Photogrammetric Week '13 Dieter Fritsch (Ed.) Wichmann/VDE Verlag, Belin & Offenbach, 2013

Unconventional LIDAR Mapping from Air, Terrestrial and Mobile

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ABSTRACT

Annually, the LS business market is growing by 15 %. In addition to surveying, several fields, such as robotics, are working closely to laser scanning. There are also large number of other technological trends that will modify the area what we know today. The paper summarizes some coming developments with laser scanning, especially related to unconventional work of LIDAR mapping from air, terrestrial and mobile. We propose that after Mobile Laser Scanning, there will be research area of Personal Laser Scanning, active multispectral laser scanning may be a practical solution for automated object recognition instead of full-waveform technology and active hyperspectral laser scanning, and 3D game engines are future visualization technique merging physical and virtual worlds. Multi-platform MLS system working on moving car, trolley, boat, sledge, all-terrain vehicle and person carrying the system have been demonstrated. The works have been implemented by the Centre of Excellence in Laser Scanning Research at Finnish Geodetic Institute, www.fgi.fi/coelasr. This paper also aims to stimulate the development of laser scanning into more unconventional usages.

1. INTRODUCTION

Laser scanning is a surveying technique used for mapping topography, vegetation, urban areas, ice, infrastructure, and other targets of interest. More precisely, Airborne Laser Scanning (ALS) is a method based on Light Detection and Ranging (LIDAR) measurements from an aircraft, where the precise position and orientation of the sensor is known, and therefore the position (x, y, z) of the reflecting objects can be determined. In addition to ALS, there is an increasing interest in Terrestrial Laser Scanning (TLS), where the laser scanner is mounted on a tripod or even on a moving platform, i.e. Mobile Laser Scanning (MLS). LS is sometimes referred to as LIDAR because of its central role. The basic principle of LIDAR is to use a laser to illuminate an object and a photodiode to register the backscatter radiation and to measure the range. The output of the laser scanner is then a georeferenced point cloud of LIDAR measurements, including the intensity and possibly waveform information of the returned light.

The history of LS is rooted in the history of LIDAR technology. Secondly, LS has benefited from the development of Global Navigation Satellite Systems (GNSS) and inertia sensors or precise positioning and orientation measurements. In 1975, NASA and other organizations developed an airborne oceanographic LIDAR system for measuring chlorophyll concentration and other biological and chemical substances. Non-scanning (profiling) profiling LIDAR was used for bathymetry, forestry and other applications in the 1970s and 1980s, which established the basic principles of using lasers for remote sensing purposes. LS has also history in the military area. The first public experiments with modern LS instruments were conducted in the early 1990s, and in 1993 the first prototype of a commercial ALS dedicated to topographic mapping was introduced.

A typical LS system consists of (1) a laser ranging unit (i.e. LIDAR) (2) an opto-mechanical scanner, (3) a position and orientation unit, and (4) a control, processing, and storage unit. The laser ranging unit can be subdivided into a transmitter, a receiver, and the optics for both units. The receiver is a photodiode, which converts the incident power received by the detector to a current at the output. The receiver optics collects the backscattered light and focus it onto the detector, which converts the photons to electrical impulses. The opto-mechanical scanning unit is responsible for the deflection of the transmitted laser beams across the flight path. The design of the deflection unit (e.g. oscillating mirror/zig-zag scanning, rotating mirror/line scanning, pushbroom/fiber scanning, Palmer/conical scanning) defines thescan pattern on the ground. A differential GNSS receiver provides the position of the laser ranging unit. Its orientation is determined by the pitch, roll, and heading of the aircraft, which are measured by an inertial navigation systems (INS).

Since the advent of ALS in 1994, this technology has been widely applied in national laser scanning campaigns to derive country-wide Digital Elevation Models (DEM) and forest inventory as well as other mapping applications. ALS-based forest inventory is now operational/commercial in Scandinavia, Baltic countries, Spain, Switzerland, USA, Canada, Australia and New Zealand. An increasing number of countries are applying ALS for national/statewide elevation modeling (e.g. The Netherlands, Switzerland, Finland, Sweden, Austria, Germany, US). The benefits are 5-10 times higher in accuracy (compared to photogrammetry), highly increased automation in processing, and significantly decreased costs. Other commercial applications include 3D city modelling, corridor mapping (powerline, road, railroad), flood risk assessment, telecom planning to name but a few other examples. Terrestrial laser scanning is feasible for all kinds of detailed 3D documentation, digital factory, virtual reality, architecture, civil engineering, archeology and cultural heritage, plant design and automation systems (robotics). Mobile laser scanning is used to applications which requires better coverage than TLS, but where lower accuracy is tolerated.

The paper summarizes some unconventional work of LIDAR mapping from air, terrestrial and mobile. Partly the work has been implemented by the Centre of Excellence in Laser Scanning Research, lead by Finnish Geodetic Institute, www.fgi.fi/coelasr. This paper also aims to stimulate the development of laser scanning into more unconventional usages.

2. TRENDS IN LASER SCANNING

Annually, the LS business market is growing by 15 %.

In ALS large areas can be covered cost-effectively and rapidly. The acquired point density (1-40 pts/m^2) is high enough, for example, for rough extraction of building roof structures and outlines. However, building façades and pole-type objects are difficult to model due to nadir-type viewing direction and, therefore, details in the buildings, such as balconies and windows, are missed. Point density in ALS is not always good enough for a more detailed road surface modelling, for example, wearing of the road surface and holes cannot be detected and modelled. TLS can produce dense point clouds from which environments can be modelled accurately. A relatively small area can be mapped with high accuracy, and several scans are needed to cover larger areas and to prevent occlusion. Therefore, the TLS based modelling is work intensive: transportation and positioning of the system, design of different scanner positions to minimize occlusions and matching of overlapping scans need a lot of manual work. MLS can be considered to fill the gap between ALS and TLS. Lehtomäki et al. (2010). The accuracy of MLS data is more close to ALS since both of these systems are based on GNSS and IMU, which produce the main error source to the measurement. In MLS, the GNSS shadows are in higher role than in ALS, and other multi-sensoral positioning technologies are needed. ALS, TLS and MLS can be considered as complementary systems. Therefore, applications based on integration of ALS and TLS/MLS are currently in development, in urban and non-urban areas. ALS/TLS integration is expected to be beneficial for forest inventories and ALS/MLS integration is expected to be useful for 3D city mapping, agriculture and fluvial studies, to name but a few examples. ALS/MLS/TLS integration is beneficial also for forest inventories, and other applications.

Also, Nokia/NAVTEQ True Cars and Google Street View Cars are collecting large data sets with lasers, but we do not yet see the results publicly. They may appear to provide 3D virtual world in the future at least from the road environment.

Autonomous-driving technologies have attracted considerable both academic and industrial interests in recent years. Navigating an unmanned ground vehicle driving through urban areas is a difficult task, and the accuracy of the location information directly impacts the safety and control stability of the UGV. The localization methods of autonomous driving can be divided into satellite-signal-based solutions and map-matching solutions (Hu et al., 2013). For map-matching-based method, an unmanned vehicle gets its position by comparing environment map with real-time perception data from laser scanners mounted on UGV (Hu et al., 2013). Google self-driving car has been reported to be commercially available to customers in three to five years (Howard, 2013).

In addition to autonomous-driving technologies, the areas of surveying and robotics are converging highly. According to Google Scholar at the end of 2012, the most cited paper in the best robotics series was “3D is here: Point Cloud Library” (Rusu and Cousins, 2011). New surveying technologies are based on point clouds obtained from lasers, images using dense matching, radargrammetry with SAR images and range cameras. Lasers and all kinds of cameras are used as perception sensors in the robotics. The differences are mainly that surveying concentrates on absolute coordinates, high absolute accuracy and post-processing where as in robotics, the local coordinate systems and relative accuracy and real-time processing are needed.

Miniaturization of sensor technology affects laser scanning significantly. There is a clear trend to multifunctional mobile devices integrating communication, computing and sensor technology into a single device. Mobile phones allow for communication, computing and sensing. A great variety of MEMS (Micro Electro Mechanical System) sensors exist that can be used to capture context information, such as temperature, atmospheric pressure, acceleration, orientation or other objects in the vicinity.

In addition to further miniaturization of sensor and computer technology, we see LS becoming more ubiquitous, which allows personal remote sensing via laser scanning (personal laser scanning, PLS). In the future, PLS can be utilized by blind persons and wheelchair-users to detect the changes in their typical walking routes. Originally, the word ubiquitous is typically attached to the word computing. Ubiquitous computing was first articulated by Mark Weiser, technologist at Xerox Palo Alto Research Center (PARC), in 1988 by the words “in the near future great number of computers will be omnipresent in everyday life, that will be interconnected in a ubiquitous network” and “it is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere”. In contrast to the era of Personal Computer, where almost everybody has one computer, in the era of ubiquitous computing everybody has many computers (Weiser, 1991). The term ubiquitous mapping is a ten year’s old concept. Ota (2004) defined the ubiquitous mapping as that people can access any map at anywhere and anytime through the information network. Morita (2004) defined that ubiquitous mapping so that it refers to the use and creation of maps by users anywhere and at any time. In the definition of Morita (2004), not only map making was included but also map use and map communication considering the interaction between map, spatial image, and the real world. However, the ubiquitous mapping is still considered very much about cartographic issues and achieving existing map information. This will, however, change in coming years. Already Kinect-type sensors have been demonstrated in many areas (Fritsch et al., 2011), and the term PLS can be attached to such systems. These systems could also contribute to peer-produced 3D modeling of objects and the world.

3. UNCONVENTIONAL MOBILE LASER SCANNING

A mini-UAV can be used to collect multi-temporal point clouds in an effective and research-friendly way for new applications. Mini-UAVs can also be used to help develop new mapping concepts, e.g., integrating the BRDF (directional reflectance distribution function), hyperspectral response, and geometry of the object into a single mapping process. The use of mini-UAV for LS is a relatively new research area (e.g. Zhao et al. 2006). Zhao et al. (2006) depicted a possible remote-controlled survey helicopter. In Nagai (2009) the focus is on integrating a 330 kg helicopter UAV with mapping sensors. Jaakkola et al. (2010) presented the first low-cost mini-UAV-based LS system, the design of which has also been used by our co-operator Univ. Tasmania. The system consists of a number of measurement instruments: a GPS/IMU positioning system, two laser scanners, a CCD camera, a spectrometer, and a thermal camera.

In Kukko et al. (2012) a multi-platform MLS system is depicted. In addition to a moving car, trolley, boat, sledge, all-terrain vehicle and person carrying the system have been used. It is evident that these proposed MLS approaches have the potential to speed up and improve the collection of 3D survey data and, thereby, widen spatial coverage with remarkable point density and quality. These platforms are applicable in various modeling tasks in the vast fields of civil and transportation engineering, archaeology and geomatics, as well as in the monitoring and understanding of processes in different disciplines of natural sciences; e.g., cryosphere and glaciology, geography, hydrology, silviculture, and agriculture. The performance of the proposed systems based on the analyses of results achieved on a permanent EuroSDR MLS test field and in situ target field studies show that the presented MLS systems can produce dense point cloud data for object reconstruction with absolute accuracy being at the level of 17-23 mm regard to plane and to elevation. The short-term relative precision of the data was estimated to be around 12 mm, provided that the internal calibration of the system is carried out appropriately. Numerous authors have reported use of mobile scanners on different platforms, but no single group of authors has a yet reported an undertaking of this scope and variability.

Figure 1: The backpack MLS system of FGI.

Presently the localization/georeferencing of MLS is applied using GNSS (Global Navigation Satellite System) and IMU technology. GNSS is strongly affected by the presence of tall dense trees and buildings. With good GNSS conditions, the reported height and planimetric accuracy of MLS data is 2-4 cm (Kaartinen et al. 2012, Haala et al. 2008), and the best laser systems provide a ranging error of 2 mm. However, in some cases, errors of several meters are reported because of positioning errors. Thus, new methods to provide improvements in the localization of the MLS system are needed. In robotic navigation, perception sensors are used for simultaneous localization and mapping (SLAM). Similar development in needed regard to mobile laser scanning.

4. UNCONVENTIONAL FOREST MAPPING WITH LASER SCANNING

Today, point cloud generation for forest informatics has multiple choices, Figure 2. Radargrammetry, interferometry and images-based point clouds (from overlapping imaging and automatic stereophotogrammetry) are can be used to give 3D canopy information from air and space. Airborne Laser Scanning (ALS) gives DTM, biomass, biomass change as well as canopy height (and height change), and their references for space-borne estimates. UAV-based TomoRadar (radar providing waveforms in microwave range) gives additional knowledge of microwave signal penetration into canopy used for modelling. Mobile Laser Scanning can also give information comparable to TLS, and it is a cost-effective field inventory technique for trunk detection and reconstruction.

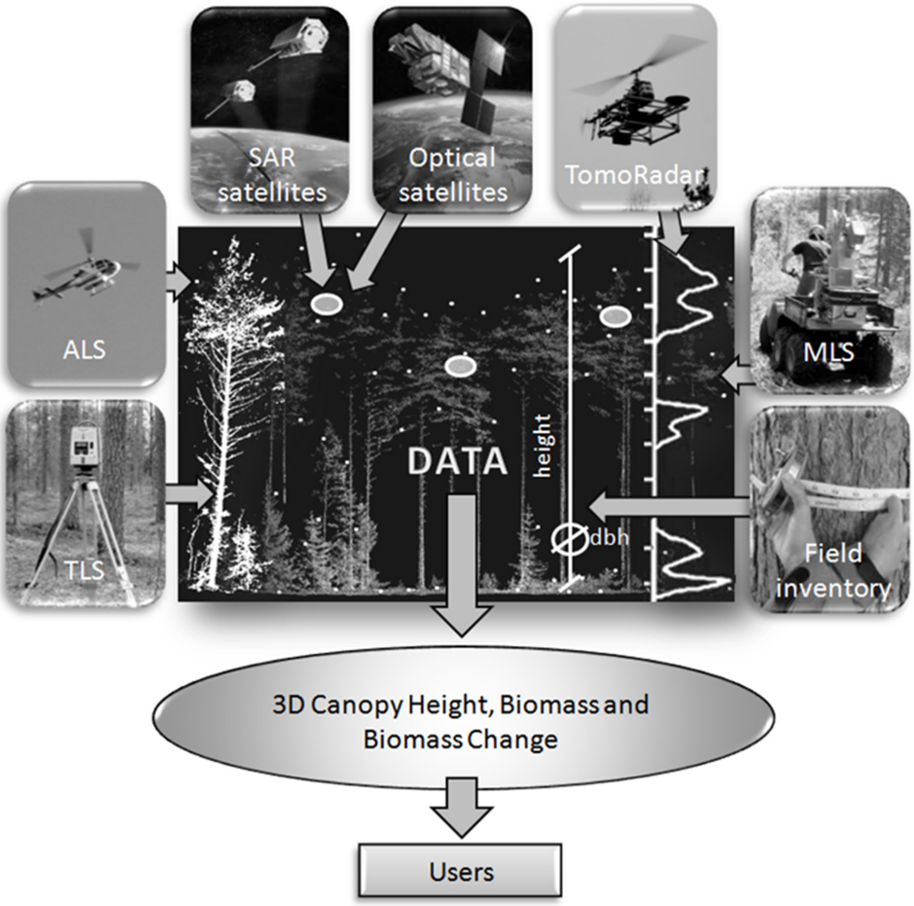

Figure 2: Variety of point cloud extraction mechanisms and other information sources for future forest inventory.

5. PROCESSING OF PERSONAL LASER SCANNING WITH CHANGE DETECTION

In the future, PLS can be utilized by blind persons and wheelchair-users to detect the changes in their typical walking routes, as planned by Hyyppä and Chen (2006). Change detection is a powerful remote sensing and robot vision process that should be applied in variety of application, and example of kids play on the technique is shown on Figure 3.

The Google self-driving car works in practice in the same way. Before self-driving a certain route, human driver must drive along the route to gather data about the environment. Then, the autonomous vehicle can compare the data acquired from the perception sensors, including laser scanner, to the previously recorded point cloud.

6. LASER SCANNING WITH ACTIVE MULTISPECTRAL RESPONSES

In order to get create complete model of the target, we need to have geometry (from point clouds), hyperspectral response and BRF response (illumination geometry known). This kind of complete model would be favorable for high-quality classification with remotely sensed data.

Figure 3: Change detection problem for kids. Find 8 differences from the left image pair. Difference image produced on the right. In image differencing, the co-registered images are simply subtracted from each other. The differences are easily detectable. Courtesy to Maapallokerho.

The major bottleneck in passive hyperspectral data processing is the illumination changes (bidirectional reflectance distribution function, BRDF) of the environment. The BRDF changes of mobile imagery are much more dramatic than in aerial imaging, since imaging is done in all geometries (e.g. towards the sun and away from the sun). Understanding illumination changes and correcting for them is a major challenge for using passive mobile hyperspectral imaging with MLS data. Therefore, it is expected that in the future active multispectral or active hyperspectral LS will become important techniques in mobile mapping. With active multi- or hyperspectral sensing, the effect of BRDF is negligible. The disadvantage of the active hyperspectral sensing, however, is the cost of the systems and more limited possibility to have high number of channels. One of the world's first full-waveform hyperspectral LS prototype has been developed at FGI (Hakala et al. 2012).

With active hyperspectral/multispectral LS, the obtained intensities or waveforms need to be calibrated. 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. With MLS and TLS absolute calibration can be quite easily performed.

Due to high costs in hyperspectral laser scanning (due to number of receivers at different wavelengths) and due to possible eye-safety problems, alternative solutions to hyperspectral LS needs to be found. If the idea is to get multiple channels to help target classification, then multispectral laser scanning or full-waveform laser scanning can be considered as alternatives. The main appeal of using the backscatter cross section rather than the intensity as measured by conventional ALS systems is that it is a physical measure of the electromagnetic energy intercepted and reradiated by objects which allows for linking measurements to electromagnetic scattering theory (Wagner, 2010). Also, the information provided by the echo width is very useful. As shown by Doneus and Briese (2006), it is possible to detect low vegetation and other objects close to the terrain surface using the echo width. Waveform technology has been studied more than 10 years, and at least in Scandinavia, the applicability is low.

Therefore, active multispectral laser scanning seems to be an attractive solution for future laser scanning. 3-4 channel system may be feasible for automated object recognition. Additionally, the beam width of each channel may differ giving different information from targets.

7. 3D TAPIOLA

From Google Play, you can find a demonstration 3D Tapiola, Figure 4, which is a FGI technology demonstration. Full complementary technology chain from MLS hardware and automated virtual reality processing into 3D game engine merging physical and virtual words were demonstrated. The system and processes were implemented by five researchers, and this is a technology we believe to become available to consumers with large city areas by large telecom&IT companies.

The ROAMER data included altogether about 160 000 profiles, each profile having 2150 points with 3D coordinates and return intensity. Data collection lasted about one hour, and covered an area 180 m by 280 m using the trolley MLS configuration. The laser data were transformed into map coordinate system (ETRS-TM35FIN with GRS80 ellipsoidal height). Due to narrow streets and high buildings, images were taken using a Canon EOS 400D digital camera. Geometry reconstruction from raw MLS data includes the following steps: noise point filtering, object classification (ground, buildings and the other objects), detection of planar surfaces, key point extraction and surface meshing. Our goal in geometry reconstruction was to utilize some key points in building model construction. These images were used to provide the textures of the building facades. For complete 3D models, the textures of the building roofs were also needed. We made use of aerial images from Bing Maps (http://www.bing.com/maps/) to obtain the textures of the building roofs. Each roof plane was made to correspond to one texture. The 3ds Max software was used in texture mapping.

Figure 4: The game engine interface of the 3D Tapiola demo.

8. NEED OF BENCHMARKING STUDIES

In remote sensing, benchmarking is used to measure the performance of a remote sensing data source, process or method using a specific test site and quality indicator resulting in a metric of performance that is then compared to other data sources or methods. Typically, it is hard to perform good benchmarking of state-of-the-art methods, since it is only the developer of the method who can process the data in all detail. Therefore, many benchmarking studies are international in nature and organized by international organizations such as the International Society for Photogrammetry and Remote Sensing (ISPRS) and the European Spatial Data Research organisation (EuroSDR). In computer vision, some of the benchmarking platforms have been made automated, so that the developers of the methods can load the results to a system giving automatically quality metrics of the method versus others.

Test site characteristics may dominate in the evaluation of the remote sensing data. For example, it is common practice to evaluate new remote sensing methods in a test field and then compare obtainable results from other works obtained in scientific literature. Since test site and data analysis characteristics are different, even wrong conclusion can be drawn. In Hyyppä and Hyyppä (2001), it was shown that stand size in forest inventory can be effectively used to modify the precision of the results. Especially studies, where stands smaller than a certain threshold were rejected, resulted in improved performance exaggerating the real output of the method.

Benchmarking activities in remote sensing should be based on high-quality reference including typical characteristics of the target. Experiences gained in past research, together with the earlier mentioned photogrammetric test field, gave justified grounds to test and develop high-quality test fields also for other remote sensing applications and use these test fields for international benchmarking of methods and systems.

Benchmarking studies can be used effectively to learn better about optimum information extraction methods. An example is taken from IPSRS/EuroSDR Tree Extraction tests. In many other applications, manual techniques are more accurate than automated techniques. Here (Fig. 5) it can be seen that several automated methods with LS point clouds are superior to manual tree extraction. This is one of the reasons why laser scanning works so well in forestry. Also, when analyzing the extraction technologies, it was found that method utilizing raw laser point cluster analysis, such as from Zürich, yielded the best results in finding the smaller trees (Fig. 6). This implied that using the original point clouds would find the smaller trees more accurately than conventional methods, such as filtered CHM. But for the dominant tree storey, there are other more optimal techniques. (Kaartinen et al., 2012).

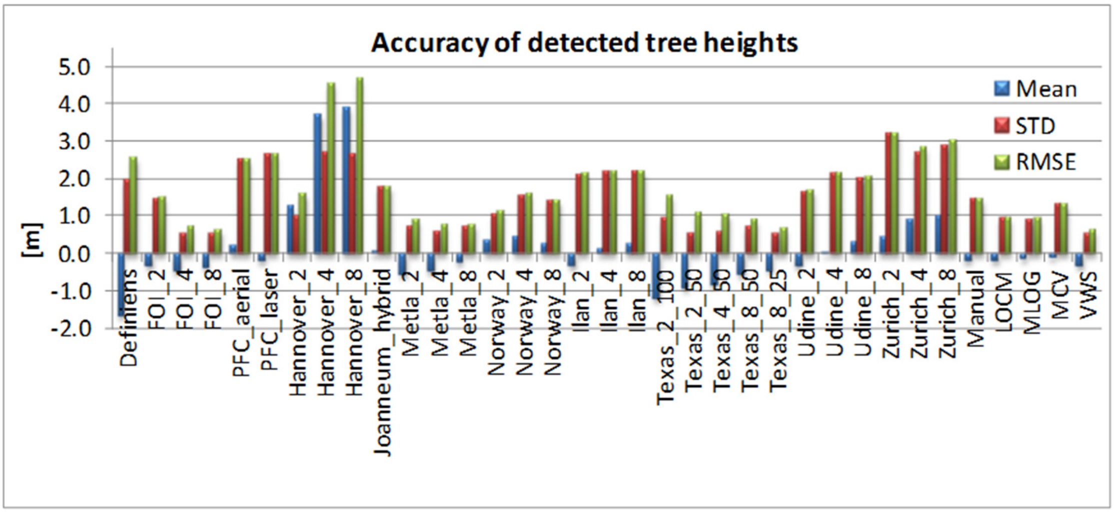

Figure 5: Accuracy of detected tree heights for all benchmarked methods. Kaartinen et al. (2012).

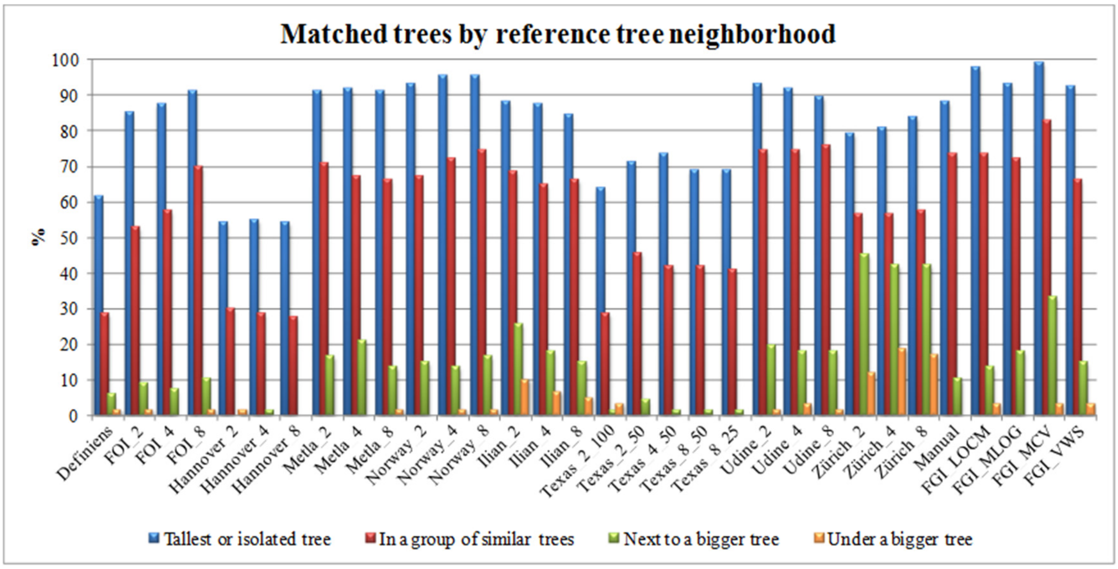

Figure 6: The impact of the tree neighborhood to tree matching. Kaartinen et al. (2012).

9. CONCLUSIONS AND OUTLOOK

The rapid progress of data acquisition instruments and sensors provides scientists with new ways to solve conventional problems. Novel theories, concepts, algorithms, new research areas and applications can be developed and demonstrated in connection with constructing sensors of unique configurations, long before the technology reaches the maturity needed in operational applications. Therefore, the development of the data acquisition sensors can be one of the most remarkable “driving” forces in the progress of specific science areas. Laser scanning can be considered as one of the technology-driven disciplines where the above-mentioned statement holds.

Our vision for future is that “laser scanning is omnipresent and affecting positively the life of every citizen in modern information society by early 2020s”. In the next two decades, new MLS and PLS systems are making LS more ubiquitous in the same sense as the first personal computing was followed by ubiquitous computing. Even autonomous robots using point-cloud-generating perception sensors may be added to the ecosystem during this timeframe. What can be said for certain is that during the 2020s and 2030s, there will be a great number of laser scanners omnipresent in everyday life. Mobile Laser Scanning is one of the main techniques to create local virtual reality. In addition to the autonomous car ecosystem, we see other ecosystems appearing having a large number of scanners: in forestry and in built environment. We see that MLS and PLS would be especially beneficial to forestry, built environment and personal mapping applications.

10. ACKNOWLEDEGEMENTS

Academy of Finland, Center of Excellence Program, is acknowledge for financial support for coming years 2014-2019.

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