

# Final Report

## Forage management optimization based on robotics and artificial intelligence

*Optimerad grovfoderproduktion baserad på robotik och artificiell intelligens*

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## Summary

Sensors mounted on Unmanned Ground Vehicles (UGVs) could become efficient scouting tools for farmer decision making. However, the requirements (e.g., operational, robotics, and artificial intelligence) for using UGVs in farm fields still need to be evaluated. This project aimed to develop a prototype for an affordable UGV (robot) and the related artificial intelligence (AI) perception framework for autonomously moving it through forage fields and collecting data using suitable sensors, such as spectrometers and cameras. The project was divided into two phases. In phase 1, the activities focused on assembling the robot, such as design, hover structure, and payload arrangement. In phase 2, we performed field trials to explore the robot's operational potential in field conditions and future needs. Some of the characteristics evaluated were stability, movement, payload configuration, and data acquisition. This evaluation was based on specified Key Performance Indicators (KPIs). The robot could be used in field conditions to continuously acquire pictures and spectral data useful for field monitoring, mainly harvested forages (leys). Most of the KPIs were successfully completed. Some future evaluations are still needed (e.g., changing robot height according to the canopy height, register both spectral and image data using the same processing unit, and evaluating the effect of the robot's speed). It would be also necessary to perform field trials with the robot and sample collection to develop models to estimate crop characteristics (e.g., forage quality and biomass).

## Cooperation with small and medium-sized enterprises, Institutions and Universities

The project was a collaboration between two university partners, SLU (Umeå) and LTU (Luleå). LTU developed and assembled the robot, and SLU analyzed the sensors and data collected.

The project also received support and collaboration from Hushållningssällskapet Norrbotten-Västerbotten for the visits and field trials at the Öjebyn Agro Park in Piteå.

Moreover, the project also received support from the I-GIS company in Denmark, responsible for the CloverSense platform, which was used to estimate the botanical composition of the images collected in the field.

## Introduction

Forages represent the highest agricultural land use in Sweden and are the most important crops of the Northern region, representing more than 80% of the total agricultural land use (Jordbruksverket, 2023). The production performance of these crops affects the whole livestock system, as forages are the primary source of feed for ruminants. Helping farmers to adjust their practices based on relevant information would increase the efficiency of the dairy and meat production industries.

Remote sensing offers relevant solutions for monitoring of crops and fields (e.g., Morel et al., 2022; Näsi et al., 2018). Satellite images cover a large geographical extent, at the cost of a moderate to coarse pixel size. Drones are another method for providing high resolution spatial information, however they are limited by weather conditions, restrictive regulations, and a limited payload. Unmanned ground vehicles (UGVs) are not affected by the above-mentioned issues and could become efficient scouting tools to help farmers in their decision-making.

UGVs are being increasingly used for various purposes in agriculture, such as phenotyping and breeding. However, the requirements to use a UGVs at a farm field are still needed. Moreover,

several challenges are posed regarding robotics and artificial intelligence before their full integration and operational use in agricultural practices. Some of these challenges can be related to, for example, the autonomy levels, the navigation performance in a dynamic and harsh environment (e.g. moving obstacles, high vegetation levels), payload capacity, precision of data collection and operation skills for the users. The continuous miniaturization of hardware and embedded systems have enabled the production of various small-size technologies and sensors at relatively low costs.

The overall aim of this project was to develop a prototype for an affordable UGV and the related artificial intelligence (AI) perception framework for autonomously moving it through forage fields and collect data using suitable sensors.

## Material and methods

The project was divided in two phases. In the first phase we worked on assembling the robot, taking into consideration its design, hover structure and payload arrangement. Then, in the phase two we performed field trials to explore the operational potential of the robot in field conditions.

### *Phase 1: Robot payload design for agricultural operations*

In the first phase of the project, we defined the requirements for the robot, considering the most suitable aspects in terms of design, platform, and navigation capacity to collect pictures and spectral data over the fields, which would be relevant for visual surveys and estimation of characteristics, such as botanical composition and biomass. More specifically, the robot was projected to be used in grassland fields with grazed pasture and harvested leys. The robot was designed to be a proof-of-concept prototype, with characteristics of being low-cost, durable, reconfigurable, and lightweight, facilitating its mobility in the field while preserving the plants.

### Base Platform Description

We chose a modified Pioneer P3-AT rover (Figure 1) with four-driven wheels and 'skid steering', a control mechanism that allows the wheels on one side of the vehicle to rotate at a different speed than the wheels on the other, enabling the vehicle to turn on place. The ground clearance is 80 mm, and the track width is 410 mm. The payload capacity of the chosen robotic platform is 40 kg, and its dimensions are length: 0.50 m, width: 0.50 m, height: 0.30 m, and weight: 14 kg.



Figure 1. Pioneer P3-AT rover.

### Platform iterative design development

To finalize the platform's development, we conducted three different iterations in simulation, making appropriate adjustments in each iteration. The Pioneer P3-AT is equipped with a specific sensor package and an arm. In the first iteration, we added a non-height-adjustable arm with the camera facing downward as it shown in Figure . In the second iteration, we opted for a height-adjustable swing arm and revised the placement of the sensors as it shown in Figure . The second iteration yielded better results in the simulation, leading us to finalize the design and technical details in the third iteration for manufacturing the robotic platform as shown in Figure .

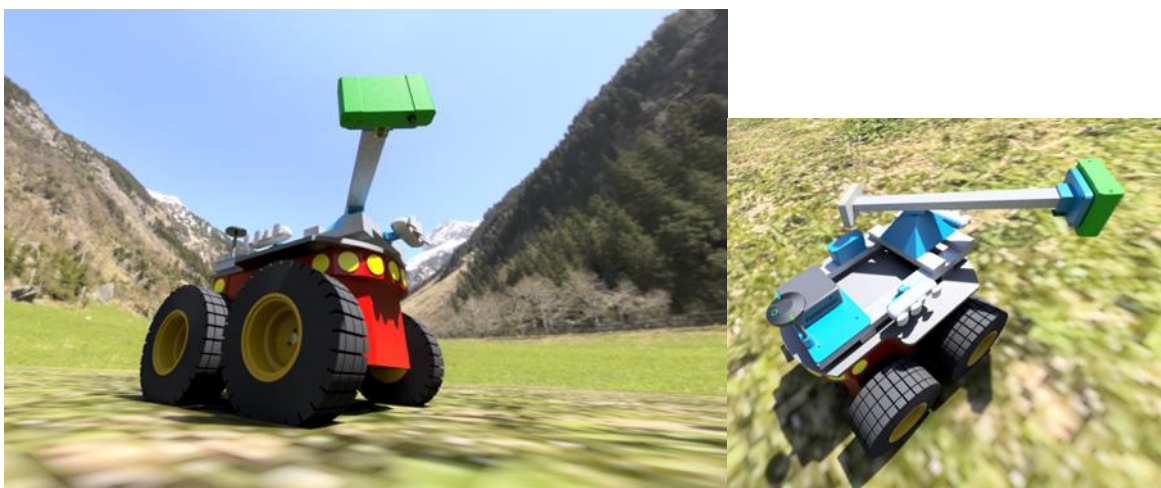


Figure 2. First iteration.

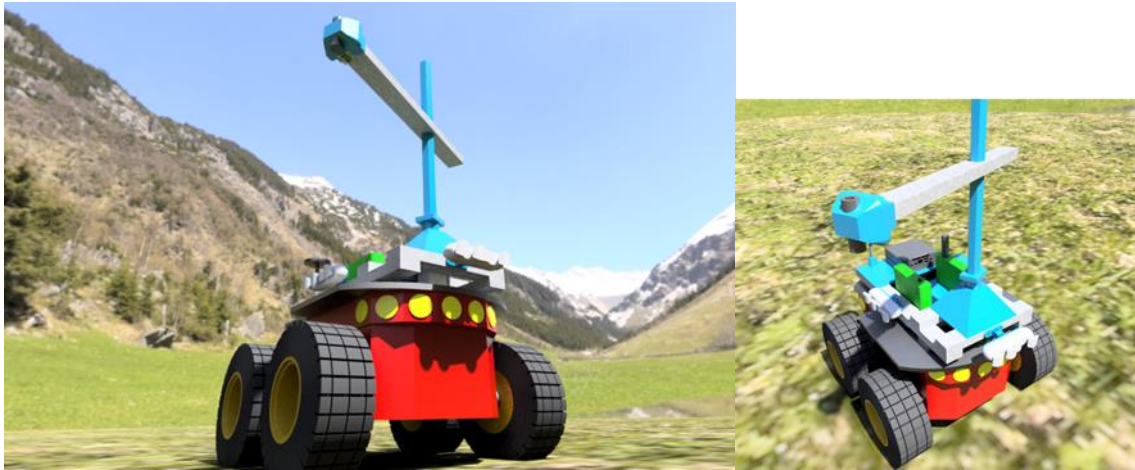


Figure 3. Second iteration.

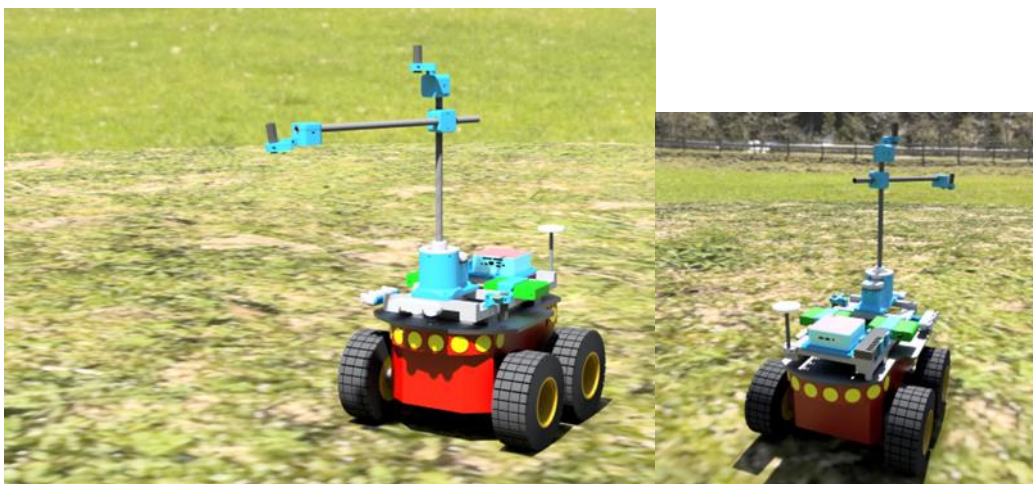


Figure 4. Third iteration.

### Conceptual Payload Design

The Conceptual Payload Design (Figure ) specifications are as follows:

- The sensor package frame is a modular design made of aluminium extruded profiles, 3D-printed parts, and carbon fibre parts, allowing for easy addition or replacement of sensors.
- The spectrometers, essential for accurate data collection, are precisely positioned. They are mounted on a motorized swing arm with an adjustable height, enabling them to face upwards or downwards for optimal data capture.
- The RGB camera is mounted facing downwards on the swing arm.
- The RGB-D cameras have adjustable mounts for different angles and are positioned to face forward and to the side.
- The GPS is located at the rear end of the platform.
- The Processing Unit, a crucial design component, is strategically positioned on top of the rover, allowing for easy access for data transfer and simplifying maintenance.
- The Low-level Control Unit is housed inside the rover.

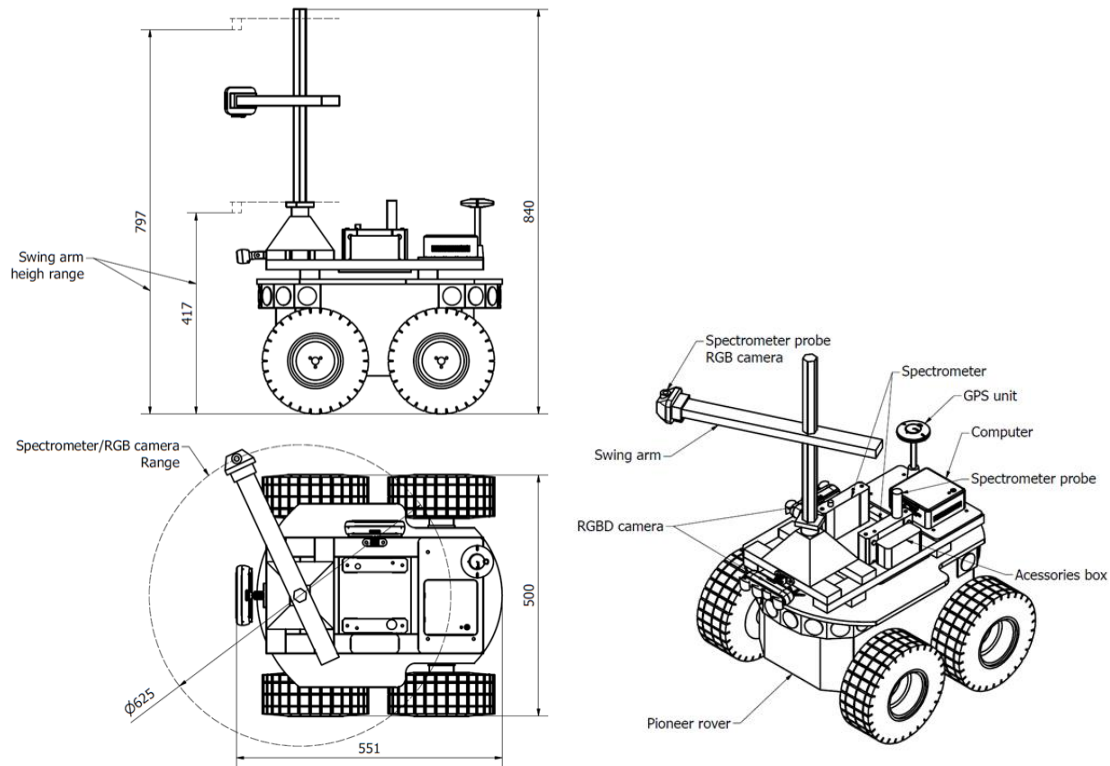


Figure 5: Conceptual Payload Design

### Sensor package on the platform

The sensor package is designed with standardized sensor mounts (similar to the GoPro-style mount). The design allows for angle adjustments and interchangeable positions, providing a wide range of possibilities. Its aluminium construction profiles further enhance its flexibility, enabling easy configuration changes and making the sensor package highly expandable. Lastly, the platform is agnostic, meaning the sensor package can be mounted on other vehicles or robots if necessary (Figure ).



Figure 6. Developed sensor package on the platform.

### Phase 2: Field trials

After finalizing the robot design and constructing the additional payload to support the sensors, field trials were performed. Before going out for the field trials, a first pilot trial was done in the surroundings of the Luleå University of Technology (Figure ). During this first pilot trial, the manual control of the robot and the functionality of the installed sensor were tested.



Figure 7. First pilot trial at LTU campus where we tested the sensor payload on a grassed area with and without slope. During this test the operation station was placed on the robot.

Then, two field trials were performed in a ley field at the Öjebyn Agro Park in Piteå, Sweden, in May and September 2023 (Figure ). The idea of these trials was to evaluate the robot's performance in real field conditions during different periods over the growing season. Some of the characteristics evaluated were stability, movement according to the sowing lines, payload configuration, and data acquisition. In more details, we tested the robot in terms of some Key Performance Indicators, including: 1) Develop, integrate and demonstrate tele-remote operation of an unmanned ground vehicle in agricultural environments for dataset collection of the crops in the field; 2) Repeatability of the operation for the UGV platform and availability for sequential missions; 3) Sensor selection and mounting configuration in the vehicle; and 4) Testing the performances of the sensors for the evaluation of agronomic traits of leys. Based on these field trials and KPIs, we could address the main challenges, needs, and future recommendations.



Figure 8. Location of the Öjebyn Agro Park.

The first trial was performed on May 31<sup>st</sup> 2023, early in the season. The second one was on September 9<sup>th</sup>, towards the end of the growing season. We verified that the robot could move out in the field when the vegetation started to grow again after the wintertime and when there was more biomass. The field used for the trials was a 5<sup>th</sup> year ley, composed of timothy and red clover.

In both field trials, we had a pre-trial planning meeting with some of the Öjebyn Agro Park staff, where we could explain the activities and have a quick discussion on the potential use of the robot in agricultural fields. In these planning meetings, we also assembled the robot with the sensors and checked the cables and accessories before going out to the field.

The spectral data and the images were captured using a viewing angle downward to the ground (0°) and with a viewing angle of 45° to explore getting information exactly from vegetation canopy from different perspectives.

The spectral data were collected using the manufacturer's software (SpectraWiz; StellarNet). After the trial, the spectral data were exported and analysed using the R software. The analysis consisted of a general overview of the reflectance profiles registered when the robot was out in the field. This overview was important to check if the reflectance profiles were consistent with motion of the robot and representative of the target objects in the area (e.g., vegetation, soil).

The RGB-D images were registered in the Intel NUC PC and stored in a shared drive after the trial. A pilot analysis was performed to verify the potential of using the RGB images to detect the botanical composition of the field while moving the robot. This analysis was done using the freely available software CloverSense (<https://cloversense.net/>), which classifies images into grass, clover and weed content.

## Results

### *Robot assembling*

During the project we developed a functional prototype of a UGV (unmanned ground vehicle), to demonstrate proof of concept and perform initial tests in the field. This robotics platform consists of a modified 3-DX Pioneer robot and a modular sensor payload. For the field experiments the following sensor payload was selected: 2x StellarNet spectrometer, 2x RGB-D Realsense camera, 1x GPS module, 1x IMU module, and an on-board computer.

Overall, the robotics platform was subjected to multiple field experiments, including testing the UGV in various terrains locally at LTU (Figure ), and then in a real field environment (Figure ). Figure highlights another aspect of the developed system, which enables the real-time interaction of the operator with the robot. As shown in the Figure, a portable operation station (laptop in this case) was used to initiate the sensor payload and data recording in a command-based approach, through a local remote WiFi link. This system can be expanded in the future for larger distance remote operation. We also tested the platform under different conditions, such as cloudy, sunny, wet, and dry grass.



*Figure 9: First field trial at Piteå. The robotic platform is shown in the field and the portable operation station is shown in the background.*

### Platform Functionalities

The platform we developed has three main functions. These include a remote control (RC) custom controller integration for manual control of the rover's motion and swing arm position, a manual configuration for swing arm height, RGB-D camera angles, and spectrometer lens angles. Additionally, it offers continuous GPS recording of the rover's position, a video stream, and continuous point-cloud recording from the sensors.

### Hardware

The hardware of the platform consists of:

- One RGB camera (Raspberry Pi High Quality Camera)
- One GPS (Here3 GPS)
- One controller (Pixhawk Orange Cube)
- One on-board computer (INTEL NUK 10) or Laptop as the Processing Unit.
- One compact tablet to register the spectral data.

### Spectral and imaging equipment

In terms of spectral and imaging equipment, the robot was equipped with:

- Two RGB-D cameras (Intel RealSense Depth camera D435);
- Two spectrometers (Blue-wave miniature, Stellarnet Inc; 350 to 1150 nm), one pointing downward to measure the ground radiance and the other upward registering the incoming irradiation (sun) and compute a reflectance factor of the field (field of view = 3°).

The RGB-D cameras have a classic RGB sensor, complemented with a depth sensor, which provides true-colour and distance (from the sensor to target, such as the leaves in the field) images and videos (1920 × 1080 frame resolution, up to 1280 × 720 depth resolution). These images can be used

to estimate botanical composition and biomass, but the models need further development, particularly the biomass modal.

The spectrometers are non-imaging sensors that collect spectral information over different regions of the electromagnetic spectrum. In this case, the spectrometers register spectral data ranging from 350 to 1150 nm. This spectral information can be used to assess biophysical characteristics of the vegetation, primarily biomass, nitrogen concentration, and forage quality.

### *Field trials*

In the first trial in May 2023, the main focused were on assembling the robot, checking the robot's movements and testing how to record the data (Figure 10).



*Figure 10. First field trial at the Öjebyn Agro Park in May 2023.*

The robot moved across the field, following and crossing the sowing lines without limitation or damaging the field. The robot also successfully captured image data using the two RGB-D cameras both while the robot was moving and when it was static in relation to the ground but moving the superior rod. Moreover, it was also able to capture images with the camera on board of the superior rod at frontal and side positions (Figure 11).



*Figure 11. Top view of the robot in the field with the top camera (superior rod) in the side position (left) and a perspective view of the robot showing the top camera in front of it (right).*

An issue with the USB port in the tablet did not allow the registration of data from both spectrometers (looking upwards to the sky and downwards – to the field), which is required to correct the reflectance of the field in relation to the total energy coming from the sun. So, for the first trial no reliable spectral data collected were collected.

In the second field trial (September 2023), the focus was to collect more data from the RGB-D camera and reliable data from the spectrometers and analyse them, as well as check the robot's performance in a field with a higher canopy vegetation (Figure 12).

The robot successfully operated in the field for several runs and approaches, such as: parallel and transversal to the sowing direction, and through a zig-zag moving over the field using a viewing angle downward to the ground ( $0^\circ$ ); parallel to the sowing direction using a viewing angle of  $45^\circ$ ; and in a static position rotating the rod. The sensors registered the data with different starting points and distances inside a field of circa 0.5 ha and a speed of circa 3 m/s. The battery life span efficiently performed without needing to be recharged. The robot did not damage the field, but it might cause some lodging. A future improvement could be to change the rover height according to the canopy height or use it mostly on grazed fields, which are generally shorter than harvested fields.



Figure 12. Perspective view of the robot in the field with the top camera (superior rod) rotating in the static position (left) and a frontal view of the robot (right).

### Spectral analysis

Figure 13 illustrates an example of post-processed reflectance spectra acquired over the different locations when moving the robot transversally to the sowing lines. They are general spectra representing the regular field characteristics with vegetation and soil, which could be used to explore the spectral variation over the fields. However, more data collection and analysis are still necessary to estimate forage characteristics, such as quality and biomass.

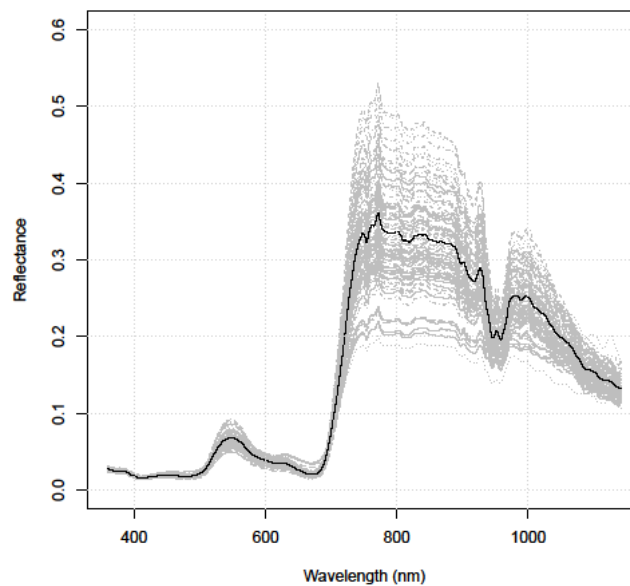


Figure 13. Reflectance spectra (grey lines) and average spectrum (black line) acquired by the spectrometers over the different locations when moving the robot across the field.

## Image analysis

Figure 14 shows an example of images captured by the RGB-D camera acquired by the camera on the superior rod with a viewing angle of 45°. These images were registered when the robot was in a static position moving the superior rod. The RGB image shows part of the field covered with grass, red clover and some weeds. On the other hand, the grey-scale colours of the Depth-image taken at the same place of the RGB image could represent the structure of vegetation in this area, with the darker areas showing areas where with lower vegetation and soil patches.



Figure 14. An example of a RGB (left) and a depth (right) image acquired by the RGB-D camera with a viewing angle of 45°.

One point to consider is the orientation of cameras, spectrometers, and the robot according to the sun's position. Depending on the orientation and time of day, the sensors can capture some shade effects. Consequently, it should be considered when planning field surveys.

Figures 15 and 16 show examples of the analysis of the RGB images in terms of botanical composition taken in two different areas in the field trial. This analysis used the algorithm freely provided by the CloverSense platform to classify the images regarding grass, clover and weed content. Figure 15 shows an area with a similar proportion of grass and clover and only a small area with weeds. On the other hand, Figure 16 shows a dominance of grasses, with a small proportion of clover and no weeds. These figures illustrate the variability of the botanical composition in the field and the potential of using cameras on board ground vehicles to assess it and support farmers in decision-making, such as nitrogen fertilization demands.

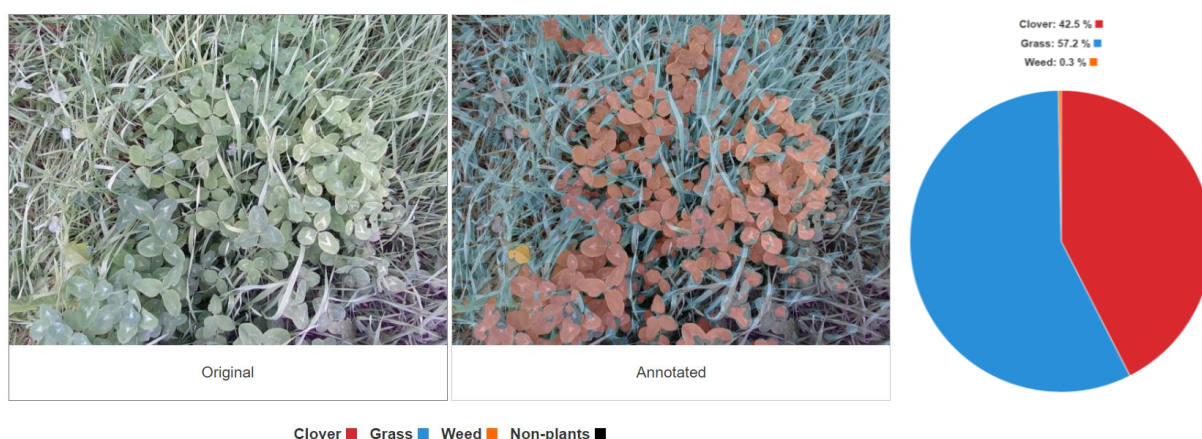


Figure 15. An example of a RGB image classified in grass, clover and weed using the CloverSense platform.



Figure 16. An example of a RGB image classified in grass and clover using the CloverSense platform.

### Key performance indicators

Based on these field trials and the key performance indicators analysed (Table 1), we could assess the project objectives and accomplishments and evaluate future development and needs. Most of the metrics were successfully completed, reinforcing the good outcomes of this project. Future approaches rely on more technical implementations, such as an adaptable height of the rover and a unique system to register both images and spectral data, and field sample collections (e.g., vegetation biomass, sorting of species composition, forage quality) to relate to the data collected by the sensors. There were some deviations from the original plan (part of the KPI No. 4) due to delays in the project schedule. The KPIs that were not accomplished were due to some unpredictable delays in the project schedule. Since we now have the baseline technology up and running, these future approaches reinforce the need for continuing this project, focusing on relating the UGV's data to field samplings.

Table 1. Key performance indicators evaluated in the field trials. Green represents the metrics with a 100% success rate, orange represents the ones that were not 100% successful, and red represents the metrics that were not accomplished.

| No. | Description of the objective   | Success metrics in form of KPIs   | Observations and future needs  |
|-----|--|---|--|
| 1   | Develop, integrate and demonstrate tele-remote operation of an unmanned ground vehicle in agricultural environments for dataset collection of the crops in the field | <p><b>KPI: 10 successful runs of the UGV in the field with operational sensor payload.</b></p> <p><b>KPI: ability to cover an area of at least 100 m<sup>2</sup>.</b></p> | <p>All the metrics were successfully achieved. No issues were observed with the battery levels or the robot assembling in the field.</p> <p>The UGV performed over 10 tele-operated runs.</p> <p>The UGV was able to cover an area of 100 m<sup>2</sup>.</p> |
| 2   | Repeatability of the operation for the UGV   | <b>KPI: 90% damage-free operation (sensors and UGV platform).</b>   | All the metrics were successfully achieved. Some lodging was   |

|   |  |  |  |
|---|--|--|--|
|   | platform and availability for sequential missions                                      | <p><b>KPI: 5 runs where the UGV follows different predefined paths while also having different starting points (traversal evaluation).</b></p>   | <p>observed in the second field trial (September 2023), suggesting the need to adapt the rover height or use it only on grazed fields rather than harvested leys.</p> <p>The UGV performed multiple runs, with different sensor configurations. We observed no damage on the UGV and sensors. During the trials, the UGV travelled in multiple directions in the field.</p>  |
| 3 | Sensor selection and mounting configuration in the vehicle                             | <p><b>KPI: Data collection from minimum 2 different sensors with 100% applicability for extracting agronomic information.</b></p> <p><b>KPI: 100% success of camera data collection from 2 different mounting locations.</b></p> | <p>In the first field trial, appropriate data could not be collected from the spectrometer. However, data collection from the spectrometers and cameras succeeded in the second field trial.</p> <p>The mounting locations and angles showed good potential to retrieve agronomic information.</p> <p>The UGV collected various datasets. The datasets contain 2-5 sensors. A minimum of two of the sensors (Spectrometer and camera) can be directly used for extracting agronomic information.</p> <p>The UGV collected datasets with cameras mounted in 4 different configurations.</p> |
| 4 | Testing the performances of the sensors for the evaluation of agronomic traits of leys | <p><b>KPI: Estimation of clover content with less than 20% error.</b></p>  | <p>We could estimate the botanical composition (grass, clover and weed content) using the</p>  |

|  |  |  |   |
|--|--|--|---|
|  |  | <p><b>KPI: Estimation of dry matter yield with less than 10% error.</b></p> <p><b>KPI: Estimation of winter survival with less than 10% error.</b></p> | <p>CloverSense platform. However, since we did not collect field samples to assess the botanical composition by manual sorting, we could not estimate the accuracy of these estimations. For the same reason, we could not estimate the dry matter yield or its accuracy.</p> <p>Besides the necessity of field sampling, another related future need is to evaluate the effect of the robot's speed on the quality of the sensor data acquisition.</p> <p>It was not possible to estimate the winter survival due to the dates when we performed the field trials.</p> |
|--|--|--|---|

## Conclusions

- The robot showed potential to be used in field conditions for continuously acquiring pictures and spectral data that can be useful to monitor forage fields, mainly harvested fields (leys).
- A future improvement could be to evaluate the possibility of changing the rover height according to the canopy height to avoid lodging and to register both image and spectral data using the same computer system to improve data harmonization and geo-location.
- There is still a need to test the impact of the robot's speed on data acquisition and estimations.
- In the future it would be necessary to perform field trials with the robot together with sample collection to build models and statistical analysis for estimating ley characteristics, such as forage quality and biomass, using both the spectral and RGB-D data.
- These future evaluations reinforce the need to continue this project, making use of the baseline technology that was developed.

## Publications

- Oliveira J., Morel J., Haluska J., Kanellakis C., Tsimpidi I., Nikolakopoulos G. and Parsons D. Robotics on leys: An Unmanned Ground Vehicle to monitor forage grasslands. 30th General Meeting of the European Grassland Federation, 9-13 June 2024, Leeuwarden, the Netherlands. Grassland Science in Europe, Vol. 29 – Why grasslands? (eISBN: 978-90-903-8494-8 / eEAN: 9789090384948)

## Presentations and Events

- Poster presentation at the 30th EGF General Meeting, June 2024. Poster title: *Robotics on leys: An Unmanned Ground Vehicle to monitor forage grasslands*.
- Reference group meetings were held in January 2022, April 2022, and March 2024, and were composed of researchers, farmers, advisors, and SMEs representatives.
- Introduced the project concept to the Böle potatis & Kött company in Piteå through email communication.
- Networking activities using the project material for establishing further collaborations within Europe.

## Films and web presentations

The field experiments were covered in media. The first one was followed on the social networks of the Öjebyn Agro Park. During the second field experiment, Vinter communication agency joined us. They interviewed some members of the team. The outcome of this will be a video and text article. The following link depicts a video demonstration from field visit tests of the developed hardware within the project: <https://youtu.be/k7oCiZcDnel>

- <https://www.ltu.se/en/collaboration/norrlandsnavet/collaborative-research/agricultural-robot-collects-data-on-grass-quality>
- [Forage management optimization based on robotics and artificial intelligence | Externwebben \(slu.se\)](#)
- [https://www.youtube.com/watch?v=k7oCiZcDnel&ab\\_channel=RoboticsandAI](https://www.youtube.com/watch?v=k7oCiZcDnel&ab_channel=RoboticsandAI)
- Social media: Öjebyn Agropark – Instagram account published a picture of the robot and mentioned the field trial and project.

## References

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Morel J., Zhou Z., Monteiro L., and Parsons D. (2022) Estimation of the nutritive value of grasslands with the Yara N-sensor field spectrometer. *The Plant Phenome Journal* 5(1).

Näsi R., Viljanen N., Kaivosoja J., Alhonoja K., Hakala T., Markelin L., and Honkavaara E. (2018) Estimating Biomass and Nitrogen Amount of Barley and Grass Using UAV and Aircraft Based Spectral and Photogrammetric 3D Features. *Remote Sensing* 10(7).