Report on 56th Photogrammetric Week (PhoWo) was held at the University of Stuttgart, Stuttgart from 11-15 September 2017.

The 56th Photogrammetric Week (PhoWo) was held at the University of Stuttgart in Stuttgart Germany, managed very ably by the new Head of the Institute for Photogrammetry and Remote Sensing, Professor Uwe Sörgel. Invited speakers presented papers in the morning sessions, and the 'PhoWo partners', comprising companies which market equipment and software for the photogrammetric, remote sensing and spatial information industries, presented workshops on their equipment and software in the afternoons. The PhoWo partners included Hexagon (Leica Geosystems), Trimble, IGI, Vexcel Imaging, Riegl, nFrames and Pix4D. The theme of the conference was *Advancement in Photogrammetry, Remote Sensing and Geoinformatics*'. During the conference, the Carl Pulfrich Award was presented to Franz Rottensteiner from Leibniz Hannover University.

Highlights from PhoWo can be summarised as follows:

- Further increase in the Mpixels available in digital aerial sensors
- The development of aerial urban mapping systems including nadir and oblique image acquisition
- Continued increase in the pulse repetition frequency (PRF) of airborne lidar
- Full wave and bathymetric lidar systems as well as Single Photon Lidar (SPL) were described
- The continued enhancement of processing software for airborne mapping systems to improve workflow, based on multi-sensor systems.
- Continued development of mobile mapping systems together with processing software
- While UAVs were not discussed specifically they are being used as a tool for a range of sensing activities
- Growth of Pix4D software with expansion into agriculture and construction
- Studies of new areas for photogrammetry, including cultural heritage, BIM and virtual reality

The opening included a musical presentation and a welcome by Professor Sörgel.

The first session entitled 'Brief Lectures by the PhoWo Partners' comprised presentations on the latest technology developments as follows.

Helmert Rosengarten (Leica Geosystems) '*RealWorld - RealCity – RealTerrain Airborne Reality Capture - The Integral World of Leica Airborne Solutions'*, referred to the forecasts of more than 4 times growth in the LBS market by 2019. He described the structure of Hexagon which is transitioning from 2D to 3D data processing and management, for which efficient workflows are essential. Products described included HxMap, a mapping system for aerial images and lidar data, ADS100 pushbroom and DMC frame camera systems, the SmartCities RCD30 with obliques and wide angle linear lidar and single photon count SPL100, mobile mapping and UAV systems. The Hexagon Imaging program (HxIP) covers US and Europe.
Alexander Wiechert (Vexcel Imaging) '*News from Vexcel Imaging*' described the new UltraCam Eagle M3 with 449 Mpixels, favourable B/H and 4 exchange lenses with 80, 100, 120 and 210 mm, a pansharpening ratio of 1:3 and FMC by TDI. The Osprey M3p with nadir 116 Mpixels and oblique images with 80 Mpixels. The UltraCam Condor M1 has 38 Mpixels cross track by 5 kpixels for nationwide mapping programs at flying heights of 2000 to 5500 m. For terrestrial sensors, the Mustang camera and lidar mounted on a vehicle, UltraCam Panther in a backpack. The UltraMap workflow is software for all sensors, including colour balancing and dehazing, dense matching, innovative editing 3D TIN with undercuts. There is no migration for lidar yet.
Andreas Ullrich from Riegl - *Advances in RIEGL's Waveform-LiDAR Technology and Waveform-LiDAR Products,* described waveform lidar technology and products for terrestrial, mobile, airborne and

UAS lidar systems. Full waveform processing is based on Gaussian decomposition and provides better analysis on lidar returns.
Philipp Grimm, IGI, Kreuztal, *Germany News from IGI;* IGI is celebrating its 40th anniversary. Past projects were reviewed as well as current corporate partners such as Open Skies. Imaging systems include DigiCam and DigiTherm; IGIvisu provides viewing of data during capture; AEROcontrol Compact is suitable for all levels of flights and all platforms; UrbanMapper includes large format camera + oblique (4x100 Mpix), RGB and RGBI; mission planning and aircraft guidance can be undertaken by CCNS-5; UM image is available for processing workflows. Miranda94 image generator radar sensor with 1.5cm resolution.
Ronald Bisio, Trimble, Stuttgart, Germany, *News from Trimble*, reviewed products including new developments. He highlighted agriculture applications using UAV to identify problems using eCongnition, such as for crops, trees, oil palm trees.
Konrad Wenzel, nFrames, Stuttgart, Germany, *Large Scale Airborne City Capturing - Challenges and Opportunities*, operates SURE software with significant number of partners to produce true orthophotos. Cities captured with 80% forward overlap and 60% sidelap or 80% for high buildings as well as obliques.
Martin Rehak, Pix4D, Lausanne, Switzerland, *Photogrammetric Innovations for Industry Applications*. Pix4D has 100+ employees. They have processed 160,000 projects and have 170 resellers. Pix4D versions are available for agriculture and BIM. Outputs include classified point clouds, vectorized plans. A crane camera uses Pix4D for processing to monitor construction.

1st Topic: "Sensors"

Michele Crosetto, CTTC, Castelldefels, Spain, *Deformation Monitoring by Means of Ground-based and Satellite SAR.*
SAR interferometry and PS Interferometry were introduced. Sentinel 1 dual pass interferometry is available. Phase differences depend on effects due to movement, atmosphere, residual topographic effects and noise which must be small. 2 images can detect displacements of from mm to dm, but to achieve higher accuracy it is necessary to use multiple images to estimate atmospheric and residual topographic effects. Phase difference is bound by estimation of phases within ±π, which is determined by phase unwrapping. Deformation is observed along the line-of-sight (LOS). Also, there is a difference in sensitivity of phase with respect to the topography and base line (movement). Examples were given using TerrSAR-X which has high resolution and thus more points can be measured. Thermal dilation maps were produced by detecting changes in elevations of roads due to temperature measured as mm/C°. There are several SAR missions planned in future that will lead to consolidation of methods. Ground based SAR exploits phase without the topographic component. This technology gives limited coverage with measurements made every few days. An example showed 45 days observations every ½ hour revealing 9 cm displacements. Real aperture radar was also described.

Andreas Reigber, German Aerospace Center (DLR), Oberpfaffenhofen, Germany, *DLR's Airborne F-SAR System.*
The airborne SAR systems which have high S/N, are flexible experimental platforms with 5 resolutions down to 0.25 m, polarimetric capability, with X, C/S, L and P bands. They have been used for experimental real-time monitoring of traffic. Comparison with lidar showed 10-20 cm noise levels. PolInSAR is being used for forest heights and biomass measurement. 3D tomography requires 5-20 parallel flights. Circular SAR imaging provides very high resolution of ¼ wavelength for continuous monitoring. Polarimetric P band reveals penetration of up to 570 m under ice layers since lower layers are very dry; it is possible to see down to 2 to 3 km under the ice. Fully polarimetric Holographic SAR is derived from multi-circular SAR. Recent campaigns were described including Arctic ice areas revealing many patterns not visible in optical images. AfricaSAR is a program for Africa. Huge corner reflectors are required for P Band SAR. Recent developments

include Digital Beam Forming (DBF) extension leading to better accuracy in radiometry. Their new system has 12 channels at 2GHz, 8 cm spatial resolution, 8.5 Gbytes/s data rates and Ka band with higher frequency than X band.

Boris Jutzi, Karlsruhe Institute of Technology, Germany, *Less Photons for more LiDAR? A Review from Multi-Photon-Detection to Single-Photon-Detection*.
Conventional (multi-photo or linear) lidar provide a small FOV, eg at 1000 m flying height the FOV is about 0.5 km. For single photo lidar (SPL) the flying height can be 10 km with much higher FOV. Conventional lidar uses time-of-flight ranging, while SPL measures a single photon which results in more noisy pico second measurements. The speaker compared the significant differences in attributes between conventional lidar, with Geiger systems and SPL. For example, Geiger transmits at 1064 nm while SPL at 532 nm which means the latter is suitable for bathymetric operations. The footprint of Geiger lidar is 0.035 mrad, while for SPL it is 0.2 mrad. Geiger tends to collect a DSM while SPL can penetrate the vegetation. Both have about the same PRF. Ranging accuracy needs further investigations.

Ralf Reulke, German Aerospace Center (DLR), Berlin, Germany, *Hyperspectral Systems: Recent Developments and Low Cost Sensors.*
Hyperspectral systems are based on layers of spectral responses and can lead to accurate classifications. There is a trade-off between spatial and spectral resolutions. While there has been significant growth in hyperspectral systems, there is a lack of expertise to work with the data. New developments in hyperspectral systems were described including ENMap, DESIS and DLR-OS, while detector technologies were also described. He listed the cost issues of hyperspectral sensing and some current systems in space.

"Cultural Heritage"

Chance Coughenour, Google, London, UK, *Preservation with Google Arts & Culture*.
He described some processing being used for documenting culture heritage. A Google digital high resolution camera is available and can be sent anywhere for recording culture heritage items. Google museum and street view is available in various locations. He is cooperating with other units in Google to improve the recording of heritage sites. There are many products being produced to significantly improve documentation of heritage sites using the resources of Google.

2nd Topic: "Autonomous Driving and Photogrammetry"
Martin Haueis, Daimler, Sindelfingen, Germany, *Mapping the World - Vehicle Localization for Autonomous Driving*
Some of the topics discussed were motivation, map content, algorithms and challenges. Map quality is demanding, since 10 cm accuracy is required for features. There are many factors for map content and navigation requirements affecting autonomous driving, including dates, behaviour, landmarks, objects on roads, lanes, navigation and connectivity. Mapping of roads today include GNSS, cameras and lidar. Navigation by GNSS alone is inadequate, since local information is required for navigation. Advanced sensor fusion is required to merge with environmental data with GNSS data, also involving deep learning. Goal: high level of classified feature maps can be stored for fleet of cars as OEM. Every car should be able to contribute to map updates in the future.

Stephan Hinz, Karlsruhe Institute of Technology, Germany, *Visual SLAM with Multi-Fisheye Camera Systems.*
The task is designed a prototype for monitoring the construction of a tunnel in Munich, based on augmented reality. 3 fisheye cameras are placed on the helmet of a worker for viewing the

construction. The cameras provide complete coverage; robust estimation of calibration is required. Accuracy achieved is 0.4 to 1.5 cm and 0.35 to 2.6 mrad for rotations. Fisheye stereo does not work. Initialisation of the system with no control points achieves virtual 3D. Parallel processing is required for real time matching on the GPU for on-line outputs. Egomotion is an extension of SALM algorithm, which applies weighting to points, and tests on radiometry. A demo was shown of tracking through a building with results of the order of cm for multiple fisheye cameras.

Thomas Luhmann, Jade University of Applied Sciences Oldenburg, Germany, Dense *Point Clouds from Combined Nadir and Oblique Imagery by Object-based Semi-global Multi-image Matching*,
The purpose is to operate SGM for multiple views, applied in object space, which is intended for complex 3D reconstruction tasks. Advantages of the method are robust results, good modelling, high resolution and good performance. This involves changing the cost functions for SGM into object space. Results are with ½ pixel accuracy. Tests were made on aerial images with 10 cm GSD where 1σ accuracy is of the order of 1 pixel. The method provides better geometry from multiple images and hence facades are visible. Tests were also undertaken on the ISPRS dataset. Good complete results were obtained with obliques which are comparable with results of SURE.

Torsten Sattler, ETH Zürich, Switzerland, *Out with the Old? Convolutional Neural Networks for Feature Matching and Visual Localization*.
The presentation provided comparisons for some tasks based on classical methods and using CNN. The first was pose determination which revealed that there was insufficient training data. Pose estimation is well understood so there is not enough reason to apply deep learning. For feature detection, the analyssis attempted to determine the properties for a good feature detector which would involve intensity regions that are suitable for matching. Then the model must be trained. They compared learning with hand crafted descriptors such as SIFT for 3 cases. CNN proved to be worse. Regarding the application of deep learning, the suggestion is to hold off replacing everything with CNN (for now). Use CNN when the current methods do not work, or methods are not prepared adequately, are task specific, and have enough training data; in any case, compare the results against simple baselines.

Franz Rottensteiner, Univ. Hannover, Germany, *Which Data Do We Need for Training? Domain Adaption and Learning Under Label Noise*
Training often has to be generated manually, so the problem is how to reduce the efforts in developing training data. The process is domain adaptation, based on source selection. Maps can be used to learn, but they include noise. The domain includes feature space and distribution; the task is to label the space using a prediction function. The approach is for instance transfer. Can we use positive and negative training data set with samples from other sources? The process iteratively adds and subtracts samples using logistic regression. An alternative approach is domain adaptation, using the most similar images, which determine domain distances or a synthetic source could be generated based on a combination of several sources. Results showed that supervised multi-sourced method gave best results by a small amount. Also exiting maps can be used with logistic regression and noise defined by a transition probability noise model and contextual classification, using conditional random field. Better results were obtained by this method to avoid manual training.

Werner Bösemann, AICON 3D Systems, Braunschweig, Germany*, Industrial Photogrammetry for Applications in Automotive and Aerospace Industry*,
AICON was purchased by Hexagon. Industry 4.0 and effects on industrial metrology were described. The role of metrology is inspection, feedback, assisted assembly (MAA). Photogrammetry offers benefits, such as single points versus surfaces, low to high frequency, and short or long term durations. He demonstrated the relationship between photogrammetry and other methods of metrology. In manufacturing, the maximum errors are important, not necessarily the residual 5%.

Applications of photogrammetry included single cameras, multi-cameras, white light scans, motion analysis. Demonstrations were given of the measurement of helicopter cabin and doors under load. Real-time analysis is possible.

3rd Topic: "Precision Farming and Remote Sensing"

Dimitris Paraforos, Institute of Agricultural Engineering, University of Hohenheim, Germany, *Precision Farming - Technology for highly efficient Production Systems*.
In agriculture objects and the environment are unstructured, which compares with industry which is more structured. Agriculture is highly complex and dynamic in space and time. Many companies are involved in agriculture. The purposes of mechanisation are to achieve higher yields, increased labour productivity, lower production costs, sustainability, and improved working conditions. Automation affects costs and sustainability; automation in machine controls; automation in process control affects soils, crop profiles and modelling; automation in planning and decision support. Assistance can be provided in farm, crop, machine, and labour management. The speaker defined precision farming which includes actions, sustainability, and response to spatial and technical variability. It reduces decision uncertainty. Variations in characteristics of fields are analysed and procedures determined for site specific applications of fertilizer according to demand to overcome low yields. Sensor based crop management is needed. This may be done by equipment to detect data and analyse the data in real time. GNSS Switch can vary parts of sprayers. Robots use lidar to detect crop lines and apply fertilizer. Outlook is for precision farms, automation, smart farms.

Arno Ruckelshausen, University of Applied Sciences Osnabrück, Germany, *Imaging Sensor Systems - Key Technology for Innovative and Sustainable Agricultural Systems*.
Various sensors are available for agriculture, non-imaging and imaging and sensors for different wavelengths, and combinations of imaging and lidar. Hyperspectral analysis for 'on the go' real time analysis of plants. The future will be individual crop farming and remote farming. Imaging is a key component.

Anja Klisch, Universität für Bodenkultur (BOKU) Wien, Austria, *The Arrival of a Game Changer: Sentinel-2 and Possible Applications for Vegetation Monitoring in Forestry and Agriculture*.
Copernicus satellite systems will ensure data for about 20 years free of charge with global coverage every 5 days. 3 TB data will be collected from one satellite coverage of the earth in 1 year. Sentinel 2 is comparable to Landsat, but has 10 m and 20 m spatial resolution and swath of 290 km, so the resolution is superior to that of Landsat 8. PC analysis was displayed together with that of Sentinel 1 SAR data. 3 bands are available for correction parameters for the atmosphere. Sentinel 2 can be used for crop monitoring. BOKU has become a member of the EODC in Austria at €1000 per year. Examples were shown of use of the data.

Peter Krzystek, Department of Geoinformatics, University of Applied Sciences, Munich, Germany, *LiDAR-based 3D Mapping of Forests*.
Lidar is available for sampling forest parameters and characteristics. The task is to detect single trees. Airborne lidar flights were acquired with leaf on and leaf off, with 20 pts/m^2, imagery with GSD of 20 m and TLS. Graph based algorithm for cluster data was used as a trained classified. They compared lidar extraction of forests with SGM derived DSM with significant differences and small gaps cannot be detected. Lidar based classification of conifers and deciduous trees can result in up to 80% overall accuracy. Classification by logistic regression based on a number of attributes. Dead trees were detected using 3D point cloud with accuracy about 90%. Fallen trees involved DTM filtering, segmentation using a shape descriptor and classification by CRF with an accuracy of about 80%. The best results are obtained with lidar and TLS.

Gottfried Mandlburger: University of Stuttgart, Germany, *Bathymetry from Active and Passive Airborne Remote Sensing - Looking Back and Ahead*.
Measuring water depth is dependent on turbidity. Examples were shown of very clear and turbid water. Bathymetry can be derived by passive sensors using radiometry and geometry and active sensors using laser scanning at 15° to 20° from vertical. IR laser is reflected by water surface and green laser is used to transmit through water, which is affected by absorption, scattering and refraction according to Snell's law. Bathymetry from radiometry requires calibration by field measurements. There is a colour to depth exponential decay due to water depth. The DFG research project on bathymetry will involve Improving the accuracy, reliability, density and completeness of DTM of the submerged topography via fusion of concurrently acquired image and lidar data.

Herbert Brockmann, German Federal Institute of Hydrology (BfG), Koblenz, Germany, *From Applied Research to Application - Remote Sensing Products for Waterway Management*.
The BfG is responsible for river and coastal water. They need to understand the remote sensing technologies, standard products and additional products. 3D structure lines can be determined from point clouds. Recently they used a UAV with images and lidar. Technology available is PSInSAR using Sentinel data to determine spatial motion. Airborne InSAR is available for elevation determination which was compared for accuracy with airborne lidar. Differences of 25 cm were revealed, but an accuracy of the order of 15 cm is required. Flood lines need to be mapped with the product needed in 24 hours. Sentinel 2 data can be used to test forecasting water levels with an uncertainly of 5 cm in 30 days. Conditions of success are focussing on operational systems, inclusion of applied research and realisation of projects by considering fundamental issues.

4th Topic: "BIM and GIS"

Andre Borrmann, TU Munich, Germany, BIM - *The Digitalization of the Construction Industry*.
2D plans are used for building construction. Various personnel are involved in planning a building. The life cycle of a building was displayed commencing with the design, preparation of the BIM, construction based on 4D/5D and ending with the demolition or renovation. BIM has special requirements to avoid conflict and errors. BIM displays 3D geometry, pre-defined construction of specific objects, linked with additional information, comprehensive digital representation, used for analysis and simulations, and it is object oriented. Hence, there is BIM based visualisation, energy analysis, quantity take-off for tendering, compliance checking, facilitates safety and access, coordination of planning, federated models approach, where each engineer maintains control of their area of responsibility, discipline models are merged from time to time. There are clear advantages for owners. There is wide implementation in USA with national guidelines. BIM has been implemented in UK since 2011 at various levels with level 2 implemented by 2016. Germany will require implementation of BIM by 2020. Photogrammetry is a bridge between the digital and physical worlds and completes the digital chain. Typical applications are, modelling, quantity take-off, quality control, progress monitoring, capture of existing facilities. In summary, BIM improves efficiency, semantic rich 3D models, challenges in contracts and processes, while survey procedures are an excellent basis.

Uwe Stilla, TU Munich, Germany, *Process Monitoring of Construction Sites by Photogrammetric Point Clouds and 4D Building Information Models (BIM)*.
The plan is to bring together GIS and BIM. GIS provides geometric surfaces, can be based typically on a standard such as CityGML which has 5 levels, and boundary surface based semantics. BIM is volume based, the standard is IFC (Industry Foundation Classes), there is one level of display and the semantics are the building levels. In order to investigate the application of photogrammetry for BIM, the construction of a building was recorded by photogrammetry every day with views from

many directions that could also be used for checking scheduling of the construction. It involved stereo cameras on the crane, UAS images, and photographs from neighbouring buildings. Stereo matching was undertaken to extract 3D geometry. Visibility was an issue on occasions. Scaffolding can also be tracked. Accuracy was of the order of 1 to 4 cm, user accuracy high, but producer's accuracy was low.

Jakob von Heyl, University of Stuttgart, Germany, *Lean Construction Controlling and Tracking using Digital Methods*.
Lean management was developed in USA in 2000, has been adopted in the automotive industry and it is being developed for the construction industry. Analysis of construction sites showed that only 31% of the time is actually devoted to construction activities. There is considerable over production and scheduling deviation leading to wastage. Data flow and control loops need to be observed through a BIM. They collected data by standard techniques using a mobile app for recording and input to a BIM. Results revealed real time awareness of delays.

Stephan Nebiker, School of Architecture, Civil Engineering, and Geomatics, Muttenz, Switzerland, *3D Imagery for Infrastructure Management - Mobile Mapping meets the Cloud*.
Infrastructure is the foundation of a modern society and there is a major challenge in establishing and maintaining it. There is a duality between 3D imagery and 3D point clouds, since and observer can lose context when zooming a point cloud. They have developed a mobile mapping system which includes 360° stereo panoramic camera system, terrestrial lidar to include trifocal tensors. 14 images are acquired in stereo. Reference data is also provided. Image based geo-referencing and use of control points were investigated for accuracy. Comparison between direct and image based referencing were tested with varying results which currently do not satisfy the accuracy hoped for of about 1 cm. Relative measurements were generally higher. The next step is automatic information extraction and BIM formation.

Thomas Kersten, HafenCity University Hamburg, Germany, *Virtual Monuments and Virtual Museums in a Game Engine – An Immersive Experience using the VR System HTC Vive*.
Virtual reality will change the future so that it will be possible to visit the past. The workflow to generate VR involves data acquisition, using UAV, cameras and laser scanning to generate 3D models and input into a game engine which is software for video games, eg Unreal 4 which is based in visual programming, and Unity. Together with glasses working in a VR environment enables free hand motion for tracking and interaction via wireless together with information menu items. Historical buildings can be recreated as they were in the past and then the user can visit the site in VR. VR and virtual museum are an attractive proposition, but none exist at present. It is an opportunity for geomatics but data volumes and internet performance may create problems.

The 57th Photogrammetric Week will be held in Stuttgart on 9-13 September 2019.
John Trinder
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