APPLICATIONS OF PHOTOGRAMMETRIC PROCESSING USING AN AUTONOMOUS MODEL HELICOPTER

Henri Eisenbeiss
Institute of Geodesy and Photogrammetry, ETH Zurich
CH-8093, Zurich, Switzerland, email: ehenri@geod.baug.ethz.ch

IC WG I/V Autonomous Vehicle Navigation

KEY WORDS: UAV, Data Acquisition, Processing, Triangulation, Digital Surface Model

ABSTRACT:
Nowadays, mini UAV-systems receive more and more attention as photogrammetric image acquisition systems. Since mini UAVs are low cost systems, namely model helicopters or airplanes, the potential of various applications is very high. Therefore, in the paper a simplified workflow for photogrammetric processing of model helicopter imagery is described. Further on, two applications, which were conducted in the last two years at IGP (Institute of Geodesy and Photogrammetry), are presented in the paper. First the documentation of an archaeological site will be introduced and second a project dealing with the generation of an elevation model of a maize field is described. The results of the projects have shown that images taken with mini UAVs are well suited for an efficient documentation of small sites in a short time.

1. INTRODUCTION

UAVs (Unmanned Aerial Vehicle) are designed to operate without a human pilot onboard. Generally, UAVs are separated into the classes of fixed-wing aircrafts, helicopters and airship-like zeppelins. Furthermore, UAVs can be classified in subcategories depending on the type, size, flying endurance and altitude of the aircraft.

In the last two years, the work of the group of Photogrammetry and Remote Sensing at ETH Zurich was focused on autonomous model helicopter, which belongs to the class of mini UAV-systems (see Eisenbeiss, 2004). These platforms have a size of up to 2 m (rotor diameter), a flight time of up to one hour and can operate up to 1 km from the base station. Additionally, mini helicopters are highly maneuverable, due to their capability to hover and to change flight direction around the center of rotation. Any low cost still-video and video camera can be fixed onboard of a model helicopter. The only limitation is the payload of the helicopter, which does not allow carrying professional cameras with more weight. In addition, the mounted camera can be turned in horizontal and vertical direction. Due to the high flexibility of mini UAVs, these systems can cover aerial and terrestrial applications using only one platform for image acquisition. Furthermore, because of the small size of the system it is possible to fly close to the area of interest and by using low cost still-video cameras with an image scale of 1:500 to 1:8000.

In this paper two different types of applications of mini UAV systems are explained. One is in the field of documentation of archaeological sites and the other deals with the generation of a precise elevation model of a maize field.

First the developed workflow for the photogrammetric processing of UAV-images will be described. Furthermore, two examples will be reported. First, Pinchango Alto (Peru), a cultural heritage site recorded for the purpose of archaeological documentation and second the surface reconstruction of two maize fields using UAV-images for agriculture investigations. The outcomes of the projects will be summarized in the conclusions. A further developed, modularized workflow for the processing of UAV imagery, which will be implemented during future work, will be briefly introduced.

2. WORKFLOW FOR PHOTOGRAMMETRIC PROCESSING OF UAV-IMAGES

The present status of our photogrammetric workflow for images from mini UAVs, which was applied to the projects Pinchango Alto and the generation of an elevation model of a maize field, is shown in Fig. 1. The illustrated workflow is similar to standard aerial photogrammetric projects, except the flight planning, which is adapted for the autonomous flight. The workflow consists of the following steps: project definition, flight planning and autonomous image acquisition, measurement of tie points (semi-automatic mode), and manual measurement of control points, bundle block adjustment, and finally DSM (Digital Surface Model) generation, orthophoto production and derivation of final products.

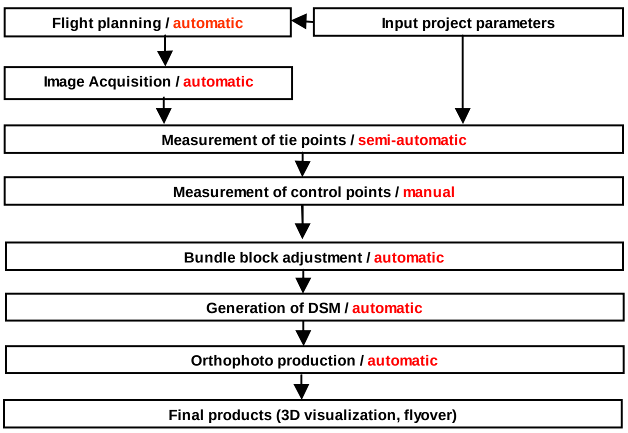

Figure 1. Simplified workflow for the processing of the UAV image data.

Within the Pinchango Alto project we established initial tools for the UAV flight planning and the DSM generation from UAV-images. For the measurements of seed, tie and control points as well as the orthophoto production, existing in-house developed software tools and commercial packages were used.

The use of different software packages decelerates the processing time of the complete workflow, since time consuming data editing and transformation has to be done.
Nevertheless, these parts of the workflow gave us first experiences in processing UAV-imagery with commercial photogrammetric software. Especially, the use of low-cost digital still-video cameras with wide angle lenses and small altitude above the surface made the work with commercial tools more complex, since they were developed for terrestrial or standard aerial photogrammetric applications.

In the following, the flight planning and the DSM production will be explained. The other procedures of the workflow were described more in detail in Eisenbeiss et al., 2005a, 2005b and 2005c.

2.1 Flight planning

The stabilized navigation system, which is GPS/INS based, and the autonomous flight capabilities of the *weControl* UAV allow a detailed and precise flight planning prior to fieldwork, defining acquisition points and certain parameters of the helicopter according to the project requirements.

After the definition of the area of interest and the required scale of the final products, the following parameters for the determination of the flight path are necessary:

- Desired image scale,
- Focal length,
- Along and across track image overlap,
- Corner points of the area, average terrain height or an elevation model,
- Velocity parameters of the helicopter between acquisition points (velocity for forward, side, climb and heading),
- Maximal height above ground, sea level and distance to the flight ground control station.

Using these informations, a flight trajectory is calculated and integrated into the flight control software *wePilot1000* from *weControl*. The flight control station and its software from *weControl* are explained more in detail in Eck (2002) Eisenbeiss et al. (2005a) and *weControl* (2006).

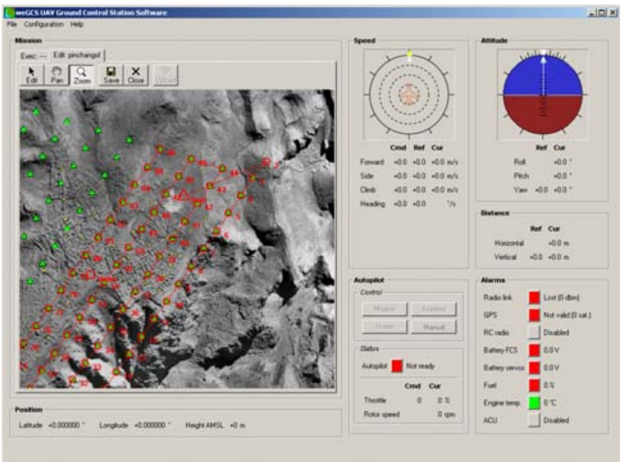

Figure 2. *wePilot1000* with an integrated photogrammetric flight path.

After loading the trajectory into the software (see Fig. 2), the helicopter is able to fly autonomously the predefined locations with a relative accuracy of 0.5 m. This accuracy guarantees meeting the pre-defined image coverage in reality across the whole observation area without gaps in the block of images.

Additionally, the flight control software allows us to change the trajectory during the flight or to correct the orientation of the platform before the image acquisition.

Due to our flight planning and the stable autonomous flight of the weControl system, the subsequent processing steps, like triangulation, DSM and orthophoto generation, are simplified.

2.2 *DSM Generation*

For DSM generation from helicopter images, we used our in-house software SAT-PP (Satellite Imagery Precision Processing), compare Zhang (2005). The matching approach is a coarse-to-fine hierarchical solution with a combination of multi image matching algorithms and automatic quality control. Using SAT-PP, it is possible to generate dense DSMs fully automatically. In comparison to the autonomous blimp project of LAAS-CNRS (Hygounenc, 2004), we use a further developed matching algorithm. In the blimp project a correlation based pixel matching algorithm using only two images per generated model was applied, whereas the SAT-PP approach combines different matching methods (area and feature-based).

Fig. 3 shows two examples (Pinchango Alto and the maize field) for the intermediate matching results of SAT-PP. The green dots are the matched feature points and the blue lines show the matched edges.

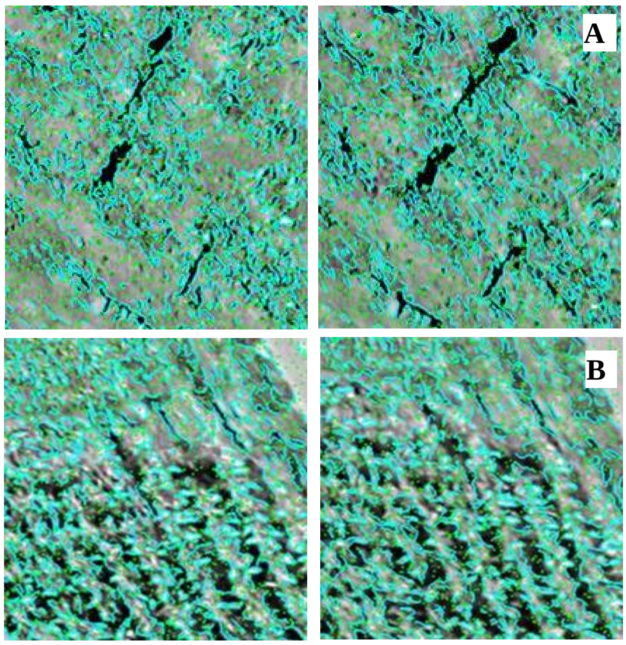

Figure 3. Feature point and edge matching of two stereo pairs using SAT-PP. A: Pinchango Alto; B: Border part of the maize field.

Due to the high overlap of the images, a multi image matching approach is utilized in addition to the standard matching

procedure. These combinations of different matching methods and the multi image approach will provide more precise, reliable and more consistent 3D models of the terrain. Accessorily, an important point is the consideration and preservation of edges. The preservation of edges is an essential factor to generate highly accurate 3D city models automatically (Eisenbeiss, 2005a).
More details of this matching approach can be found in Zhang (2005) and Zhang and Gruen (2004).

3. DOCUMENTATION OF AN ARCHAEOLOGICAL SITE (PINCHANGO ALTO)

The photogrammetric documentation of Pinchango Alto is a project conducted in cooperation with the German Archaeological Institute (KAAK, BONN, Germany), the companies weControl, Helicam in Zurich and Riegl Measurement Systems GmbH in Austria (Reindel and Gruen, 2005).

Pinchango Alto lies 400 km in the south of the Lima (Peru) close to the town Palpa and the area where the Nasca Lines are situated.

The project offered the opportunity to apply new systems for 3D recording and modeling of archaeological sites. For the documentation, two modern recording technologies were chosen: 1) a camera system mounted on a mini UAV and 2) a terrestrial laser scanner. The processing of the terrestrial laser data was published in Gaisecker (2005).

Using the mini UAV-system (see Fig. 4), it was possible to fly precisely along a predefined flight path from the flight planning phase. In Pinchango Alto, a mini UAV developed by weControl (2006) and Surveycopter (2006) was used. The image acquisition parameters were:

• Image scale: 1:4000
• Size of the area: 250 x 150 m^2
• Side and end lap: 75 percent
• Flying height above ground: ~56 m.
• Camera: Canon D60 (6.3 MPixel, f=14 mm)

Figure 4. UAV flying over Pinchango Alto.

After image acquisition by the mini UAV system, which could be completed in one day field work, the data were processed using different photogrammetric software packages. By stitching the images from Pinchango Alto using PhotoStitch from Canon (see Fig. 5) we had the possibility of a first assessment of the image acquisition, quality of the images and image coverage.
For the orientation of the images, first the tie points were measured using LPS (Leica Photogrammetry Suite) in manual and semi-automatic mode. Due to the large amount of blunders for tie point measurement in mountainous areas, the author compared the results from LPS with our in-house developed bundle adjustment software (BUN). Using the software BUN, more blunders were detected than in LPS.

Figure 5. The stitched image (from 8 original images) of the main part of Pinchango Alto showing the most important structures like small agglutinated rooms, compounds with larger rooms, open spaces and holes (mining areas).

Therefore, a posteriori standard deviation of unit weight (observation in cm) of the bundle adjustment was improved from 6 to 1. Using the in-house software SAT-PP, which was modified to process amateur digital frame sensors, finally a DSM with a footprint of 10 cm for the complete area was produced (compare Tab. 1). The produced DSM was compared with a laser DSM (with 5 cm footprint). For the 3D comparison with the software *Geomagic Studio* we achieved an average distance of less than one centimeter and a RMSE of six centimeter. The biggest differences occurred mainly on the walls and on the mining entrances (holes). Examples for both (walls and mining entrances are shown in Fig. 6b and 6c.

Finally, an orthophoto (see Tab. 1) with a footprint of 3 cm and a high quality virtual flight over Pinchango Alto were generated from the helicopter images. A snapshot of the overflight is shown in Fig. 6a.

Table 1. Products from the UAV images of the Pinchango Alto Project.

Products	**Type**	**Specifications of product**	
		Resolution or Footprint	***Number of elements***
UAV images	Image	~3 cm	85 images
UAV-DSM	Regular raster	10 cm	~4.7 million points
UAV-DSM + UAV images	Orthophoto	3 cm	1 orthophoto

The results of the Pinchango Alto project are described more in detail in Eisenbeiss et al., 2005a, 2005b and 2005c and Pinchango 2006. Generally, the autonomous flying model helicopter used in Pinchango Alto met the high expectations. It was possible for us to document 95 % of the area in just one day. The missing 5 % could not be acquired due to some technical problems and time limitation for field work. The main problems with data acquisition came from dusty conditions and the time which was needed for battery recharge and the limited capacity of the gas tank of the helicopter. Therefore, several long breaks were necessary during fieldwork. Data processing allowed the elaboration and visualization of a detailed 3D model that will now serve as a basis for further archaeological research.

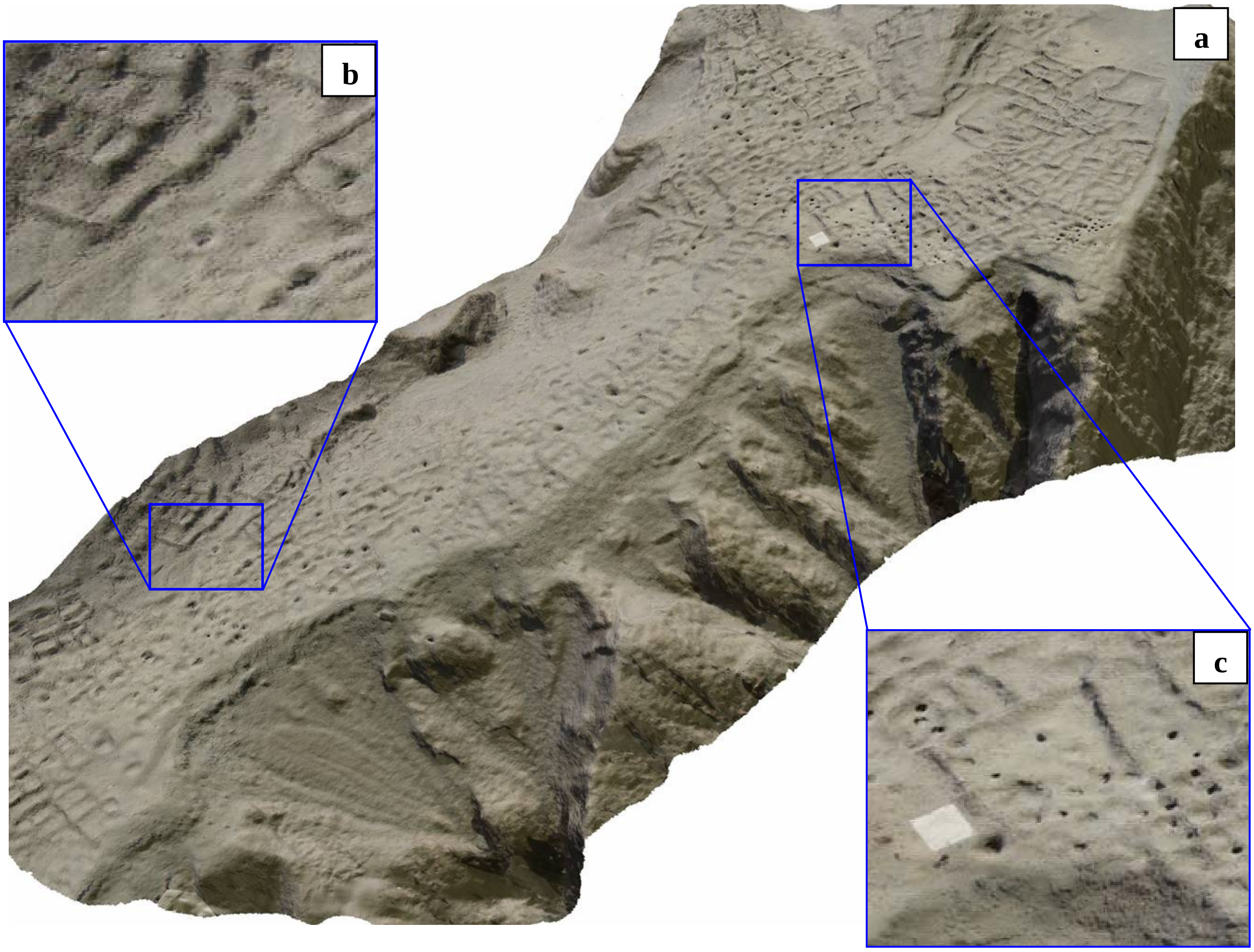

Figure 6. a) Snap-shot of the overflight with the texture from the orthophoto. b) A zoomed-window over the orthophoto showing the walls. c) A zoomed-window over the orthophoto showing the holes.

4. PROCESSING OF IMAGES OF A MAIZE FIELD

Pollen dispersal, which is a research topic for the Institute of Plant Science ETH Zurich, has to be considered with respect to potential risk of transferring a transgene from genetically modified (GM) crops to the conventional crops. Therefore, the influence of inclination on pollen dispersal in maize had to be analyzed. For the analysis of the pollen dispersal a precise DSM had to be generated.

The small size of the objects and the need for high resolution and high accuracy favored the use of UAV-based photogrammetry. A typical oblique image taken above the maize field is shown in Fig. 7. The maize field is situated close to Effretikon in the north of Zurich (Switzerland). In the figure, the inclination of the field can be seen. Further on, in the middle of Fig. 7, the border between the transgene crops (simulated with yellow maize) and the conventional crops (white maize) are visible.

Because of the requirements of the project, it was not possible to fly with manned airplanes or helicopters. Using a model helicopter, it is feasible to fly close to the object and reduce the costs for the image observation to a minimum. The large image scale from the UAV-images allowed accurate measurements and the derivation of dense elevation data. All data were collected within 3 hours. Terrestrial surveying techniques like theodolite and GPS receiver would have allowed measurement of single points, but the generation of a dense elevation model with a grid spacing of 25 cm would be more time consuming.

Figure 7. A typical oblique image of the maize field. The arrow shows the border between the two maize crops.

For the generation of a dense elevation model, images from an autonomous flying model helicopter, similar to the system used in Pichango Alto, were acquired. The parameters of the project are:

• Image scale: 1:4000
• Size of the area: 250 x 80 m^2
• Side and end lap: 75 percent
• Flying height above ground: ~80 m.
• Camera: Canon 30D (8.3 MPixel, f=22 mm)

Additionally, the image quality was influenced by the chromatic aberration, which is more visible in images acquired using cameras with wide angle lenses. Therefore, before starting the processing of the images, the colour images were reduced to a grayscale image using the green channel. The green channel was selected, since this channel shows the smallest displacement caused by the chromatic abberation (see Kaufmann and Ladstaedter, 2005). After preprocessing the orientation of the images was done using *ISDM (Image Station Digital Mensuration)* and *ISAT (Image Station Automatic Triangulation)* both from *Intergraph*. The measurements of tie points using the C*lassic Point Measurement* tool from *LPS* failed, since this tool only allows measuring the tie points in the monoscopic measurement mode. Measuring the points in the monoscopic mode was not suitable, since movements of single plants in the maize occurred during the observation of images. These movements were mainly caused by wind. Furthermore, the texture of the maize images is highly repetitive, therefore the movements made it even more difficult to measure tie points.

Using the software package *ISDM*, which allows for stereo tie point measurement, it was more feasible to measure tie points. The stereo point measurement tool from *LPS* would have been also useful for this process, but the tool was not accessible for us at this time.

After measurements of tie and 5 control points the bundle adjustment was done with *ISDM*. RMS value of image point residuals along x and y axes was 0.5 and 0.7 pixel.

After image orientation, a DSM with 10 cm resolution was produced using SAT-PP. An example for the quality of the matching is shown in Fig. 3 (A). In the figure the feature points and edges are shown. An orthophoto was generated with 3 cm grid size in object space by using the produced DSM. Fig. 8 shows a snapshot from the orthophoto. In the figure, the structures are well visible, even the single crops. Further on, the produced elevation model, the orthophoto and the field measurements of the out crossing in maize are integrated into a GIS-System. In future work, these measurements will be evaluated by the Institute of Plant Science ETH Zurich.

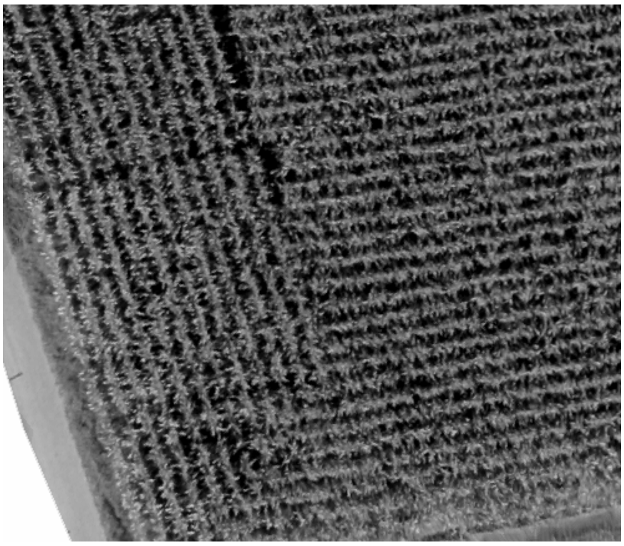

Figure 8. A reduced resolution of a snapshot by factor 2 from a part of the orthophoto of the maize field.

5. CONCLUSIONS AND FUTURE WORK

In the paper the results of the photogrammetric processing and automatic DSM generation for cultural heritage and agriculture application were presented.

These applications showed the potential of UAV-systems for measurement applications in difficult environments and areas where standard geodetic and photogrammetric acquisition systems often encounter problems and the data acquisition would be more time consuming compared to UAV-systems.

UAV platforms are very flexible and allow the use of off-the-shelf cameras or camcorders, according to the application. Nevertheless, until now no commercial software package can handle the complete workflow for the processing of UAV images. Mainly, problems during the processing occur due to the reason that the software packages are developed for aerial or terrestrial applications. However, image acquisition using autonomous model helicopter is a combination of both methods. The distance to the object is similar to terrestrial image acquisition as the viewing direction can be oblique. On the other hand, the image can be taken perpendicular to the surface.

Our experiences have shown, that the data processing is time consuming, due to the reason that several software packages have to be used in order to achieve suitable and accurate results. In addition, the data transfer between the tools is a source of error, since they usually do not support common exchange formats. Further on, still the workflow contains a lot of manual effort, e.g. for measurements and editing. Therefore, the existing workflow will be changed in future work to a modularized system.

The modules will be the following:

- Project parameters
- Flight planning
- Autonomous photogrammetric flight
- Quality check of the data
- UAV Block Triangulation
- DSM, Orthophoto, 3D Model

The modularized workflow for various applications will be developed in a way that the individual modules can be replaced and changed without influencing the remaining modules. The modules will communicate with each other via interfaces, which will allow fast processing of the data.

In the frame of the Pinchango Alto project , future work will focus on the archaeological interpretation using the produced data.

The next step of the maize field project is to evaluate the influence of the slope, derived from the elevation model, and wind direction for the pollen dispersal in maize. Further on, we will record new maize fields with more inclination to verify our method

ACKNOWLEDGEMENTS

The author thanks Jafar Amiri Parian and Martin Sauerbier from IGP (ETH Zurich) for their contributions to the paper. Furthermore, the author thanks Peter Stamp head of the Institute of Plant Science (ETH Zurich) for the collaboration in the maize field project.

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