

## PHOTOGRAMMETRIC NEWS: Licentiate's and Master's Thesis 2008-2012

In following, we highlight the abstracts of Licentiate's and Master's thesis in the fields of photogrammetry and remote sensing published during the years 2008-2012 in the Helsinki University of Technology and Aalto University. The University changed its name in the 1<sup>st</sup> of December 2010 from the Helsinki University of Technology to Aalto University. However, the professorship has remained as Photogrammetry and Remote Sensing.

### Licentiate's Thesis 2008-2012:

**Ahokas, Eero** (2008): On the quality of airborne laser scanning data

**Kaartinen, Harri** (2008): Evaluation of building extraction methods based on airborne laser scanning and aerial images

**Karila, Kirsi** (2008): Evaluation of building extraction methods based on airborne laser scanning and aerial images

**Karjalainen, Mika** (2008): Agricultural Remote Sensing Using Synthetic Aperture Radar Images

**Kukko, Antero** (2009): Road Environment Mapper - 3D data capturing with mobile mapping

**Vilhomaa, Juha** (2008): Development of a production process for a national elevation model

### Master's Thesis 2008-2012:

**Cohen, Juval** (2011): The influence of vegetation on snowmelt and surface albedo

**Davidsson, Jonne** (2009): Airborne laser scanner derived digital terrain and surface model production in tropical climate

**Hartikainen, Lauri** (2010): 3D city models and their potential use in Finnish municipalities

**Hatunen, Suvi** (2009): Radiometric Calibration of Satellite Images for Mosaicing and Change Detection

**Kareinen, Juha** (2008): Updating NLS Topographic Database from laser scanner data

**Klang, Outi** (2010): Stereo image analysis and 3D reconstruction in MATLAB

**Krooks, Anssi** (2012): Laser scanning in tree structure modelling

**Mielonen, Teemu** (2010): Estimating stem volume of individual trees with aerial images and laser point clouds

**Mikola, Johan** (2012): Motion capture of a javelin throw using high-speed cameras

**Nevalainen, Olli** (2012): Validation of Hyperspectral Light Detection and Ranging (LiDAR) in Chlorophyll Estimation

**Ojala, Mikko** (2009): Laser bathymetry

**Pajula, Kimmo** (2008): Digital aerial photo production based on direct georeferencing

**Pekkanen, Katja** (2011): Occupational exposure to crystalline silica in railroad construction: Evaluating the health risk and exploring a method for remotely sensed dust detection

**Posti, Maarja** (2012): New workflow for the registration of mobile laser scanning point clouds

**Rosnell, Tomi** (2010): Photogrammetric Mapping with a Compact Camera and a Radio Controlled Helicopter

**Tani, Lassi** (2010): Implementation of the Topographic Database Download Service

**Vaaja, Matti** (2010): Mobile laser scanning for mapping river point bars and banks

**Ventin, Jakob** (2012): Measuring indoor environments with a mobile laser scanner system

**Vinni, Päivi** (2010): Deformations of stereo models and comparison between digital elevation models produced by laser scanning and stereo photogrammetry

**Ylönen, Paula** (2008): The Production Process of Aerial Photomaps

## **ABSTRACT OF THE LICENTIATE'S THESIS**

**Author:** Eero Ahokas

**Title of the Thesis:** On the quality of airborne laser scanning data

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Prof. Juha Hyypä

**Number of pages:** 72

In this thesis the quality of airborne laser scanning (ALS) and also the calibration of the intensity data are discussed. The objective of this thesis was to

- 1) Analyze the quality of elevation and planimetric accuracy of ALS data
- 2) Test whether the DTM accuracy is significantly affected by the incidence angle
- 3) Improve the calibration of the ALS intensity.

In the five case studies two tackle the elevation and planimetric accuracy, one deals with the significance of incidence angle and the last two analyse the calibration of ALS intensity data.

The density of the forest plays an important role in laser pulse penetration to the ground through the foliage. Scanning angles up to 15 degrees seem to be usable for high altitude laser scanning in boreal forest zone. High altitude laser scanning gives precision that is about  $\pm 20$  cm (std), which is good enough for most terrain models required in forested areas. Since accuracy of the DTM does not deteriorate rapidly when number of ground points decreases, then final effect of the scanning angle can be relatively low, at least in boreal forest areas. Studies indicate that also 20 degrees scan angle is appropriate in the areas with no or limited vegetation.

The portable brightness targets facilitate the relative calibration of ALS intensity measurements as the use of Spectralon reference panels in laboratory. The painted portable tarps are good enough for calibration reference purposes for the laser intensity.

An intensity correction method should be used as a pre-processing part of data handling. As a result the usability of intensity values may increase in practical applications. The ALS technology is developing rapidly. Pulse repetition frequencies and number of points per square metre are increasing all the time. The quality of the new sensors should be further researched in the future.

**Keywords:** Airborne laser scanning, quality, intensity, calibration

**Language:** English

## **ABSTRACT OF THE LICENTIATE'S THESIS**

**Author:** Harri Kaartinen

**Title of the Thesis:** Evaluation of building extraction methods based on airborne laser scanning and aerial images

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Prof. Juha Hyyppä

**Number of pages:** 118

The objective of the study was to evaluate the quality, accuracy, feasibility and economical aspects of semi-automatic and automatic. Building extraction methods based on laser scanner data and aerial images. This thesis is based on the EuroSDR project "Building Extraction".

In this thesis the used test sites, data sets as well as used reference data are described. The building extraction methods used by the participants and methods used in accuracy evaluation are explained. Produced 3D city models are depicted and analysed especially in respect to accuracy, used data and the level of automation. Finally, discussion and conclusions are given.

Data sets from four test sites were delivered to the eleven participants of the project. For each test site the following data were available: aerial colour images, camera calibration and image orientation information, ground control point coordinates and JPEG-images of point locations, laser scanner data and cadastral map vectors of selected buildings (vector ground plans).

Presently, photogrammetric techniques and hybrid techniques combining photogrammetry and laser scanning provide the highest accuracy and level of detail in 3D city reconstruction. Despite the high amount of research during the last decade, the level of automation is still relatively low. Improvement in automation can be achieved most significantly by utilising the synergy of laser scanning and photogrammetry. The photogrammetric techniques are powerful for visual interpretation of the area, measurement of the building outlines and of small details (e.g. chimneys), whereas laser scanning gives height, roof planes and ridge information at its best.

**Keywords:** Laser scanning, photogrammetry, building extraction, accuracy, building outline, point cloud

**Language:** English

## **ABSTRACT OF THE LICENTIATE'S THESIS**

**Author:** Kirsi Karila

**Title of the Thesis:** Use of advanced radar remote sensing techniques to detect subsidence in built environment in Finland

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Prof. Juha Hyyppä

**Number of pages:** 73

The subsidence of buildings is a common problem in urban areas at different locations, and precise information on subsidence is essential. In this thesis traditional methods to detect and measure building subsidence, leveling and satellite positioning, are compared to the methods based on interferometric synthetic aperture radar (INSAR) data. The state of art of advanced INSAR techniques or persistent scatterer interferometry (PSI) is also reported.

Two case studies in Finland, for Turku and Helsinki, are presented in this thesis. A test site for PSI building subsidence was established in Turku on the basis of precise leveling measurements. Reference data on subsidence from cities' authorities was also available. A set of ERS and ENVISAT satellite data for the area was obtained for both test sites and processed using a PSI algorithm. For Turku the results of the PSI analysis and precise leveling were compared with each other to validate the subsidence rates for individual buildings. For Helsinki another PSI result was also available and studied.

Validation of the PSI results was affected by a number of problems, particularly spatial and temporal differences. Building subsidence occurring at a rate of a few millimeters per year can be detected on the basis of satellite-borne SAR data using PSI. However, the parameters of the PSI analysis and the quality of output products should also be carefully considered when interpreting the results.

It was concluded that PSI is feasible in pinpointing problem areas in a built-up or otherwise stable environment and is a suitable technique for measuring building subsidence, since buildings usually act as persistent scatterers. The absolute accuracy of the technique depends on the datasets and parameters, and it cannot be determined without artificial reflectors with a known scattering source. Traditional survey methods are still needed where precision in measuring building subsidence is paramount.

**Keywords:** SAR interferometry (INSAR), building subsidence, persistent scatterers (PS)

**Language:** English

## ABSTRACT OF THE LICENTIATE'S THESIS

**Author:** Mika Karjalainen

**Title of the Thesis:** Agricultural Remote Sensing Using Synthetic Aperture Radar Images

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Prof. Juha Hyyppä

**Number of pages:** 72

Agriculture is the most traditional and the basis for other industries. About third of the world population and work directly in agriculture supplying food for the rest of the population and providing raw materials to other industries. The trade of the agricultural products may also have a major impact on the economy of countries, especially on the developing ones. Remote sensing provides techniques for agricultural application and especially satellite-borne synthetic aperture radar (SAR) has an important role due to its all-weather imaging capability. Using SAR images, nearly real time agricultural monitoring can be realized covering large agricultural areas.

This thesis summarizes the use of SAR images in agricultural remote sensing based on the recent international scientific articles and the case studies carried out at the Finnish Geodetic Institute. In the case studies, ERS-2, Radarsat-1 and Envisat SAR images have been used. The study areas located in Hue Vietnam and in Seinäjoki Finland. Reference measurements of the soil surface and vegetation canopy properties were collected in the field surveys, which were carried out simultaneously with the SAR image acquisitions. The time series of Radarsat-1 and Envisat SAR backscattering were similar to the ones represented in the earlier international studies. The growth of the crops causes variations to the recorded SAR backscattering, which enables many applications such as crop species classification and yield estimation. SAR images have also great potential in detection of yield damages, especially in the case of flooding, due to the cloud penetrating imaging capability. However, according to the Radarsat-1 results the detection of lodging was unsuccessful, because of the possibly inappropriate polarization. The major crop species in Seinäjoki area were classified with the accuracy of 74.7% using 12 Envisat dual-polarization (VVIVH) SAR- images. In the Hue test area, rice detection was considered feasible when the SAR derived area was compared with the statistics provided by the local authorities. Crop yield estimation or prediction from the SAR images is very challenging due to the fact that complete information about soil surface and vegetation parameters is typically missing. In the Hue case  $R^2$  of 0.61 was achieved for the fresh biomass estimation using ERS-2 images. On the other hand,  $R^2$  of 0.55 was achieved for crop height estimation in Seinäjoki case using Envisat images.

In the near future, we are entering the era of new SAR satellites. The spatial resolution will improve and fully polarimetric measurements will become available. Therefore, it can be anticipated that the use of SAR images in agricultural remote sensing will become more feasible. However, a lot of research is still needed in order to more comprehensively understand the backscattering mechanisms in the vegetation canopies and to develop suitable models for operational agricultural applications.

**Keywords:** SAR, agricultural monitoring

**Language:** English

## **ABSTRACT OF THE LICENTIATE'S THESIS**

**Author:** Antero Kukko

**Title of the Thesis:** Road Environment Mapper - 3D data capturing with mobile mapping

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Prof. Juha Hyyppä

**Number of pages:** 158

The objective of this thesis was to build a mobile mapping system for three-dimensional data acquisition for automatic modelling of the environment. The sub-objectives were to develop suitable system calibration methods, to test and analyse the system performance, and to develop appropriate georeferencing and filtering tools for the mapping sensor data. Further, the possible research and application scenarios for a mobile mapping were developed.

ROAMER system consists of an integration platform, a GPS-INS navigation system, a laser scanner, CCD cameras and synchronization electronics. Additionally, reference station and real-time correction information for the GPS data affect the system operation. The platform integrating the mapping and navigation sensors tightly together was designed and built as an elemental part of this study.

The exterior orientation of the mapping sensors were determined by a laboratory calibration procedure. The laser scanner was oriented to the GPS-INS body frame with three-dimensional targets and tachymeter measurements. Cameras were oriented to the scanner coordinate system through a bundle adjustment.

Filtering methods were developed for noise reduction in the point clouds produced with the ROAMER. These were tested for the real data, and the effect of different parameter values on the data was visually analysed.

The georeferencing of the laser scanner derived points was carried out by a Matlab tool developed and implemented in the project. The resulting point clouds were compared to the digital base map to derive conception of the system performance.

In the research and development performed in this study resulted in working system for mobile mapping. The georeferencing of the laser points was successfully implemented for operative use. At best conditions, the ROAMER was capable of providing dense point cloud with accuracy of 2-5 cm without further post-processing. Suitable methods and parameters for doing effective filtering for the ROAMER point clouds were found in the study.

ROAMER was found to be applicable for mobile mapping. Its compactness and versatility makes it possible to use it in diverse research and application purposes in the fields of research carried on the Department of Remote Sensing and Photogrammetry in the Finnish Geodetic Institute.

**Keywords:** mobile mapping system, calibration, data collection, georeferencing

**Language:** English

## **ABSTRACT OF THE LICENTIATE'S THESIS**

**Author:** Juha Vilhoma

**Title of the Thesis:** Development of a production process for a national elevation model

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Prof. Juha Hyyppä

**Number of pages:** 102

The thesis describes the start of the production of a new national elevation model and the development of a new production process and analyses the impact of such a new production technique on the need of knowledge and the productivity of work concerning elevation model production.

The requirement of a new national elevation model production is based on the recommendation provided by the Ministry of Agriculture and Forestry. The elevation model working group recommended laser scanning to be used as the production method, and as a result the National Land Survey started to explore how laser scanning could be used for scanning wide areas. As the technique proved to be useful, a series of development projects was carried out for testing the method, defining the parameters for a new elevation model and elevation data and also for planning and providing a new production process. An object of the development projects was also to increase the use of laser scanning data to other areas of operation, such as the forestry sector, and therefore a wide network of co-operation partners was gathered for the projects.

The thesis describes the characteristics of alternative production techniques of an elevation model that are relevant to this kind of production. Furthermore, essential features of implemented development projects and their results are described.

The organization also had to acquire the required know-how in order to introduce the new method. The need for knowledge in a decentralized organization varies, from planning operations and management of resources to profound technological expertise and practical working skills. In addition to obtaining technical development results the planning of the development projects aimed to acquire a fair amount of the required know-how for a large number of people. The introduction of such a new technique increases the productivity of work about 2-3 times in the national elevation model production compared to the currently used photogrammetric method, and simultaneously improves the quality of elevation data.

**Keywords:** Laser scanning, digital terrain model, photogrammetry

**Language:** Finnish

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Juval Cohen

**Title of the Thesis:** The influence of vegetation on snowmelt and surface albedo

**Supervisor:** Prof. Henrik Haggrén

**Instructors:** D.Sc. (Tech.) Jouni Pulliainen, D.Sc. (Tech.) Kari Luojus

**Number of pages:** 90

Surface albedo has a great influence on earth's energy balance, because it determines the relation between reflected and absorbed solar radiation on the ground. Therefore it is important to examine the factors which have high influence on the surface albedo. One of these factors is snow cover. Albedo difference between snow covered and snow free ground in tundra areas is usually around 0.6. Therefore, by slowing or delaying the snowmelt process, it is possible to decrease the amount of absorbed solar energy on the earth surface.

The main goal in this work is to examine the influence of vegetation amount on snowmelt timing, and by this, to discover the indirect influence that vegetation has on the surface albedo in Northern tundra areas. This is done by studying first the vegetation on the ground using Corine Land Cover 2006, Globcover 2009 and Landsat products. Then, statistical analyses of different time series remote sensing products such as MODIS, Globsnow and Landsat, considering the vegetation, snowmelt and surface albedo is done.

The test site is located in the Northern parts of Norway and Finland, where tundra vegetation is the most common land type. A comparison of NDVI, fractional snow cover and albedo between the Finnish and the Norwegian side of the test area is done, based on a presumption, that vegetation on the Norwegian side is denser than on the Finnish side.

The results of this work indicate that indeed vegetation is more abundant, and also snow melts faster on the Norwegian side. This of course has an affect also on surface albedo, which is lower on the Norwegian side during the melting season. Lower albedo results higher solar energy absorption, and therefore more energy is absorbed on the Norwegian side. The magnitude of this difference in the absorbed energy between the Norwegian and the Finnish side is calculated in this study.

**Keywords:** Remote sensing, tundra, albedo, vegetation, snow, snowmelt

**Language:** English



## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Jonne Davidsson

**Title of the Thesis:** Airborne laser scanner derived digital terrain and surface model production in tropical climate

**Supervisor:** Professor Henrik Haggrén

**Instructor:** Kari Suominen

**Number of pages:** 63

This master's thesis is based on a survey project that took place in a remote location in Cambodia. The survey was flown with a helicopter from an altitude of 1200 meters above ground level. The equipment used was a Leica ALS50-II and RCD105. The goal in this master's thesis was to introduce airborne laser scanning and different products that can be produced from a single flight with the assistance of a measurement capable digital camera. Also the focus is on the processing and production of a digital terrain and surface model. The produced digital terrain and surface models were compared to the NASA SRTM model.

The results show that the SRTM model is closer to the surface model for this project area. The effect of ALS parameters in point distribution was also studied. It was concluded that after a FOV of 30 degrees the transmission degrades resulting in less ground points than with smaller FOV's. For the study area approximately 2% of all the laser points were from the ground level. This is a relatively small number but due to the structure of the forest type it is fairly reasonable.

**Keywords:** Airborne laser scanner, DTM, DSM, direct georeferencing

**Language:** English

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Lauri Hartikainen

**Title of the Thesis:** 3D city models and their potential use in Finnish municipalities

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Anna Erving

**Number of pages:** 63

A 3D city model is a wide-area digital spatial data set, which consists of three dimensionally modeled terrain, buildings and other structures. 3D city model may also include, for example, hydrographic and traffic network data and it may also hold semantic data of the objects.

This thesis reviews current use and potential ways to use 3D city models in Finnish municipalities. This thesis also inspects current practices of how municipalities use spatial data. Geographic Information Systems used in municipalities are also referred.

In addition, this thesis presents information about the source data needed and the techniques used in 3D city modeling. Modeling of urban environment is typically based on use of aerial (nadir and oblique imagery) and terrestrial imagery, laser ranging (LiDAR) and/or field measurements. This thesis also presents information about the concepts of surface model types and the data models used in city modeling.

So far 3D city models are scarcely used tools in Finnish urban planning and other municipal processes. 3D design models and visualizations are used to some extent in detailed urban planning. Final part of the study consists of interviews which show that the level of knowledge in 3D city modeling and the ability to process and exploit city models varies considerably in different municipalities. There are also big differences in standardized practices of using city models - if such have ever been created.

**Keywords:** 3D city model, urban environment, building modeling, semantic data model, CityGML

**Language:** Finnish

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Suvi Hatunen

**Title of the Thesis:** Radiometric Calibration of Satellite Images for Mosaicing and Change Detection

**Supervisor:** Prof. Henrik Haggrén

**Instructors:** Pekka Härmä, Markus Törmä

**Number of pages:** 62

In this Master's Thesis the radiometric calibration of satellite images is explored where the aim is to make mosaic for change detection purposes. There are two kinds of correction that form the radiometric calibration, sensor based corrections and image based corrections. The focus of this Thesis is the latter corrections.

The Thesis examines the effects of atmosphere and land surface in electromagnetic radiation, with atmospheric correction methods presented generally and ATCOR2- and SMAC-methods precisely. These methods use information of atmospheres optical conditions, with the first method from parameters and the second method from images. Results of these methods are the surface reflectances.

With ATCOR2- and SMAC-method an atmospheric correction is made for two images which overlap each other. The similarity of the surface reflectances in these two images are examined separately for both methods. In this study the visibility and aerosol optical depth values are also explored.

In addition, a histogram matching method for mosaicing heterogeneously corrected satellite images is introduced. It produces a mosaic with similar reflectances for change detection.

The atmospherically corrected mosaic IMAGE2006 was made at the Finnish Environment Institute as part of CORINE2006 land cover classification. In CORINE2006 an up-to-date classification and change detection between CORINE2000 and CORINE2006 will be produced.

**Keywords:** remote sensing, atmospheric correction, aerosol optical depth, mosaic of satellite images

**Language:** Finnish

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Juha Kareinen

**Title of the Thesis:** Updating NLS Topographic Database from laser scanner data

**Supervisor:** Prof. Henrik Haggrén

**Instructors:** Petri Rönholm, Jurkka Tuokko

**Number of pages:** 76

The master's thesis is part of a reform in National Land Survey of Finland (NLS), in which they have started a production of nationwide elevation model from laser scanner data in spring 2008. The NLS is going to update their entire elevation model of Finland by using laser scanning system in the next 10 - 15 years. The NLS has also started to determine whether it could use the laser scanner data in the process of updating the NLS Topographic Database.

The objective of my master's thesis was to study is it possible to utilize the laser scanner data produced for nationwide elevation model in updating NLS Topographic Database. The aim wasn't to create a complete manufacturing process but to find out needs and create ideas. The new methods for updating the NLS Topographic Database can be fit for use now or in couple of years' time. A particular challenge was that the laser scanner data which the NLS uses is sparse - only 0.5 - 1 point/m<sup>2</sup>.

In my master's thesis I present the NLS's existing process to update NLS Topographic Database, clarify the needs to develop the NLS Topographic Database, which were determined in a customer's needs survey done earlier, and I also examine existing research of detecting terrain objects from laser scanner data. In addition, I also study in detail the detecting of buildings from sparse laser scanner data by classification tree method and present the new ideas of using laser scanner data in updating the NLS Topographic Database in the future.

The experimental work was to detect buildings from segmented laser scanner data by classification tree method, in which the classification parameter was Normalized Difference Vegetation Index (NDVI) calculated from aerial photographs. The results of the classification were that 92 % of the buildings were detected correctly, when also partly detected buildings were taken into account. The percentage of buildings detected completely was 84 %. The percentage for wrongly detected buildings were only 4 % and 8 % of the buildings were not detected at all.

The possibilities to utilize laser scanner data in updating the NLS Topographic Database in the future were presented in the master's thesis. Ideas presented here were that for example terrain objects, such as buildings, could be highlighted as hints to cartographers from laser scanner data. Cartographers can also use the laser scanner data to support visual interpretation made from aerial photographs. In addition, laser scanner data can also be used when metric height from ground surface is required for buildings of NLS Topographic Database.

**Keywords:** Laser scanner data, update, topographic database, building detection

**Language:** Finnish

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Outi Klang

**Title of the Thesis:** Stereo image analysis and 3D reconstruction in MATLAB

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Dr.-Ing. Manfred Wiggenhagen

**Number of pages:** 62

The primary idea was to create a program for MATLAB that would analyze two stereo images and be able to detect corresponding points in them. The study was interesting since there were not studies like this to be found even though MATLAB is common software among schools and universities.

The suggested program uses correlation, standard deviation and relative orientation parameters to solve the positioning of the corresponding points in the second image of the image pair. Results that the program produces are relatively good considering that MATLAB is not the best platform for image analysis. Four image pairs are studied and their results are presented and discussed on how well the MATLAB program is able to find the points and how the 3D-reconstruction works in PhotoModeler.

**Keywords:** Photogrammetry, MATLAB, Feature extraction, corresponding points, 3D-reconstruction, MATLAB, PhotoModeler

**Language:** English

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Anssi Krooks

**Title of the Thesis:** Laser scanning in tree structure modelling

**Supervisor:** Prof. Henrik Haggrén

**Instructors:** PhD Sanna Kaasalainen

**Number of pages:** 50

Optimization of wood supply chain and monitoring climate change and human impact on environment creates ever growing need for accurate 3D information of biosphere. Carbon footprint of forests requires information of the size distribution of above ground biomass when logging waste is used as bioenergy. Terrestrial and aerial laser scanning are promising methods to produce dense 3D data from forests and single trees but automation of the data processing is challenge.

In this master thesis a novel tree cylinder modelling algorithm developed at Tampere University of Technology is tested with 43 pines growing in the same test plot. Branch size distribution is calculated and divided in classes according to tree height. Hypothesis is that tree height and other ALS derivable tree metrics could be used to make large scale estimations of forest canopy structure when growing conditions are similar.

The results point out that connection between tree height and size distribution of branches is present. The method can be further developed by improving data collection methods. Needles on the branches could be detected and classified using laser scanner intensity or spectral information from active hyperspectral LiDAR. Data acquisition could be sped up by use of mobile laser scanning.

**Keywords:** laser scanning, modelling, silviculture

**Language:** Finnish

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Teemu Mielonen

**Title of the Thesis:** Estimating stem volume of individual trees with aerial images and laser point clouds

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Prof. Juha Hyyppä

**Number of pages:** 52

The aim of this master's thesis is to estimate the individual tree volume using aerial photographs and laser scanning point clouds. A CIR (Colour Infrared) image, in the scale of 1:20 000, and two laser scanning point clouds, in the density of approximately 5 and 10 pulses per square meter, were used in this study. The 78 carefully measured pine trees were used as a reference data.

The volumes of the individual trees were estimated using the individual tree crown (ITC) approach. In this study, the individual tree volume was determined from (1) an aerial image, (2) laser scanning point clouds and (3) combining the both methods in the way that only the height of the tree was given from the laser scanning point cloud. These three methods were compared with each other.

The result of the study shows that the aerial image ITC approach was significantly improved by including the height of tree from the laser scanning data. The coefficient of determination ( $R^2$ ), for the volumes of the individual trees, was 0.14 with aerial image ITC approach.  $R^2$  was 0.54 after including the height from the laser scanning data.  $R^2$ 's were 0.67 and 0.68 respectively with the two laser scanning data sets which are significantly better than with the aerial image ITC approach (0.14). In addition, this study shows that the height of individual trees is the most important geometric parameter for stem volume estimation that can be provided by remote sensing methods.

**Keywords:** Laser scanning, aerial photography, individual tree crown (ITC), crown height model (CHM), segmentation

**Language:** Finnish

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Johan Mikola

**Title of the Thesis:** Motion capture of a javelin throw using high-speed cameras

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** D.Sc. (Tech.) Petri Rönholm

**Number of pages:** 53

Among top athletes, motion analysis has become a widely used method to track the movement in their technique. The motion capture method enables athletes to improve their performance. Although several methods have been used to implement motion capture, these have proven unpractical for motion analysis. This research uses movement capture to analyze a javelin throw with stationary high-speed cameras. The thesis presents photogrammetric methods for use in a motion capture system. These methods allow the 3D coordinates of the object to be determined from the pictures created using the motion capture method.

Experimental work to perform motion capture was carried out during research. This experiment was made to comply with the principles of the theory part. The purpose of the experimental work was to implement a successful motion capture of javelin throw by using three different motion capture methods. The thesis experimentally compares three different motion capture methods of a javelin throw: digitizing, feature extraction and marker tracking. One goal of the experimental work was to identify stages in the motion capture process. Another goal was to reveal the properties in the three different methods. Each of these methods determined the positions of the object points as function of the time.

This study found that successful motion capture process was dependent mainly on two factors: the illumination in the scene and the quantity of light reaching the image sensor. Comparison of the motion capture methods revealed significant differences between them. Since each method was found to have its own benefits and drawbacks, this study was unable to recommend any one of these as the best method. Thus, the right method for motion capture of a javelin throw should always be chosen with respect to its use demand.

**Keywords:** Motion capture, high-speed photogrammetry, javelin throw

**Language:** Finnish



## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Olli Nevalainen

**Title of the Thesis:** Validation of Hyperspectral Light Detection and Ranging (LiDAR) in Chlorophyll Estimation

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** PhD Sanna Kaasalainen

**Number of pages:** 50

The purpose of this thesis is to validate the first prototype of a full waveform hyperspectral LiDAR instrument developed in the Finnish Geodetic Institute (FGI) in chlorophyll estimation. The instrument efficiently combines the benefits of passive and active remote sensing sensors. It is able to produce 3D point clouds with spectral information included for every point which offers great potential in the field of remote sensing of environment.

The performance of the hyperspectral LiDAR instrument in chlorophyll estimation was validated by finding chlorophyll sensitive vegetation indices using hyperspectral LiDAR data and validating their performance in chlorophyll estimation. The amount of chlorophyll in vegetation is an important indicator of vegetation photosynthetic capacity and stress. Consequently, chlorophyll estimation is a widely studied subject in the field of vegetation remote sensing.

The chlorophyll estimation was performed by calculating 28 published vegetation indices to ten Scots pine shoots and oat samples with varying health. Reference data was acquired by accurate laboratory chlorophyll and nitrogen concentration analysis. The performance of the indices in chlorophyll estimation was determined by linear regression and leave-one-out cross-validation.

The results indicate that the hyperspectral LiDAR instrument holds a good capability to estimate vegetation biophysical parameters such as the chlorophyll concentration. The results were good especially with the Scots pine shoot dataset.

The instrument used and presented in this thesis already holds much potential in various environmental applications. As the hyperspectral LiDAR technology matures, it will provide a significant improvement to the remote sensing of environment.

**Keywords:** remote sensing, hyperspectral, LiDAR, laser scanning, vegetation index, chlorophyll estimation, active sensing

**Language:** English

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Mikko Ojala

**Title of the Thesis:** Laser bathymetry

**Supervisor:** Prof. Henrik Haggren

**Instructor:** Tero Sievänen

**Number of pages:** 67

Laser scanning can roughly be divided into topographic and bathymetric surveying. This thesis focuses on the latter but also the topographic surveying is studied quite thoroughly to cover the basic physical principles of airborne laser scanning.

Airborne bathymetry hasn't yet been executed in Finland even though its benefits are recognized worldwide. Reasons for this are for example lack of equipment and funding. Bathymetry is however a rapidly developing technology and its cost efficiency make it a respectable choice.

The purpose of this thesis was to study airborne lidar equipment, the methods used in the surveying and the benefits and limitations of both of these. In addition the data gathered from the surveying, the processing of the data and the final products produced from the data are examined as well as the problems that occur in these.

The data in its raw form isn't very usable. In order to get information from the data, it is to be modified in a so called post processing. First the depth and water levels height information is extracted from the data. This stage also includes transforming the data into such form that it can be handled in various software programs. For instance matching of the flight lines, removing of erroneous points, coordinate transformations and creating surface models are done in these programs.

The most common problems in bathymetry are for example erroneous points, compatibility of the flight lines and classification of rocks in the sea floor etc. However for most of these there is a solution available.

By studying the final products it was evident that by combining different methods of viewing the data more information could be extracted from it. Utilization of different methods is especially useful in quality control although the end user of the product is presumably interested only in the depth information that is used for instance in the production of nautical charts.

**Keywords:** laser scanning, depth information, data processing, final products

**Language:** Finnish

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Kimmo Pajula

**Title of the Thesis:** Digital aerial photo production based on direct georeferencing

**Supervisor:** Prof. Henrik Haggren

**Instructor:** Jan Biström

**Number of pages:** 82

The field of photogrammetry has been under big technical revolution during the last years. Complete digital workflow has been the main topic in many researching projects and it has been explained in many presentations. Now digital aerial camera has become a standard tool in photogrammetric image acquisition. Cameras are based on large CCD-matrices or CCD-line sensors. This has affected a lot for everyday working routines when there are not film based thinking and workflow anymore.

In addition it has been achieved another big technical improvement. Image orientation is the most important element in any photogrammetric project. GPS has already been used in aerial photo acquisition over ten years but now also orientation angles of images can be solved directly. The key for this is the combination of GPS and IMU measurements. Direct sensor orientation is the term when we are talking about direct determination of exterior orientation parameters. When these parameters have been solved traditionally in aerotriangulation, now we can say that direct sensor orientation together with system calibration and also integrated sensor orientations are new alternatives to aerotriangulation. In this diploma work these technical improvements will be explained. Also there is practical part where has been researched the accuracy of the exterior orientation parameters when there has been used different amount of ground control points.

**Keywords:** digital aerial camera, georeferencing, aerial triangulation.

**Language:** Finnish

## ABSTRACT OF THE MASTER'S THESIS

**Author:** Katja Pekkanen

**Title of the Thesis:** Occupational exposure to crystalline silica in railroad construction: Evaluating the health risk and exploring a method for remotely sensed dust detection

**Faculty:** Faculty of Engineering and Architecture

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Anu Asikainen

**Number of pages:** 68

Occupational exposure to excessive amounts of dust may result in negative health effects, since most exposure to crystalline silica takes place via dust particles. The negative effects are caused by inhalable dust and especially respirable dust that reaches the pulmonary alveolar region. Excessive exposure to crystalline silica may result in diseases such as silicosis, pulmonary tuberculosis, several extrapulmonary diseases, renal diseases, and various autoimmune disorders. In addition, crystalline silica is classified as a carcinogen to humans.

In railroad construction and maintenance operations, the handling of track ballast is the major source of crystalline silica exposure. Track ballast is usually made of crushed granite, in which the percentage of crystalline silica may reach 30 %. The operations on track ballast are performed by various machines, which create dust when manipulating the ballast layer. Thus, machine users and railroad workers are potentially exposed to dust and crystalline silica.

The exposure to crystalline silica was evaluated by personal sampling and static measurements performed according to the European standards. Machine users working on the ballast cleaning machine and the tamping machine were the groups with the largest measured exposure. In addition, the railroad workers working nearby the heavy machinery are potentially exposed to larger amounts of crystalline silica. The exposure levels inside the machine cabins were noticeably lower. However, the exposure levels are highly dependable on the quartz content of the ballast used, which in turn varies greatly between different construction sites. Nevertheless, the risk assessment suggests that preventive measures should be introduced in order to minimize the health risk.

The amount of respirable and thoracic dust around the Ilmala railroad yard construction site was mapped by using Landsat TM and ETM+ imagery from July 2010. The atmospheric reflectance is linearly correlated with the amount of particulate matter in the air, which is monitored continuously by the Helsinki region air quality monitoring stations. By using linear regression, models were built for mapping the PM10 concentration around the Helsinki region. Certain industrial areas and heavy traffic were recognizable on the dust maps, but the Ilmala region didn't stand out as a particularly dusty region.

**Keywords:** occupational exposure, dust, crystalline silica, atmospheric reflectance, dust mapping

**Language:** English

## ABSTRACT OF THE MASTER'S THESIS

**Author:** Maaria Posti

**Title of the Thesis:** New workflow for the registration of mobile laser scanning point clouds

**Supervisor:** Prof. Henrik Haggrén

**Instructors:** D.Sc. (Tech.) Petri Rönholm, Heikki Luukkonen

**Number of pages:** 82 + 8

Vehicle-borne, or mobile, laser scanning offers a fast and cost-effective method for mapping large areas, such as cities, in great detail. Despite the assets, the post-processing stage of the mobile laser scanning process, where the point clouds are corrected and registered, still requires much time-consuming manual processing. Although many methods have been suggested to quicken the point cloud production process, these methods appear either ill-suited or deficient for on-the-fly mobile systems such as Optech Lynx Mobile Mapper. In contrast, little research has been conducted on increasing automation in the current registration process. This thesis aimed to form a workflow for the automatic registration of mobile laser scanning point clouds.

In order to form the workflow, the theoretic background on mobile mapping was explored, including error sources, the current processing procedure and previous research. To finalize the workflow, two mobile laser datasets collected by Lynx were analyzed for trajectory errors. Finally, the formed workflow was tested for the reliability of automated pair forming as well as for the accuracy of the achieved registration.

The results achieved in the thesis proved to be promising. It was learned that the automated pair forming procedure, based on the assumed behavior of trajectory coordinate errors, formed pairs flawlessly in the tested case. This automated process replaces the step in the original registration process where the processor manually associates a control point in the point cloud with its reference (true) location. The results for latter part of the test, however, were slightly less successful. The relatively high control point errors may have resulted from many reasons, for instance the control point type (building corners) and the uncertainty related to the manual definition of point coordinates. Regardless this fact, based on visual observations, the registered point cloud matched the used reference datasets relatively well.

The results of the thesis demonstrate the potential of the formed workflow, utilizing the automatic segmentation of building corner points, in three aspects. Firstly, it appears to be possible to automate the previously manual pair forming process. Secondly, the model is likely to provide sufficient accuracy for practical purposes. Thirdly, there are readily available methods to implement the methods not yet specified in the workflow in detail, such as the automatic extraction of control points. Despite the potential, several issues – such as the generalizability of the algorithm test results and the practical implementation of the formed workflow – were not addressed in the thesis. These and other topics listed at the end of the thesis will be researched in the future.

**Keywords:** mobile laser scanning, registration, trajectory errors, urban environments, workflow

**Language:** Finnish

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Tomi Rosnell

**Title of the Thesis:** Photogrammetric Mapping with a Compact Camera and a Radio Controlled Helicopter

**Supervisor:** Professor Henrik Haggrén

**Instructor:** D.Sc. (Tech.) Eija Honkavaara

**Number of pages:** 95

Recent development in the field of Unmanned Aerial Solutions, UAS, has led to a more popular use of these solutions. The Finnish Geodetic Institute acquired an unmanned quadcopter in 2008. The copter came to be a part of reflectance research as an aerial photogrammetric platform.

The goal of this Master's thesis was to study the photogrammetric mapping capability of a solution formed by the quadcopter and a compact camera. The main goal for the research was to find out the accuracy of the camera in photogrammetric mission and to form a photogrammetric work method for the quadcopter and the compact camera.

The work method included signalized known ground control points, accurate camera calibration, imaging with large 90% overlaps, image rectification with calibration parameters, single image orientation of the rectified images, automatic measurement of corresponding image points and bundle triangulation.

The formed method was tested in a built environment and in a photogrammetric test field. Acquired test results were somewhat contradictory. Point determination accuracy at the test field operation was one image pixel which corresponded to an accuracy of 1- 2 cm on the ground. The automatically formed digital terrain model was in correct shape and comparable to a digital terrain model formed by images from digital aerial camera DMC. Heavy three dimensionality compared to imaging distance caused various problems in the campaign with built environment. The result achieved from the built environment was not comparable in accuracy with the campaign from the test field.

The greatest challenge of the master's thesis was to handle images from a compact camera with software designed for digital images from an aerial measurement camera. A successful usage of a compact camera in aerial photogrammetric mapping mission one should incorporate close range photogrammetric solutions to a mapping software.

**Keywords:** UAV, Photogrammetry, single image orientation, photogrammetric work method

**Language:** Finnish

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Lassi Tani

**Title of the Thesis:** Implementation of the Topographic Database Download Service

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Antti Rainio

**Number of Pages:** 69

Spatial data field has changed due to the development of information technology. Before spatial data was scattered but now it is made available through web services, towards which spatial data markets have been strongly developing. Spatial datasets can be combined through web services, which spatial data infrastructure coordinates. The Inspire directive directs the formation of a national spatial data infrastructure. It defines a number of web services, and according to the directive, the spatial data the governmental agencies produce, must be available in the web service interfaces and compatible with the Inspire Data Specifications.

Literature section of this thesis presents the Inspire directive, its spatial data products, Inspire timetable and web services. The section also presents the various XML technologies.

This thesis focuses on a study performed in the National Land Survey. The research problem of the thesis was to examine, how to implement Inspire compatible Download Service using Topographic database. Download Service belongs to the Inspire defined web services, and the authority must therefore deliver their spatial datasets through web with Download Service.

In the section where the theory is applied two different service architectures were examined. In the first one a direct link to the Topographic database was tested, and in the second one a filestore was tested as the source of the service. Web Feature Service was built in the section. The results showed that the Download Service can be set up relatively quickly. Different architectural solutions are also presented.

**Keywords:** Download Service, Web Feature Service, Topographic database, Inspire, XML

**Language:** Finnish

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Matti Vaaja

**Title of the Thesis:** Mobile laser scanning for mapping river point bars and banks

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Prof. Juha Hyyppä

**Number of pages:** 50

The M.Sc. thesis was part of the GIFLOOD project (Developing mapping and modeling approaches as a part of flood risk management business) funded by TEKES. One of the main aims in the project is to test and develop different kind of laser scanning models and combine them with other mapping data. Flood mapping and flood risk related business became an interesting topic in 2007, when the EU flood directive came into force. According to the directive member states are obligated for identify potential major flood zones and flood risks.

The objective of the thesis was to investigate the performance of mobile laser scanning in river environment. Work included the accuracy assessment of mobile scanning based elevation models and developing of mobile scanning approach for change detection. The methods of change detection were height difference images and volume calculation. Furthermore, this work presents the background and principles of mobile mapping.

The laser scanning data of this work were measured in the northern Lapland on river Pulmankijoki. Measurements were undertaken in late summer 2008 and 2009. The mobile mapping system, used in the study, was developed in co-operation with Helsinki University of Technology, Finnish Geodetic Institute and University of Turku. It was mounted on the boat and the cart in order to map river point bars and banks. The reference data were collected with the terrestrial laser scanner and GPS measurements.

The RMS errors and standard deviations of mobile laser scanning in non-vegetated areas ranged between 2.3-17.6 cm and 2.3-7.6 cm. In river banks, where the ground surface was classified under the vegetation, the corresponding errors were 15.7-28.4 cm and 11.6-27.2 cm. The example of change detection demonstrates that the explanation degree of mobile scanning based height difference surface is 0.93 with corresponding terrestrial laser scanning surface.

The mobile scanning data can be utilized in flood modeling, river dynamic studies and hydraulic modeling. Compared to traditional airborne laser scanning, mobile scanning suits better for mapping of small areas. Method can be used also to acquiring very precise multi-temporal data for change detection. The accuracy of mobile scanning system is almost in same level as terrestrial laser scanners. The biggest challenges are related to GPS positioning and data processing.

**Keywords:** Mobile mapping, laser scanning, river environment, elevation model, change detection

**Language:** Finnish



## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Jakob Ventin

**Title of the Thesis:** Measuring indoor environments with a mobile laser scanner system

**Supervisor:** Prof. Henrik Haggrén

**Instructors:** Prof. Juha Hyyppä, Antero Kukko

**Number of pages:** 72

Mobile laser scanning has developed from being a research topic to commercial applications during the past years. However, mobile laser scanning has not been utilized indoors until now. The biggest challenge in indoor mapping is positioning of the measurement platform, since it cannot be realized by using global satellite navigation.

The objective of this thesis was to investigate how well the mobile mapping system ROAMER, which was developed by the Finnish Geodetic Institute, is suited for mapping indoor environments. The point cloud that was utilized in this thesis was measured inside the Finnish Geodetic Institute in Masala. The measured point cloud was compared against control points measured by total station.

The accuracy of the point cloud was improved by using TerraSolid Oy's software. The point cloud was manipulated in three different ways using targets. The targets were fastened to the floor. The measured point cloud deviated on average 155.4 cm from its true position. By manipulating the point cloud its accuracy was significantly increased. The best result was achieved by manipulating the point cloud using all targets. In this case the point cloud deviated on average 4.3 cm from its true position. The standard deviation in this case was 3.9 cm.

The measured point cloud as such is not well suited for applications that require measurements of high accuracy. By manipulating the point cloud its accuracy can be significantly increased. The manipulated point cloud can be used for applications such as making indoor maps or modeling.

**Keywords:** Mobile mapping, laser scanning, indoor environments

**Language:** Finnish

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Päivi Vinni

**Title of the Thesis:** Deformations of stereo models and comparison between digital elevation models produced by laser scanning and stereo photogrammetry

**Supervisor:** Prof. Henrik Haggrén

**Instructors:** Petri Rönholm, Olli Sirkiä

**Number of Pages:** 87

This master's thesis was made for the Aerial Image Center of the National Land Survey of Finland (NLS). The object of the thesis was to examine how errors in exterior orientation parameters affect the accuracy of coordinate measurements on stereo models and digital elevation models (DEM) generated using stereo models.

Effects of both individual errors and combination of errors in exterior parameters were tested using aerial photographs taken in scales 1:16 000 and 1:31 000. Testing was carried out by adding errors to the rotation matrices and/or to the coordinates of the projection centers images and by measuring a set of points from stereo models. The measurements were then compared with measurements made from the stereo models whose orientation parameters were not tampered with. It was concluded that model deformations follow the theory but their effect depends on numerous aspects and is therefore so versatile that it is impractical to set an unambiguous error limit to the orientation parameters that would guarantee the quality of stereo models.

In addition, a 10 x 10 meter digital elevation model (DEM) was compared to a 2 x 2 meter DEM generated from LiDAR point cloud in order to see if systematic effects, caused by orientation errors of stereo models would show up on a photogrammetrically generated DEM. Visual comparison demonstrated that the 10 x 10 meter DEM contains vertical random errors of -2 to 2 meters as specified in its description and also that it was not possible to distinguish any systematic effects of orientation errors in stereo models.

**Keywords:** Stereomodel, aerotriangulation, elevation model, deformation

**Language:** Finnish

## **ABSTRACT OF THE MASTER'S THESIS**

**Author:** Paula Ylönen

**Title of the Thesis:** The Production Process of Aerial Photomaps

**Supervisor:** Prof. Henrik Haggrén

**Instructor:** Jenni Puupponen

**Number of pages:** 87

The objective of this thesis is to describe the production process of aerial photomaps by extending the production process of a traditional map to be more applicable for an aerial photomap. The end product of the production process is considered to be a printed aerial photomap. The production process can be divided into three phases which are design, execution and reproduction.

In the aerial photomap process the required material includes orthophotos and various map data. The data should be up to date and of good quality so that the reconciling of the data is possible.

The layout of the map is decided during the design phase. It is designed with the help of map elements such as scale, symbols, and texts while paying attention to qualitative objectives. A few starting points like the purpose of use, scale, and the need for generalization taken into consideration during designing. Because orthophotos alone provide plenty of detailed information, it is important to notice the impact of it to the layout of the aerial photomap.

The execution phase includes the choosing, acquiring, and, if necessary, processing of the data to enable successful reconciling. Processing map data means execution of a necessary generalization to map data and processing orthophotos means enhancement of the photo by editing shades and contrast to improve the appearance. The reconciliation takes place when the processing of the data is finished and is at the same scale, and map projection. The reproduction involves colour system conversion from RGB to CMYK and when all the necessary data is reconciled to one file and the colour system is in applicable form the aerial photomap is printable.

As experimental work five aerial photomaps were made for this thesis of two different areas. Based on these maps the uses of aerial photomaps were examined. Aerial photomaps can be used for different purposes depending on scale and the portrayed area. They are suitable for large-scale maps where the details of orthophotos can be distinguished.

**Keywords:** aerial photomaps, orthophoto, production process of a map

**Language:** Finnish