Sektion 7: Smart Farming

Session 7: Smart Farming

From traditional weed mapping to an autonomous robot: developments and results from Hungary

Von traditioneller Unkrauterfassung zum autonomen Roboter: Entwicklungen und Ergebnisse aus Ungarn

Péter Reisinger, István Borsiczky*

Széchenyi István University, H-9200-Mosonmagyaróvár, Vár tér. 2., Hungary
*Corresponding author, istvan@tomelilla.hu

DOI 10.5073/jka.2018.458.054

Abstract

We are developing precision weed control technology in Hungary since 2000. From the beginning, for financial reasons, we focused our attention on the map-based technology. The post-emergence weed control method developed for winter wheat begins with weed mapping, continues with post-processing of information and ends with creation of application maps with GIS software.

In the first five years, we have developed the weed mapping methodology. Based on experiments and calculations, we have found the solution in a Hungarian method based on weed coverage. The field is divided in 0.5-hectare quadrats and the weed coverage of each quadrat is estimated. The information is georeferenced with DGPS coordinates. The processing algorithm considers the coverage limits for all weed species with focus on the presence of dangerous weeds, selects the cells where chemical weed control is mandatory and the cells with low risk, where the absence of chemical protection can be allowed. At the beginning, we have used a conventional, tank mix sprayer, later we have switched to a twin tank, direct injection machine. From 2008 to 2016 the technology was tested on 1237 hectares, 38 fields, 2459 quadrates in total. We can report 51% average herbicide saving for the nine-year interval. The advantages of the developed method are cost-effectiveness and safe weed detection. The disadvantage is the high expenditure of time by the weed expert because the whole field must be covered.

As a further development, we have created an autonomous weed mapper in 2016. The result is a significant increase of image samples. The used office environment improves the accuracy of image processing, the identification of species and coverage estimation.

Keywords: Autonomous weed mapping, manual weed mapping, precision weed control, robot

Zusammenfassung

Seit dem Jahr 2000 entwickeln wir in Ungarn Techniken für die teilflächenspezifische Unkrautbekämpfung. Seit Beginn konzentrierten wir uns aus finanziellen Gründen auf die Erstellung von Unkrautverteilungskarten (Kartentechnik). Die Methode zur Nachauflauf-Unkrautbekämpfung wurde für Winterweizen entwickelt und beginnt mit der Unkrautkartierung und der Datennachbearbeitung von Informationen und endet mit der Erstellung von Applikationskarten mit GIS-Software.

In den ersten fünf Jahren haben wir die Methoden zur Unkrautkartierung entwickelt. Nach Experimenten und Berechnungen fanden wir die Lösung in einer ungarischen Methode basierend auf dem Unkrautdeckungsgrad. Dabei wird das Feld in 0,5 Hektar große Quadrate geteilt und der Unkrautdeckungsgrad wird für jedes Quadrat erfasst. Die Informationen sind georeferenziert mit DGPS-Koordinaten. Der Verarbeitungsalgorithmus berücksichtigt Deckungsgrade mit Fokussierung auf das Vorkommen von gefährlichen Unkrautarten, wählt die Zellen, in denen eine chemische Unkrautbekämpfung erforderlich ist, sowie die Zellen mit geringem Risiko, in denen auf eine Unkrautbekämpfung verzichtet werden kann. Zu Beginn haben wir eine konventionelle Feldspritze verwendet, die wir später zu einem Twin Tank mit Direkteinspeisung verändert haben. Von 2008 bis 2016 wurde die Technologie auf 1237 Hektar, 38 Feldern auf insgesamt 2459 Parzellen getestet. Wir konnten für die neun Jahres-Intervall eine durchschnittliche Herbizideinsparung von 51 % ermitteln.

Die Vorteile des entwickelten Verfahrens sind die Wirtschaftlichkeit und die sichere Unkrauterkennung. Der Nachteil ist der hohe Zeitaufwand durch einen Unkrautexperten, da das gesamte Feld abgedeckt werden muss.

Als Weiterentwicklung wurde im Jahr 2016 ein autonomes Fahrzeug zur Unkrauterfassung konstruiert. Dies führt zu einer signifikanten Erhöhung der Bildanzahl. Die verwendete Office-Umgebung verbessert die Genauigkeit der Bildverarbeitung, die Unkrautartenerkennung und die Ermittlung des Deckungsgrades.

Stichwörter: Automatische Unkrauterfassung, manuelle Unkrauterfassung, präzise Unkrautbekämpfung, Roboter

Introduction

The research on precision plant production began 20 years ago in Hungary, primarily by developing methods for precision nutrient management. Since 2000 we have started to review the foreign experiences, study the details and the developed methods. We examined the possibility of adaptations for Hungary. The effective, mostly on-line methods developed in Western Europe were barely applicable due to financial reasons. On the other hand, the researchers and practicing professionals are using a well-developed Hungarian weed mapping method for more than 70 years.

Over the past 17 years, we have tried to develop our own, complete, off-line method with integration of the traditional Hungarian weed surveying method as the input side of the site-specific weed management. Additional tasks were the optimization of sampling grid, size of the sample plots, assets used for weed-mapping and finding solutions for many other logistical problems.

The following task was processing the information input, creation of the weed controlling algorithm and in the final phase we have prepared the controlling commands for the sprayer. We have used site specific weed management primarily in winter wheat, since 2008. At the beginning, we have used a conventional, tank mix sprayer, later we have switched to a twin tank, direct injection machine. From 2008 to 2016 the technology has been tested for 1237 hectares, 38 fields, 2459 quadrates in total. We can report 51% average herbicide saving for the 9-year interval.

The results of the robot-technological innovations of the recent years requested the re-thinking of our previously developed method. We have developed a weed-mapping, self-propelled robot and we have tested the device in different crops.

Weed mapping methods: presentation and qualification from the point of view of precision weed control

The most important element in planning precision weed control and herbicide application is the selection and development of the adequate weed surveying method. On cultivated areas weed populations show high heterogeneity regarding the occurring species and their density (GERHARDS et al., 2000; HAMOUZ et al., 2004). Many factors have an influence on the composition of a plant assemblage; the most important are ecological factors and agrotechnology, as an anthropogenic element.

According to UJVÁROSI (1957), a great eminence in the field of Hungarian agrobotanics, the effectiveness of weed control in a field is depending mostly on the knowledge of weed species and their quantitative proportions. As a further consideration, the effectiveness of site-specific weed control depends on the accuracy of surveying and detection of the weeds.

Weed surveying methods have developed from natural vegetation research procedures and can be divided into two groups: exact methods and estimation methods. In the European weed research publications, the authors do not mention the name or type of weed mapping methods. JOHNSON et al. (1995) pointed out that farmers are not taking the advantage of precision weed control, the high level of herbicide savings, because there is no standardized method for weed-map creation.

MERTENS et al. (2002) surveyed fields in Germany. In 2000 and 2001 they have surveyed the surroundings of 382, respective 500 villages, on untreated corn fields, counting the species and density of weeds on 0.1m^2 areas. CHIRILLA and BERCA (2002) surveyed 237.000 hectares on 3676 sampling plots from 1974 to 2000 in South East Romania. Weed phenology, height and density were recorded. KROHMANN et al. (2002) counted weeds on 0.4m^2. LITTERSKI and JÖRNS (2004) recorded the coverage of the species. For precision weed mapping HAMOUZ et al. (2004, 2006) used the weed density of the 0.25m^2 sampling areas. NORDMEYER (2006) used weed counting on 2x0.1m^2 areas.

The disadvantage of the exact method is the slowness and if the weeds are completely removed, the surveying cannot be repeated. Methods based on estimation are not as accurate, but they are faster, simpler, cost effective and with enough practice we can get good results.

BALÁZS (1944) laid the foundations of the most commonly used method for weed surveying in Hungary. The weed density (coverage) is estimated on a scale, based on bisection of the sampling area. Table 1 shows estimations of weed coverage (rows nr. 1, 3 and 5) and values of Balázs (rows nr. 2, 4 and 6).

Tab. 1 Relationship between Balázs values and weed coverage (%).

Tab. 1 *Beziehung zwischen Balázs Zahlen und Unkrautdeckung (%).*

Weed coverage%	**100,00**	**87,50**	**75,00**	**62,50**	**50,00**	**43,75**	**37,50**	**31,35**	**25,00**
Balázs value	6	5-6-6	5-6	5-5-6	5	4-5-5	4-5	4-4-5	4
Weed coverage%	**21,87**	**18,75**	**15,62**	**12,50**	**10,93**	**9,37**	**7,81**	**6,25**	**5,46**
Balázs value	3-4-4	3-4	3-3-4	3	2-3-3	2-3	2-2-3	2	1-2-2
Weed coverage%	**4,68**	**3,90**	**3,12**	**2,49**	**1,87**	**1,24**	**0,62**	**0,36**	**0,10**
Balázs value	1-2	1-1-2	1	+-1-1	+-1	+-+-1	+	0-+	0

Miklós Ujvárosi, a leading personality of the Hungarian agrobotanics made further developments and as a result it became known as "Balázs-Ujvárosi weed surveying" method (furthermore B-U method).

The advantages of the B-U method:

- mathematically correct, the data can be processed with computers, versus the Braun-Blanquet scale
- no measuring instruments needed, can be learned and executed relatively quickly
- the estimation method can be developed to an exact method (it is compatible with photo-optical procedures)
- the intervals properly represent the small coverage differences, coverage percentage pictures better the damages caused by weeds (area-competition) than weed counting
- the measurements (samplings) are repeatable

The method is widespread only in the Hungarian practice, because the authors have not published it in the foreign literature. The Fifth National Weed Survey (2007-2008) was published in English language too, with a profound description of the Balázs-Ujvárosi method (NOVÁK et al., 2009).

Practical validation of the B-U method with a wide-spectrum handheld camera

The B-U surveying method is practiced by Hungarian herbologists for more than a half century. Regarding the mapping method we had no comparison between the estimated values and margin of error. We have tried to prove the relative accuracy of the B-U method. Our research was conducted on wheat fields (stubble), at the Training Establishment of the University. We took near-field pictures with a multispectral CMOS handheld camera and in the same time we have surveyed the plots according to the B-U method. The number of samples were 43 (n=43). After image calibration we have evaluated all pictures and the coverage (canopy %) values were calculated. Later we have removed the overexposed images and reduced the number of samples to 32 (n=32). For image processing we have used BRIVE 32 and ENVI 4.0, for statistical calculations the

SPSS 12 software. The coordinates of the sample quadrants were recorded with TRIMBLE geodetic instrument, Omnistar correction.

Table 2 shows the results of comparisons. Without the overexposed images, the average coverage (%) of the digital images dropped from 43.65% to 35.34% and the correlation rose from 0.63 to 0.92.

Tab. 2 Statistical results of comparison between digital image processing and traditional surveying.

Tab. 2 *Statistische Ergebnisse des Vergleichs zwischen digitaler Bildverarbeitung und traditioneller Erfassung.*

n=43	**Coverage - evaluation of total digital images**	**Coverage - results of the traditional B-U surveying**
Average	43,65	29,07
Variance	23,25	19,98
CV%	53	69
Correlation	0,63	
n=32	**Coverage - evaluation of digital images (overexposed removed)**	**Coverage - results of the traditional B-U surveying**
Average	35,34	30,2
Variance	20,04	21,45
CV%	56	71
Correlation	0,92	

The question of sample density and size of surveying plots

Key issues of successful precision weed control are the sample density and size of sample plots. The weed-mapping is a tiring and time-consuming field work. As a result, the number of samples is aimed to be at the lowest cost and maximum information content. HAMOUZ et al. (2004, 2006) investigated for several years the spatial and temporal stability of weed populations. It was found that the quality of the weed maps and the success of the site-specific weed management are affected first and foremost by the size of the sampling grid and the size of the sampling plot.

Several variations have been tried out, from a few meters sampling grids (5-7.5 m) versus large (50-90 m) grids. JOHNSON et al. (1995) created 711 sampling grids of 20 × 40 m parallel to the direction of cultivation, surveyed and counted weeds on the points of intersection. After processing the entire database (20 × 40 m), they have got to the 80 m × 80 m (93 surveying plots) grid. The German researchers in the development of the on-line precision weed control applied complete survey of the entire field. In this case, the sample rate is not a methodological problem (GERHARDS et al., 2002; OEBEL, 2004).

In our own research we have considered both above mentioned criteria to be important. The density of sampling sites was researched on cereal stubble at the University in Mosonmagyaróvár, on field No. 10. (Lat. 47.900356, Long. 17.256317) in August 2002. The field was divided in 18 m wide bands along the tramlines and we have created 0.2-hectare grids (18 m x 111 m). Accordingly, in the intersections we have placed the 2 × 2 m surveying and sampling plots, 85 pieces in total. We have performed weed-surveys on all 85 plots according to the B–U method and later we have optimized the number of trial plots with data reduction and data grouping. In the first data reduction every second survey has been deleted. As a result, we have got 43 plots, each representing 0.4 ha area. The next step was deleting every third sample from the original database. As a result, we have got 30 plots, each representing 0.6 hectares. After these steps we have created the dominance order and we have researched the changes in the ranking of species.

Tab. 3 Relationship of weed species frequency and size of sampling area.

Tab. 3 *Beziehung der Unkrautartenhäufigkeit und der Größe der Probenahmeflächen.*

Dominance order	Area represented by sampling plots 0.2 ha	0.4 ha	0.6 ha
1.	Chenopodium hybridum	Chenopodium hybridum	Mercurialis annua
2.	Mercurialis annua	Mercurialis annua	Chenopodium hybridum
3.	Vicia spp.	Vicia spp.	Vicia spp.
4.	Chenopodium album	Chenopodium album	Chenopodium album

It was found that the frequency of weed species does not change significantly depending on 0.2, 0.4, 0.6 hectares sampling rate (Tab. 3). Processing the data, we have found no significant difference between the headlands, middle of field, or the intersections of the sampling grids (REISINGER et al., 2003). In spring 2005 we have researched sample density in the outskirts of the Baracska village (Lat.: 47.263470; Long.: 18.740297), in an untreated, 0.5-hectare winter wheat. Typically, a composition of dicots occurred: *Helianthus annuus* (volunteer), *Papaver rhoeas*, *Cannabis sativa*, *Sisymbrium sophia*, *Galium aparine*. Perennial weed species were not found in the area. The 18 m × 278 m plot was divided with braids into 2 × 2 m quadrants (sub-plots), (n=1251; 9 rows and 139 columns) then we have measured the coordinates in the center of the plots with high accuracy Trimble Pathfinder Power DGPS instrument. Later we have surveyed each quadrant according to the B-U method. The data was recorded in Excel spreadsheets and processed according to various criteria:

mean coverage of weed species in 1251 trial plots
occurrence of different weed species
optimization of the number of samples with data reduction

For optimizing the number of sampling plots the following reductions were made from the database:

only the rows from extremes were considered (n=278)
only the middle row has been processed (n=139)
every 10.-th plots of the middle row was taken into consideration (n=14)

The following table shows the high degree of significance between the results of various data reductions and the full set of data. We examined data obtained from every 10-th surveying plot of the middle row (n=14) and we have found significant results with the full set of data.

Tab. 4 Sample reduction and occurrence of weed species.

Tab. 4 *Probenreduzierung und Auftreten von Unkrautarten.*

Species	Data from all plots	Data from the plots of the extreme rows	Data from the plots of the middle row	Data from every 10-th plot of the middle row
	n=1251	n= 278	n=139	n=14
	Incidence % of weed species			
Helianthus annuus (volunteer)	99,84	100	100	100
Cannabis sativa	99,84	100	100	100
Papaver rhoeas	88,41	87,36	88,5	71,43
Sisymbrium sophia	69,86	67,87	74,8	78,57
Galium aparine	0,32	0	0	0

SD 5 % 0.989***

From the experiments and practical experience, we found that the 0.5 hectares sample grid provides sufficient information for weed surveying- if the winter wheat is in good, even condition in the spring. It is important, however, to point out a few details. For precision weed control a sampling grid of 0.5 hectares (71 m x 71 m) should be overlaid on the field. The surveying plots should be positioned in the center of the quadrates formed by the grid. Navigation in the field, the coordinates of the numbered surveying plots and direction of travel should be planned and executed with a DGPS instrument. The surveying expert should keep a record of weeds of the first plot. While walking to the second plot, the expert is scanning the canopy with his eyes and records the weed species with 0.1% coverage, which have not occurred on the previous plot. Considering an average human line of sight this way we can survey 100-110 m^2 of every 0.5 hectares.

The size of surveying plots

In practice, the Balázs-Ujvárosi method uses 2 m x 2 m plots for precision weed control. The sub-meter accuracy of the used Trimble Pathfinder Power DGPS during development provided acceptable return accuracy to the 2m x 2m plots. The 2 x 2-meter quadrate is perspicuous, well manageable and walking around the perimeter the weed coverage can be exactly surveyed.

Optimization of precision weed control process in winter wheat

In countries with advanced agriculture the environmental approach is continuously growing, and pesticide and herbicide reduction programs are being introduced gradually (NORDMEYER, 2006). The precision weed control can be effective on fields with low or medium weed infestation, (GERHARDS et al., 2000). NORDMEYER and ZUK (2002) in their three years investigations found that the herbicide savings against monocotyledonous weeds was from 16.6% up to 55.3%, against dicotyledonous weeds from 23.9% up to 53.5%, against the *Galium aparine* from 25.5% up to 66,7%. NORDMEYER (2006) pointed attention on the possibility of large herbicide savings because of postemergence precision weed control in winter wheat (1999 to 2005). In some years 70-85% of the area remained untreated. Herbicide savings exceeded 50%. Regarding the yield, there was no difference between the treated and untreated areas. Considering the weed conditions of Hungary, the introduction of precision weed control methods is possible mainly in cereals and winter rape.

The almost two decade-long development of precision weed control around the world developed two distinct models, which are:

online (real time)
offline (post processing, map based)

Western European researchers and developers focused on the on-line (real-time) precision weed control models. Precision herbicide applications are based on detection software, developed focusing mainly on the morphological characteristics of weeds. On-line precision weed control methods are based on RGB or the multi-spectral cameras, fitted on the spraying tractor (OEBEL et al., 2004). After image conversions and special processing, they have received a set of binary images where the weed species are characterized by distinct white silhouettes, while the soil and environment are black. The images and coordinates are stored in the computer of the tractor. The other precision weed control model is the "map-based" procedure. The results of weed surveys are collected and sorted in databases and spraying maps are prepared with different algorithms. In map-based methods, collection and processing of data are separated in time from spraying, unlike the online method, where data collection and execution of the process are in real-time.

The Hungarian precision developments did not follow the mainstream Western European trends. In our vision precision spraying a second step is used, previously the weed species of the field and their quantities should be surveyed. We can select the appropriate active herbicide substance based on the survey data. Today we are using a smartphone application to carry out the field work. The application starts with importing or recording (walking around) the field boundaries. In the next step the surveying grid and numbered surveying plots are generated. 254 weed species are included in the application with their life-forms and the coverage values of the B-Ú method, all selectable from menus with a push of a button.

Materials and Methods

The RAU Spidotrain 2800/18 sprayer was equipped with two, GPS-controlled, variable rate ready, direct injection tanks, 70 liter each (Injection Pump, Raven Industries, Sioux Falls. USA). The output of the injection tanks was connected directly into the water pipe, just before the section control valves via a „Turbo" mixer. This device creates a very strong turbulence in the water and the injected chemical is mixed with water instantaneously. Based on the procedure and algorithm described earlier we have created and imported the spraying map into the console. We have used AgLeader SMS software and AgLeader InSight console with steering system, Trimble RTK base station. The "A" tank contained the stock solution of Aurora Super SG (carfentrazone-ethyl + mecoprop-p), herbicide for monocotyledonous weeds, and the "B" tank was liquid Axial One (pinoxaden + florasulam + cloquintocet-mexyl) commercial herbicide. In the main tank of the RAU sprayer we have mixed Stable SL (chlormequat) stem strengthener. The sprayer was programmed to work with a 300 l/ha water volume, with the constant 2 l/ha Stable SL mixture. The tractor was spraying continuously the water + strengthener mixture. When it reached a cell containing more T1 life-form dicotyledonous weeds with coverage more than 5%, or zero tolerance weeds, the „A" tank switched on and Aurora Super SG 1 kg/ha dose was sprayed. The "B" tank worked only when the sprayer reached cells infected with *Apera spica-venti* and 1 l/ha Axial One was sprayed. All important details of the precision treatments were stored in the tractor's console.

The converted machine is capable of handling the following 4 variations:

- spraying the 2800 liter strengthening mixture from the main tank, without herbicides
- strengthening mixture + direct injection tank „A" with selective herbicide for dicotyledonous weeds
- strengthening mixture + direct injection tank „B" with selective herbicide for monocotyledonous weeds
- strengthening mixture + direct injection tanks „A" + „B" with selective herbicide for dicotyledonous and monocotyledonous weeds

Results

The 71.16-hectare Vadépuszta field (Lat. 46.611771, Long. 17.791038) was treated with Aurora Super SG (1 kg/ha) on 40.54 hectares, 57% of the total area (Fig. 1) The Axial One herbicide, 1 l/hectare, was used on 18.71hectares, on 24% of the total area (Fig. 2). It can be concluded that we have reached a 43% saving for Super Aurora SG and 76% for the Axial One herbicides. We have surveyed the wheat field before the harvest and concluded that there has been no damage arising from weed infestation and the field remained free of weeds.

The precision weed control cannot be used in all agronomic conditions. The basic rule is that precision control technology is not applicable to crop failures caused by poor drilling, sparse, or poor condition plants. It is not recommended in cases where stricter rules override the economic threshold approach (e.g. zero weed tolerance for seed production). Beyond the technical requirements of precision weed control trained technicians and herbologists are the key factors of success. In the development stages the field should be inevitably evaluated before and after harvest (Reisinger et al., 2008). In the light of all the above, precision weed control is a solution to major herbicide savings.

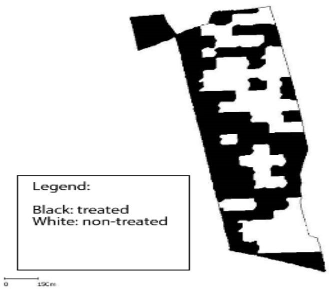

Fig. 1 Distribution of non-treated area (white) and area (black) treated with Aurora Super SG herbicide, 1 kg/ha.

Abb. 1 *Verteilung der unbehandelten (weiß) und Bereich (schwarz) mit Aurora Super SG Herbizid, 1 kg/ha behandelt.*

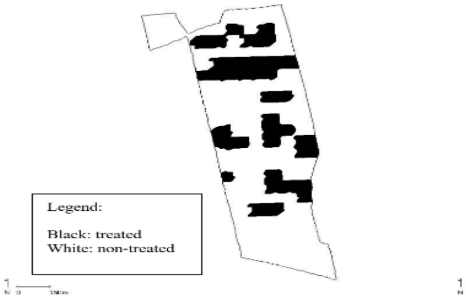

Fig. 2 Distribution of non-treated area (white) and area (black) treated with Axial One herbicide, 1 L/ha.

Abb. 2 *Verteilung der unbehandelten (weiß) und Bereich (schwarz) behandelt mit Axial One Herbizid, 1 l/ha.*

Tab. 5 Precision weed control in Vadépuszta, Hungary, results from 2008-2016.

Tab. 5 *Präzise Unkrautbekämpfung in Vadépuszta, Ungarn, Ergebnisse von 2008-2016.*

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total
Area	184	195	102	177	119	126	170	69	95	**1237**
Number of fields	6	3	3	4	4	4	10	2	2	**38**
Surveys	368	390	204	342	237	241	335	141	201	**2459**
Untreated area %	68	76	38	51	65	55	31	25	52	**51**

The autonomous weed mapping robot

We have started to research the different weed surveying methods 40 years ago (REISINGER, 1977). We tried out many tools for weed mapping (hot-air balloon, powered hang gliders, helicopters, helicopter drones), but none of these was suitable for precise detection of weed species and their quantitative conditions. Then we tried satellite imagery, hyperspectral cameras for identification of *Ambrosia artemisiifolia* (KARDEVÁN et al., 2006). The results were unsatisfactory. After a lot of extensive research, we concluded, that precision weed control technology requires near field weed surveying by skilled professionals. The method developed by us is not widely spread, primarily due to the tedious and time-consuming walking.

As a further development, we have turned to robotics and we have created an autonomous weed mapper in 2016. The autonomous vehicle is moving on the field towards the preprogrammed surveying plots and is capturing georeferenced, perfect quality, sub-millimeter resolution images of the canopy. The images are analyzed by experts on high-resolution displays in the office, and processed according to the B-U method. The results are processed in Excel sheets based on the developed algorithm and prescription maps are generated with AgLeader SMS software. This tool (the robot) allows us to significantly increase the number of surveys without walking on the field. The main components of the weed robot: the camera system (20/21), electric drive train (33/44), steering, guidance and machine control (34, 41), GPS navigation system (51), telemetry system (54), are visualized on Figure 3.

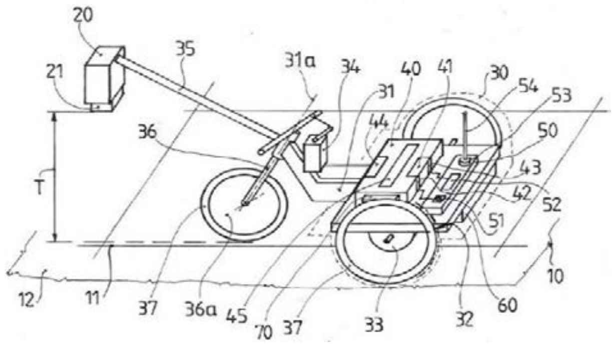

Fig. 3 Weed robot - Structural image from the patent description.

***Abb. 3** Unkrautroboter - Strukturbild der Patentbeschreibung.*

In spring 2017, we have tested the robot in winter wheat, winter barley, spring barley and beans. The number of digital images collected in four days exceeded more than 1000. We have processed the images under office conditions, on high resolution screens. Due (or despite) to the initial lack of routine, the images were processed and the excel sheets were created in 8 hours. The robot and the method are covered with patent protection.

Acknowledgements

We thank ing. Laszlo Farkas for the machinery, GIS instruments and land for the research we have carried out. Thank you for your helpful advice.

References

BALÁZS, F.,1944: A növénycönológiai felvételek készítésének újabb módja. Bot.Közl. **41**, 18-33.

BORSICZKY, I. and P. REISINGER, 2017: Demonstration of an autonomous photo-optical weed mapper. Joint EWRS workshop of the Working Groups Physical and Cultural Weed Control and Crop-Weed Interactions. Nyon, Swizerland, 2-5 April 2017.

CHIRILLA, C. and M. BERCA, 2002: Wichtige annuelle Unkräuter im Südosten Rumäniens in Abhängigkeit von Bodentyp und textur. Zeitschrift für Pflanzenkrankenheiten und Pflanzenschutz, Sonderheft **XVIII**, 131-139.

GERHARDS, R., M. SÖKEFELD, C. TIMMERMANN, P. KROHMANN and W. KÜCHBAUCH, 2000: Precision weed control – more than just saving herbicides. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, Sonderheft **XVII**, 179-186.

GERHARDS, R., M. SÖKEFELD, A. NABAUT, R. THERGURG and W. KÜHBAUCH, 2002: Online weed control using digital image analisis. Zeitschrift für Pflanzenkrankenheit und Pflanzenschutz, Sonderheft **XVIII,** 421-427.

HAMOUZ, P., J. SOUKUP, J. HOLEC and K. NOVAKOVA, 2004: Field-scale variability of weed distribution on arable land. Zeitschrift für Pflanzenkrankenheiten und Pflanzenschutz, Sonderheft **XIX**, 445-45.

HAMOUZ, P., K. NOVAKOVA, J. SOUKUP and L. TYSER, 2006: Evaluation of sampling and interpolation methods used for weed mapping. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz (Journal of Plant Diseases and Protection) Stuttgart, Sonderheft **XX**, 205-215.

KARDEVÁN, P., P. REISINGER, J. TAMÁS and A. JUNG, 2006: A parlagfű detektálás távérzékelési módszereinek vizsgálata. I. rész. -A távérzékelési képek osztályozási hatékonyságának növelése a parlagfű (Ambrosia artemisiifolia L.) reprezentatív spektrumainak terepi DGPS mérésekkel történő kiválasztásával, Magyar Gyomkutatás és Technológia. **6**(2), 53-69.

KROHMANN, P., C. TIMMERMANN, R. GERHARDS and W. KÜCHBAUCH, 2002: Ursachen für die Perzistens von Unkrautpopulationen. Zeitschrift für Pflanzenkrankenheiten und Pflanzenschutz, Sonderheft **XVIII**, 261-268.

LITTERSKI, B. and S. JÖRNS, 2004: Der Einfluss extensiven Anbaus von Winterroggen auf die Segetalflora und – vegetation – eine Untersuchung in Nordostdeutschland. Zeitschrift für Pflanzenkrankenheiten und Pflanzenschutz, Sonderheft **XIX**, 65-72.

MERTHENS, J., M. SCHULTE, C. STEDEN and K. HURLE, 2002: Deutschlandweites Unkrautmonitoring in Mais – erste Ergebnisse aus den Jahren 2000 und 2001. Zeitschrift für Pflanzenkrankenheiten und Pflanzenschutz, Sonderheft **XVIII**, 115-122.

MOLENAAR, M., 1994: Remote Sensing and Geographical Information Processing. Wageningen University. The Netherlands.

MOORE, I.D., E. GESSLER, G.A. NIELSEN and G.A. PETERSON, 1993: Terrain analysis for soil specific crop management. Second International Conference on Site-Specific Management for Agricultural Systems, ASA-CSSA-SSSA. 27-51.

NORDMEYER, H. and A. ZUK, 2002: Teilflächenunkrautbekämpfung in Winterweizen. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, Sonderheft **XVIII**, 459-466.

NORDMEYER, H., 2006: Teilflächenunkrautbekämpfung im Rahmen des Reduktionsprogramms chemischer Pflanzenschutz. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, Sonderheft **XX**, 165-172.

NOVÁK, R., I. DANCZA, L. SZENTEY and J. KARAMÁN, 2009: Arable Weeds of Hungary. Fifth National Weed Survey (2007-2008). Ministry of Agricultural and Rural Development, Budapest, 93 pp.

OEBEL, H., R. GERHARDS, G. BECKERS, D. DICKE, M. SÖKEFELD, R. LOCK, A. NABAUT and R.D. THERBURG, 2004: Teilschlagspezifische Unkrautbekämpfung durch raumbezogene Bildverarbeitung im Offline (und Online)-Verfahren (TURBO) – erste Erfahrungen aus der Praxis. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, Sonderheft **XIX**, 459-465.

REISINGER, P., 1977.: A gyomfelvételezés módszereinek összehasonlító vizsgálata, Növényvédelem, **XIII**, évf. 8. Sz, 359-361.

REISINGER, P. and B. CSUTORÁS, 2008: Precíziós gyomszabályozás tapasztalatai és eredményei őszi búzában. Magyar Gyomkutatás és Technológia (Hungarian Weed Research and Technology) **IX**, 1, 39-47.

REISINGER, P. and T. KŐMÍVES, 2012: Map-based precision weed control in winter wheat. Magyar Gyomkutatás és Technológia (Hungarian Weed Research and Technology) **13**(1), 65-73.

REISINGER, P., G. PINKE, I. DANCZA and R. NOVÁK, 2012: Gyomfelvételezési módszerek In: Novák R., Dancza I., Szentey L., Karamán J. (szerk.) Az ötödik országos gyomfelvételezés Magyarország szántóföldjein. 570 p. Budapest: Vidékfejlesztési Minisztérium Élelmiszerlánc-felügyeleti Főosztály, Növény- és Talajvédelmi Osztály, 2012. pp. 16-27.

TAMÁS, J. and P. REISINGER, 2004: Széles spektrumú kézi kamera alkalmazhatósága a terepi gyomfelvételezés során. Magyar Gyomkutatás és Technológia (Hungarian Weed Research and Technology) **5**(2), 43-51.

Ujvárosi, M., 1957: Gyomnövények, gyomirtás. Mezőgazdasági Kiadó. Budapest, 78-80.