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# 3D TERRESTRIAL LASER SCANNING FOR FIELD CROP MODELLING

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**Abstract**

Terrestrial laser scanning provides highly accurate and dense 3D measurements of an object. This technology leads to several applications, for example in topographic surveys, forestry, and as-built documentation. Few developments exist in the area of agriculture and precision farming. In this contribution, multi-temporal 3D terrestrial laser scanning was applied for field crop modelling. The time-of-flight laser scanner Riegl LMS-Z420i was used three to five times per year to estimate plant height distribution of the field crops winter wheat, spring barley, and sugar beet. In 2008 and 2009, the area under investigation was a single field. As a further development, data from plots with different crop varieties of barley and sugar beet were analysed in 2010. As a result, within-field variability was detected by using crop surface models (CSM) and crop volume models (CVM). Single plants were successfully detected. The results will be compared with additional data in the future.

**Keywords:** agriculture, crops, terrestrial laser scanning, modelling, surfaces

## 1 Introduction

Laser scanning is an active remote sensing technique which is capable of direct range measurements between the laser scanner and the reflecting target (Heritage & Large 2009). The results are highly accurate 3D point clouds. Laser scanning, known as Light Detection and Ranging (LIDAR), can be used on airborne platforms, known as Airborne Laser Scanning (ALS), on mobile platforms, known as Mobile Laser Scanning (MLS), as well as on terrestrial platforms, known as Terrestrial Laser Scanning (TLS) (Vosselmann & Maas 2010). 3D point clouds are used for various applications, for example for 3D modelling of buildings and cities, as-built documentation, cultural heritage documentation, forensics or forest inventories.

Crops are generally affected by management, topography, diseases, and weather (Kravchenko et al. 2005). The impact of topography can be derived by DGPS surveys, corresponding geostatistical interpolation methods and terrain analysis (Kaspar et al. 2003). The development of statistically correct yield stability maps is already possible with ALS data (McKinion et al. 2010).

For the detection of single plants and biomass calculation, Ehlert et al. (2008, 2009) use low-cost triangulation and time-of-flight scanners mounted on a tractor. Site-specific crop parameters, such as plant height, biomass density and coverage for optimizing management are estimated. For different crops, the relation between mean height and biomass density is calculated ($R^2 > 0.75$). Lumme et al. (2008) investigate plant height in differently fertilized plots with a phase-shift scanner mounted on a 3 m rack. They also apply a multi-temporal approach and find a strong correlation between plant height and grain yield and detected single ears. In the publication of Hosoi & Omasa (2009), a triangulation based scanner is used to estimate carbon stocks in single plants.

In contrast to these introduced approaches we applied a time-of-flight laser scanner to estimate crop parameters on a larger field level (Hoffmeister et al. 2011). The data is collected with the objective to establish crop surface models (CSM) and crop volume models (CVM). The detection of within-field variability is possible.

In this contribution, we present the surveys of a single field of sugar beet in 2008 and winter wheat in 2009 as well as a crop variety experiment with different varieties of sugar beet and spring barley in 2010. Several approaches are used to derive plant parameters on field level.

## 2 Methods

The TLS LMS-Z420i, manufactured by Riegl (Riegl LMS GmbH 2010), was applied for all observations. The time-of-flight range measurements have an accuracy of 1 cm and a range from 2 m to 1000 m. The recorded resolution of all measurements was 0.8 cm at a distance of 10 m. A high-resolution digital camera, Nikon D200, was mounted on the head of the laser scanner for recording RGB-photos. These can be used to colourise point clouds and to texture corresponding surfaces.

The different positions of the laser scanner were measured by a highly accurate DGPS, the Topcon HiPer Pro (Mansfeld 2004). The relative accuracy of this device is approx. 1 cm. To estimate the direction of the point cloud, several highly reflective targets were also measured by the DGPS. With regard to the larger ranges and to save time, a new reflective target was developed.

These large, highly reflective cylinders (diameter: 7.6 cm, height: 10.5 cm), which are easy to detect by the laser scanner, were fixed on ranging-poles (Fig. 1). All scan positions can be estimated by a small number of DGPS measurements due to the multiple use of ranging-poles.

### 2.1 Survey of a Single Field (2008 and 2009)

The single survey field is located at Selhausen (N 50° 51' 58'', E 6° 26' 50''), about 40 km west of Cologne. It is one of the test plots of the project CRC-TR32: 'Patterns in Soil-Vegetation-Atmosphere Systems: Monitoring, Modelling, and Data Assimilation' (CRC-TR32 2010). Within the CRC-TR32, the focus is set on three intensively investigated sub-basins of the Rur catchment area. The field is located in the sub-basin representing arable land use. It is around 405 m by 105 m large and covers an area of about 4.3 ha. On three dates in 2008 and five dates in 2009, six to eight scan positions around the field were used to achieve a whole consistent point cloud of different growth stages. The laser scanner was fixed on a tripod, which lifts the sensor up to 1.8 m (Fig. 2). Corresponding tape-measurements of the plants were conducted at every survey.

### 2.2 Survey of Different Crop Varieties (2010)

In 2010, the method was applied in another study area. Test fields at Klein-Altendorf (N 50° 37' 18'', E 6° 59' 16''), 20 km southwest of Bonn, were monitored. The survey was conducted within the project CROP.SENSe.net (CROP.SENSe.net 2010), which is an interdisciplinary research network for sensor technology for crop breeding and management. Four different varieties of spring barley (two replications) and sugar beet (four replications) had been planted on similar plots each with a size of approx. 3 m by 20 m.

The laser scanner was mounted on a tractor with a hydraulic platform in a height of approx. 4 m (Fig. 3). Further measurements, for example biomass sampling, hyperspectral measurements, and hyperspectral imaging were conducted by other research groups within CROP.SENSe.net. Again, the plant height was measured with a tape at each survey in each plot.

*Fig. 1: Ranging-pole and developed reflector for the laser scanning measurements*

*Fig. 2: TLS survey of sugar beet (left side) in 2008: Laser scanning device, digital camera and DGPS mounted on a tripod*

*Fig. 3: Laser scanner mounted on the platform (above), scanning barley test plots. The platform is mounted on a specifically extended tractor, with a 3 m axis (below).*

*Fig. 4: Detailed pictures of the field in Selhausen: Sugar beet in different growth phases, taken from the same perspective*

## 2.3 Post-Processing

The registration of each scan position was facilitated by directly georeferencing every point cloud. The highly accurate DGPS measurements of each position of the laser scanner and one reflector for orientation were used. Afterwards, the implemented ICP-algorithm (Multi-Station Adjustment, MSA) enhanced the registration (Besl & McKay 1992). The colourisation of the point clouds was possible by assigning RGB-values to each point, taken from the recorded pictures of the digital camera (Fig. 4, here only shown in grey scale).

After removing obstacles and surrounding points, CSMs were generated by triangulation of each point cloud. For the processing of the CSMs and the corresponding comparisons, a mean raster of 20 cm pixel space was used. All CSM results were compared with each other and led to maps of height differences. For CVM calculation, these triangulated surfaces were utilized to estimate volumes. The differences of these volumes are an estimation of the crop volumes. All estimations were calculated with Riegl's software RiSCAN PRO.

The collected data of 2010 was also pre-processed with RiSCAN PRO. However, the DEM (Digital Elevation Model), derived from the first measurements and CSMs for all further dates were calculated with ESRI's ArcMap to achieve a higher resolution. Single plants were detected by analysing intensity values of the laser scanner, which exist for each point. This method was controlled by manually identifying single plants in several subsets. These single plant points were connected to generate the rows of plants and then single plant positions were estimated every 20 cm along these rows. They were connected to the already mentioned CSMs and led to points for each single plant in a plot, with information of growth height from every survey date.

## 3 Results

Major results of the presented procedure were maps of plant height at a high resolution. As shown in Figure 5, patterns of the topography a) as well as management patterns were detectable. Plant height is dependent on absolute height. For example, an area on the east side was ploughed after heavy rain and stagnant moisture. The lower west side was also affected by this problem.

For the area in Klein-Altendorf (2010), the same approach was used to generate maps of plant height differences (Fig. 6). Here, again sugar beet is presented. The differences of the DEM derived from the survey of late May and the last survey of early August are shown. Higher plants of the sugar beet variety "Maurica" are clearly visible in every replication. Furthermore, in one of the two plots with the same cultivar, the extracted biomass samples during the season are indicated by larger dark spots, for example in plots no. 115 and 116 in the north-west corner.

Intensity values were used to derive positions of single plants and the results are checked by manual detection of single plants in several subsets. The rows of plants were established based on the extracted points. For modelling approaches and to achieve more accurate results, single plant points were automatically set. Afterwards, the results of the derived crop surface model were associated to the points as an attribute (Fig. 6: detailed map).

## 4 Discussion and Outlook

### 4.1 Single Field 2008 and 2009

The survey of the presented single field in Selhausen (chapter 2.1) with the laser scanner and according equipment is possible in one day. The method of using just two DGPS measurements and the MSA procedure is very feasible and fast. During the acquisition, a lot of noise disrupted the measurements, which had to be trimmed. However, for the setup on the tripod, with a maximum height of 1.8 m, the results are very useable. An optimized scanning process and post-processing lead to highly accurate results within a short period. The problem of resampling data to a lower resolution of 20 cm to avoid computing failures will be solved with ESRI's ArcMap in the future.

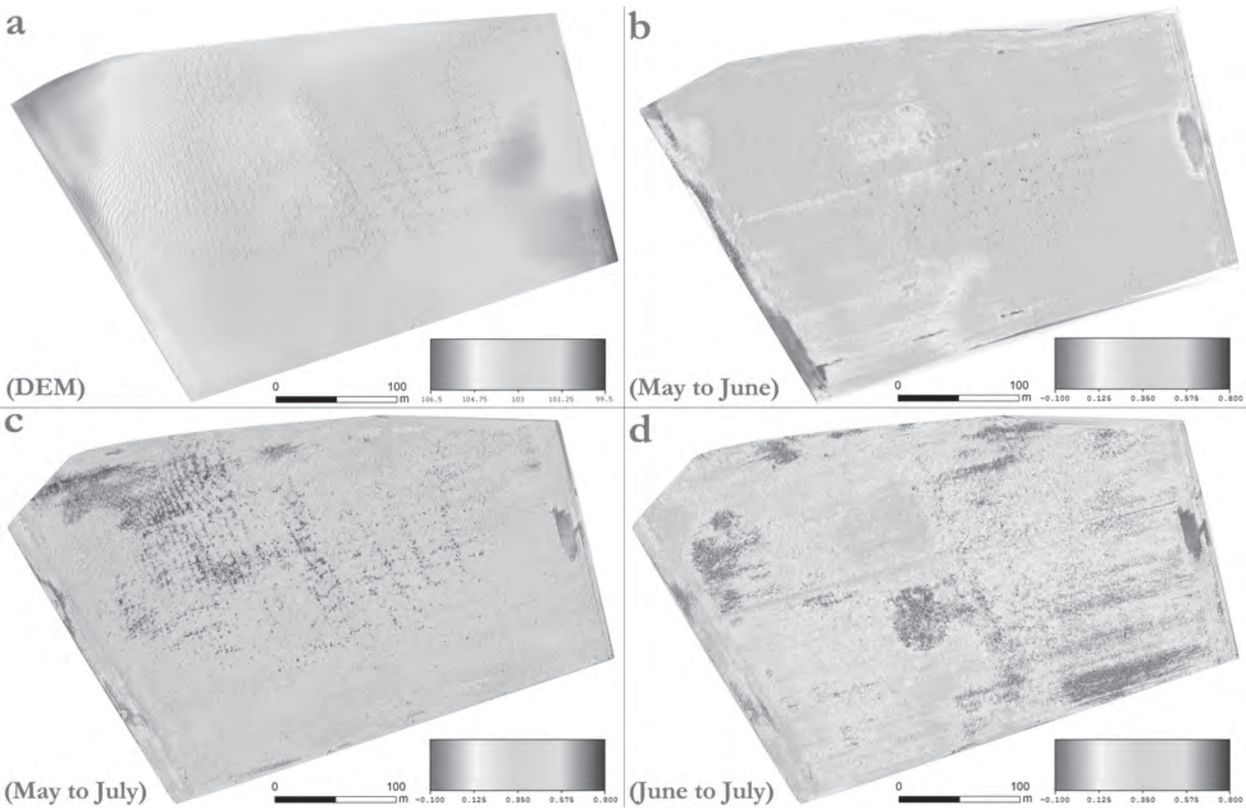


*Fig. 5: Maps of the single sugar beet field in 2008: a) The DEM and b)-d) according height differences in meter between several dates, showing management patterns and areas of minor crop height*

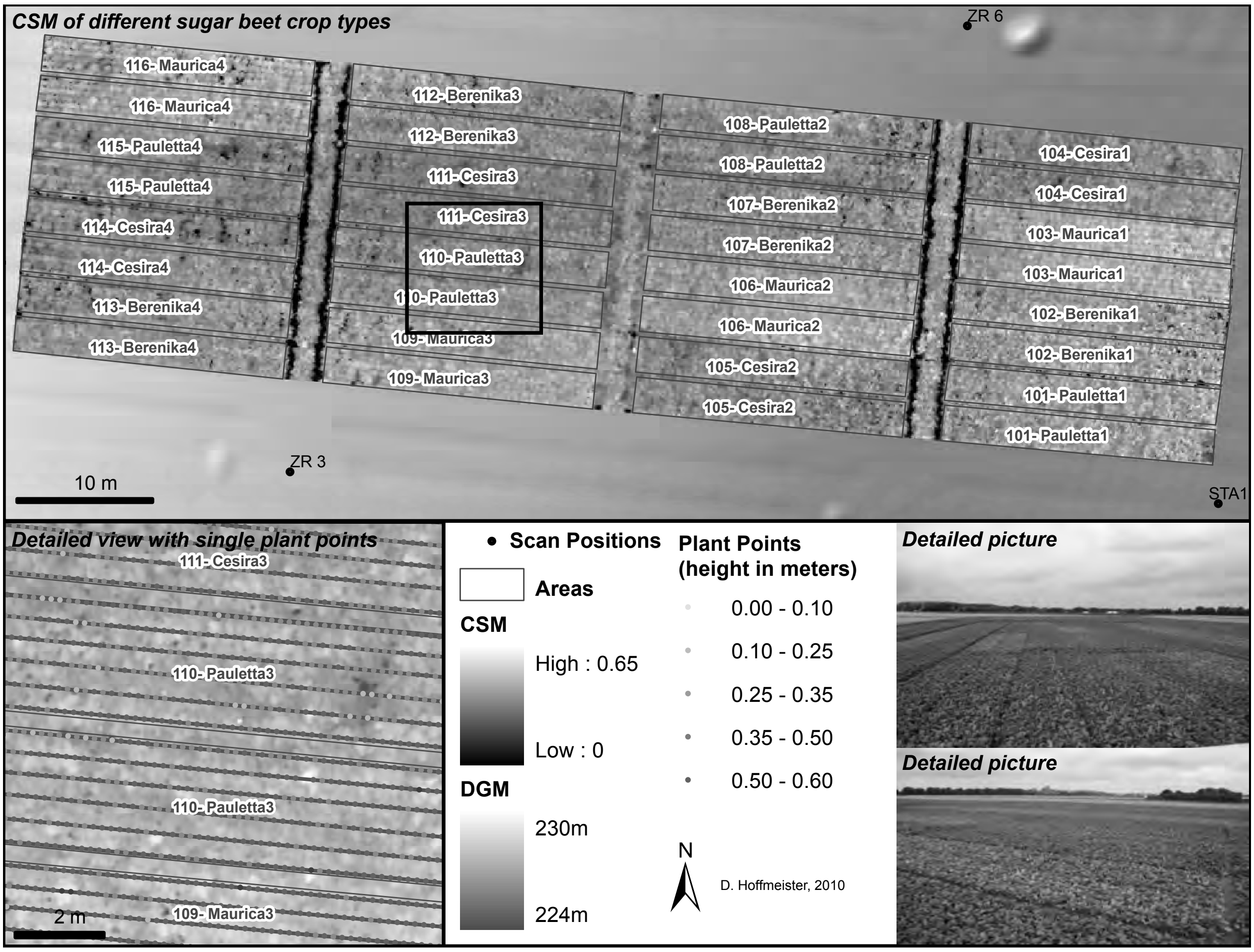


*Fig. 6: Map of height differences between late May and early August 2010 for sugar beet plots. Detailed view of plant points representing plant height and according detail pictures showing differences in the plots.*

The resulting maps represent crop height differences very well. Detected patterns were also visible in the field and are supported by the tape-measurements. For this data set, the detection and modelling of single plant points was established, as well as a higher resolution of the CSM. Based on these maps, a rate of died plants and yield loss can be calculated.

Crop growth is highly dependent on micro-topography. The results will be compared with an ALS survey of late July 2008 (Hoffmeister et al. 2010). Intensity values of this survey show the same patterns as detected in the presented maps of crop height growth.

## 4.2 Crop Varieties 2010

The established survey method of the single field in 2008 and 2009 in Selhausen (chapter 2.1) was reused for pattern and change detection of different crop varieties in 2010 in Klein-Altendorf (chapter 2.2). To enhance this method, a platform on a tractor, with an average height of approx. 4 m, was used to achieve more detailed data. The data is again georeferenced and pre-processed in RiSCAN PRO. Moreover, most calculations are conducted with ESRI's ArcGIS to achieve a higher resolution and a more sophisticated interpolation method.

Additionally, single plant point detection is possible, which can be connected to the generated CSMs. More investigations have to be conducted on intensity values and the need for recalibration (Höfle & Pfeifer 2007, Wagner et al. 2008). The first results presented here show the great potential of the adjusted method. More results are expected, when all further measurements, for instance hyperspectral data, will be available.

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