Design of an Autonomous Robotic System for Corn Field Works

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Abstract The task of vehicle-type product design has never been trivial. The paper shows the concept of a work in progress, a research work by a multidisciplinary team, ready to use the available and most modern automation equipment right where it is needed – down at the earth in this case. The project shall allow for autonomous 0-24 presence of specially designed device – a robot taking care of corn fields, eliminating weeds and performing other usually manual functions keeping the shape of the field and ground at level and in extent freed of limitations that can exist in case of a human labor. It is in the same time bringing some fresh interests to agriculture as such, and may even bring some part of people back to this business, rather than escaping to other nowadays more popular fields for some.

Keywords: agronomy, logistics, robotics, precision agriculture, laser, herbicides, reduction, drives, automation, computer vision, artificial intelligence, machine learning

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1 Introduction

There are a few drivers introducing the need for automation in agriculture, but perhaps the strongest one comes from the side of effects of using agrochemicals for long periods, often indiscriminate and abusive, and the negative effect they bring on health and sustainability of natural resources[1]. While reverting to manual weeds removal and field works sounds like a part of solution, the problem of sustaining the manpower needed to maintain such approach as well as efficiency of food production comes into focus. Therefore, the efforts of introducing automation to agriculture at all levels seems like a logical development, and this paper explains one and several of the approaches and possibilities, coming from a team of experienced automation experts.

This paper describes the work in progress therefore mainly focuses to the design phase and interesting challenges, while some details are not shown on purpose.

2 Robotics and automation approach

2.1 Industrial revolutions

Through the history the industry has had declared a few important milestones also called industrial revolutions, invoked by invention of steam machine, electrical energy application and line type production respectively. The 4-th and 5-th industrial revolutions are relatively fresh and are related to automated lines implementing robotics and advanced automation using systems like the artificial intelligence (AI) or advanced computer vision (CV). There is no doubt that all of these had a great effect to agriculture as well, where in addition, internal combustion engines shall be added to the list of important technical inventions.

[1] Ueta, J.; Pereira, N.L.; Shuhama, I.K.; Cerdeira, A.L. Biodegradação de herbicidas e biorremediação: Microrganismos degradadores do herbicida atrazine. 1 ed. Brasil: [s.n.] , 1997. 545p.

2.1.1 The automation approach

Every technical device that performs some industrial process without the need of human manipulation can be considered an automation element. The possibilities of automation grow scientifically all the time and nowadays ranges all the way usage of advanced methods like the AI and CV, and also aims for mobility, compactness and energy efficiency, even the human collaboration. Automation is also usually in relation to usage of programming, drives, actuators, and many mechanical components, therefore the field of operation is wide and often called Mechatronics.

When approaching towards the solution, there are many universal principles, which are similar in both industrial automation, and special branches like the precision agriculture field. Since laws of physics that apply are the same, it is possible to apply many parallel proven practices on both fields, as will be shown in this paper.

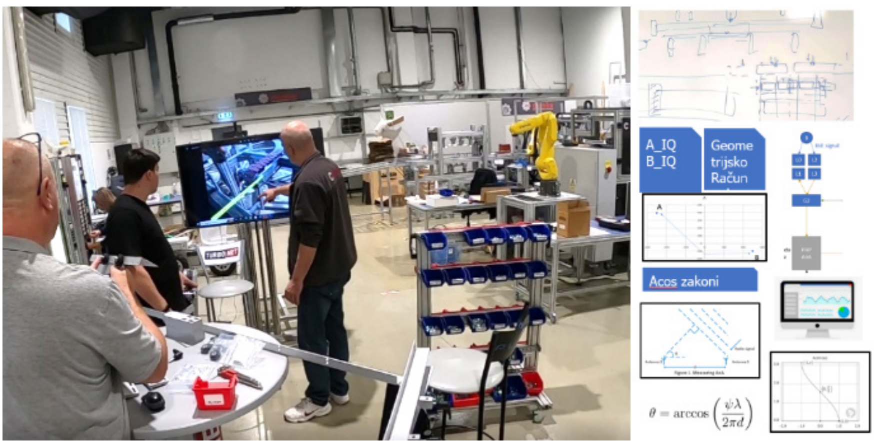


Figure 1: Ideation and multi-disciplinary design in industrial automatization
Source: Damko R&D Centre internal Archives – Photograph / Project report 2020.

In addition to visible part of an industrial automation project (like the production line, robotic arms) there is usually a complex invisible framework »backend« part containing of programs, interfaces, databases and many other elements, which can be considered as a software part of the project.

3 Design of the robot for application in agriculture

The design of every system shall start with defining the goals and afterwards researching the available technology, defining the possibilities to reach the goals under reasonable circumstances, not neglecting the economical dimension.

In the moment of this project development (2020. – 2023.) the state of technology is such that following developments are highlighted and worth of considering and therefore considered in the project:

- Computer vision application
- Artificial intelligence
- Lasers technology (positioning and weeds removal)
- GPS and other positioning systems/methods
- Advanced Battery systems
- Communication protocols (BT, LoRa etc.)

It is obvious that field works require movement through the field and therefore the robot for this application shall be a vehicle, where several traction options are available. The application of robot however must not be viewed only from the prism of currently most used technologies (e.g. wheels) as there are other options possible and some of them are shown below.

Figure 2: Some of possible traction methods applicable for Agriculture robots
Source: Websites: www.ZentaRobots.com ; www.global.agilex.ai – Commercial websites

Since one of the automation design principles is also to think of the box, the project in subject is also about to seek the selection of ideal platform for the system.

4 Project goals

The goals of the project are based on the current needs in agriculture, as well as on the technology state and possibilities, and can be roughly described as:

- Reduction of weeds presence with minimum human labor
- Reduction of agrochemical usage
- Increasing the crop output
- Design of an autonomous self-sufficient system concept

If goals are to be described in a sentence, it would be to allow for manual like operation by a robot, providing significant reduction of unwanted elements like herbicides usage and pollution in general, aiming for eco production.

The selection of crop to be planted for the project was defined early in the project, where corn has been selected.

5 Project resources

The resources needed for such an R&D project consist of human researcher's manpower, hardware, software, and specifically for agronomy – a test field with polygon – a corn field.

Figure 3: A test polygon during planting and in it's full growth phase
Source: Damko R&D Centre internal Archives – Photograph 2022.

Table 1: Project resources

Item	Resource type	App. Quantity	Duration
1	Researchers & admin	8 – 12	3 yrs
2	External cooperants	4	3 yrs
3	PC & other computers	5	3 yrs
4	Microcomputers	25	1,5 yrs
5	Other equip. and materials	50	3 yrs
6	Prototyping equipment	-	2,5 yrs
7	Test fields (with works and services)	100 Ha	2,5 yrs

Source: Damko R&D center's internal work reports / resource planning system for IRI 2 Project (estimation)

The most important resource are the qualified researches in field of automation and agronomy with competence in field of mechatronics, agronomy experts inside team or outside in form of cooperation.

6 The initial project progress

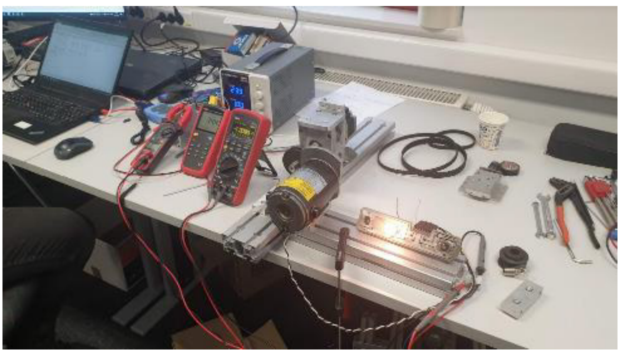
It has been realized from the start of development that many samples used to test will be required, and there is a challenge about that since crops growing depends on the time of the year. Therefore, the focus is put on the efforts to record useful footage in as early phases as possible. This has been achieved in the first year by creating an initial platform vehicle – camera carrier, which also served for initial vehicle properties and performance definitions.

Figure 4: The initial platform used for creation of initial videos and photos
Source: Damko R&D Centre internal Archives - Photograph 2020.

The initial footage has been taken on the borrowed fields already in full growth, and later on in the season the designed platform is used for driving and taking footage during the growth in the purposely prepared polygons.

Having the useful footage at the disposal, the initial computer vision analyses become possible, as well as initiating the machine learning applications. While developing the computer vision and main software parts, the possibilities opened to design the next prototype version, drives, and all the subsequent systems.

Since achieving autonomy is the important part of this project, combined with economy, every bit of design had to be considered from this side as well. Also, since there are clear timelines to be meet, there was no place for mistakes performance-vise, and therefore to select any component a lot of researching time is spent and all the critical parts were tested before becoming part of the next prototype.



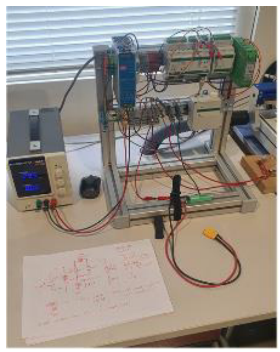


Figure 5: Test setups for testing drives (left) and batteries/battery packs (right)
Source: Damko R&D Centre internal Archives - Photograph 2021.

The intensive research, trail, selections and testing shown many interesting results, especially important since the supply chains have been broken in 2020. and many characteristics cannot be trusted, and some of them are even not defined for this kind of application. Batteries, for example often hold much smaller capacity than declared, and such details are critical for a prototype like this one to be proven.

Initial results of computer vision (and machine learning) part of the project emerged very early in the project, and also defined the type of specific equipment to be onboarded to the next prototype. And the type of components and the specification naturally changed during the project due to the new findings coming out as a result from a detailed research work.

Some of the first results emerged form computer vision / machine learning field of the project. Models created had been able to detect and recognize corn plants very soon. It however took a lot of time to develop the system that can recognize effectively using a lot of different hardware and software platforms to be optimized and fitted into autonomous robot had to be tested.

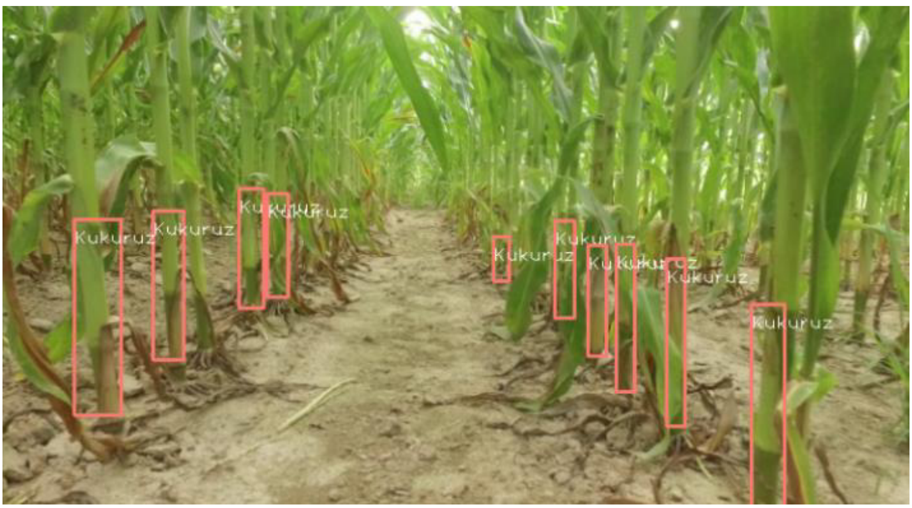


Figure 6: Visualization of the corn crops recognition on half-grown plants
Source: Damko R&D Centre internal Archives – Reports 2021.

In all the cases, the machine learning algorithms are used, creating the various models with certain number of labeled images, selected by a human, and training the respective model with certain number and type of images.

Training repetitions	Average Accuracy	%
0	0,000000	0,00%
1000	0,671013	67,10%
2000	0,721634	72,16%
3000	0,757533	75,75%
4000	0,771892	77,19%
5000	0,818656	81,87%
6000	0,827235	82,72%

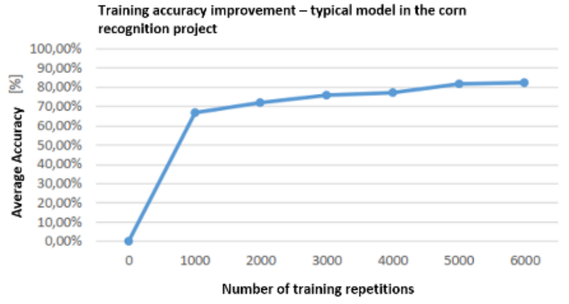


Figure 7: Average recognition accuracy vs. Number of training repetitions
Source: Damko R&D Centre internal Archives – Reports 2021.

The training efficiency depends on number, quality and timing of selected images, as well as on hardware performance. Therefore, it can typically wary from a few hours to a few weeks of training time.

In addition to machine learning type recognition, the other computer vision possibilities are observed and researched as well, like the contour's detection, colors and shapes types etc. As the goal of the project is to dissect weeds from the useful plant, all these can be useful.

Figure 8: Corn crop isolated in the picture based on computer vision methods
Source: Damko R&D Centre internal Archives – Reports 2022.

7 The second prototype design

After initial tests, the properties and selection of equipment needed to be driven on the autonomous robot became much more defined. Therefore the approx. weight to be taken to the field also became known and equaled to 75 kg together with the vehicle as the initial approximation.

The requirement to achieve the autonomy goals in the first place and the experience with the initial prototype led to the important decision that the next prototype shall not be a wheel type but a tracks type vehicle.

Figure 9: The initial assembly of track type vehicle as a second prototype platform
Source: Damko R&D Centre internal Archives – Photograph 2022.

The next steps consisted of defining the rest of equipment and fitting the complete system into the newly designed prototype, for the goal of having reliable autonomy tests to be performed. Other than autonomy, the driving characteristics and the weight handling characteristics had to be tested this way, since this type of prototype is the last step before the final testing to be performed in last phases of the project – in order to provide a practical proof of concept.

The vehicle is design as a prototype, but in the same time needed to provide for easy maintenance, and modifications and extensions to be done in the future, since at the time of vehicle design, not all the project circumstances could be known, especially the ones requiring field tests to be determined.

In addition to drive and main controls, mentioned so far, the concept needed to provide for an effective communication with the external control systems, so that tests can be done properly, so that is one other system to be fitted and antennas to be considered.

Localization at the field to be combined with autonomous driving is another field that is researched in details. Both GPS and other technologies are observed and planned to aid the main system.

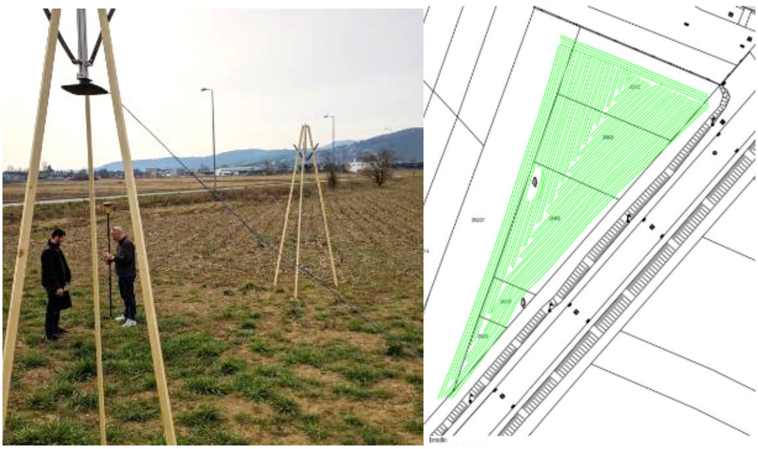


Figure 10: Navigation technologies testing during the fall time and the recorded map of polygones to be used

Source: Damko R&D Centre internal Archives – Photograph / Reports of IRI 2 Project 2021.

After the definitions are determined, the second prototype has finally been assembled and put to some test drives in the last season before the final testing, assuring the quality research work during winter period. The autonomy goals are achieved, and the rough preliminary data shows that only 35% of the energy is presumed to be consumed on traction, while 25 % shall be consumed on the computing power and the rest 40% remains for the execution elements, like lasers or other, sensing, communication and localization systems. The shares shall be finally determined at the final season tests, and the complete system adjusted accordingly.

Figure 11: The second prototype operating in the field – test drive with computer vision
Source: Damko R&D Centre internal Archives – Photograph 2022.

The prototype in this phase already consists of all the main components, and is able to drive, operate, receive and send information in basic procedures. Also, there are initial successful tests of autonomous driving done, while completion is the subject of winter research works, programming and final tests on a fresh plants to be planted. The prototype now looks as shown on the Figure 10.

8 Plant Recognition & Weed removal research results

During the development of vehicle, the focus of machine learning is also put on the plant's recognition, in order to find the other plants that are competing with the crops – the weeds. As already explained, the recognition of crops has been very successful and some results demonstrating the performance are visually shown at Figures 11 and 12.

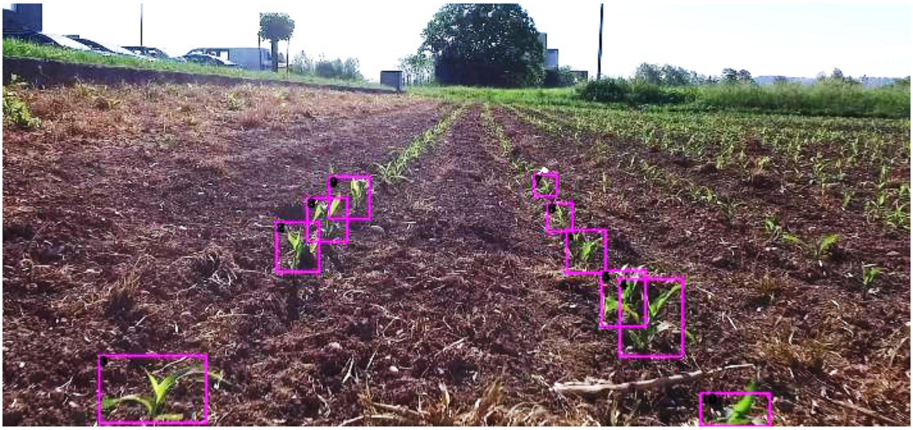


Figure 12: Plants recognition in later stages – on small emerging plants
Source: Damko R&D Centre internal Archives – Reports 2022.

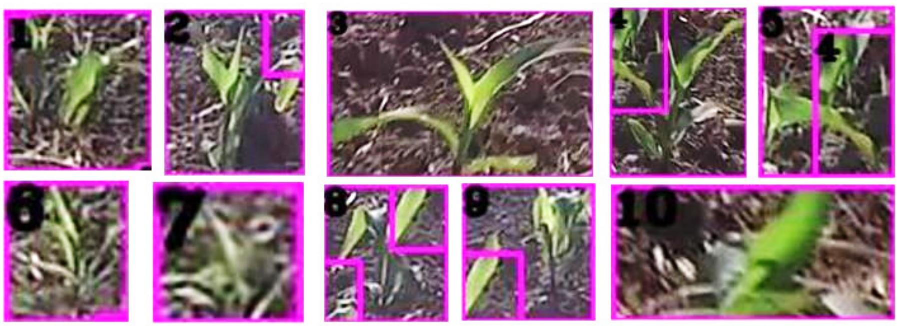


Figure 13: The details of 10 plants recognized by a computer on the image
Source: Damko R&D Centre internal Archives – Reports 2022.

The images on the Figure 13 have a noticeably low resolution, and it is interesting to observe the ability of the algorithm to correctly detect the corn plants even in such conditions (Picture shows the real resolution feed into the system and the video compression is the reality to be dealt with). It may be subjective and arguable, but it may also be challenged if human could do such a task better than a machine if presented to this sequence of images. To further demonstrate the power of algorithms, it may also be said that some middle-performing algorithms researched have so far been able to make more than 25 recognitions of 10 or more plants on the moving image (video) – each second.

For the needs of both detection and removal of weeds, both indoor setups and outdoor sites have been used for research.

Figure 14: Indoor preparation and growing of various plants for testing
Source: Damko R&D Centre internal Archives – Photographs 2022.

There are many executive elements planned to be researches, main of which are related to laser technology. Therefore, lasers have been extensively tested on various plants. Timings and plant recovery observations are some of the research focuses.

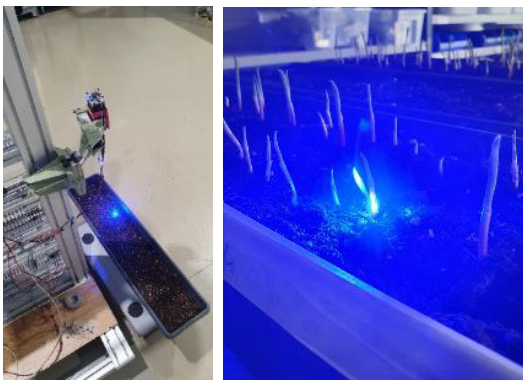


Figure 15: Exposing a plant to a laser beam – indoors
Source: Damko R&D Centre internal Archives – Photographs 2022.

There is a wide range of laser selection available today, and there are cons and pros of using a laser for this purpose. However, due to the nature and possibilities to turn on and off quickly, lasers remain the main removal method in this project where economy and compactness are important goals.

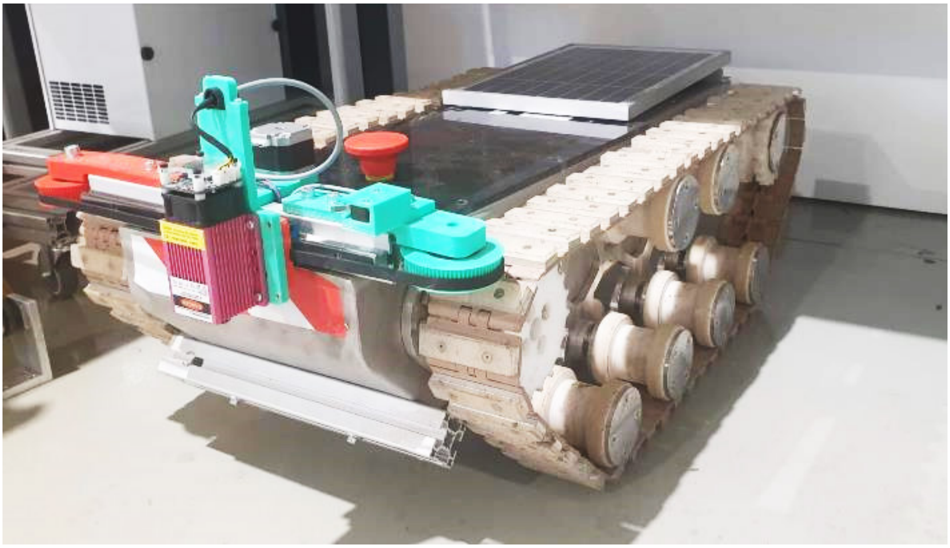


Figure 16: The laser cutter attachment mounted on the second prototype
Source: Damko R&D Centre internal Archives – Photographs 2022.

9 Conclusions

The paper shows the status of research in progress, in which results are already visible proving that possibilities exist to use the explained methods in Agronomy. Robotics in Agronomy already emerge at many fields, and this one shows its unique approach to some details. The concept is proven so far, at the possible areas as the prototype is already operating and some concepts are fully researched.

The project is scheduled to be finished by the fall of 2023, by when the rest of the tests and complete functional test are expected to be finalized.

Notes

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