Institute as examples. The paper concludes with an outlook to the next years of research needs with topics such as ALS in forestry, intensity calibration of LS, MLS accuracy, MLS for change detection, integrated use of MLS and hyperspectral sensing, use of mini-UAVs for LS and indoor MLS/mobile mapping.

1. INTRODUCTION

Laser scanning (LS) is a remote sensing technique based on ranging measurements used, e.g., for mapping of topography, vegetation, urban areas, ice and infrastructure. It is also often referred to as Light Detection And Ranging (LiDAR) because it uses a laser to illuminate the earth's surface and a photodiode to register the backscatter radiation. Since the development of the first laser in 1958, lasers have been widely used for military intelligence and surveying. Some of the first studies using laser to remote sensing included airborne oceanographic lidar for measuring chlorophyll concentration and other biological and chemical substances, military, bathymetry and forestry applications. After GPS, IMU and scanning mechanism were attached to laser ranging measurements, first for the military purposes in 1980s, and later on for surveying purposes, field what is currently known as Airborne Laser Scanning (ALS) was born. Commercial ALS systems have been available since 1994. Currently ALS is extremely feasible for large area mapping with high accuracy e.g. for elevation and forest modeling. Elevation accuracy of 5-10 cm is common, where as planimetric accuracies ranges between 20-80 cm depending on the flying height and IMU characteristics. Several countries have performed or are collecting country-wide LS data for multipurpose use. Elevation models, standwise forest inventory and corridor mapping are good examples of commercial activities. In Scandinavia, standwise forest inventory is increasingly assisted by ALS reducing the costs of inventory data.

Terrestrial Laser Scanning (TLS) differs from ALS in that the scanner is mounted in a fixed position, i.e. on a tripod, and the ranging takes place across a large spherical angle-of-view. Scans are primarily used for the reconstruction of man-made targets in e.g. architecture, civil engineering, archaeology, cultural heritage, and robotics (Vosselman & Maas 2010). TLS is feasible for detailed small area surveys having typically radius for high-density scan less than few tens of metres. Processing of TLS is time consuming for large areas having more than hundreds of scans. A short summary of recent TLS studies focusing on modeling of the environment includes studies such as Mazzarini et al. (2008), Heritage et al. (2009), Hiremagalur et al. (2009), Hodge et al. (2009), Kersten et al. (2009), Lee et al. (2009), Pu and Vosselman (2009), Sturzenegger and Stead (2009), Tansey et al. (2009) and Teufelsbauer (2009). A raw scanned data set contains a huge number of points, and the recognition of objects in point clouds is essential for 3D object recognition. Data from TLS and close-range images are used only for small area modelling due to the slowness of acquisition and manual registration.

Mobile Laser Scanning, also called Mobile Terrestrial Laser Scanning, (MLS) is currently a rapidly developing area in LS where laser scanners, GNSS and IMU are mounted onboard a moving vehicle. MLS can be considered to fill the gap between ALS and TLS. In MLS, the data collection can be performed either in so-called stop-and-go mode or in continuous mode. The stop-and-go mode corresponds to conventional TLS measurements and therefore MLS, hereafter, refers to the continuous model, i.e. the use of continuous scanning measurements along the drive track. In addition to laser scanners, the data acquisition sensors can include, e.g., digital cameras or video cameras. Data provided by MLS systems can be characterized with the following technical parameters: a) point density in the range of 100-1000 pulses per m^2 at the 10 m distance, b) distance accuracy of 2-5 cm, and c) operational scanning range from 1 to 100 m. Recent studies on MLS systems and their accuracy as well as environmental modeling done with MLS can be found in Barber et al. (2008), Brenner (2009), Clarke (2004), El-Sheimy (2005), Früh and Zakhor (2004), Graham (2010), Haala et al. (2008), Hassan and El-Sheimy (2008), Jaakkola et al. (2008), Kukko et al. (2007), Kukko and Hyyppä (2009), Lehtomäki et al. (2010), Li et al. (2004), Lin et al. (2010), Lin and Hyyppä (2011), Manandhar and Shibasaki (2002), Petrie (2010), Shen et al. (2008), Steinhauser et al. (2008), Tao and Li (2007), Weiss and Dietmayer (2007), Yu et al. (2007) and Zhao and Shibasaki (2003a,b, 2005). Currently, there is an increasing number of research systems (e.g., Geomobil (ICC), GeoMaster (University of Tokyo), Lara-3D (Ecoles des Mines de Paris), ROAMER and Sensei (FGI), and commercial and custom-made systems (for example Optech Lynx mobile mapper, Streetmappers of 3D Laser Mapping based on Riegl scanners, Mitsubishi using Sick LMS 291, Riegl VMX-250 integrating two Riegl VQ-250 scanners, Topcon-made systems to Google IP-S2 having three Sick LMS 291 scanners, Trimble Trident-3D based on Sick and Riegl scanners Petrie, 2010). The amount of data produced by such systems is huge (at the rate of 0.25-1 M pts/s), and manual processing of the data is very time-consuming, which prompts a need for automated methods that decrease the amount of manual work required to produce accurate 3D models. At present, it is possible to use software and methods developed for terrestrial and airborne laser scanning, but due to different scanning geometry, different point density and the fast processing needed, algorithms for MLS data processing need also to be developed separately (Jaakkola et al., 2008).

Due to the rapid development of LS in various forms of new applications and methodologies, in the following some new possibilities of LS are demonstrated using the latest works done at the Finnish Geodetic Institute as examples. The following new possibilities are depicted in detail: ALS in forestry, intensity calibration of LS, MLS accuracy, MLS for change detection, integrated use of MLS and hyperspectral sensing, use of mini-UAVs for LS and indoor MLS/mobile mapping.

2. STATE-OF-THE-ART IN ALS AND FOREST INVENTORY

Trees are important topographic object in various applications. They are vital in forest field measurements (diameter breast height as an important measure) and modelling (many models based on individual tree properties). Position and size of trees are important for city maps, city planning and computer graphics producing virtual environments. Trees are also important for carbon balance of the Earth. Forests have also high economic and ecological importance, e.g. in Finland, about 76% of the land area is forested, which is the highest percentage amongst the European countries. International interest in biomass detection is strongly related to forest health photosynthetic activity and other processes related to carbon cycle and climate variation. There is a growing need and constant shortage of data for improved tools for monitoring, e.g., biomass change, photosynthetic activity, and other processes related to carbon cycle and climate variation.

Approaches to derive forest information from airborne laser scanning (ALS) data has been conventionally divided into two groups, those based on statistics of canopy height (called as area-based techniques, e.g. Hyyppä and Hyyppä, 1999, Næsset 2002), and those based on individual tree detection (called as individual-tree-based techniques, e.g. Hyyppä and Inkinen, 1999). Presently area-based techniques are operationally applied in Scandinavian standwise forest inventory and Erik Næsset will be granted Wallenberg Prize for the developments in area-based techniques in October 2011. The area-based methods does not utilize neighborhood information of laser returns, where as in individual-tree-based methods the neighborhood information is applied using pattern recognition to locate individual tree positions and to derived attributes of individual trees. As already stated in earlier individual-tree-based techniques, the tree position, crown size and tree species can be measured from the ALS data at individual or tree group level, and other individual tree attributes can be estimated using e.g. the measured features. Since Villikka et al. (2007), also density-related and height-related features derived from first and last pulse ALS data, have been used in the estimation of tree attributes of individual trees. A large number of various forest parameters (e.g. tree height, basal area, volume, LAI, tree species proportions, growth, above-ground and below-ground biomass, proportion of live and dead tree biomass, diameter, diameter distribution, height-diameter curve, site index, defoliation, woody debris, fire fuel metrics) have been shown to be extracted from ALS data during the last 10 years. In addition to conventional inventory of the canopy, other interesting applications have been created using ALS, such as bird habitat modeling, forest gap dynamics, detection of small trees in the boreal-alpine transition zone as indicator of global change, assessment of property for taxing, traffic noise assessment, impact assessment, documenting protected environment, mapping of forest damage, snow depth distribution, forest road design, quantity of seedlings, and determination of stands first thinning maturity.

Individual-tree-based and area-based methods are increasing converging and even area-based techniques can utilize effectively individual-tree-detection and features derived from individual trees or group of trees, thus the importance of individual tree detection techniques is increasing. In recent studies of individual-tree-based inventory, it has been highlighted that the key issue is the individual tree detection algorithms (e.g. Yu et al. 2010). Originally, individual tree recognition started with manual interpretation from analogous aerial images, and then continued with attempts to automate this task (e.g. Gougeon and Moore, 1989). During the last years, several attempts to improve both image and laser based individual tree detection have been reported. An international comparison of using ALS for individual tree detection was reported in Kaartinen and Hyyppä (2008). In that, it was concluded that the individual tree extraction method is the main factor on the achieved accuracy, and point density increase is marginal to the method variation during the EuroSDR/ISPRS Tree Extraction comparison. It was shown also that there is a need to calibrate the results of individual tree based methods confirming the converging of the methods. Both methods have started to use non-parametric estimation techniques, thus, the main difference in the methods is mainly based on the features used, either individual-tree-based features or percentile-type features not utilizing the neighborhood information of the samples.

Currently the state-of-the-art in ALS and forest inventory and future research needs can be summaries as following:

- Individual-tree-based and area-based methods are increasing converging, e.g. non-parametric estimation techniques used increasingly for all inventories
- Individual-tree inventories are typically calibrated with sample trees to reduce the bias of individual tree estimates
- Both individual-tree based inventory and area-based inventories are calibrated with field reference plots to reduce the bias for larger areas.

- Full-waveform ALS is expected to improve the quality of ALS assisted forest inventories. Improvements are studied both at area-based and individual-tree-based inventories.
- Tree species recognition is currently the major lack in operative inventories, and, thus, concepts such as integration of LS and hypespectral imaging or deriving tree species from intensity and waveform are studied.
- TLS and MLS techniques are currently being studied to automise the plotwise forest inventory, and especially for the collection tree diameters, basal area and ideally for the reconstruction of the whole trees in the plots. When airborne data is used for individual tree inventory, then field reference trees (from TLS) needs to be matched with trees found in ALS. This allows also the possibility to correct the registration mismatch between the data sets. At area-based inventories, the matching is done at plot level and planimetric registration errors cannot be carried out.

3. STATE-OF-THE-ART IN INTENSITY CALIBRATION OF LS

In laser scanning, intensity (I) value is often recorded for each point as well. The intensity represents the momentary measured power or amplitude value of the received pulse for discrete return lasers. With full-waveform lasers, the total received power corresponding to the backscattering cross-section can be calculated from the intensity waveform. The need for radiometric calibration of the LS intensity stems from the possibility of using calibrated intensity as additional feature for object classification and object characteristics estimation. Some possible examples of using calibrated intensities include tree species classification, object classification in MLS, NDVI of multi-wavelength intensities, and street sign detection in MLS. Even uncalibrated intensities can be used to register LS and imagery data.

Radiometric calibration of LS intensity data aims at retrieving a value related to the target scattering properties, which is independent on the instrument or data acquisition parameters. There are two types of calibration, i.e. relative and absolute calibration.

Relative calibration of LS intensity means that measurements from different ranges, incidence angles and dates are comparable for the same system. The factors affecting received intensity in the relative calibration are spreading loss, backscattering properties versus incidence angle, transmitter power changes, especially when PRF is changed, and atmospheric properties. Since most of the material are rough at LS wavelengths, the effect of incidence angle is small in ALS, but has to be taken into account in TLS and MLS where incidence angles of higher than 20 degrees occur.

Absolute calibration of LS intensity means that the obtained corrected value of intensity describes the target properties and corresponding values obtained from various sensors are directly comparable. In absolute calibration, the obtained and relatively corrected intensity values are linked with known values (e.g. backscattering coefficient or reflectance) of the reference objects. The methods, how absolute calibration can be carried out, include 1) use of tarps (Kaasalainen et al. 2005) or 2) use of gravel or other natural material (Kaasalainen et al. 2009) the reflectance/backscattering coefficient is known. The tarps, gravels and natural materials can be measured using e.g. laboratory systems allowing backscattering measurements, calibrated NIR camera operating in the same wavelength region, and calibrated reflectometer. Since in airborne surveys it is hard to get simultaneous intensity reference measurements done, it is possible to assume basckscattering properties of objects, for example, based on backscattering library data.

As the interest in the radiometric calibration has increased during the recent years, a large number of studies have been published in the recent years. The first radiometric calibration methods and their applications have been presented by Coren and Sterzai (2006), Ahokas et al. (2006), Wagner et al. (2006), Höfle and Pfeifer (2007), and Kaasalainen et al. (2009). Physical concepts of laser scanner intensity calibration are depicted in Wagner (2010).

EuroSDR (European Spatial Data Research) hosted a project "Radiometric Calibration of ALS Intensity" during years 2008-2011, in co-operation with FGI and TU Wien, and the following conclusions were made to the LS calibration:

1. The momentary return recorded as intensity is assumed to correspond to backscatter power in discrete return lidars. This is roughly valid only with flat surfaces where beam is fully filled with the surface, therefore, this type of calibration can be made with ”only pulses” (first of many, last of many, intermediate returns are obtained with beams partly seeing multiple targets and even range correction, thus, is unfeasible to be calibrated without further work (see Korpela et al. 2010b)
2. Radiometrically calibrated products are
   - Cross-section σ (vs. radar cross-section [m^2]) with full-waveform system
   - Backscattering coefficient γ *or* σ^0 (area-normalized cross-section values), σ is also sometimes related to the cross-section of the incoming beam, $A_i \cos\theta$ (referring to γ) could be used instead of the illuminated target area A_i (referring to σ^0)
   - Backscattering coefficient only approximated in discrete return systems since the echo width is assumed to be constant.
   - See Wagner (2010) for more details.
3. Meta data should be saved for each flight track
   - System, system properties (transmitter power statistics, e.g. versus PRF/PRR changes) should be documented
   - GNSS and IMU tracks are need to calculate exact range and incidence angle information along the track
   - Traceable AGC allowing original intensity calculated from AGC information is needed. For AGC calibration, the reader is referred to Vain et al. (2010). In the present version of the Leica laser scanner, slower changes of AGC are easier to be corrected than in the case of Vain et al. (2010) where AGC was rapidly changing. Even without AGC correction, Korpela et al. (2010a) produced good classification accuracies for objects.
   - Atmospheric information (of each acquisition period) even though it presently seems that standard atmospheric value are adequate for relative calibration of intensity
4. Mapping agencies and companies should start to provide relatively calibrated intensities for the users as soon as possible, since that should not provide additional costs. Production of relatively calibrated intensities needs some changes to the processing software.
5. In the processing, radiometric strip adjustment (parallel information in overlapping strip should be used to enhance intensity) is recommended for future. So-called model based correction (based on lidar equation) is recommended to be used for calibration (see e.g. Wagner 2010, Höfle and Pfeifer 2007). Experience has shown that system parameters, ranges and even systems may change in one complete laser survey. Also, overlapping information may be used to minimize variation in the data and to determine constants in the correction formula (Gatziolis 2011).
6. Calibrated NIR camera, reflectometer or laboratory systems are needed for high-accurate intensity radiometric absolute calibration. Presently FGI and TU Wien have needed capacity. Since natural targets change properties as function of time, need for

simultaneously or near-simultaneously collected measurements is needed. That is easier to accomplish with TLS and MLS, but harder at ALS. It should be noticed that objects have different properties at different wavelengths (reference measurements needs to be made at same wavelength). Since simultaneous measurements are relatively easy to be accomplished with TLS and MLS, absolute intensity calibration is recommended in surveys where intensity is applied.

7. Better documentation of systems for system changes is needed allowing more robust calibration. Presently in absolute calibration, every campaign has to be separately absolutely calibrated since there is no information of system changes between the campaigns. Work preserving absolute calibration of the LS systems is needed.
8. Since many laser scanners utilize a look-up-table (LUT) for the correction of the range information as a function of intensity, and objects having various intensities are necessary for absolute calibration of scanners, it could be possible to improve both the absolute calibration of intensity and range LUT accuracy with the same calibration.
9. Data producers should use better the dynamics of the intensity, e.g. in some campaign (Kaasalainen et al., forthcoming) the intensity raw values varied between 0-150 counts (sensor units) instead of 0-4095 counts allowed by the 12-bit format.
10. Incidence angle effect is small until 20 degrees off nadir. In MLS and TLS, spread loss and incidence angle effects are mixed and incidence angle has to be taken into account since they exceeds the 20 degrees.

4. MLS ACCURACY

The MLS accuracy is limited mainly by the GNSS signal degradation in urban and forest-covered environments. This disadvantage of GNSS can be partly corrected by appropriate data fusion approach of GNSS (GPS), IMU and odometer. The most common data fusion approach is to use Kalman filter of different flavors.

The MLS accuracy has been studied in good GNSS conditions. According Haala et al. (2008), feasibility of the StreetMapper system to produce dense 3D measurements at an accuracy level of 30 mm in good GNSS conditions was demonstrated. Further, remaining differences between the point clouds from different scanners due to imperfect boresight calibration of the upward looking scanner could be corrected during post processing. Similarly, in the EuroSDR Mobile Mapping project “Road Environment Mapping Using Vehicle-based Laser Scanning”, a test site was established in Espoonlahti (Finland) for accuracy assessment of MLS systems in good GNSS conditions. A 1700-m-long test site collected with terrestrial scans, and ground control points (GCP) around the test site using repeated VRS- and RTK-GPS-measurements (Kaartinen et al., forthcoming) was used as reference for planimetric and height accuracy assessment of three mobile laser systems (two commercial and FGI ROAMER). References for planimetric accuracy included poles, building corners and curbs. Points were cut into two sections for measurements (points below 50 cm above ground for pole and curb targets and 1 m section for 5 m above ground for building corners). Planimetric accuracy of the systems varied between 15 to 29 mm even though the calibration between several scanners of the systems was not optimal. The planimetric error increased as a function of range, especially with two systems out of three. Height deviation of the systems varied between 13 to 39 mm. Height deviation was affected by roll error in some systems. As a summary, major errors sources in all systems were due to GNSS/GPS, errors in relative orientation between GNSS/IMU and sensors and errors in relative orientation between scanners.

Under degraded GNSS conditions, Haala et al. (2008) reported a georeferencing error up to 1m for the horizontal position. They also reported that despite the limited quality of the absolute accuracy, 3D point measurements during bad GNSS conditions are still useful, especially if mainly their relative position is exploited. They gave an example that the standard deviation of such data is only 5 cm if points from two scanners are combined and 2.6cm if the points are separated for each scanner. Thus, such data is feasible for the extraction of features of windows or passages, if a certain error for their absolute position is acceptable.

Since accuracy of best laser systems in MLS are capable to estimate range with less than 2 mm and direct georeferencing dominates in the error process, improvement of georeferencing solution is needed. Possibilities to improve the georeferencing solution includes

- Better calibration of relative orientation of the multiple scanners used in the single MLS system
- Better calibration of relative orientation of the MLS system in general
- Automatic/manual detection of objects (the position of which is known) from the roads sides that could be used to improve the georeferencing
- Development of new data fusion approaches for MLS

5. MLS FOR CHANGE DETECTION

Modern road environment faces a lot of changes all the time. Updating of e.g. road map for cars and pedestrians is done mainly manually. Multitemporal MLS provides possibilities to fully automatically monitor almost all changes in the road environment. Satellite images are used for change detection by applying image differencing and, thus, multitemporal road environment point clouds can be used to detect changes in a similar way. A change detection method should automatically find the changes in the studied area and update the corresponding map, model or database accordingly. Change detection can be done in many different ways: comparing raw point clouds, colored point clouds, voxels, range images, surface models or modeled objects. The simplest and most universal way to do comparison between two point clouds is to measure distances between points in different point clouds and see if a point in one point cloud has neighbors nearby in the other point cloud, otherwise the point is marked as a potential change. Adding color data into the point clouds gives additional clues about the possible changes. If colors are used, caution is recommended, since e.g. illumination changes, reflection and registration errors may have negative influence on usability of color information. In some cases, these problems can be reduced by calibration processes in order to produce comparable colors. Voxel-based processing could prove to be very efficient as the processing is heavily simplified when compared to point-wise processing. This is caused by grouping multiple points into a single voxel, which also inherently gives the local neighborhood of any given voxel or point. 3D point clouds from MLS systems can be converted to 2D range images in order to apply existing image processing techniques. One advantage of using image planes and highly developed and powerful image processing techniques is that the processing speed typically increases significantly.

The possibilities of MLS for mapping topographic changes has been demonstrated in Vaaja et al. (2011). By test locating in a 58 km-long tributary of the River Tenojoki (Tana) in the sub-Arctic and using a mobile laser scanner ROAMER mounted on a boat and on a cart with a fixed-point terrestrial laser scanner data as reference, as well as a difference elevation model technique, Vaaja et al. (2011) demonstrated the capability of MLS (on a boat) in erosion change mapping, using sandbars and river banks as examples. The measurements were based on data acquisitions during the late summer in 2008 and 2009. The coefficient of determination (R^2) of 0.93 and a standard

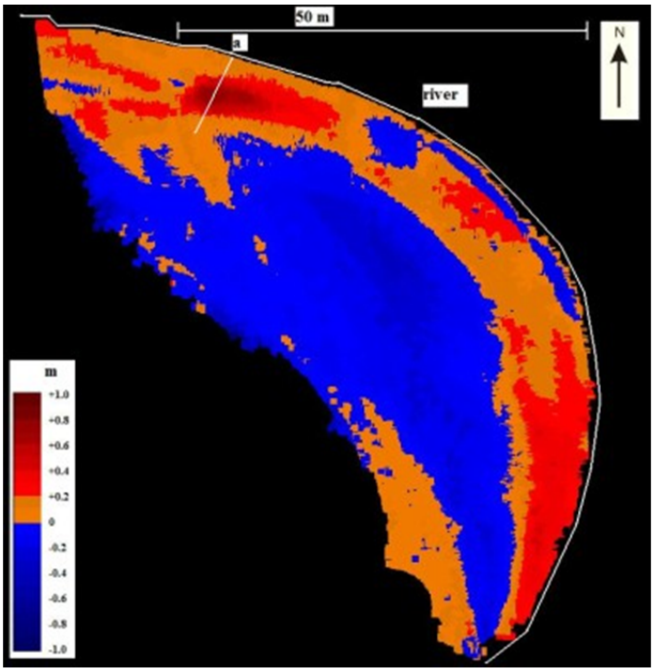

Figure 1: Map of topographic changes derived with bi-temporal MLS data in river Tana. Vaaja et al. (2011).

error of 3.4 cm were obtained as metrics for topographic change mapping based on mobile laser scanning. This, however, required a systematic elevation error calibration of the data.

The possibilities of MLS for mapping biomass changes has been reported e.g. in Jaakkola et al. (2010) and Lin et al. (2011).

MLS is extremely feasible for change detection, but the changes due to geometry have to be separated to those due to real changes in the objects.

6. USE OF MINI-UAV FOR LS

The use of mini-UAV for laser scanning is a new research area (e.g. Zhao et al. 2006). Zhao et al. (2006) depicted a remote controlled helicopter supplied with navigation sensors, namely GPS, and laser range finder or altimeter to be used for future topographic surveys. Use of larger UAV having a laser scanner includes studies such as Nagai et al. (2009). In Nagai (2009) the focus is on integrating a 330 kg helicopter UAV with a laser scanner, CCD cameras, IMU and GPS. Jaakkola et al. (2010) presented a low-cost mini-UAV-based laser scanning system, the quality of the system and its feasibility for tree measurements. The system consisted of a number of measurement instruments: a GPS/IMU positioning system, two laser scanners, a CCD camera, a spectrometer and a thermal camera.

Objects can be characterized in the optical and infrared regions for example by their geometry, reflectance or backscattering properties as a function of wavelength or frequency, and bidirectional reflectance distribution function. The knowledge and interaction of the electromagnetic radiation between the object and these characteristics gives the needed information for developing intelligent processing methods and applications in the field of remote sensing. The development of methods and applications typically require better resolution of images or higher sampling of the objects in order to be able to determined optimal and cost-effective acquisition parameters.

Method development and basic research could utilize the mini-UAV LS, e.g., in the following way:

- Multitemporal ALS surveys are expensive and complicated to be arranged. The use of mini-UAV LS allows the collection of multitemporal point clouds in an effective and research-friendly way.
- Development of new mapping concepts. The mini-UAV systems, such as Sensei (Jaakkola et al. 2010) allow new remote sensing concepts to be studied, e.g., integrating the BRDF (directional reflectance distribution function), hyperspectral response and geometry of the object.

7. INTEGRATED USE OF MLS AND HYPERSPECTRAL SENSING

Present trend in mobile mapping is the collection of images and possibly laser scanner point clouds. Concerning automatic extraction of objects and classification of objects, the point clouds information has been shown to provide relatively high accuracies. By using both the images and point clouds, the objects classification accuracy can be enhanced. If the automatic modeling of the environment gets increased emphasis, higher accuracy for object classification can be obtained by integrating laser point clouds with hyperspectral data. Adding hyperspectral sensors to MLS is a straightforward process, since both the LS and hyperspectral requires direct georeferencing (GNSS/IMU). Hyperspectral images have improved classification capability over objects where as the image resolution is decreased when compared to digital camera images. Considering the registration problems between images and point clouds, it may be even possible to produce hyperspectral LS without passive imagery as shown in Kaasalainen et al. (2007).

Puttonen et al. (2011) presented the first results of using mobile laser scanning and hyperspectral sonsor data in tree species classification. Tree species classification and the separation of coniferous and deciduous trees were carried out in a city experimental garden in the City of Espoo, Finland. The results demonstrated that a fused data set consisting of LS-derived and hyperspectral features outperformed single-source data sets (either LS or hyperspectral) by a significant margin. The best overall coniferous and deciduous tree separation result was 95.8% when two LS-derived shape and two hyperspectral features were applied using a Support Vector Machine (SVM). The corresponding best tree species classification result including ten species in the analysis was 83.5%. The results were obtained using a low number of predictors to give a more realistic view of the potential of the data.

The concept shown in Puttonen et al. (2011) can be used in general towards improved classification of road-side environment using both LS and hyperspectral sensors. The combined data of LS and hyperspectral is expected to be even more feasible for change detection processes. The major bottleneck in hyperspectral data processing in mobile context is the illumination changes (bidirectional reflectance distribution function, BRDF) of the environment. In the mobile use, the BRDF changes are much more dramatic compared to aerial imaging, since imaging is done in all geometries (e.g. towards to sun and along the sun). Correction and understanding illumination changes is the major drawback in using passive hyperspectral with LS data. Therefore, it is expected that in future active multispectral or hyperspectral LS, which proper radiometric calibration scheme, is an important technique in mobile mapping. With active hyperspectral sensing, the effect of BRDF is negligible. The disadvantage of the active hyperspectral sensing is the costs of the systems and more limited possibility to have high number of channels.

8. INDOOR MAPPING

The need for 3D maps does not stop to outside environments. There is also an increasing need to get 3D models inside the buildings. Presently inside models are created using 2D floor plans and images or using multiple scans of TLS. When the indoor models become more complex, there is also a need for more flexible mapping systems. Indoor mobile mapping or indoor mobile laser scanning is a new coming trend in mobile mapping. According to the manufacturers, "Indoor Mobile Mapping Solution creates an excellent 2D floor plan which contains a level of detail previously unavailable. Every chair, every object in the interior will appear in the floor plan. The floor plan contains exactly what is in the space as compared with conventional floor plans which are drawn by hand." (Trimble, 2011)

Indoor mobile laser scanning is based on high-quality laser scanner and high-quality IMU technology. Odometers and other sensor technology will help in improving the quality. The needed georeferencing solutions of indoor mobile laser scanning require improvements beyond those needed for outdoor MLS.

9. CONCLUSIONS AND OUTLOOK

Laser scanning is a new and emerging technology and perhaps an own discipline in the future. It is hard to describe the state-of-the-art of LS with about ten pages, therefore I selected to pick some demonstration case studies to show the potential of LS for near-future research needs and applications. The paper concludes with an outlook to the next years of research needs with topics such as ALS in forestry, intensity calibration of LS, MLS accuracy, MLS for change detection, integrated use of MLS and hyperspectral sensing, use of mini-UAVs for LS and indoor MLS. The fast adaptation of LS into society and industry has been due to the high potential of the LS in various applications. Due to high quality in the data, even non-optimal methods and processes have resulted in satisfaction of the end users. But that does not stop the need to have more benchmarking activities related to extraction methods and the need for new research.

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