WATCHING GRASS GROW - A PILOT STUDY ON THE SUITABILITY OF PHOTOGRAMMETRIC TECHNIQUES FOR QUANTIFYING CHANGE IN ABOVEGROUND BIOMASS IN GRASSLAND EXPERIMENTS

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ABSTRACT:

Grassland ecology experiments in remote locations requiring quantitative analysis of the biomass in defined plots are becoming increasingly widespread, but are still limited by manual sampling methodologies. To provide a cost-effective automated solution for biomass determination, several photogrammetric techniques are examined to generate 3D point cloud representations of plots as a basis, to estimate aboveground biomass on grassland plots, which is a key ecosystem variable used in many experiments. Methods investigated include Structure from Motion (SfM) techniques for camera pose estimation with posterior dense matching as well as the usage of a Time of Flight (TOF) 3D camera, a laser light sheet triangulation system and a coded light projection system. In this context, plants of small scales (herbage) and medium scales are observed. In the first pilot study presented here, the best results are obtained by applying dense matching after SfM ideal for integration into distributed experiment networks.

1. INTRODUCTION

Globally distributed experiment networks have recently emerged as a powerful tool for environmental research across spatial and temporal scales. One example is the Nutrient Network (NutNet) collaborative composed of over 40 replicated grassland plot experiment sites spread throughout six continents. Key elements in the success of such networks are the low-cost of experiment setup and the data consistency benefiting from identical treatments and sampling [Borer et al., 2014]. A key ecosystem variable is the annual quantitative determination of aboveground biomass on defined grassland plots. The current standard for sampling aboveground biomass is by harvesting a portion of the plot, drying the harvest and weighing it - obviously a destructive method with potentially impacts on the plot. Visual estimation or non-destructive physical measurement methods by experts have also been applied, but visual estimation suffers from subjectivity and a lack of repeatability of measurements, and physical measurements require significant sampling effort.

Photogrammetry promises efficient techniques to provide detailed 3D representations of grassland plot vegetation as a basis for biomass estimation, and complementary to the standard destructive methods. Obviously, due to the filigree structure of grassland plot vegetation, 3D representations provided by any photogrammetric technique will never be perfectly complete, and the volume derived from a subsequent 3D surface model is not equal to biomass. Therefore, a quantitative relation between the volume derived from 3D representations of plot vegetation and the actual plot biomass has to be established by imaging and harvesting representative sample plots in different scales, which is not addressed in the paper.

2. RELATED WORK

The study is focused on validating photogrammetric solutions to determine aboveground biomass on remote experiments sites and for low-budget research. Prior work includes testing the potential of TOF devices, dual stereo cameras, and SfM with subsequent dense matching. An extensive research of 3D imaging systems for agricultural applications is given by Vázquez-Arellano et al., 2016. TOF devices have been explored for imaging individual plants and with some preliminary testing on grass canopies. An experiment with a Microsoft Kinect v1, which uses triangulation with pseudo-random pattern projection, unveiled difficulties imaging individual plants under direct sunlight, but showed promising results for estimating height in grassland canopies at dusk [Azzari et al., 2013]. In contrast, an experiment with the Microsoft Kinect v2, based on a TOF measurement principle, found moderately strong correlation to ground truth plant height and biomass under direct sunlight in outdoor conditions [Andújar et al., 2016]. This experiment also showed an overestimation of plant volume because only the top of the canopy was captured, a problem to be encountered with future use of SfM for biomass estimation as well. The affect of various environmental conditions on two TOF

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Use of binocular stereo photogrammetry has been explored in plant phenotyping to measure plant shoot structure, leaf angle distributions and canopy structure of single or monoculture broadleaved crops [Fiorani and Schurr, 2013; Biskup et al., 2007]. Binocular stereo systems will likely fail for plants with thin branches and narrow sheets due to ambiguities in image matching (Maas and Kersten, 1997).

The application of Structure-from-Motion (SfM) techniques is increasingly recognised as a powerful low-cost alternative to laser scanning techniques for the generation of 3D point representations. Recently, studies for biomass estimation applying SfM with subsequent dense matching show promising results using terrestrial images as well as aerial images captured by Unmanned Aerial Vehicles (UAVs) [Lussem and Bareth, 2017; Forsmoo et al., 2018; Cooper et al., 2017; Bedell et al., 2017; Brocks et al., 2016; Ota et al., 2015]. Besides biomass, Jay et al. (2015) show the successful usage to estimate the height and leaf area of broad-leaved agricultural crops in monocultures.

3. SURVEY

In a pilot study on the potential of non-contact photogrammetric techniques for generating 3D representations of grassland plot vegetation, four photogrammetric approaches were examined on small- and medium-scale target plots including a “smart” Time-of-Flight (TOF) 3D camera using Google Project Tango, a laser light sheet triangulation system, a coded light projection system and, finally, SfM techniques. Targets for surveying different photogrammetric approaches varied because of logistical constraints.

**Time-of-Flight 3D camera** With establishing Project Tango, Google provides a comprehensive high performance low-cost device with inbuilt TOF 3D camera planned to develop augmented reality (AR) applications. In this study, the target for the TOF was a small, heterogeneous grass of about 50 cm above ground imaged outdoors at midday using a modified version of the Tango application “Java Point Cloud”. With regards to this, 3D point clouds can be captured in a supported depth range of 4 m.

**Laser Light Sheet Triangulation** Beside TOF 3D cameras, laser light sheet triangulation was used to scan a *Petroselinum crispum*, characterized by very dense and curly leaves. With the measurement device MicroScan a laser line is moved by hand over the object of interest while a camera observes deformations due to the surface structure. Thereby, the sensor is fixed on a calibrated mechanical arm for determining the sensor pose while moving the device and thus, to align the individual scan stripes. This approach allows to capture about 30,000 points per second with single point accuracy of about 0.1 mm regarding a measuring volume about 1.5 m.

As a basis for applying SfM and dense matching in the pilot study, two plots of 2.2 x 2.2 m² were imaged from 60 camera positions moving a camera around the plots in a height of about 2.5 m. A few ground control points (GCPs) and four calibrated scale bars were placed into the scene as a basis for scaling and referencing of the 3D model (see figure 1). The imaged plots differ in species type and growth structure. The first dataset covers a plot primarily composed of low-rising *Onobrychis vicifolia*, a legume species; the second plot is primary composed of the forbs species *Daucus carota* reaching a height of approximately 0.5 m. Both datasets were processed applying the commercial SfM software package Agisoft PhotoScan.

4. EVALUATION

**Time-of-Flight 3D camera** The application of the Google Project Tango TOF-device turned failed almost completely due to daylight and vegetation reflection properties. On the other hand, the surface of an adjacent road could easily be captured but on the other, the approach failed as soon as the tablet was pointed...
The best results were obtained by applying Structure-from-Motion (SfM) techniques to determine camera intrinsic and extrinsic parameters as well as a sparse 3D point cloud being densified using posterior dense matching. This resulted in a very high accuracy and degree of automation, but inherently suffers from the viewing angles, sometimes unavoidable projecting patterns from one side of a blade of grass and taking the camera image from the other side as can be seen in figure 4. Moreover, the entire system is very space-, time- and cost-intensive in construction, calibration and purchase. In this study, the system was installed in one hour, calibrated in two hours regarding the binocular cameras and projector in relation to the measurement volume and 3D data was captured in additional two hours. Thus, the technique is neither an option nor a perspective for NutNet but rather intended for high-precision indoor measurements, e.g. quality assurance in automotive.

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