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RoboWeedSupport-Sub Millimeter Weed Image Acquisition in Cereal Crops with Speeds up till 50 Km/H

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***Abstract*—For the past three years, the Danish project, RoboWeedSupport, has sought to bridge the gap between the potential herbicide savings using a decision support system and the required weed inspections. In order to automate the weed inspections it is desired to generate a map of the weed species present within the field, to generate the map images must be captured with samples covering the field. This paper investigates the economical cost of performing this data collection based on a camera system mounted on a all-terain vehicle (ATV) able to drive and collect data at up to 50 km/h while still maintaining a image quality sufficient for identifying newly emerged grass weeds. The economical estimates are based on approximately 100 hectares recorded at three different locations in Denmark. With an average image density of 99 images per hectare the ATV had an capacity of 28 ha per hour, which is estimated to cost 6.6 EUR/ha. Alternatively relying on a boom solution for an existing tracktor it was estimated that a cost of 2.4 EUR/ha is obtainable under equal conditions.

***Keywords*—Weed mapping, integrated weed management, weed recognition.

I. Introduction

THE tools for Precision Agriculture are ready, but the implementation is only marginal due to complex data handling, weak system integration and an insufficient economic return of the investment [1]. The economic and environmental potential are significant for site-specific weed management (SWM) [2]–[4]. The five major technical challenges for SWM: 1) variable lighting, 2) leaf occlusion, 3) growth status, 4) independent multiple herbicides application, and 5) real-time discrimination of weed species [5], [6]. University of Hohenheim and Aarhus University have been leading in weed recognition, weed mapping, dose and herbicide optimization. The H-Sensor for real time weed detection [7]–[9] and the Amaspot for patch spraying (AmaSpot Sensor Nozzle System, [10]) are good examples of emerging commercial products. However, common for both are that they are hardware costly with limited abilities in weed discrimination and multi herbicide optimization. In addition, several researchers are working on using cameras to crop/weed discrimination providing increased herbicide savings [11]. [12] presents a system only recognizing crop plants and injecting micro droplets of glyphosate onto the weed seedlings with more than 99% savings. Reference [13] did likewise but removed weeds mechanically. Both however have a limited capacity.

Research has demonstrated distinguishing abilities of different weed species [14]–[17]. However, none is suited for implementation on a spray boom in their current state, as they are limited in the number of supported weed species or are dependent on human interactions. Decision Support Systems (DSS) for Integrated Weed Management (IWM) shows unexploited herbicide reduction of 30-50% in cereals [18]–[23]. However, DSS do not fit well into farmers usual practices by requiring manual field inspections and identification of weeds constituting a major obstacle [19]. For the past three years, the Danish nationally funded project, RoboWeedSupport, has sought to bridge the gap between the potential Crop Protection Online (CPO) or IPMwise based herbicide savings and the required field inspections [24]. Initially smartphone cameras and later unmanned aerial drones (UAS) were used to collect images from the field for semi-automated weed discrimination and classification [25]. However, the target expense of approximately 1.4 EUR disqualified the two latter solutions. The aim of this work is to present and estimate the capacity and economics of a high-speed camera prototype capable of recording crop/weed images with a horizontal velocity up to 14 m s^{-1}.

II. Materials and Methods

Three farmers in Denmark from the regions Jutland, Funen, and Zealand with autumn seeded winter wheat were selected prior to any herbicide application. Since the capacity of the prototype system were uncertain with regards to stability and capacity each of three farmers had at least 50 hectares ready for weed mapping and were visited at different dates. The ATV used as carrier were an Can-Am Outlander 500 XT with Trimble SPS 851 RTK-GNSS.

A. The Prototype High-Speed Camera

The camera system (Fig. 1) was based on a 5.0 Mpixel USB 3.0 camera (Point Grey, GS3-U3-51S5C-C) mounted with a 16mm lens (Edmund optics, 86-571). Illumination was provided by a ring flash (AlienBees, ABR800). The camera was mounted within the ringflash using a custom 3D printed bracket (nylon), the bracket consists of a holder for the camera, a spring around the perimeter for an auto-centering press-fit and a relief area for resting on the back of the flash unit. The

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flash unit itself has its perimeter mounted with epoxy to a 3D printed ring, upon which four oil dampened shocks has been mounted in order to dampen shocks and vibrations otherwise transferred to the camera setup. The shocks and camera setup is again mounted in an aluminium frame with lexan windows on the sides and top for weatherproofing. The aluminium frame was mounted to the ATV at three points, one at the hitch point and two on either side of the rear luggage rack ensuring horizontal and vertical stability. Inside the aluminium rack was also mounted a LiFePO4 battery, power supply and an embedded computer.

B. The ATV Based Image Acquisition Procedure

An embedded linux based computer (Nvidia TX1) received the current position through the GNSS receiver mounted on the rear of the ATV with an update rate of 10 Hz. Based on the euclidean distance to where the last image was recorded, the camera system was triggered when the distance were more than 10 meters. The trigger caused an image to be recorded together with the last received position, the time of recording and the image number, counting from startup of the system. This metadata was stored as part of the filename and the image data (Bayer pattern) in 16 bit PNG format.

When entering a field to be mapped a reference image of a calibration plate were recorded (See Fig. 2). The calibration plate enabled automated calibration and verification of the color balance, focus, effective resolution, and imaging area. Different weeds had been added to the calibration plate for human interpretation.

After recording the calibration plate and performing visual inspection, a physical switch is set to auto. Initially, the ATV follows the perimeter of the field ensuring detection potential of entering novel weeds. Hereafter the ATV covers the rest of the field in a systematic manner between the tramlines trying obtain a 10x10 m sampling grid.

C. Economic Assumptions

Two economic scenarios are considered 1) mapping as an ATV service 2) mapping by the farmer using a dedicated 24 m hydraulic boom with three cameras. Investment, capacity, time, service and fuel estimate are derived from initial field tests using an ATV and otherwise estimated. Other costs are estimates based on knowledge on investments and normal farm capacity and unit cost scaled to different mapped areas.

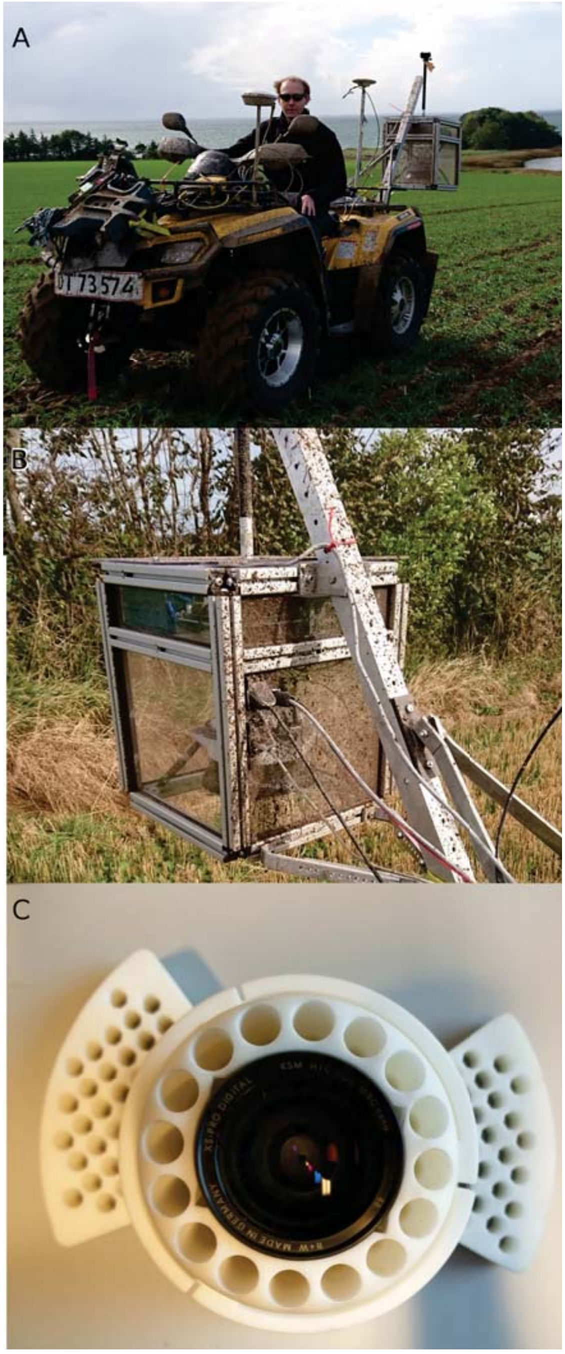

Fig. 1 (A) The ATV mounted up with RTK GNSS and the prototype camera (B) Close up of the high-speed camera after heavy rain during mapping. (C) 3D printed camera bracket

D. Investment

Acquiring an ATV mounted with a high-speed camera ready to go is estimated to an investment of 23.490 EUR. Initial price estimates indicate a commercial camera price around 8000 EUR. Driving with more than 30 km/h speed on terrain require an ATV with sufficient power and therefore are estimated 11400 EUR to a powerful 850cc ATV. Camera and ATV customizations, fittings and mounts are estimated to 2000 EUR. A 1 m accuracy GPS are estimated can be purchased for approximately 1400 EUR. As a dedicated mapping system for the farmer are proposed a 24 m hydraulic foldable boom mounted in a 3-point suspension on a tractor mowing with an average velocity of 12 km/h. On the boom is mounted three cameras, one in the centre and two in the end of the boom giving an overall 12 meter distance between cameras. This means using a 24-meter boom like described in a field with 36-meter between the tramlines. The ATV have in early test used 0.3 litre fuel/ha estimated at a cost of 1 EUR/L. ATV service is estimated for each 1000 kilometres at a price of 300 EUR per service. For further details on the assumptions and details with regards to estimating the capacities and costs

Fig. 2 (A) Calibration plate for automated and human quality verification (B) Close up of an image recorded with 12.5 m/s (45 km/h)

for weed mapping with an ATV and a tractor with a 24 m camera boom with three cameras.

III. Results

The ATV based image acquisition were collected across a wide variety of conditions with regards to field size and shape (Fig. 3), weather, soil type and topography. Despite heavy rain and dusty condition, the lens and the flash never became dirty. The image quality illustrated in Fig. 2, bottom was constant throughout all fields independent of light and weather conditions with one exception. Water droplets on the leaves did lower the crop/weed image a little but not to a severe extent, which in several cases have been the case with smartphones (not published) and drone collected images [26]. Studying Fig. 3 and Table I it seems like rectangular or elongated fields (A, B, C, and K) increase the ratio of time above 30 km/h. Field F was the biggest field but the tramlines were orthogonal to the longest side of the field. Furthermore, steep hills forcing sideway driving resulted in lower velocity and capacity. The average capacity was 28 ha per hours varying from 16 ha/h in the smallest field (G) up to 40 ha/h.

TABLE I
Performance Measures from ATV Based Weed Imaging in 11 Cereal Fields Covering 109 Hectare with an Average Imaging Density of 99 per Hectare and Capacity of 28 Ha per Hour

Sub plot	Region	Area [Ha]	Time spent [mm:ss]	Distance driven [m]	Time per ha [mm:ss]	Pics per ha	Time spent < 30 km/h	Ha per hour
A	Funen	8.9	12:48	9018	01:26	86	24%	40
B	Funen	10.1	18:25	3781	01:49	101	27%	32
C	Funen	4.7	12:39	6493	02:40	133	37%	22
D	Funen	11.5	18:37	17160	01:38	80	48%	35
E	Jutland	7.2	14:35	21150	02:02	80	61%	28
F	Jutland	21.9	50:11	10733	02:18	89	61%	25
G	Jutland	2.7	09:32	6608	03:30	134	78%	16
H	Jutland	4.6	09:28	5459	02:05	81	74%	28
I	Sealand	16.1	39:18	16080	02:27	103	59%	24
J	Sealand	4.4	10:43	9838	02:27	119	41%	24
K	Sealand	17.0	28:59	3842	01:42	87	30%	34

A. Economy

Using the annuity model on an investment of 20.000 Euros, with a 6% interest rate per year and a loan term of 5 years a yearly annuity of 4780 EUR are calculated. With an increasing yearly mapped area the annuity cost are reduced as shown in Fig. 4. Costs that define the operation are divided into 1) preparation 2) mapping time, 3) internal transport between fields on the farm, 4) transport between clients and service provider, data handling, 5) fuel and 6) Annuity cost 7) other costs e.g. service, repairs, etc. A ready to go ATV with installed camera are estimated an investment around 20.000 EUR based on initial experiences. The capacity with a two weeks windows for the ATV and the tractor setup with 24 m and 36 m tramlines are 1980 ha, 2592 ha, and 3888 ha, respectively. This result in total costs of 6.6, 3.8, and 2.4 EUR, respectively.

IV. Discussion

The work demonstrates that it is possible to collected high resolution images with a simple high-speed camera mounted on an ATV sampling with a velocity up to 50 km/h. The average capacity was 28 ha/h collecting approximately 100 images per hectare. The cost assuming a capacity of 1900 hectare on a two week window was estimated to 6.6 EUR/ha which is relatively far from the aim of 1.4 EUR (10 DKK) per hectare. Somewhat surprising the target cost of 1.4 EUR/ha seems almost obtainable for a tractor-mounted system with three cameras mounted 12 m apart in a 36 m tramline system with a total cost of 2.4 EUR/ha. The system can drive can potentially operate as a 24/7 service. Therefore, the sprayer tractor may be used when the spraying conditions are not optimal. Hence cost effective weed mapping seems within reach in a commercial version of the system presented in this work.

V. Conclusion

This work demonstrates it is possible to perform image acquisition for weed mapping in a 10 m grid for a total cost ranging from approximately 2.4-6.6 EUR. Somewhat surprising the suggested tractor based setup seems significantly cheaper than the ATV setup used in this work.

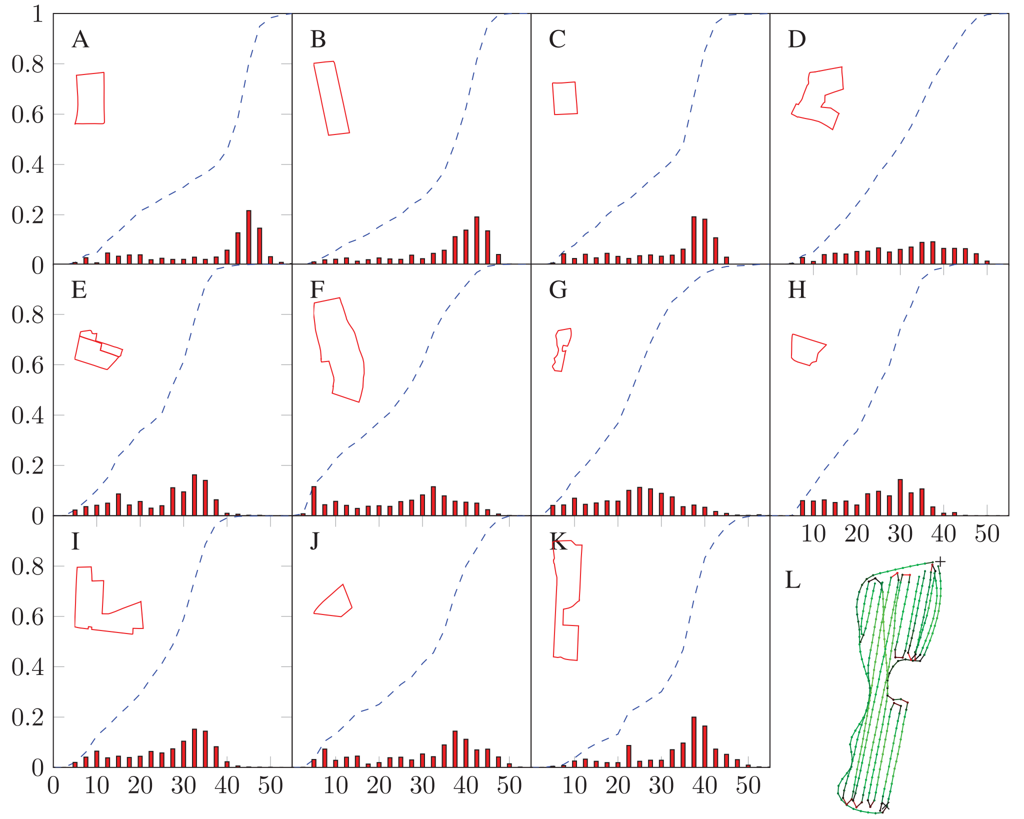

Fig. 3 Overview of the 11 mapped fields with regards to their relative size and shape (The red polygon in the upper left of each plot). The cumulative velocity (blue punctured line) and histograms (red bars) of the velocity distribution for each field are shown for each field. Table I have additional statistics linked via the character A-K naming of each subplot. Subplot shows the recorded track for the 2.7 ha field G, which is also used by [16]

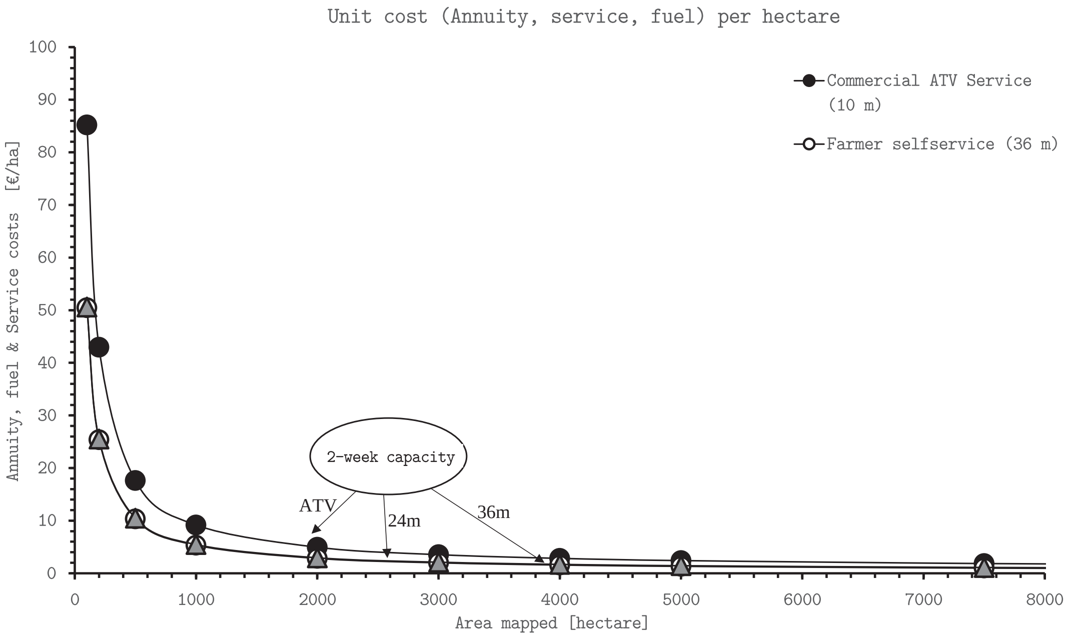

Fig. 4 Annuity and ATV service + fuel cost as a function of yearly mapped area

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