# Reconstruction of geo-referenced maize plants using a consumer time-of-flight camera in different agricultural environments

Manuel Vázquez-Arellano[1], David Reiser[1], Miguel Garrido Izard[2], Hans W. Griepentrog[1]

**Abstract:** Crop phenotyping is a prerequisite to enable robots doing agricultural tasks, evaluating crop status for farm management, and relating genotypes to phenotypes for crop breeding among others. Optical three dimensional (3-D) sensors have been preferred since they provide more information about the complex plant architecture. The improvement of time-of-flight (TOF) cameras together with their reduced economical costs have provided an appropriate tool for tasks that require detailed information of the agricultural environment. In this paper, 3-D reconstruction of maize is performed in different environments, from controlled greenhouse to the open field, to evaluate the capabilities of a consumer camera.

**Keywords**: 3-D sensors, time-of-flight, agricultural automation, plant phenotyping

## 1    Introduction

Crop phenotyping is a prerequisite to enable robots doing agricultural tasks, evaluating crop status for farm management [Gr10], and relating genotypes to phenotypes for crop breeding among others; yet it remains a bottleneck [FT11] due to the time-consuming measuring methodologies and systems. Moreover, it is also important that the acquired sensor data is accurately and precisely geo-referenced to know the position in space of every plant and plant element. Advances in off-the-shelf 3-D vision sensors are opening new possibilities since they provide more information compared with two dimensional (2-D) sensors in a cost-effective manner; however, it comes at the cost of more computer power and data handling.

The Kinect v2 is an example of a consumer TOF camera (CTC) that has appealing characteristics like: high depth image pixel resolution, near infrared (NIR) stream for night vision, and a relative robustness against sunlight. For geo-referencing optical information, real time kinematic-global navigation satellite system (RTK-GNSS) is limited to outdoor conditions and its accuracy (centimetre-level) is not better than the (sub-centimetre-level) robotic total station; therefore, the latter was used for this research.

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[1] University of Hohenheim, Institute of Agricultural Engineering, Garbenstrasse 9, 70599, Stuttgart, Germany, mvazquez@uni-hohenheim.de
[2] Laboratorio de Propiedades Físicas (LPF)-TAGALIA, Technical University of Madrid, 28040, Madrid, Spain, miguel.garrido.izard@gmail.com

The aim of this research is to present a methodology for reconstructing maize plants using a CTC mounted on a field robot. This robot navigates in different agricultural scenarios using a robotic total station for geo-referencing the position of the CTC, and thus, the generated point clouds.

## 2 Material and Methods

A robotic platform, depicted in Figure 1, developed at the University of Hohenheim, was used for data acquisition. The dimensions of the robotic platform are: length 600 mm, width 500 m, height 1100 mm. The vehicle carries a CTC for data acquisition mounted on an extruded aluminium frame. The robotic platform software was developed using the Robot Operating System (ROS Indigo), an open source middleware running on Linux (Ubuntu 14.04), and programmed in a combination of C++ and Python programming languages. For fast calibration, point measurement, and importing data from the total station into ROS; the Trimble SCS900 Site Controller (Software Version 3.4.0) was used. The prism position data was time stamped and helped to refer the transforms to the global frame [Re15].
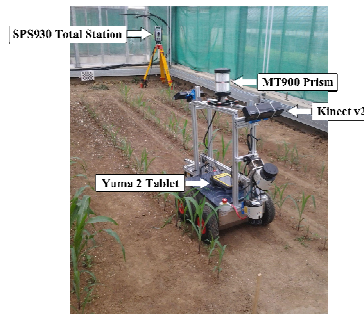


Figure 1: Robotic platform for 3-D data acquisition in a greenhouse and the utilized total station.

The SPS930 robotic total station (Trimble Navigation Limited, Sunnyvale, USA) was used to track the precise position of the vehicle by aiming at the Trimble MT900 Machine Target Prism, which was mounted on the top of the vehicle at a height of 1.07m. The total station data was sent to a Yuma 2 Tablet Computer (Trimble, Sunnyvale, USA). The CTC has a measurement range between 0.4 and 4.5 m, and it was mounted at a height of 0.94 m with a downwards view at an angle of 30°. The CTC outputs three image streams: a depth image stream of 512 x 424 pixels, a NIR stream of 512x424 pixels, and a colour stream of 1920x1080 pixels. Depth, infrared, and Red-Green-Blue (RGB) images were acquired from 23.04.2015 to 01.07.2015, and a total of 9 tests were done driving the robot through the tracks using a remote joystick at a constant speed of *circa* 0.05 m s$^{-1}$. Every track was passed two times starting from each side.

# 3    Results and discussion

A first trail was done using two CTCs mounted on the robot, one pointing forwards and the other backwards, in order to have two different perspectives and to avoid passing two times through the same track. However, the high amount of data simultaneously coming from the two CTCs rapidly overloaded the computer acquisition system. Therefore, it was decided to use only one CTC and drive two times through the same track from opposite sides. Due to the high spectral reflectance of plants in the *NIR plateau* (737-1000 nm), it was possible to obtain depth images of maize in different lighting conditions as shown in Figure 2.
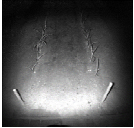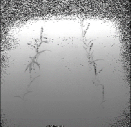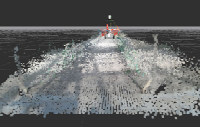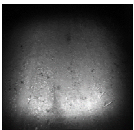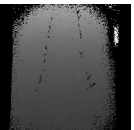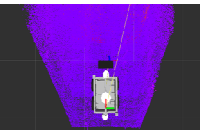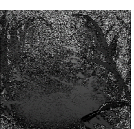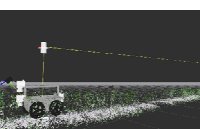
| Environment | Lighting | RGB image | NIR image | Depth image | Point clouds (3-D reconstruction) |
|---|---|---|---|---|---|
| Greenhouse | Sun shadow | | | | |
| Greenhouse | Night | | | | |
| Open field | Sunny | | | | |

Figure 2: CTC output in different environments, lighting conditions, and maize heights (*mean height$_{greenhouse\ sun\text{-}shadow}$*=98 mm, *mean height$_{greenhouse\ night}$*=50 mm, *mean height$_{open\ field\ sunny}$*=500 mm).

Preliminary results (Figure 3) show that it is possible to reconstruct maize assembling point clouds in different agricultural environments and light conditions. At night, the maize 3-D reconstruction was possible with the least amount of noise; inside the greenhouse, the light variability was a source of noise; and in the open field, most of the depth image (excluding maize plants) was saturated by noise. The wind conditions were favourable during the data acquisition in the open field, and if they were not, a wind protection could have been used- as most of the robotic phenotyping platforms do.
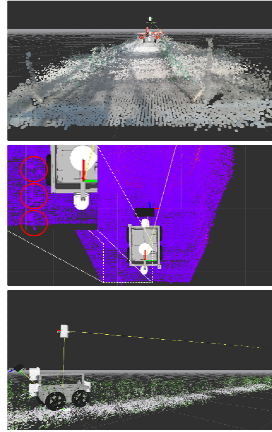
Figure 3: Point cloud reconstruction of maize in greenhouse in sun-shadow (top), greenhouse at night (middle) with the maize inside the circles, and open field in a cloudless sunny day (down).

## 4   Conclusions

The CTC used in this research has a lot of potential in agricultural applications mainly due to the capability of providing depth information under different lighting conditions. Although it was designed for other purposes, it has shown that it can stream depth information under different environments, and even though it does not perform well under sunlight, it is still possible to obtain depth data of maize. Better results would be expected if a shadowing device is used. Surface reconstruction algorithms like Kintinuous could be also applied to the point clouds for a better representation of the leaf surface; however, it was out of the objectives of this research.

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