Introducing a New Class of Survey-Grade Laser Scanning by use of Unmanned Aerial Systems (UAS)

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Key words: UAS, laser scanning, survey-grade, power line inspection, echo digitization

SUMMARY

Unmanned Aerial Systems (UAS) – until some years ago mostly restricted to the use for military applications – are about to enter the commercial and civil market. As a consequence, advanced systemsfor professional surveying purposes are getting available.In order to meet the requirements of UAS applications relying on LiDAR, *RIEGL*introducesa new class of survey-grade laser scanners represented by the new VUX-1 which has been presented on the market earlier this year. This class opens up new possibilities of using laser scanners with UAS in commercial and civil surveying and monitoring applications.

We provide insights to the employed technologies as well as to integration and operation of the instrument. The results of first field tests are analyzed with respect to measurement precision, resolution, and other application-related aspects like provided point attributes

The new *RIEGL* VUX-1 is a very lightweight and compact laser scanner, meeting the challenges of emerging survey solutions by UAS and ultra-light aircraft, both in measurement performance and in system integration. With regard to the specific restrictions and flight characteristics of UAS, the scanner is designed to be mounted in any orientation. It is tailored for platforms with limited weight, space, and supply power for payloads. The entire data set of an acquisition campaign is stored onto an internal 240 GByte SSD and/or provided inreal-time via the integrated LAN-TCP/IP interface for post-processing.

The VUX-1 offers high-accuracy laser ranging based on *RIEGL*'s unique echo digitization and online waveform processing, which enables achieving superior measurement results even under adverse atmospheric conditions, and the evaluation of multiple target echoes. The scanning mechanism is based on an extremely fast rotating mirror, which provides fully linear, unidirectional and parallel scan lines, resulting in excellent regular point distribution. Employing such cutting edge LiDAR technology enables operation at up to 500 kHz effective measurement rate, with a maximum scan speed of 200 scans/sec, and at an operational flight altitude of 350 m.

With its high-resolution multi-target capability the instrument is excellently suited for agricultural and forestry applications, power line, railway track or pipeline inspection, as well as surveying of urban environments, surveying and monitoring in open-pit mining, or terrain and canyon mapping, to name just a few possible applications.

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1. INTRODUCTION

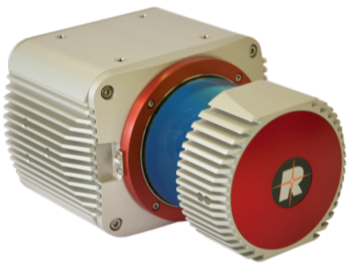

Fig.1: *RIEGL*VUX-1 Laser Scanner

Unmanned Aerial Systems (UAS), until recently primarily restricted to military use, are rapidly entering civil and commercial market. While legislating authorities have been anxious, for years, to prepare forappropriately cautious yet steady integration of remotely piloted aircraft into civil airspace, the public awareness of these new airspace participants and the related issues has grown with a somewhat polemic media presence of UAS and with the widespread availability and actual use of remotely piloted aircraft models provided by the consumer industry: Easily available model airplanes and helicopters and build-it-yourself-kits for multi-rotor aircrafts, employed by users who soon equipped their model aircraft with equally available digital consumer cameras. Numerous research institutes, of course, had similar ideas, only, what they had in mind was not an overhead family snapshot, but to explore the abilities and potential of a new surveying era. The need for state-of-the-art equipment – meaning the aircraft and its command- and integrated sensor system, became evident.

For security reasons, national regulations assign an airspace segment to the currently discussed class of small to mid-size UAS that separates them from general aviation traffic. This zone fits the flight performance of UAS: they are set to use where conventional aircraft reach their limits. In short: UAS are allowed, as well as qualified, to approach the surfaces and objects they are meant to survey or inspect and they usually don't request specifically regulated airfields or airports for take-off and landing. This makes them a perfect tool to be set to use on the spot for versatile inspection tasks and for the survey of areas difficult to access.

The number of promising – and convincing – applications is rising: another proof of the innovative, creative potential of this new branch of surveying by UAS.

In order to serve this market, *RIEGL* introduces a new class of survey-grade laser scanners specifically designed for UAS. In the following, we provide insights on the employed technologies as well as on integration and operation of the UAS Laser Scanner

*RIEGL*VUX-1. The applications are analyzed with respect to measurement precision, resolution, and other application-related aspects like, e.g. special point attributes, thus opening up new possibilities of using laser scanners on UAS in commercial and civil surveying and monitoring applications.

2. *RIEGL* VUX-1: PERFORMANCE DATA AND PHYSICAL DIMENSIONS

The factors that have been taken into account for the development of the UAS Laser Scanner *RIEGL*VUX-1 can be grouped into two main concerns:

- First, designing a sensor that can be carried by various types of UAS, respecting physical limitations and system integration aspects.
- Secondly, evaluating the main scanning-applications for UAS and providing survey-grade scanning performance ideally tailored for these scenarios.

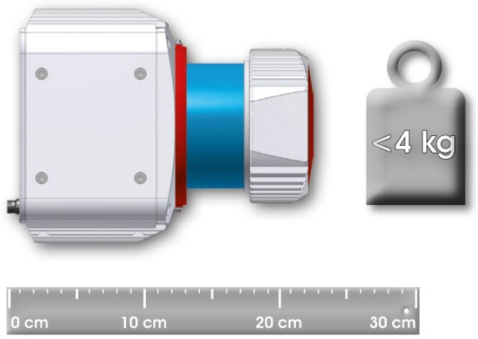

Fig.2: Physical dimension

With a size of 225 x 180 x 125 mm and a weight of less than 4 kg, the *RIEGL*VUX-1 stands out with its lightweight design andoutreaching measurement rates. Performance data are mentioned in the table below (Table 1).

Table 1: *RIEGL*VUX-1 Specifications

eye safety class	Laser Class 1
max. range @ target reflectivity 60 %	920 m
max. range @ target reflectivity 20 %	550 m
minimum range	5 m
accuracy / precision	25 mm
laser pulse repetition rate (PRR) @ 330° FOV	up to 550 kHz
max. effective measurement rate	up to 500.000 meas. / sec
field of view (FOV)	up to 330°
max. operating flight altitude AGL	350 m / 1.150 ft

The *RIEGL* VUX-1 offers high-accuracy laser ranging based on echo digitization and online waveform processing, thus enabling to achieve superior measurement results even under adverse atmospheric conditions.

The scanning mechanism itself is performed by an extremely fast rotating mirror, which provides fully linear, unidirectional and parallel scan lines, resulting in excellent regular point distribution. Employing such cutting edge LiDAR technology allows operation at up to 500 kHz effective measurement rate, with a maximum scan speed of 200 lines/sec, at an operational flight altitude of up to 350 m.

The entire data set of an acquisition campaign is stored onto an internal 240 GByte SSD and/or provided as real-time data via the integrated LAN-TCP/IP interface for post-processing.

The charts below (Fig 3, Fig 4) demonstrate the performance envelope using a specific Pulse Repetition Rate (PRR) setting.
Given example: Using a PRR of 550 kHz would provide a maximum measurement range of 280 m (920 ft), on natural targets at 60 % reflectivity and a maximum measurement range of 160 m (480 ft), on natural targets at 20 % reflectivity. Considering a flying altitude of 100 m (330 ft) above ground level and a flying speed of 30 kn (approx. 15.4 m / s), the maximum point density of approx. 57 points / m² is obtained at nadir measurement direction, and approx. 37 points / m² at an exemplary slant range of 155m at an scan angle of 50 °.

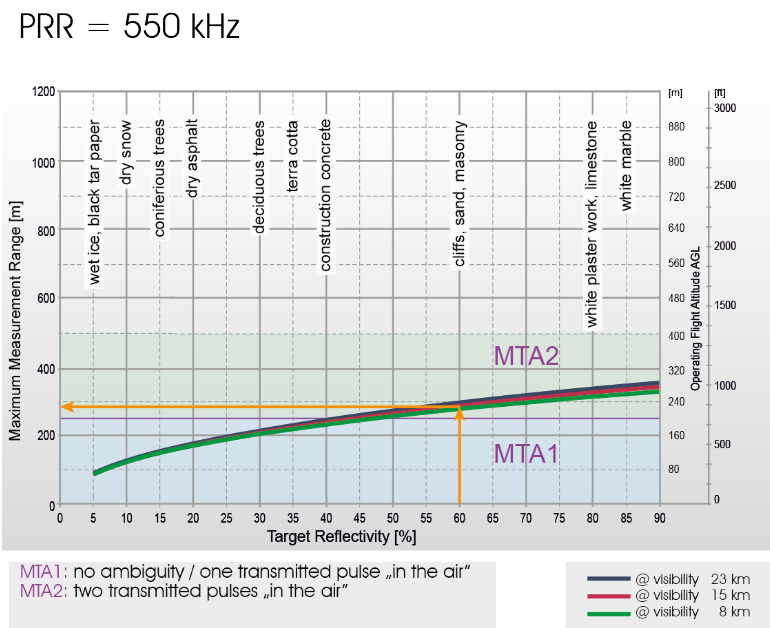

Fig.3: Performance envelope-1, 550 kHz

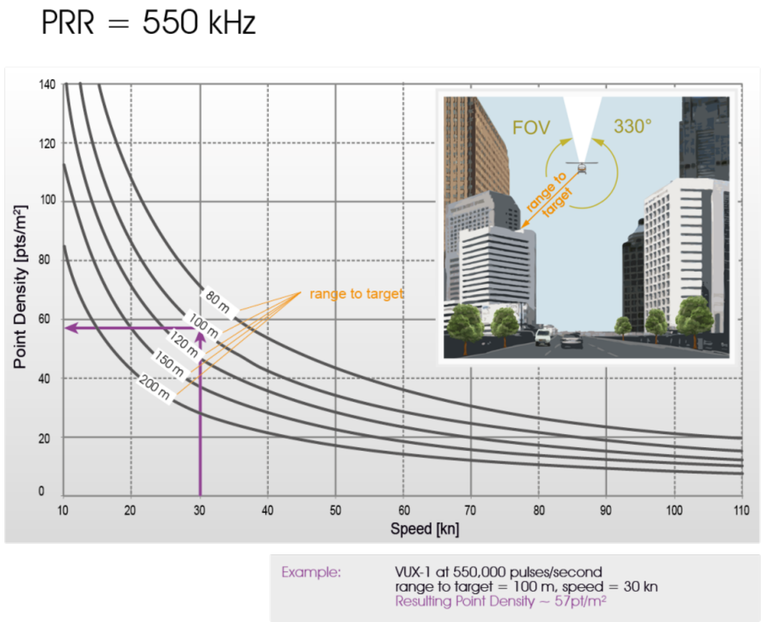

Fig. 4: Performance envelope-2, 550 kHz

3. SYSTEM SET UP

The *RIEGL*VUX-1 scanner is very compact and aerodynamically designed, and may be mounted on various types of unmanned aerial platforms observing the respective limitations in weight-and-balance. Apart from these physical limitations, the flight characteristics of different types of aircraft and the deriving perspective on the surfaces to be surveyed have been taken into account.

Fig.4: Example: planned integration of *RIEGL* VUX-1 with Flying-Cam SARAH 3.0 ©

The scanner can be easily mounted to professional UAS by using the available mounting points. The example above (Fig. 5) shows a possible integration of *RIEGL*VUX-1 on the front of Flying-Cam SARAH 3.0, produced by renowned Belgian UAS manufacturer Flying-Cam.
The sensor provides additional interfaces for remote control and autonomous operation by using *RIEGL*'s RiACQUIRE-Embedded software, or any flight/mission guidance.
Designed for a direct IMU integration directly on the bottom of the scanner, the *RIEGL*VUX-1 can be mounted on nearly any UAS which fits to the given requirements (Fig.

6).

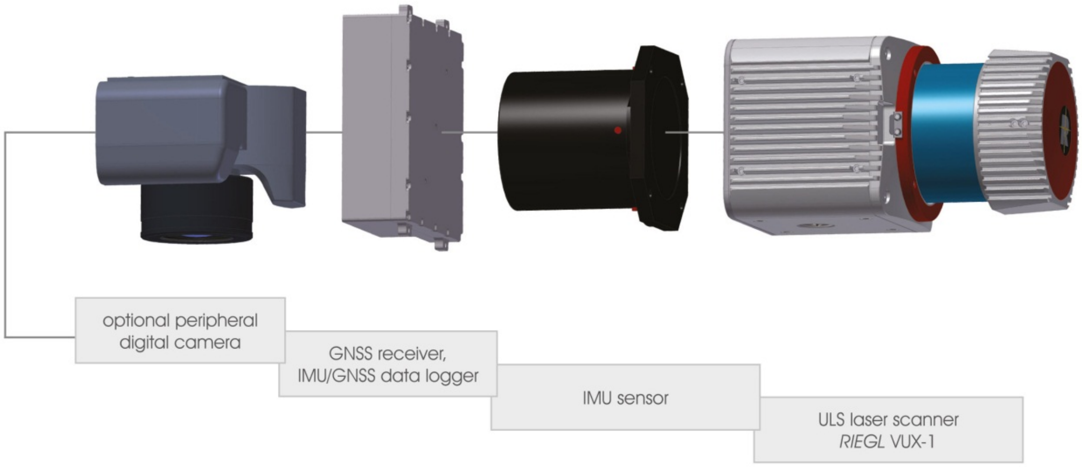

Fig.5: Design concept, *RIEGL*VUX-1 setup with IMU/GNSS and optional camera

RIEGL's software RiACQUIRE-Embedded is operated on the laser scanners own internal control computing device. It enables remotely controlling the laser scanner from a ground station PC and supports features like, e.g., configuring scan parameters, configuration of interfaces to IMU/GNSS subsystems or optional external digital cameras, and start/stop of data acquisition. Online geo-referencing of scan data is performed by making use of IMU/GNSS monitoring data. The resulting point cloud data is efficiently compressed and available for transmission via radio data-downlink for nearly real-time visualization of the area covered on the control ground station. Furthermore RiACQUIRE-Embedded collects and displays vital information like, e.g., the operational status of the laser scanner, the IMU/GNNS subsystem and optionally installed camera devices.

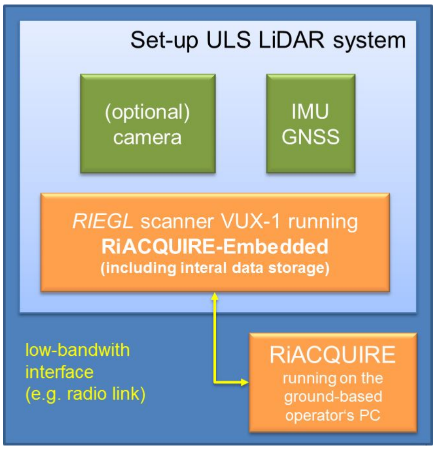

Fig.6: Set-up Unmanned Laser Scanner (ULS) LiDAR system

4. KEY FEATURES

Main arguments for the usage of UAS are safety and efficiency: they are to be employed in dangerous areas or under circumstances that prevent to carry out a safe on-board piloted flight. Efficiency concerns mostly the affordability of aircraft and maintenance costs as the economic benefit gained in fast or repeated surveying missions.

The same arguments apply for sensors to be carried on-board UAS. Airborne laser scanning has proven an extremely reliable and efficient method for numerous topographic tasks. Now, the advantages of laser scanning technology have to be ideally exploited for UAS missions. The term unmanned laser scanning, ULS, has been introduced in order to define surveying by UAS as an additional, innovative application of laser scanning, not meant to displace airborne laser scanning but rather to close the gap between airborne, terrestrial, and mobile surveying. These considerations have determined the key features of the *RIEGL*VUX-1:

4.1 Field of View (FoV)

Operation from a low altitude allows for close proximity to lateral objects and vertical surfaces and structures, both in urban context as in, for example, narrow valleys, as shown in the pictures below (Fig. 8, Fig. 9). This, together with the consideration of UAS ability to swivel and turn for changes of perspective has led to the decision to provide the *RIEGL*VUX-1 with a very large field of view of 330°, and a high measuring range.

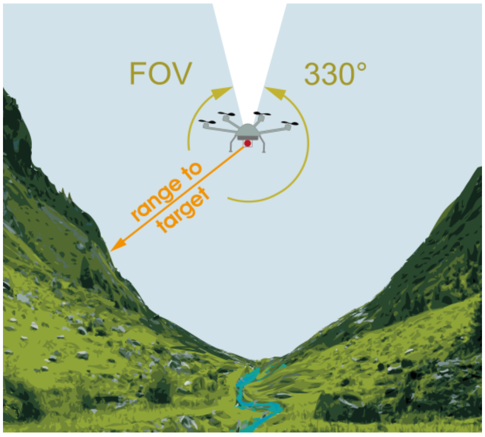

Fig.7: FoV, valleys

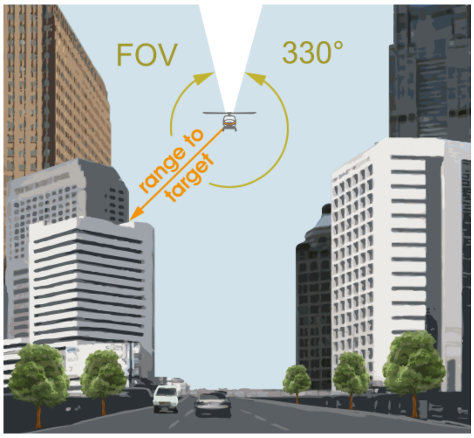

Fig.8: FoV, urban canyons

4.2 Multiple Target Capability

The ranging technique of *RIEGL*'s airborne laser scanners relies on digitization of each received target echo and subsequent online waveform processing. It accounts for utmost measurement accuracy and the capability of resolving multiple target return situations, i.e. when the emitted laser pulse may be scattered by targets of several layers of e.g., dense vegetation. Based on this technique each echo identifies several targets, tagged with additional attributes like the calibrated target reflectance or echo pulse shape deviation,

supporting further point cloud classification algorithms with viable information.
With this high-resolution multi target capability the instrument is excellently suited for agricultural and forestry monitoring, as well as power-line inspection and mapping applications.

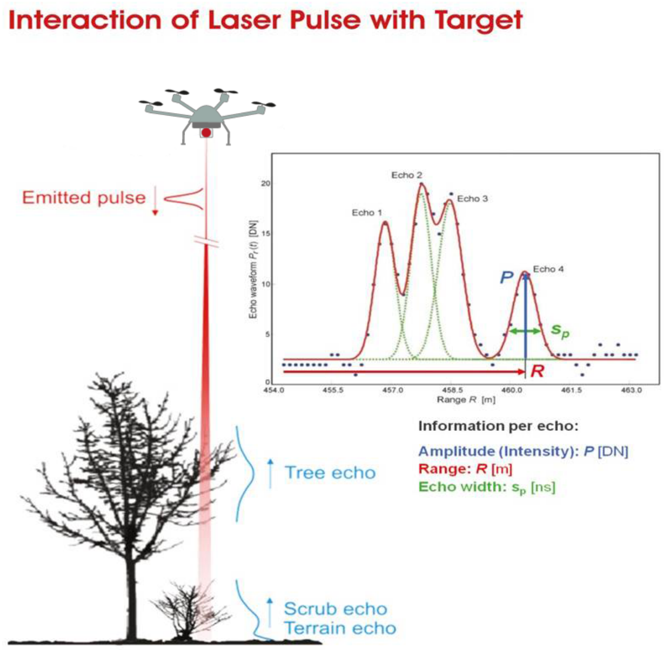

Fig.8: Interaction of Laser Pulse with Target

4.3 Multiple-Time-Around Data Acquisition and Processing

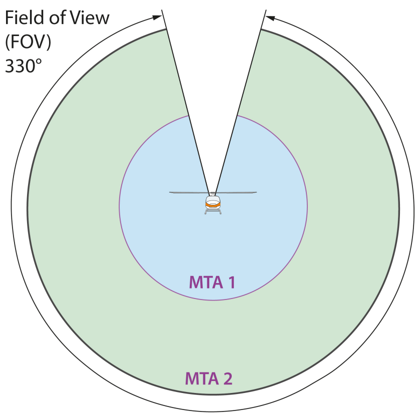

Fig. 9: Multiple-Time-Around (MTA) Data Processing

An important advantage of pulsed time-of-flight laser ranging over phase-based measurement techniques is the capability to reach very long measurement ranges even at high pulse repetition rates. However, there is a constraining factor – the speed of light - which causes, if not counteracted, an ambiguity in range measurement.

When scanning at a pulse repetition rate of e.g. 550 kHz, measurement ranges above approx. 250 m become ambiguous and cannot be determined unequivocally any longer. This situation, known as multiple-time-around (MTA) or multiple-pulses-in-the-air (MPiA) occurs when the time-of-flight of a laser pulse to and from the target is longer than the pulse repetition interval of consecutively emitted laser pulses. *RIEGL* is using a proprietary method based on a specific modulation scheme applied to the train of laser pulses and a sophisticated algorithm for resolving ambiguous target ranges (Fig. 11). That is accomplished fully automatically by the plugin “RiMTA”, an integral part of the raw scan data converter “SDCImport”, without sacrificing processing speed.
In ULS, although operated at significantly lower flight altitudes compared to classical airborne laser scanning, ambiguous target echo situations nevertheless may arise as a consequence of the *RIEGL*VUX-1 high measurement rate and its long-range perspective as a consequence of the wide field of view. Therefore, the implemented multiple-time-around processing technique is of vital importance.

5. APPLICATIONS

The instrument *RIEGL*VUX-1 is excellently suited for the following surveying scenarios for UAS:

- Forest Inventory
- Power Line, Railway and Pipeline Inspection
- Topography in Open-Pit Mining Areas
- Terrain and Canyon Mapping
- Surveying of Urban Environments
- Corridor Mapping
- Flood plain Mapping
- Vegetation Growth Monitoring in High Precision Agriculture
- Archeology and Cultural Heritage Documentation
- Construction-Site Monitoring
- Urban Area Mapping
- Traffic Accident Documentation

In the following paragraphs, we describe and discuss some exemplary applications of UAS LiDAR campaigns.

5.1 Application 1: Forestry

In forestry and general vegetation mapping, the advantages and efficiency of LiDAR technology are obvious: Airborne Laser Scanning is not only the proven solution for the generation of digital terrain models, but it also offers stunning results in applications such as deadwood detection, biomass calculation and habitat monitoring, where the richness of information contained in the digitized echo data plays a crucial role in identification, analysis and interpretation of the surveyed areas.

With its extremely high pulse repetition rates of up to 550 kHz the *RIEGL*VUX-1 provides an outstanding high density point cloud, which is excellently suited for forestry applications. For determining ground conditions the excellent vegetation penetration capabilities plays an important part in generating very detailed digital terrain models (DTM).
For monitoring tree growth, points classified as vegetation are used to estimate the relative canopy height and enable the comparison of different height models collected over a certain period of time.
In order to plan further cleanup efforts, fallen trees can be identified as linear structures in the point cloud classified as low vegetation. By using the previously created DTM, the model clearly shows roads and trenches as well as results of slope instability and erosion.

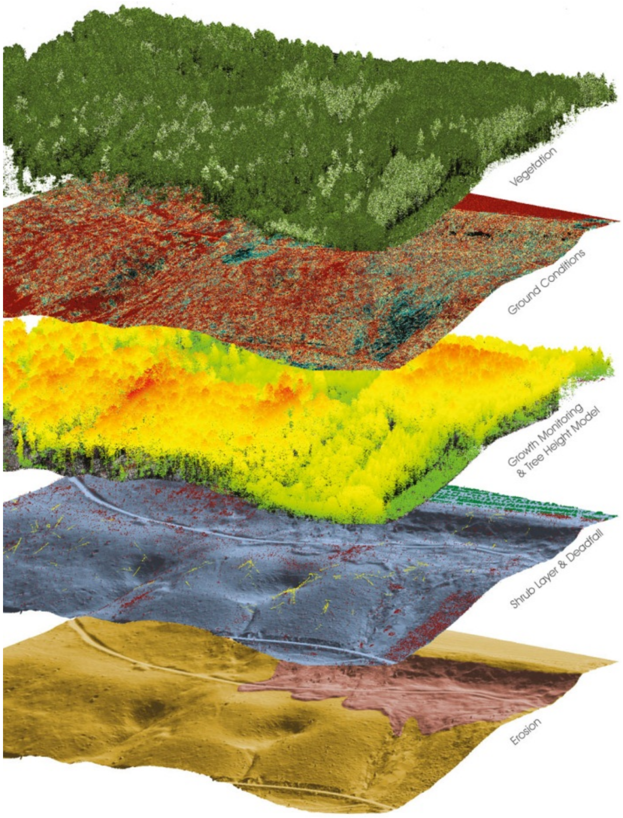

Fig.10: Application-Forestry

5.2 Application 2: Power Line Inspection & Infrastructure Monitoring

The current status of power lines and towers is subject of periodical monitoring. Until now, this has been carried out by helicopters typically flying at low speed and at lowest possible altitude above the structures to achieve high density images and point clouds. This inspection is thus not only dangerous, but also very time consuming, and, due to the high amount of personal and operating costs, expensive. Furthermore, in some areas the time for inspection is restricted by noise abatement regulations, a fact that further complicates surveying missions.
The advanced technology provided by UAS equipped with a survey-grade laser scanner, is therefore considered a convincing economic benefit for this kind of application.

By adjusting the scan pattern of the *RIEGL*VUX-1, the capability to detect even very fine features, such as cables, is augmented. This can be easily done by defining the laser parameters using *RIEGL*'s acquisition software RiACQUIRE-Embedded.
The dataset displayed below is an example of step-by-step filtering of raw data and the facilitated or even automated extraction of features. The additional information contained in the scan data serves to identify and to classify targets.
Powerline monitoring is therefore considered a very promising ULS application not only enhancing data acquisition but making use of the full potential of data analysis.

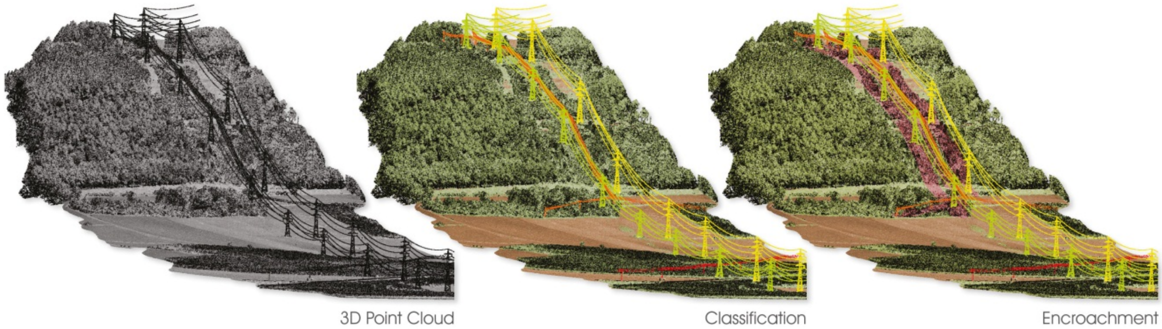

Fig. 11: Power Line Inspection

5.3 Application 3: Topography in Open-Pit Mining Areas

Laserscanning in open-pit mining areas is an efficient, cost effective method to generate data for volume calculation and the analysis of stockpiles and sediments. Surveying the topography of mining areas by UAS facilitates the generation of complete datasets even in complex areas that are difficult or dangerous to access by conventional means.
Comparison of repeatedly surveyed areas serves as a basis to detect and monitor landslides or other changes due to, e.g. meteorological influences.
Specific software solutions for mining applications allow automated surface extraction and feature modeling as well as breakline extraction out of the scan data, thus providing the standard results to mining customer requirements.

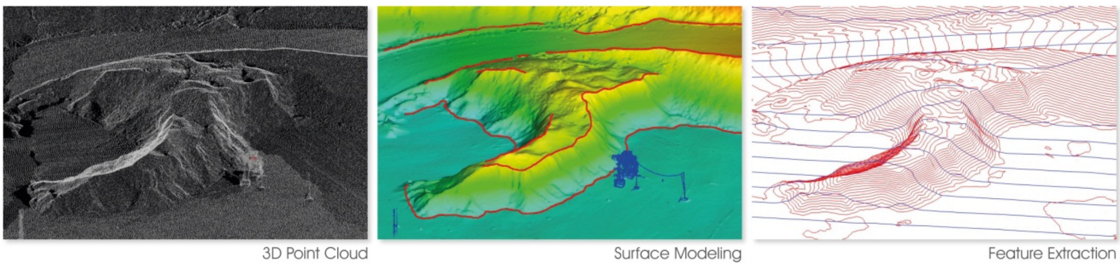

Fig.12: Surface Modeling, Feature Extraction

6. CONCLUSION

Within the last decade, 3D laser scanning has obtained an uncontested position in surveying.

In the beginning, the innovative technology was effective but difficult to apply. Nowadays, user-friendly acquisition software and processing tools enable a straightforward exploitation of information-rich scan data for smoothly and efficiently generating the desired application-specific 3Ddata product. *RIEGL*'s long-term expertise in laser scanning proves to be the perfect basis for adapting that technology to UAS usage.

RIEGL's experience in integrating laser scanners together with other sensors into systems for airborne, naval and ground vehicles, has led to adapting laser scanning smoothly to UAS usage. With the *RIEGL*VUX-1, a first UAS laser-scanner, providing survey-grade performance, has been introduced and its capabilities and key features have been illustrated on several example applications.

The benefits of laser scanning by UAS are explained: the potential of UAS surveying missions is enhanced by use of a state-of-the-art surveying tool that reliably provides very complex and significant data. At the same time, onboard unmanned aircraft, laser scanning is carried to areas that were not easy, or even impossible to reach before: low altitudes, narrow straits, zones of hindered view, shadowed in areas. ULS, unmanned laser scanning, allows for closeness in exploring distances. The gap between terrestrial and classical high-altitude airborne scanning is bridged.

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BIOGRAPHICAL NOTES

Philipp Amon is working with *RIEGL* Laser Measurement Systems since 2010 and is mainly responsible for the mobile and airborne market. He is currently working on his BSc in Industrial Engineering from the HFH Hamburg. A few publications have been published related to terrestrial and mobile laser scanning, applications of laser scanning and photogrammetry.

Ursula Riegl is Assistant to the CEO at *RIEGL* Laser Measurement Systems GmbH located in Horn, Austria.
She holds a Magister degree in comparative literature and roman languages from Vienna University, Faculty of Humanities.

Peter Rieger is responsible manager for airborne laser scanning products at *RIEGL* Laser Measurement Systems GmbH located in Horn, Austria.
He received a MSc degree in telecommunications engineering from the Vienna University of Technology in 2002. His research interests cover ranging techniques in scanning LiDAR, with emphasis on methods for resolving range ambiguities, full waveform analysis, and inertial navigation/GNSS.

Martin Pfennigbauer holds a Dipl.-Ing. Degree and a PhD from Vienna University of Technology where he worked from 2000 to 2005 at the Institute of Communications and Radio-Frequency Engineering. Since 2005 he is with *RIEGL* Laser Measurement Systems, presently as Director, Research & Intellectual Property. Dr. Pfennigbauer's special interest is the design and development of lidar instruments for surveying applications with focus on rangefinder design, waveform processing, and point cloud analysis.

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