

RECENTLY PUBLISHED LICENTIATE'S AND MASTER'S THESES AT AALTO UNIVERSITY, FINLAND

In following, we highlight recently published Licentiate's and Master's Theses at Aalto University with abstracts in the fields of photogrammetry, laser scanning and remote sensing.

Licentiate's Theses:

Kurkela, Matti (2013): Development of processes for photogrammetric measuring and modelling of indoor spaces emphasizing design and visualization perspectives

Nurminen, Kimmo (2015): Georeferencing and stereo model formation of aerial oblique photographs

Master's Theses:

Gröhn, Simo (2013): Applicability of mobile laser scanning to road surveying

Julin, Arttu (2012): Automated building reconstruction from airborne laser scanning

Kaksonen, Tommi (2014): Structured light-based 3D surface measurement using a multi-camera system

Kekäläinen, Mika (2015): Automated texturing of 3D models using georeferenced images

Klemets, Anna (2013): The mapping process of a mobile mapping system

Linjama, Perttu (2013): Fusion processes for mobile and airborne laser scanning data and applications of fused data in urban environments

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Moisander, Mikko (2014): Supporting operational observations of snow water equivalent with remote sensing data

Näsi, Roope (2014): Mapping of forest insect damage using hyperspectral aerial images

Pulkkinen, Joel (2015): Laser scanning in electricity network maintenance

Ranta, Iiro (2015): Photogrammetric deformation measurement of a metal structure

Rantanen, Jesperi (2014): Quality assurance of aerial triangulation using photogrammetric surface models and laser scanning data

Ruuskanen, Sami (2015): Measuring the volume of complex shaped objects by laser scanning

Saukko, Ville (2015): Planning the reutilization of an observatory

Siikonen, Samuel (2013): Determination of accuracy of a range camera using planes as the method

Simola, Saija (2014): Methods for improving geometric quality of mobile laser scanning data in forest environment

Sirkiä, Joni (2015): Requirements for initial data in photogrammetric recording of rock joint surfaces

Tähtinen, Suvi (2015): Indoor modelling – case Startup Sauna

Vinter, Reeta (2015): Utilization of LIDAR data and street view images in road environment monitoring

ABSTRACT OF THE LICENTIATE'S THESIS**Author:** Matti Kurkela**Title of thesis:** Development of processes for photogrammetric measuring and modelling of indoor spaces emphasizing design and visualization perspectives**Date:** 14.10.2013**Number of pages:** 81**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Prof. Hannu Hyypä**Abstract**

The aim of the thesis was to develop a photogrammetric indoor modeling method for designers. In the research, spatial 3-D measuring and modeling solutions from different disciplines were utilized. In addition, a photogrammetric measuring method for indoor modeling was developed. The objective of the modeling was to produce a simple, but geometrically accurate, 3-D surface model for design and visualization purposes.

The workflow of the developed method included camera calibration, image acquisition, geometric image correction, importing images to visualization software, exterior orientation of images, 3-D measurements, 3-D object reconstruction, visualization of reconstructed objects, and exporting 3-D models to other software. Camera calibration was carried out using in-situ self-calibration. The geometric distortions of images were corrected using software developed in this study. The software utilized an 11 parametric perspective camera model.

The developed measuring and modeling method for indoor spaces was well applicable to design-use, as the measuring and modeling process was simpler and more user friendly than in existing alternative methods. The measuring accuracy of indoor spaces was sufficient for design-use and it could be further increased in the chosen areas of models by adding more images to the bundle adjustment. The method introduced new opportunities to visualization of indoor spaces, because it enabled the use of modified texture images more fluently than in existing methods. Also, there were more options available for the re-texturing of completed models. In addition, the time needed for modeling and visualization was reduced.

The design of new fixed furniture installations to the modeled indoor space was possible, because the accurate dimensions of rooms were known. In addition, geometrically accurate models can be applied for, e.g., designing visual elements of commercial environments, such as vinyl graphics. New designs can be easily evaluated with photorealistic representations already during the design process. The designer is able to get visual feedback from alternative solutions with the help of images, videos or virtual environments. Photogrammetrically derived 3-D models of indoor spaces help to create novel solutions and innovations for facility business and learning environments.

Keywords: photogrammetry, design, indoor measurements, 3-D, modeling, indoor space**Language:** Finnish

ABSTRACT OF THE LICENTIATE'S THESIS**Author:** Kimmo Nurminen**Title of thesis:** Georeferencing and stereo model formation of aerial oblique photographs**Date:** 26.04.2015**Number of pages:** 148**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Eija Honkavaara, Prof. Juha Hyyppä**Abstract**

Aerial oblique photographs have long been a marginal information source in the field of photogrammetry. Traditional map compilation techniques are largely based on vertical photographs in which the major scale variation source is the object height. With oblique photographs the scale is also dependent on the tilt angle and is varying in respect of the image point's coordinate component measured from isocenter along principal line. The relief displacement and obstruction of view may be unacceptably high for some applications.

Main reason opting for oblique photographs is their greater terrain coverage compared to vertical photographs taken with the same camera. For viewing purposes and object recognition it may also be advantageous to use obliques. Ability to design the fly paths not directly above the target area is favourable for reconnaissance missions. Convergent oblique photographs can be used for obtaining better base-height ratio. Automatic and semiautomatic digital methods are removing many hindrances to application.

General photogrammetric principles, such as collinearity equation, apply also to oblique photographs. Photo mensuration is essentially the same as it is with vertical photographs. The aim of this study is to clarify the geometrical terms and limitations of oblique aerial photographs. Due to variety of imaging sensors involved some alternative image orientation approaches are shortly described. Also the most important historical practices based on oblique photographs are presented. Georeferencing is the means of tying the image to the object coordinate system. This can be done by using ground control points, fitting to an already georeferenced base image or direct georeferencing with GNSS/IMU-system. Stereo model formation is based on classical relative orientation, but the varying overlaps, scale-dependent image observations and sometimes disadvantageous base-height ratio add to diversity from vertical case.

The results of experimental studies are shown and the accuracy potential is evaluated. Emphasis is on the mathematical background.

Keywords: Oblique photographs, georeferencing, stereo model, direct linear transformation, camera calibration, additional parameters, direct georeferencing, image matching

Language: English

ABSTRACT OF THE MASTER'S THESIS**Author:** Simo Gröhn**Title of thesis:** Applicability of mobile laser scanning to road surveying**Date:** 13.10.2013**Number of pages:** 125**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Petri Rönholm, Nina Raitanen**Abstract**

The objective of this M.Sc. Thesis was to study the suitability of mobile laser scanning for road surveying. Literature research was used to establish test methods to be used to determine the suitability of mobile laser scanning for road surveying. Data used in the study was measured in Valtatie 6 -road with Trimble mx 8 -mobile laser scanner. Suitability for road surveying was evaluated in the following categories: accuracy, efficiency, measurement of the condition of the road surface, measurement of road asset condition and modelling of road geometry and road layout criteria.

Absolute accuracy and precision of mobile laser scanning was examined. Best absolute accuracy was achieved with ground control points spaced 100 meters apart. Largest error was 2.5 cm in XY plane and 1.1 cm in height. Precision was defined as standard deviation of 3 mm. Mobile laser scanning efficiency was studied by measuring the density of measurements on the road surface. Afterwards a comparison between different measurement methods was made by comparing the differences of measured surfaces. Point density of mobile laser scanning was measured at over 4,000 points per square meter on the road surface. Because of the highest point density, mobile laser scanner was able to model best the road surface. Suitability for measurement of road surface condition was in longitudinal road profile, cross-profile and pavement damage mapping. Problem in longitudinal road profile measurements was low point density in the direction of the road. Evaluation of suitability for measuring cross-section of the road was carried out comparing mobile laser scanner measurements to profile laser measurements. Rut and water rut of the road surface was inspected. Mobile laser scanner gave same results as profile laser measurements. Road pavement damage mapping was implemented successfully by manually observing cracks from orthophotos and point cloud. Road asset condition was addressed by examining road markings, traffic signs, railings and bus stop shelters. Condition of road markings was examined from orthophoto and intensity feature of measured points. Condition of structures of other objects was studied from point cloud. Texture was analysed from photos taken by the mobile scanner. Suitability for modelling of road geometry and road layout criteria was inspected by computing descriptors used in road planning. These descriptors include for example longitudinal road section, cross-section, sight distances and component fitting, modelling of road geometry and road layout criteria with mobile laser scanner was found to work generally very well.

Mobile laser scanner performed excellently in road surveying overall. With help of image and point cloud data mobile laser scanning brings effective and fully three-dimensional modeling to road surveying. Thus, it could be possible to develop new methods for road construction and maintenance. With mobile laser scanning it is possible to model the environment much more extensively than with any other road surveying method at the moment.

Keywords: Mobile laser scanning, road surveying**Language:** Finnish

ABSTRACT OF THE MASTER'S THESIS

Author: Arttu Julin

Title of thesis: Automated building reconstruction from airborne laser scanning

Date: 03.12.2012

Number of pages: 59

Thesis supervisor: Prof. Henrik Haggrén

Thesis advisors: Petri Ronnholm, Jonne Davidsson

Abstract

The objective of this M.Sc. thesis was to investigate how aerial laser scanner data, and especially its point density, affects the performance of the automated building reconstruction. The literature review of this thesis focuses on giving an overview of a point cloud based automated building reconstruction as most of the existing literature is focused only on individual aspects of the topic.

The aerial laser scanner data used in this work was acquired in the area of the city of Pietarsaari in spring 2012. The automated building reconstruction test was made with the point cloud processing software of Terrasolid Oy. A base map of class 1 e was used as a reference data for validating the reconstruction results. In order to investigate the effects of the point density, five different datasets (10; 5; 2.5; 1.25 and 0.6 points / m²) were produced from the original point cloud by scaling down the point densities. The aerial laser scanning data consisted of three different test areas with distinct types of buildings: a residential area, an apartment building area and an industrial area.

Results show that the average plane accuracy of the automatically reconstructed building models is below 50 cm when the point density is above 5.5 points / m², which meets the standard error requirements for a measured point in a class 2 base map. Furthermore, the average height accuracy of the models meets the class 1 e requirements in a flat terrain.

Moreover, the results of this study indicate clearly that the point density affects the performance of automated building reconstruction. According to the measurements and a visual interpretation the quality of the reconstructed building models deteriorates as the point density decreases.

Keywords: Building Reconstruction, Building Detection, Airborne Laser Scanning, Quality

Language: Finnish

ABSTRACT OF THE MASTER'S THESIS**Author:** Tommi Kaksonen**Title of thesis:** Structured light-based 3D surface measurement using a multi-camera system**Date:** 3.11.2014**Number of pages:** 48+17**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Petteri Pöntinen**Abstract**

The purpose of this master's thesis was to identify a structured light-based 3D surface measurement method that could provide the most robust measurement results using a multi-camera system. The thesis compares structured light methods used for surface measurement. To determine the accuracy, reliability and repeatability of these methods, a flat surface and a car door were measured using a measurement system consisting of 16 cameras and a projector. Lines and circles were used as projected features. Gray coding was used to detect corresponding points between images, and an epipolar line-based method was also tested. The study, commissioned by Mapvision Oy Ltd, will be used for ensuring quality control in the automotive industry.

The literature show that the robustness of the different methods essentially depends on the limitations of the specific application. The most robust methods for measuring static objects are based on projecting multiple different patterns on the scene. For moving objects, the most robust measurement results are achieved with one-shot methods. The study results found that one of the most robust multiple-shot methods in the multi-camera system is based on using vertical and horizontal lines as a structured light, which yielded an accuracy of 0.02 mm when measuring a flat object, with the best repeatability occurring at 0.02 – 0.05 mm when measuring a car door. In contrast, the repeatability for large flat surfaces was 0.02 – 0.2 mm, with the worst reliability being observed near steep surfaces. This study demonstrates that epipolar lines offer an effective alternative to Gray coding for detecting corresponding points.

Keywords: Structured light, surface measurement, multi-camera system, photogrammetry**Language:** Finnish

ABSTRACT OF THE MASTER'S THESIS**Author:** Mika Kekäläinen**Title of thesis:** Automated texturing of 3D models using georeferenced images**Date:** 09.02.2015**Number of pages:** 60**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Lingli Zhu**Abstract**

The purpose of this thesis was to form automated texturing of 3D models from georeferenced airborne images made with the Pictometry technique. As an exemplary application, a 3D building model was generated. The study aimed to texture the building models based on photogrammetry knowledge, to be realized with Matlab software. The data in this thesis were bought from Blom and it consisted of images and image parameters. National Land Survey (NLS) airborne laser scanning (ALS) point clouds of the research area were also employed in this thesis.

The first step was the investigation of the Pictometry -technology adopted, followed by an examination of the oblique and nadir view images and the parameters and their units of measurements in the data files from several research articles.

The object space coordinates were estimated from the images with the inversion of the collinearity equation. The collinearity equation was applied, for example, to visualize and verify the right position of the three-dimensional (3D) coordinates in the image. The original building point cloud data were in the coordinate system of “valtion vanha järjestelmä” (VVJ), eventually transformed to the current ETRS TM35FIN coordinate system with the height system N2000.

Unfortunately, the attempt to generate a fully automatic Matlab program from the original data was unsuccessful because the orthophoto of the façade was not the complete façade. The obtained orthophoto had been transformed in the vertical and horizontal direction compared to what it was expected to be. It was possible to generate a semi-automatic system from the original data but the corrections to the coordinates needed to be defined for each image separately. From the semi-automatic system, it was possible to make realistically-looking three-dimensional models of buildings, with the location of the building positioned in the real coordinates.

Another approach to generate automated texturing was to recalculate the internal orientation (IO) and the external orientation (EO) parameters with other programs. This was done because there were tens of metres of error in the coordinate measurements compared with the real coordinates, and tens of pixels of an error in the image coordinates compared with the real image coordinates. Applying these regenerated orientation parameters enabled automated texturing from the known model vertex coordinates or the coordinates measured from the image.

Keywords: Oblique imaging, texturing, 3D modelling, automation, image orientations**Language:** English

ABSTRACT OF THE MASTER'S THESIS**Author:** Anna Klemets**Title of thesis:** The Mapping Process of a Mobile Mapping System**Date:** 11.03.2013**Number of pages:** 94 + 5**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Petri Rönnholm**Abstract**

The topic of this Master's Thesis is the mapping process of mobile mapping. The aim is to study the process practically through an example project and theoretically by creating a graph containing all stages of the process. The aim of the example project is to create a 3D city model using the Trimble MX8 mobile mapping system. Another topic in this thesis is combining different data sets such as aerial, mobile and static point clouds and images.

The mobile mapping process consists of four stages. The first stage is the planning stage. An execution plan is created using information regarding the site and the requirements regarding the data. The execution plan will impact all the following stages in the process. The planning stage also includes site preparation. The next stage is the data collection when all the data needed from the site is collected. A very important part of the data collection is the quality assessment. Quality assessment during data collection is vital for collecting good quality data.

After data collection the next step is to start processing the data. This stage can be split into three stages. The first one is processing of the positioning data. The next stage is to process the point cloud and the images. And finally, the last stage is to create deliverables. The processing stage is the most time consuming and laborious stage in the whole mobile mapping process.

In the example project two different kinds of 3D city models are created. Both of them include combining mobile and aerial datasets. The first model consists of a colored point cloud. The point cloud is colorized using color values from the images. The second one is a more traditional 3D city model with vectorized buildings and a surface model draped with images.

Keywords: Mobile Mapping, Mobile Mapping System, Mapping Process, 3D City Model**Language:** Finnish

ABSTRACT OF THE MASTER'S THESIS**Author:** Perttu Linjama**Title of thesis:** Fusion processes for mobile and airborne laser scanning data and applications of fused data in urban environments**Date:** 29.05.2013**Number of pages:** 64**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Petri Rönholm**Abstract**

Mobile and airborne laser scanning data are generally used apart from each other. However, by fusing the data, the advantages of both methods can be taken, i.e. the reach of the airborne laser data and the accuracy of the mobile laser data. The main objective of this thesis was to examine the data fusion process, the methods used during that process and the applications of the fused data in urban environment.

The main research methods used were literary research and experimental work. At the beginning of the literary review, the fundamentals of the laser, laser ranging and laser scanning were introduced. Next, the point cloud fusing methods and the data fusion process were carried out. From the fusion methods, the ICP algorithm and the least square method were studied carefully. The fusion process was observed to divide on four substeps: data preprocessing, point registration, data merging and data fusion. At the end of the literary review, the fused data applications in urban environment were presented. The most important applications include 3D city models and road environment elevation models.

The experimental work section covers the data fusion process on practice. The data used was measured using mobile- and airborne laser scanners in Jyväskylä during 2011. The airborne data was delivered as preprocessed and registered but the registration of the mobile laser scanning data was implemented by experimental work in this study. The data registration and fusion were done by using Terrasolid software. Some of the main applications of the fused data were also implemented by experimental work. Both the literary review and the experimental work sections fulfilled the expectations of this study. In the future, research could be continued by including the static terrestrial laser scanning to the fusion or by concentrating more accurately on some individual application.

Keywords: mobile, airborne, laser, scanning, lidar, fusion, merging, applications, urban, city, building, model**Language:** Finnish

ABSTRACT OF THE MASTER'S THESIS**Author:** Nils Mesterton**Title of thesis:** Automatic spatial data quality validation using open source software**Date:** 30.11.2015**Number of pages:** 57 + 17**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Antti Jakobsson**Abstract**

European National Mapping and Cadastral Authorities (NMCAs) are in the process of creating a harmonized pan-European spatial data framework in the European Location Framework (ELF) project. ELF project consortium consists of 30 organizations, and the project is set to be completed by 2016. The main goal of the project is to enable easier access to harmonized INSPIRE data in cross-border and pan-European use cases. Data quality validation is an important part of the harmonization process, making it easier for a user to determine whether or not a dataset can be utilized for a specific purpose. Automatic data quality validation ensures that a dataset complies with data requirements before it's added to the ELF. Automatic data quality validation is a relatively quick method for assessing spatial data consistency even throughout an entire database. This adaptive method can be applied on every phase of the spatial data life cycle.

The objective of this thesis was to evaluate if open source tools could be used for enabling automatic data quality validation on ELF-compatible spatial data. PostGIS database software was used to implement quality tests based on ELF data quality requirements. Quantum GIS software was used for managing the database and for viewing, processing and constructing test data.

Results indicate that PostGIS offers all analysis capabilities required for validating consistency of spatial data. Uncertainties lie in the performance aspect of the test environment because some of the tests indicated lengthy processing times. Reliability of the re-search could be improved by comparing the presented solution to an existing software product.

Optimization methods are presented for further development. It is also suggested that the presented method would be suitable for developing an open source software library or a quality validation tool.

Keywords: Data quality validation, spatial data, PostGIS, PostgreSQL, open source, ISO, OGC, ELF, ESDIN, INSPIRE

Language: Finnish

ABSTRACT OF THE MASTER'S THESIS**Author:** Mikko Moisander**Title of thesis:** Supporting operational observations of snow water equivalent with remote sensing data**Date:** 22.5.2014**Number of pages:** 75**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Heidi Sjöblom, Sari Metsämäki**Abstract**

Snow water equivalent (SWE) is used to measure how much water would form should whole of a snow pack melt instantly at its current location. Information about snow water equivalent is needed in many applications e.g. flood forecasting, controlling water level of power plant reservoirs, planning for forestry and crop irrigation and as input and control variable for many environment research purposes including climate change research. Traditionally snow water equivalent has been measured with in-situ samples or by interpolating weather station observations. Observation networks however tend to be quite sparse and time intervals between sampling can be long. Another option to provide information on snow water equivalent is by using space-borne microwave observations. Satellite instruments make it possible to have observations each day, and thanks to large swath of the instruments, global coverage can be reached within few days. Standalone radiometer observations can be somewhat imprecise. Correct interpretation of the brightness temperatures observed by the radiometer requires accurate information on attributes of the snow pack itself, on vegetation cover and about composition of atmosphere over the observed area. Rarely are all this data available for the entire area observed by the instrument. To increase the reliability and the accuracy of snow water equivalent estimates, radiometer observations can be assimilated with background information about the spatial distribution of snow depth. This information can be derived from synoptic weather station network. In this thesis work the suitability of radiometer data for purposes of the Finnish environment institute's operational observations of snow water equivalent is investigated. Advanced Microwave Scanning Radiometer for EOS (AMSR-E) and Special Sensor Microwave / Imager (SSM/I) data interpreted with Helsinki University of Technology (HUT) snow emission model and assimilated with snow depth data from Finnish Meteorological synoptic weather stations from years 2011 to 2013 are compared with in-situ observations from Finnish snowline network and with areal snow water equivalents calculated thereof. Error rates and spatial and temporal distribution of differences in snow water equivalent between products are investigated, and factors affecting the difference and suggestions how to narrow down the difference are given.

Keywords: snow water equivalent, passive microwaves, satellite remote sensing, operative hydrology, modelling, AMSR-E, SSM/I, snow lines, data-assimilation, HUT snow emission model

Language: Finnish

ABSTRACT OF THE MASTER'S THESIS**Author:** Roope Näsi**Title of thesis:** Mapping of forest insect damage using hyperspectral aerial images**Date:** 10.11.2014**Number of pages:** 61**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Eija Honkavaara**Abstract**

Insects cause significant economic losses in forestry worldwide. Insect damage has also increased recently in Finnish forests due to the impact of climate change. In particular the population of the European spruce bark beetle has increased as a result of the warm summers and resulted in losses of millions of euros. It is important to identify trees to which they have attacked in order to initiate operations to prevent their spread. The objective of this study was to investigate how the damages by bark beetles can be mapped by using a new miniaturized hyperspectral camera that is based on Fabry-Perot Interferometer (FPI). The camera has developed in Finland and can be operated from almost any type of aerial vehicles. Furthermore, the FPI camera collects frame-format images enabling stereoscopic measurements. This provides a possibility for generation of dense point clouds and digital surface models; this is not possible with the conventional expensive hyperspectral instruments based on whiskbroom or pushbroom scanning.

For the empirical investigation, remote sensing data over areas of damages by bark beetles were collected in Lahti, Finland by the FPI spectral camera and commercial off-the-shelf SLR camera Nikon 3DX from a small manned aeroplane platform Cessna Cardinal RG. Field reference measurements were carried out in 30 field sample plots of size of 16 m by 16 m to identify impacts of bark beetles in every spruce. By comparing the field observations and spectral data from the FPI camera, we investigated if it is possible to identify damages by bark beetles using the FPI camera. Furthermore, a literature review was carried out to find out which remote sensing techniques have been used in the past to detect and map damages by insect pests in forests.

The collected remote sensing data were used to produce digital surface models and hyperspectral image mosaics. These allowed us to make damage maps, where every tree in the research area was classified as a broadleaf tree or healthy, infected or dead spruce. This was performed by training several different supervised classifiers using spectral features of trees in the field sampling plots. The best results were achieved by using the Spectral correlation mapper (SCM); the classification accuracy of broadleaf trees was 96 %, healthy spruces 55 %, infected spruces 64 % and dead spruces 81 %. It was challenging to classify healthy and infected spruces because their spectral features differed only slightly from each other. The results indicated that the FPI spectral camera is a potential alternative for the identification of damages by bark beetles. It was concluded that the novel light-weight, low-cost remote sensing technology enables new possibilities for the early identification of insect damages, in comparison to conventional technologies with heavy and expensive instrumentation.

Keywords: Insect damage, European spruce bark beetle, FPI camera, hyperspectral data, radiometry, photogrammetry, remote sensing

Language: English

ABSTRACT OF THE MASTER'S THESIS**Author:** Joel Pulkkinen**Title of thesis:** Laser Scanning in Electricity Network Maintenance**Date:** 20.04.2015**Number of pages:** 68 + 21**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Petri Rönholm, Petri Rauhakallio**Abstract**

When extreme weather events are increasing, power cuts have become more common. At the same time society's dependence on the electricity has increased. In addition, legislation and regulation in many countries are tightening and it requires electricity network companies to achieve better power distribution reliability. This will drive electricity network companies to develop electricity network maintenance.

At the present, electricity networks are inspected mainly by traditional inspection methods i.e. ground inspection and visual helicopter inspection. Newer, data-based (laser scanning- and aerial photography-based), data collection from a helicopter can also be used in electricity network inspections and maintenance. By laser scanning, power line corridor can be modelled to the 3D-model and for example vegetation changes can be monitored accurately.

The purpose of this master's thesis is to gather information primarily from laser scanning of the electricity networks, but also from ground inspection and visual helicopter inspection. Different inspection methods are also compared to each other. In this thesis was made a survey to the European electricity network companies. By survey examined above mentioned three inspection methods; for example method commonness, costs, advantages and disadvantages. In addition, was investigated which kind of data from electricity network can be achieved by different inspection methods. The thesis introduces electricity networks, laser scanning and the most common electricity network inspection methods.

One conclusion of the thesis is that data-based inspection method is not currently most used inspection method. Furthermore, it may also be noted, that the most comprehensive information from different network components are obtained by ground inspection. The fastest and the most accurate inspection method is data-based helicopter inspection.

Based on the results of this thesis, the best combination of inspection methods is combination of ground inspection and data-based helicopter inspection. In the future, electricity networks are inspected by UAVs with laser scanner and by stereo photographs taken from satellite.

Keywords: Airborne laser scanning, aerial photography, electricity networks, electricity network maintenance, electricity network inspection.

Language: Finnish

ABSTRACT OF THE MASTER'S THESIS

Author: Iiro Ranta

Title of thesis: Photogrammetric deformation measurement of a metal structure

Date: 07.04.2015

Number of pages: 68+6

Thesis supervisor: Prof. Henrik Haggrén

Thesis advisor: Petri Rönnholm

Abstract

Close-range photogrammetry provides an efficient way of obtaining knowledge of a measured target by the means of remote sensing. In this study the theory of photogrammetry is dealt with and the feasibility of using a photogrammetric method of measurement to practical application is explored. Specifically deformation measurement of a large structure using multi-camera system is studied. The practical part consists of validating the photogrammetric method in trial measurement performed in controlled environment and of the actual deformation measurement of the large structure. The goal was to determine how well photogrammetric method works in deflection measurement of an arduously measurable metal structure.

Keywords: Close-range photogrammetry, deformation

Language: Finnish

ABSTRACT OF THE MASTER'S THESIS

Author: Jesperi Rantanen

Title of thesis: Quality assurance of aerial triangulation using photogrammetric surface models and laser scanning data

Date: 26.05.2014

Number of pages: 62+7

Thesis supervisor: Prof. Henrik Haggrén

Thesis advisor: Risto Ilves, Petri Rönnholm

Abstract

Aerial triangulation is used to solve attitude and position information of aerial image block. Possible errors left after the triangulation were studied by comparing a photogrammetric surface model made from aerial mapping images to surface model made using laser scanning. Literature review studied the theory of these surface models and different algorithms used to create them.

Several methods and areas are tested to compute a difference between the two surface models but there is a fundamental one metre elevation difference between the models. On open areas like fields the difference is only 0.13 metres but is up to 4 metres in forest areas. If all the triangulated images have 1 or 2 metre error in their positioning, the error is visible only if it is in height coordinate. If the position of one image has an error of 1 or 2 metres it causes a deformation in the surface model. Deformations smaller than two metres in size are not visible however because of large random errors. Nevertheless, the method does not require large amounts of active working time to compute so it has potential in aerial triangulation quality assurance if the systematic error between the data sets can be decreased.

Keywords: Aerial triangulation, laser scanning, quality assurance, terrain surface model

Language: Finnish

ABSTRACT OF THE MASTER'S THESIS**Author:** Sami Ruuskanen**Title of thesis:** Measuring the volume of complex shaped objects by laser scanning**Date:** 20.5.2015**Number of pages:** 106**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Petri Rönholm**Abstract**

The purpose of this thesis is to develop a method to measure the volume of industrial container vessels through laser scanning and fitting a piecewise polynomial surface to the point cloud. The method should be able to give the complete volume of the vessel and also the volume up to a given height to be used in production when the height of the liquid head is measured. In the case study the inside of the container vessel was scanned from three stations and the point clouds were registered with an ICP-algorithm and the erroneous points were removed manually. Floor and wall points were extracted from the cloud. A RANSAC approach was used to fit a cylinder to the wall for indexing and a uniform non-rational B-spline surface was fitted to the wall points.

Measuring the volume was based on defining a horizontal section. Horizontal sections were formed by freezing the vertical index and as a result of that a self-closing piecewise polynomial curve was obtained. The volume of the container vessel was obtained through a double integral by first defining the equation of the area of the section by using Greens' integral. The equation of the area was then integrated piecewise over the vertical axis up to the given height. The complete volume of the industrial container vessel yielded by the proposed method was 2495716 liters and the volume after subtracting deadwood was 2494962 liters.

The proposed method is suitable for continuous approximate cylindrical or conic objects. The limitations of the method are the following. Firstly it has problems modeling thin extrusions. Secondly, curved objects might require merging multiple models together or a completely different method. Finally, sharp edges and perfectly horizontal surfaces can't be accurately represented with uniform base-functions and non-uniform base functions are needed instead.

The accuracy of the proposed method was tested by calculating the standard deviation of the surface fitting and conducting a reference measurement with a test vessel. A point cloud was produced with a triangulating laser scanner and the volume of the vessel was calculated using the proposed method. A reference volume was obtained by weighing the vessel both empty and filled with water and using the known density of water to calculate its volume. Standard deviation was 1.98 mm and the reference measurement showed a difference of less than 0.3 % in volume between the two methods.

Keywords: B-splines, volume, surface model, laser scanning, point cloud, NURBS**Language:** Finnish

ABSTRACT OF THE MASTER'S THESIS

Author: Ville Saukko

Title of thesis: Planning the reutilization of an observatory

Date: 25.05.2015

Number of pages: 42

Thesis supervisor: Prof. Henrik Haggrén

Thesis advisor: Prof. Martin Vermeer

Abstract

The aim of this master's thesis is to research and present possible uses for an observatory located at Aalto university premises in Otaniemi. The observatory was decommissioned at 1970's when GPS replaced celestial navigation as the most important positioning method. The observatory is currently being reutilized and the project is coordinated by professor Henrik Haggrén.

To support suggestions presented in the results this thesis explains basics of science popularization, introduces the present state of the observatory in question, gives examples of other observatories, Introduces LUMA center and presents the fundamentals of celestial positioning that the observatory was originally used for.

The results present suggestions for uses that could be utilized in the observatory in the future. This thesis is meant to be used as a basis for continuing the project and as groundwork for future research on this subject.

Keywords: Observatory, Science Popularization, Celestial navigation

Language: Finnish

ABSTRACT OF THE MASTER'S THESIS**Author:** Samuel Siikonen**Title of thesis:** Determination of accuracy of a range camera using planes as the method**Date:** 25.02.2013**Number of pages:** 54**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Petri Rönholm**Abstract**

Object of this thesis was to determine the accuracies of a range camera which uses phase difference method (Camcube 3.0) to calculate distance images and an instrument which uses laser triangulation method (Kinect). Accuracies were determined by measuring six planes placed in a test field which is constructed precisely for this thesis. Data of Camcube and Kinect were compared with measures from photogrammetric method, which means in this thesis measuring 3D data from pictures taken with digital camera. The accuracies in two sections: the build accuracy and the position accuracy. The build accuracy was calculated using error distances between data points associated to an average plane. A statistic factor used to compare the accuracies was a standard deviation of the error distances. The first step in calculating position accuracy was to transform the data from Camcube and Kinect to the coordinate system of the photogrammetric data. Transformation was calculated by registration of corresponding planes from both data sets. Finally, the position accuracy was calculated from the distance difference between planes from two data sets.

For the purpose of reliable accuracy comparison, digital camera and Camcube were calibrated. Lens distortions were removed from both cameras. In addition, the Camcube's distance error was corrected. The Distance error was compensated in two different methods. One of these methods attempted to minimize, at the same time, the periodic error of a signal.

The Orientation of the planes with respect to the instrument was found to have a vital role in the accuracy of the distance measurements. In the case of Camcube the data was systematically farther away than data gained from the photogrammetric method. In Kinect's data some planes were closer and some farther when compared to photogrammetric data. The build accuracy of Camcube data sets were 14.605 mm and 9.321 mm (with periodic compensation). In the case of Kinect the build accuracy was 21.208 mm.

Software used in this thesis were iWitness, Geomagic and Matlab. iWitness was used in calibrating digital camera. Geomagic was used in calculating accuracy values and coordinate transformations. Acquisition of the data and error compensations for Camcube were solved using Matlab.

Keywords: Range camera, Accuracy, Camcube, Kinect, Matlab**Language:** Finnish

ABSTRACT OF THE MASTER'S THESIS**Author:** Saija Simola**Title of thesis:** Methods for improving geometric quality of mobile laser scanning data in forest environment**Date:** 02.10.2014**Number of pages:** 75**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Antero Kukko**Abstract**

Mobile laser scanner can measure environment, where other laser scanners cannot or where they are hard to use. Airborne laser scanning can't measure tree stems from above. It is hard and slow to move terrestrial laser scanner. If laser scanner's position is known, only then points from objects can be saved with correct position. Position of laser scanner can be defined with combining global navigation satellite system and inertia-system in mobile mapping. Computational route of MLS is called trajectory. Trajectory can be defined with GNSS-IMU-observations. GNSS cannot be connected to satellites in forest environment all the time. Inertia-positioning cannot keep correct positioning quality for long. Then it is not possible to reliably know where points should be mapped in a real world. That means that geometric quality of the data decreases.

Intersections within the trajectory were sought for improving geometric quality of MLS-point cloud. Intersections were points, where laser scanner measured at least twice in different times. It is possible to find two different set of points around those intersections for mutual matching. By matching the set of points it is possible to reduce positioning error between the set of points. The point cloud and corresponding trajectory for this study were measured by mobile laser scanner Akhka R2. Reference point cloud was measured with terrestrial laser scanner from the same area. Matlab-program was used to implement the matching method. TerraScan-program was used for processing point clouds and comparing results.

The geometric quality of the point clouds was improved for forest environment in N- and elevation directions. Improvement took place in forest environment between the test and the reference point clouds. Improvement in the elevation direction was approximately 0,01 m between the test and the reference point clouds and 0,12 m inside the test point clouds in forest environment. In the elevation direction 71 % of the set of points between the test and the reference point clouds and all of the set of points inside the test point clouds were improved in forest environment.

Improvement in the N-direction was approximately 0,01 m between the test and the reference point clouds and 0,02 m inside the test point clouds in forest environment. The geometric quality in N- and elevation directions was better inside the test point cloud than between the test and reference point clouds in forest environment by using the implemented matching method. The geometric quality of the whole dataset was improved in elevation direction by using the implemented matching method. The geometric quality of the whole dataset got worse in heading-angles by using the implemented matching method. It is important to improve geometric quality, so that MLS can be used reliably in the forest environment.

Keywords: Laser scanning, mobile, MLS, TLS, ALS, PLS, forest mapping, 3D, accuracy, point cloud, GNSS/INS, GPS, positioning, geometric quality**Language:** Finnish

ABSTRACT OF THE MASTER'S THESIS**Author:** Joni Sirkiä**Title of thesis:** Requirements for initial data in photogrammetric recording of rock joint surfaces**Date:** 30.11.2015**Number of pages:** 83**Thesis supervisor:** Prof. Mikael Rinne**Thesis advisor:** Lauri Uotinen**Abstract**

Deriving parameters to represent mechanical properties of rock mass in a scale of nuclear waste disposal project requires conducting a large scale in-situ test. Representativeness of one test for a large region of interest is questionable. Photogrammetric recording of rock joint surfaces aims to develop surface replication procedure to offer an alternative for determining mechanical properties of rock joints with laboratory scale testing of rock joint surfaces.

The purpose of this research was to identify errors on photogrammetric replication of rock joint surfaces through evaluation of change in surface geometry during the replication process. The study was conducted as a part of KARMO (Mechanical Properties of Rock Joints) research program, financed by VYR (Nuclear Waste Management Fund) through KYT2018 (Finnish Research Programme on Nuclear Waste Management) research programme. Data for this thesis was compiled mainly from separate bachelor and master thesis works conducted for the research program earlier. The bachelor thesis works were conducted by Pauliina Kallio and Laura Tolvanen, and the master thesis work was conducted by Eero Korpi.

The investigations for this thesis were conducted partly by a literature study that focused on quality of photogrammetric modelling and the factors affecting the accuracy of the model, and partly by developing measuring metrics for evaluation of geometrical change in the replication surface. The developed metrics was applied in a study to clarify the changes undergone by replica models in different stages of the replication process. The results show that the photogrammetric replication of rock joint surfaces is unable to reliably replicate the original rock surface. An average result for a replica sample is to lose 2 percent of surface roughness on casting mold production, and to lose 6 percent of surface roughness in casting of replica sample. The results also show that the photogrammetric modelling procedure works well in special cases (5 out of 33 samples), and is able to produce high quality results for modelling a surface digitally. Finally the thesis presents a recommendation for photogrammetric configuration to be used in photogrammetric replication of rock joint surfaces in the future.

Keywords: Photogrammetry, recording, rock joint, discontinuity, roughness, characterization**Language:** English

ABSTRACT OF THE MASTER'S THESIS

Author: Suvi Tähtinen

Title of thesis: Indoor modelling – Case Startup Sauna

Date: 20.5.2015

Number of pages: 82+8

Thesis supervisor: Prof. Henrik Haggrén

Thesis advisor: Ville Lehtola

Abstract

This thesis studies indoor 3D modelling using three different imaging methods for collecting spatial data. Additionally data collection and data processing processes are studied and the quality of spatial data collected with different methods. Three different three-dimensional point clouds are compared. One is generated using laser scanning, second photogrammetrically from photographs and third with the combination of Matterport depth camera and cloud service. Modelling subject is Startup Sauna, located in Espoo.

The thesis studies usability and explains why traditional photography and Matterport imaging are suitable for beginners for their usability, and why laser scanning is not.

With the tested methods it is possible to generate three dimensional visual presentations of the subject in addition to the actual point cloud data. Further processing of point clouds into textured surface models is out of scope of this thesis.

Keywords: Matterport, depth camera, laser scanning, photography, 3D modelling, indoor modelling, Startup Sauna

Language: Finnish

ABSTRACT OF THE MASTER'S THESIS**Author:** Reeta Vinter**Title of thesis:** Utilization of lidar data and street view images in road environment monitoring**Date:** 20.04.2015**Number of pages:** 64+2**Thesis supervisor:** Prof. Henrik Haggrén**Thesis advisor:** Mikko Ojala**Abstract**

Utilization of laser scanning has increased during the past few years in many fields of applications, for example, in road environment monitoring. Mild winters, increasing rainfalls and frost are deteriorating the surface and structure of the road causing road damages. The road environment and its condition can be examined for example with laser scanning and street view images.

Utilization of laser scanning data and street view images in road environment monitoring was studied in this thesis. The main focus was on the road damages and drainage. Also individual trees were detected nearby road scenes. TerraModeler and TerraScan software were used for investigations. Five different lidar datasets were used to detect road damages and drainage. Both mobile and helicopter-based lidar data were available from Jakomäki area. In Rauma case, there were two datasets collected from the helicopter but the point densities were different. In addition, to helicopter-based lidar data, there were also street view images available from BlomSTREET service in Hyvinkää case. The results between the datasets were compared. Aim was to investigate if same damages can be found from the several datasets that have different point densities. Lidar data for individual tree detection was collected by helicopter from Korppoo area. Tree locations were also measured with a tachymeter to get reference data for automatic detection. Heights of the trees were manually determined from the point cloud. Manually measured heights and locations were compared with automatically detected ones.

Detection of rut depths, slopes and drainage is possible from the high point density datasets. From lower point density datasets it is not possible to detect for example rut depths. Point cloud is possible to color by slopes, which may give some information about rut locations even from lower point density datasets. Obtaining slopes and drainage accurately is also possible from lower point density data. With TerraModeler water gathering points can be obtained. Panorama pictures from BlomSTREET can be utilized for ensuring if there is a rainwater outlet or if water will gather as a puddle. Tree locations were detected in a meter accuracy with automatic method. Successful detection of tree heights and locations is dependent on many things. Successful classification of the data and creation of tree models are the most important parameters.

Keywords: Individual tree detection, laser scanning, road damages, street view images**Language:** English