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CONSTRUCTION AND MEASUREMENT TECHNOLOGY OF THE THÜNOCOPTER FOR CONTACTLESS INSPECTION OF CROP CANOPIES: FIRST MEASUREMENTS WITH A LOW-COST IMAGE ANALYZING SYSTEM

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Abstract

This work is about the mechanical construction and the measurement system of the ThünoCopter. Both, the mechanical construction and the measurement system (sensors, 32 bit microcontroller board and image analyzing system) of the ThünoCopter will be presented and first measurements of the low-cost image analyzing system will be shown. Climate changes and limited natural resources are the challenges for agriculture in a world where the population is still increasing and farm land may be decreasing for the next 50 years. On the one hand plant breeders need tools to measure many parameters like crop cover, crop temperature, etc. which are important for an optimal growth of plants. On the other hand improved conservative production methods for a sustainable agriculture can only be developed and tested practically if these parameters can be measured reliably and the relationship between these parameters and the plant growth is well known. The composition of the soil, the climate conditions, the supply with water and fertilizer and the use of plant protection chemicals determine the growth of every crop during its vegetation period. In order to have a UAV-based method for contactless crop inspection during the vegetation period - from tillage to harvesting - the ThünoCopter has been developed on the base of an Oktokopter by Mikrokopter. The ThünoCopter has a height of approx. 50 cm and its diameter is approx. 1 m. While flying along predefined routes, the measurement system of the ThünoCopter measures the crop temperature, the air humidity and temperature, the global radiation, and it takes photos which are processed onboard in near real-time with the aim of detecting rows and weeds. The ThünoCopter has been developed and optimized in weight and robustness (mechanical and electrical construction). A low-cost image analyzing system has been brought into operation. First measurements will be shown and discussed. Afterwards an outlook for improvements and further research activities is given.

Keywords: Angström, BeagleBoard-xM, ExG, linux, landing platform, microcontroller, NDI, Mikrokopter, OpenCV, ThünoCopter, UAV

1. Introduction

Climate changes and limited natural resources are the challenges for agriculture in a world where the population is still increasing and farm land may be decreasing for the next 50 years. The German newspaper Welt (Welt Newspaper 2013) published a serious survey which has arrived to the conclusion that the number of extremely hot days is also still increasing. Therefore plant breeders need tools to measure many parameters like crop cover, crop temperature, etc. which are important to find plants for an optimal growth at climatically changed conditions. On the other hand improved conservative production methods for a sustainable agriculture can only be developed and tested practically if these parameters can be measured reliably and the relationship between these parameters and the plant growth is well known. The composition of the soil, the climate conditions, the supply with water and fertilizer and the use of plant protection chemicals determine the growth of every crop during its vegetation period.

In order to have a UAV-based method for contactless crop inspection during the vegetation period - from tillage to harvesting - the ThünoCopter has been developed on the base of an Okto XL by Mikrokopter. For this reason it is possible to collect information from canopies without entering fields.

Meanwhile multicopters have become cheaper and different commercial and noncommercial projects are available for buying and for self-construction (Multicopter Table, 2013), but the development for a wide use and for crop inspection is still in progress. For analyzing agriculturally used fields, multicopters with a high payload are necessary because for measuring fertilization, weed infestation and drought stress only different sensors can give an overview of whole plant and crop situation. For these research and development activities the multicopter, the measurement system and the image analyzing system must be modular and expandable.

This work is about the measurement system of the ThünoCopter. The mechanical construction and the measurement system (sensors, 32 bit microcontroller board and image analyzing system) of the ThünoCopter will be presented and first measurements of the low-cost image analyzing system will be shown. This approach was aimed firstly to get a robust multicopter platform and secondly to bring a modular expandable measurement system with a low-cost image analyzing system into operation. Simple algorithms were tested related to their processing time on the BeagleBoard-xM. These first measurements will be discussed and afterwards an outlook for improvements and future work and further research activities is given.

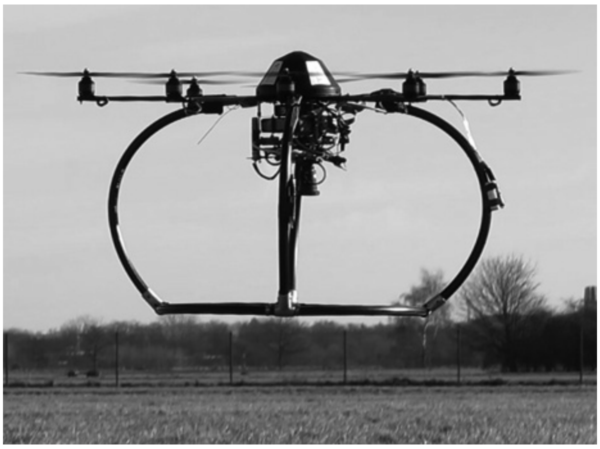

Fig. 1: Test flight of the ThünoCopter

2. Material and Methods

The ThünoCopter in its present stage of extension (Fig. 1) is based on the Okto XL by Mikrokopter (MikroKopter Project, 2013) and was extended by a landing platform, a measurement system (sensors for crop temperature, air humidity and air temperature and for global radiation) and by an image analyzing system as well. The mechanical construction of the ThünoCopter has been modified for robustness by an additional improved landing platform which protects the measurement system, image analyzing system and sensors during regular landings. Also damages would be reduced if the pilot has to make crash landings.

As shown in Fig. 1, the landing platform (weight: 900 g) consists of a closed circle (at the bottom of the photo, shape not visible) and of four round feet which are stably connected to four of the eight arms of the ThünoCopter. The mechanical connection from the round feet to the closed circle is a hinge. All four round feet and the circle are made from polyethylene pipes.

The measurement system (Fig. 2) consists of a self-developed 32 bit microcontroller board which reads out the sensors for crop temperature, air humidity and air temperature, global radiation and the GPS receiver in order to add a time stamp to the measured data. Measured data, sampled images and the flight path are synchronized in time so that an analysis of data, track and images is possible.

The measurement system and the image analyzing system are fixed to the lower side of the multicopter

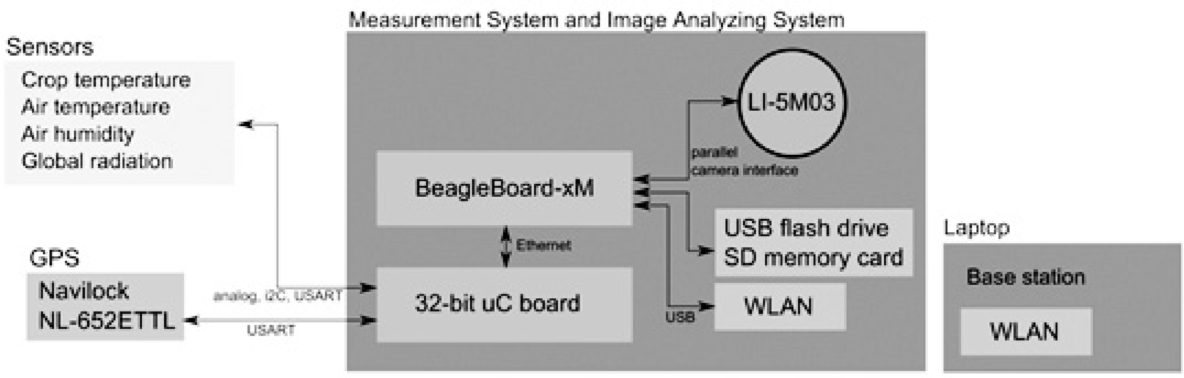

Fig 2: Illustration of the measurements system and the image analyzing system

(Fig. 1). Measured data and images have a mismatching because of their different aperture angles. Due to the roll and nick angle during flight the GPS position of measured date differs in latitude and longitude from the ThünoCopters GPS position. This fact has to be considered for data analysis, but for image analysis this is not so important because mismatching is visible in the images.

Originally the photos which were taken during flight should be streamed via wireless LAN (WLAN 801.11g) to the base station, but the latency period of transmitted frames was too high. For this reason the original photos are processed on the BeagleBoard-xM via OpenCV and the processed images are stored on a USB flash drive or an SD memory card.

For the hardware platform of the image analyzing system a BeagleBoard-xM (Fig. 3) was chosen because it is low-priced (ca. 150€) and has an acceptable performance. Also hardware and software are well documented on different web pages (Beagle Board Project, 2013).

Compared to classic microcontroller boards the BeagleBoard-xM is an embedded system which works with an operating system. Texas Instruments integrated on the BeagleBoard-xM their processor TI DM 3730 from the ARM-family which was enhanced by a digital signal processing unit (DSP) with fixed-point operation. Computationally intensive algorithms can be calculated on the DSP. Through the parallel camera interface the TI DM 3730 is connected with the camera module LI-5M03 (2592 x 1944 pixel) by Leopard Imaging.

In Fig. 4 the typical spectral characteristic of the LI-5M03 camera module and the used wavelength filters for our experiments are shown. Via i2C bus the electronic amplification and the shutter time of the camera can be controlled.

Different linux distributions can run on BeagleBaords, but Angström (Angström Linux Project, 2013) is one of the most popular ones. On the BeagleBoard-xM an Angström distribution with a kernel version 2.6.28 was installed. As a base for the image analyzing system the open source library OpenCV (OpenCV Project 2013) was chosen, which already contains a lot of standard algorithms like edge detection operators. Differences in performance of different ARM devices and different vision operators were shown by Coombs & Prabhu (2011). A comparison of OpenCV with the Matlab and SimpleCV image analyzing libraries is given on the Open Machine Vision Framework blog (2013) where the advantage in speed of OpenCV is described. This widely-used library is also available for the robotic operation system ROS (ROS Project, 2013) which can be implemented in mobile machinery.

In remote sensing there were different color indices introduced to extract parameters like greenness from RGB images (Meyer & Neto 2008). Three popular param-

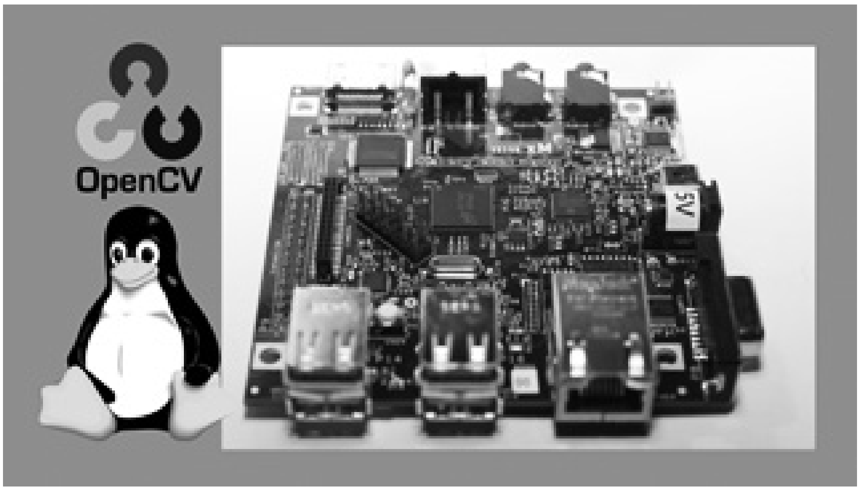

Fig. 3: BeagleBoard-xM with Angström linux and OpenCV

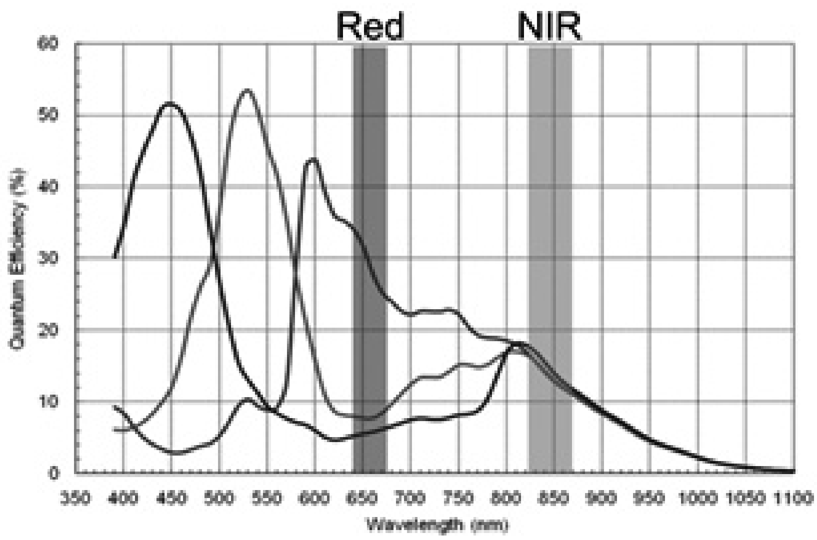

Fig. 4: Spectral characteristics of the LI-5M03 modules and spectral bands of the used optical filters

eters are the excess green index *ExG* (1), the normalized difference vegetation index *NDI* (4) and the normalized green red index *NGRDI* (5).

$$ExG = 2g - r - b \qquad (1)$$

$$r = \frac{R_0}{R_0 + G_0 + B_0}, g = \frac{G_0}{R_0 + G_0 + B_0}$$

$$\text{and } b = \frac{B_0}{R_0 + G_0 + B_0} \qquad (2)$$

$$R_0 = \frac{R}{R_{Max}}, G_0 = \frac{G}{G_{Max}} \text{ and } B_0 = \frac{B}{B_{Max}} \qquad (3)$$

$$NDI = \left(\frac{G - R}{G + R}\right) \qquad (4)$$

$$NGRDI = (NDI + 1)128 = \left(\frac{G - R}{G + R} + 1\right)128 \qquad (5)$$

On contrary to the *NDI* a white calibration for red, green and blue is necessary if the ExG is going to be calculated. These parameters were calculated pixel by pixel on the BeagleBoard-xM and by using the Otsu's method for thresholding their binary images were found and saved on a USB flash drive or an SD memory card.

A function for white balancing with a Styrofoam plate was implemented and the Canny operator was tested for edge detection. All algorithms were tested in relation to their processing time from image capturing till saving on a memory.

3. First Measurements

As a result of use and tests in practice the ThünoCopter with its total weight of about 3.6 kg can be landed in a soft way and the measurement system will not get damaged. During the landing operation, the construction guarantees bouncing and damping. Furthermore the distance between ground and the rotating propellers was increased so that the roughness of ground has a reduced influence on a take-off. After a quick take-off the pilot can start with his measurements.

As one fundamental condition to analyze the growth progress in crops with a UAV the researcher has to plan the flight path which should change only slightly during the vegetation period in a way that measurements at different times are comparable. Fig. 5 shows a comparison of the flight path, track points from the flight controller (FlightCtrl. 2.1) and track points from the measurement system on a maize field with central pivot irrigation.

This comparison displays that estimated flight tracks by the flight controller and tracks by measurement system are very similar. It is not clear whether the deviations from the flight path are true or both GPS receivers determine a GPS position with roughly the same faults since both very similar Ublox receivers are influenced by the same faults in GPS navigation. As it can be seen from Fig. 5, the distance between waypoints and tracks results to 6 m in maximum; the radius of the waypoints amounts to 10 m. In addition, the flight tracks were influenced by the wind. Only for wind speeds below 3 m/s it is possible to follow the flight path without vulnerability to failures.

So far, these different sources of errors have an effect on measured data. One of the first flight tracks for collecting photos with different wavelengths is shown in Fig.

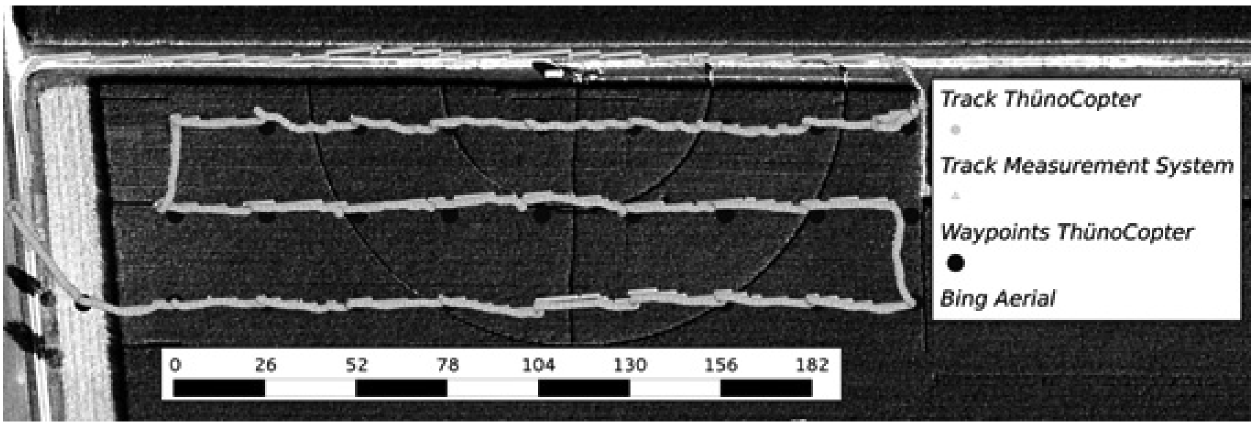

Fig. 5: Waypoints, track points from flight control system (FlightCtrl) and track points from the measurement system on a maize field with a central pivot irrigation

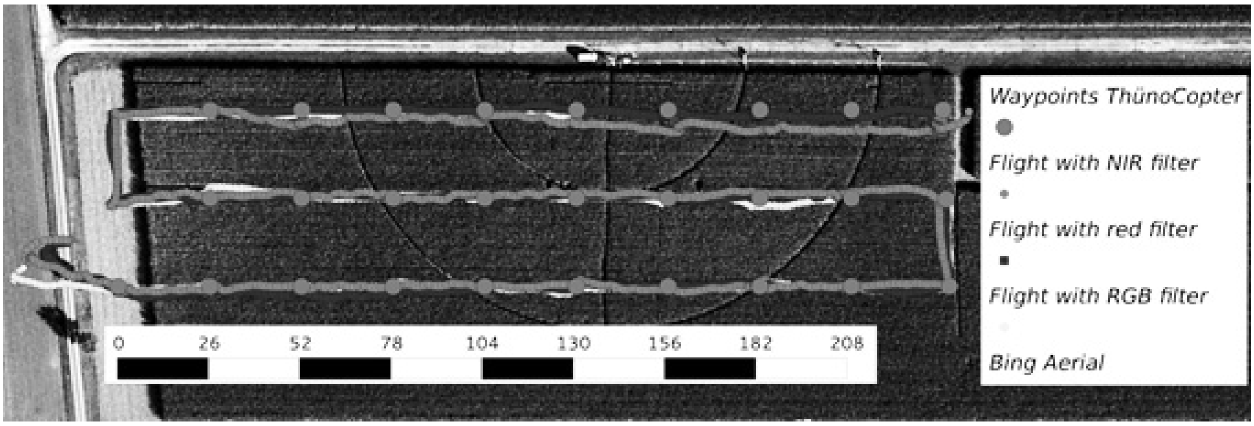

Fig. 6: Waypoints and tracks of a repeated flight over a maize field

6. For every flight the pilot has to change the lithium polymer battery with a capacity of about 6600 mAh since one load is enough for one flight with a velocity of 1.5 m/s over a distance of ca. 770 m in ca. 660 s if the ThünoCopter is stopping at the waypoints. Due to the fact of a sample frequency of 5 Hz for measuring air temperature, crop temperature, etc., a spatial resolution of 0.3 m is reached.

In Fig. 7a there is shown an original image of a maize field which is influenced by the lens vignetting of the whole camera system. This effect influences the first measurement of the NDI and the ExG index as well. In opposite to the estimation of the ExG index, the NDI is less sensitive to the influence of vignetting and luminance, but is also visible in Fig. 7b.

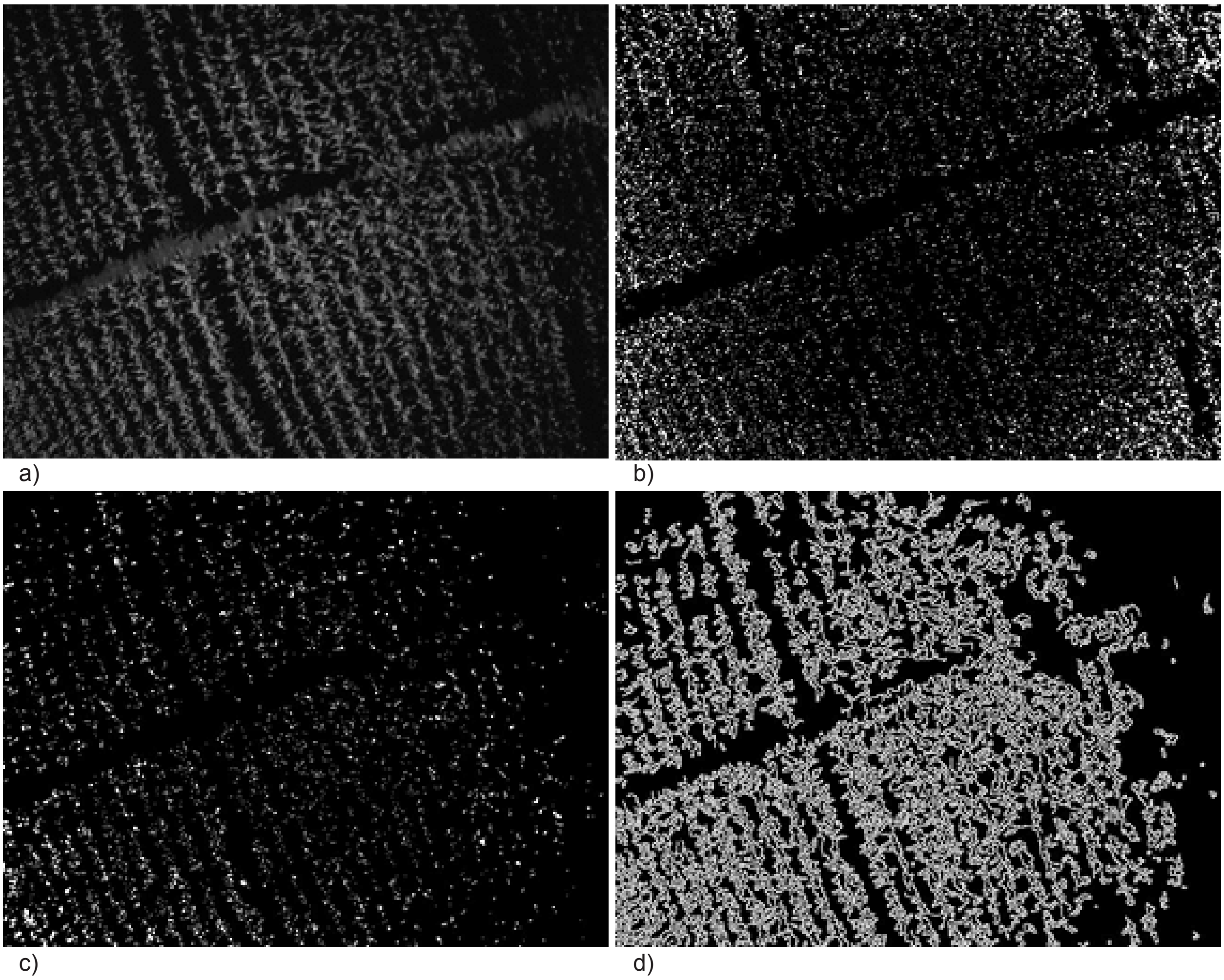

Fig. 7: Exemplary results of first measurements with the image analyzing system in a height of ca. 15 m above canopy a) Original image b) Binary image of NDI c) Binary image of ExG d) Canny edge detection

From Fig. 7c we can see that the greenness of very dark regions is not detected. Therefore white balancing should be adapted spatially in order to reduce the vignetting effect. Also the influence of fast alternating luminance can be reduced if the global radiation sensor is used for an OpenCV-based adaption. As demonstrated in Fig. 7d, also edge detection depends on quality of the original images and on the distance between crop and multicopter.

Further first measurements have been flights over a maize field with different wavelength filters for estimation the NDVI, but the white of styrofoam reference was not available in this measurement. Again the vignetting effect is visible in original image without white balancing (Fig. 8a), in the red image (Fig. 8b) and in the NIR image (Fig. 8c) after a repeated flight over a maize field.

For previous experiments and for following displayed data of processing time all original images were resized to 648 x 486 pixels. An important result from this experimental setup was the fact that a spatial resolution of ca. 3 cm can be reached if the distance between canopy and ThünoCopter is less than 15 m. Only increasing the image size can improve the resolution.

As shown in Tab. 1, capturing and saving images is most time-intensive and the root mean square (RMS) deviation for processing has the biggest variances of 116 ms and 288 ms. A simple Canny edge detection requires only 64 ms on the BeagleBoard-xM whereas Coombs & Prabhu (2011) have measured under roughly the same condition a time of 79 ms with a OMAP 3350 processor at 720 MHz.

Without having a closer look at Tab. 1, we can summarize that the so far implemented algorithms take a time of 1163 +/- 310 ms from capturing over resizing, calculation of NDI and ExG, Canny edge detection to finally saving on an SD memory card. At a speed for flight of 1.5 m/s this results to a spatial resolution of 1.74 m.

4. Conclusions and Future Work

The usage of the landing platform over the vegetation period in 2013 has shown that the complete measurement system was protected, but flight time could be enhanced if other materials with less mass density were used for the construction of an improved landing platform, which is less sensitive to the influence of wind.

Without improving the Canny algorithm or improving the calculation of the NDI and ExG, better results can be expected if a more suitable auto iris video lens for the camera is found so that the exposure during flight

a) b) c)

Fig. 8: Images of a repeated flight over a maize field a) RGB b) red filter c) NIR filter

	Example (Fig. 6) [ms]	Mean [ms]	Minimum [ms]	Maximum [ms]	RMS [ms]
Capturing images	313	416	287	1493	116
White balancing, resizing images	222	222	115	2263	84
Calculation of NDI, ExG and their binary images with Otsu's method	330	211	125	820	101
Canny edge detection	106	64	40	144	25
Saving original image, NDI and ExG binary image on the SD memory card	344	250	124	5273	288
Total	**1315**	**1163**	**735**	**6120**	**310**

Tab. 1: Typical processing time for processing the images

is more regular and if an adaption algorithm to reduce the vignetting effect will be found. It is realistic to detect weeds in machine tracks of maize fields if the algorithms for the NDI and ExG would be improved and extended due to the fact that all green plants between the rows have not been seeded.

Further steps for the extensions of the image analyzing system is the implantation of the approach presented by Kraft (2003) to calculate the crop covers in near real-time of crops during a vegetation period.

How far it is possible to reduce the time of processing depends firstly on the improvements of the algorithms and secondly on whether computationally intensive steps can be calculated on the DSP. Furthermore, the capturing and storage should be accelerated because they are most time-intensive. If the time of processing is reduced, more images could be analyzed at the same time. Hence the image analyzing system can be accelerated and more measurements with a higher speed of flight are possible. Up to now the image analyzing system can execute the steps described in chapter 4 in 1163 +/- 310 ms. For autonomous machinery this fact in combination with the possibility to use the DSP for processing intensive algorithms is a good base for further R&D activities. In summary it can be said that a multicopter with a measurement system and an image analyzing system has been brought into operation which is modular and expandable.

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