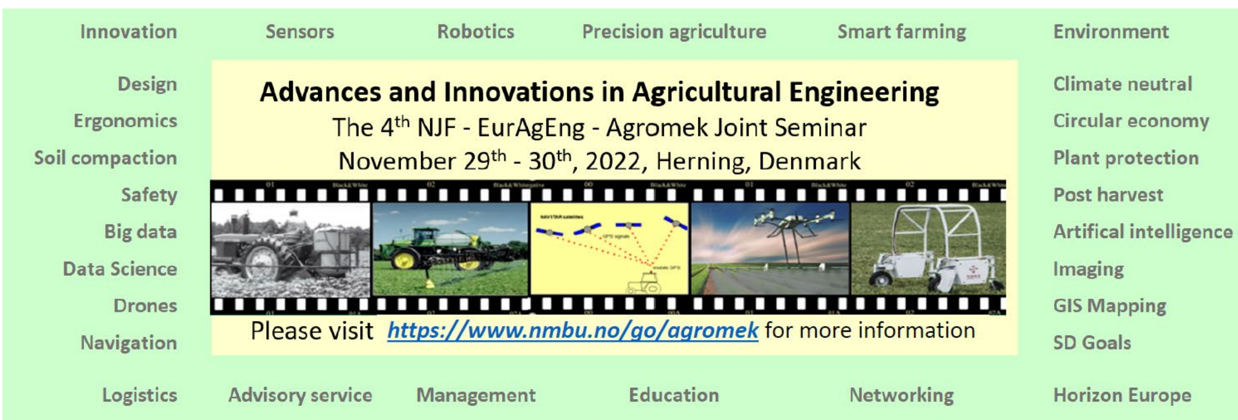
BOOK OF ABSTRACTS

NJF seminar

Advances and Innovations in Agriculture

The 4th NJF - EurAgEng - Agromek Joint Seminar



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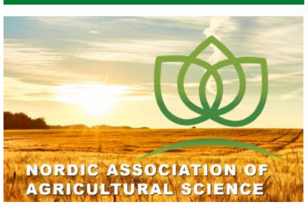

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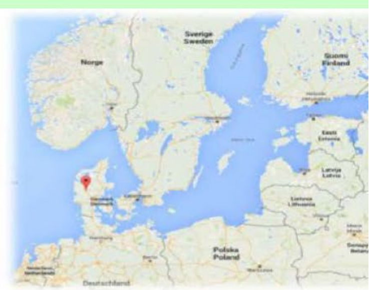

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CONTENT LIST

AGRICULTURAL ROBOTS FOR NEW SUSTAINABLE CROP PRODUCTIONS

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Keywords: robotics, sustainable production systems, future outlook

Today there is still an increasing demand for more sustainable, efficient and divers crop production systems. The more efficient the production resources are used the higher the mitigation of fertilizer and pesticide use, negative climate effects, soil quality degradation and economic costs. Highly automated robots can contribute to reach these aims although society is partly discussing skeptically the directions of these product developments. Developments like further intensifications for higher yields within conventional production systems with even more negative environmental effects and monocultures are predicted as dystopian scenarios. However, farm robots may perhaps lead to an ecological utopia where swarms of small robots help in overcoming problems in productivity, biodiversity and of course labor requirements (Daum 2021).

When robots shall become a reasonable component within the near future of production systems they have to be integrated into an IT system. Regardless of the directions of developments, these IT systems will consist of at least four components: (i) the Internet of Things (IoT) or machine-to-machine communication including standardized data ontologies, (ii) cloud and edge computing, (iii) big data analytics and artificial intelligence (AI) and (iv) robotics with mobile and stationary units (Griepentrog 2019, Bökle et al. 2022). Looking at the development of Precision Agriculture principles the technology will further develop like obvious in Digital Farming but the aims are still the same for the last almost 30 years: Addressing spatial and temporal heterogeneity to increase the efficiency of resource use.

Today it seems that at least two different trends in robot types exist. The first type is of almost the same power size as conventional tractor implement systems and the second one is a small lightweight robot.

Some equipment manufacturers are showing and partly already offering powerfull autonomous machines for conventional production systems. These platforms can be coupled with existing implements on a farm, thus the system implementation and integration seems less difficult and costly. Even 300 kW cables-based electric tractors without batteries were developed and investigated (Tarasinski et al. 2018). For using implements with ISOBUS the robot can even conduct the machine communication on that existing standard. This robot type can be regarded as a new step of mechanization, because it continues the efforts to minimize labor costs not only by size and speed but now in directly substituting the machine operator. Regarding the operations in terms of cultivation there is of course no difference to the current mode e.g. like using section control and other advanced implement functions. Therefore, to allow new cultivation opportunities these strategies have almost no further potential or just continue the current management strategies in crop husbandry.

Obviously, there is a second trend in robotics today: Autonomous small robots which are mainly specialized on particular operations. To compensate for small size and low speeds multiple machines as swarms can be used and hence, be easily adapted to different farm or field sizes. This leads to significant reductions in investment costs. The low area output can even be converted into an advantage: It helps to accept autonomous agricultural robots, because many field operations that a robot has to perform can be carried out (i) much more accurately at low driving speeds, (ii) with better soil protection due to low machine weights and (iii) above all with less energy. Examples are small robots for seeding and weeding, because they can better utilize the precision farming principles: sensors for providing useful information about soil and crop conditions and actuators for adapted high quality working functions on micro spots with high spatial resolution (Griepentrog et al. 2022). Small robots can also contribute to more easily mechanize strip-intercropping systems which highly contribute to increase biological diversity in cropping systems (Alarcón-Segura 2022).

In general, the move away from large working widths with heavy machines also means that fields no longer need to be as large and cleared out as much as possible. Traditional landscape features (e.g., hedgerows, ponds) can even be reintroduced, as they do not negatively impact productivity and area capacity for small autonomous machines. They can simply be mapped once and then included in the operation planning. Therefore, a significant increase in the biodiversity of our agricultural landscapes can be achieved or reestablished but keeping high levels of productivity and automation.

In the application of agricultural robotics, we are still at the beginning, although there are already first commercial applications.

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PILOT PROJECT ON PRECISION FARMING

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Deterministic models are increasingly being used to aid farm management and inform policy making and compliance. In this project, requested by The Danish Agricultural Agency in 2018, the Agricultural Production Systems sIMulator (APSIM) and the Danish mechanistic simulation of agricultural fields (DAISY) modelling frameworks were both configured to simulate the environmental effects of precision fertilization. Simulation was done for the growing seasons 2015 to 2019, for different soil types, texture, drainage, measured weather, etc., and was reflecting the most common site-specific fertilization practice among 20 pilot farmers. Precision fertilization is considered as a mean to reduce nitrate leaching from arable crop production. The project objective was to estimate the extent that precision fertilization is an alternative to catch crops after growing cereals or rapeseed. The conversion factor between precision fertilization and catch crops were estimated 11:1, and requires documentation of spreading/spraying of fertilizers with equipment providing section control, wedge spreading, border spreading, and variable rate application, and that the following three measures are met*: 1) Determining the nitrogen requirement for each field, 2) Implementation of site-specific fertilization and variable rate application, and 3) Determination of the nitrogen content in livestock manure and other organic fertilizers (only to be met if livestock manure is applied). Overall, the three measures was estimated to have an effect of 2 kg N/ha in reduced nitrogen leaching from the root zone for agriculture with less than 80 kg N/ha applied as organic fertilizer and 3.2 kg N/ha reduction for agriculture with more than 80 kg N /ha applied as organic fertilizer. The effect of measure 2 was estimated to have a general effect of 2 kg N/ha in reduced N leaching.

* cf. 'Plantedækkebekendtgørelsen', BEK nr 742 af 30/05/2022, The Ministry of Food, Agriculture and Fisheries of Denmark

REDUCING THE CLIMATE IMPACT OF SWEDISH AGRICULTURE - FIELD TRACTOR ELECTRIFICATION

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Agriculture is a sector that both contributes to climate change and is also highly likely to suffer from it´s effect. It has been stated as a goal to avoid increasing the global temperature over pre-industrial levels and several different ways of achieving this is being explored in research and policy. One project that connects to agriculture and food systems is the Mistra food future project that includes a work package with the express goal of reaching an agricultural system with net-zero greenhouse gas emissions. Currently 11 research publications and 11 project reports have been published in the scope of the project, of which one will be explained more in detail in this abstract, namely the electrification of agricultural field machinery.

Electrification of field machinery would yield multiple advantages such as lower impact fuels, higher efficiency, local fuel production and no local emissions (Lagnelöv et al., 2020). However, it has historically been deemed unsuitable due to low energy carrying capacity of batteries compared to diesel fuels, since it would incur a high operator cost and a low work rate capacity. Self-driving technology is also said to be a key driver in making electric tractors possible (Lajunen et al., 2018), as multiple smaller machines that work up to 24 hours per day can complete the same tasks in an equal or shorter time than a single, manned tractor and make electrification feasible. It also allows for the use of lighter machine, which would reduce harmful soil compaction. The increasing weight of field tractors have led to detrimental soil compaction, with at one-third of Europe's arable land suffering from soil compaction in 1990 (Hamza & Anderson, 2005; Keller et al., 2019), with reduced yields and increased energy use as results. In this way, self-driving technology can both improve the economic prospects of electric tractors and provide a reduction in soil compaction.

In this study, we have compared the economy and environmental impacts with and without soil compaction effects between a conventional diesel tractor (250 kW, 10,800 kg) and two self-driving electric tractors (50 kW, 3000 kg). The comparison was done through dynamic simulation of the machinery system of a 200 ha mid-Swedish grain farm working on clay soil, with further analysis being done using an economic analysis of the total annual cost (Lagnelöv, Dhillon, et al., 2021) and a life cycle assessment (Lagnelöv, Larsson, et al., 2021). We didn´t include harvesting, inputs, seeds and implement, as the focus was on the tractors. Included effects from soil compaction was a yield loss, increased energy use and reductions in hydraulic conductivity (Graves et al., 2015; Keller et al., 2017; Keller et al., 2019). The results were then used to calculate the potential effects on a national level, encompassing 2.6 million arable ha in Sweden.

It was shown that the work rate of the self-driving, battery–electric system met or exceeded that of conventional diesel tractors. It was also shown that the it reduced the yearly GHG emissions from the entire life cycle, from 246 kg CO2eq./ha for the conventional tractor to 80 kg CO2eq./ha for the battery-electric tractors. The majority of the reduction came from the change to a cleaner fuel that was used more effectively. However, battery production also had a large impact. Economically, the battery-electric tractors had a larger investment cost but a lower operational cost, which led to a total lower annual cost, for a reduction of 32-37%. On a national level, electrification of agricultural machinery could reduce the GHG emissions of agricultural machinery with up to 434 million kg CO2eq. per year, an 81% reduction.

This shows that self-driving electric tractors can reduce the annual machine costs and the climate impact due to changes in fuel, reduced fuel use and lighter vehicle weight, both on farm and national level. In this way, it can be an important tool for a future net-zero GHG agriculture.

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A LOW-COST ROBOT PLATFORM FOR SWARM APPLICATIONS IN AGRICULTURE

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Keywords: Robotics

Agriculture has been facing a variety of problems including climate changes, a growing population, high costs for energy and labour, and an increasing awareness and demand for environmental-friendly food production. Over the last decades robots have been pointed out to solve several of those problems. Especially in countries with high labour costs a notable number of robotic systems have been developed for a wide range of applications, including sensing, seeding, weeding, harvesting and many more (Oliveira et al., 2021). The scope of this abstract is the subtopic of mobile ground robots, typically wheeled vehicles that autonomously execute a certain task in an agricultural setting. The author presents a small, energy-effective, and low-cost robot that can be used in applications that do not require heavy loads, e.g. precision seeding, sensing or mechanical weeding. In addition, its low costs make it possible to scale up multiple robots to cooperative swarms that work larger areas in less time (Blender et al., 2016).

The motivation for this work was to find an autonomous system that can execute a given task at significant less system and energy costs compared to existing robot systems and conventional methods, i.e. typically the use of tools connected to a tractor. The task in mind was mechanical weeding in early-season cereals, because at this stage weed plants are typically small and not much force is needed to cut them or pull them out. As pointed out earlier other applications are possible, but due to its small size the load capacity is limited, which reduces the number of applications.

The implementation of the robot is based on the SVEA platform (Jiang et al., 2022), which is basically an four-wheel drive remote-controlled car that was adapted to drive autonomously. For that, the control signals for the steering servo and the motor speed are taken over by a single-board computer, e.g. a Nvidia Jetson Nano, that is running the Robotics Operating System (ROS). For the purpose of agricultural applications on open fields it was necessary to implement several adaptions. The electronic modules were fit into an enclosure for suitable ingress protection. In addition, the robot is equipped with an RTK-GNSS module and a stereo camera for navigation. The base vehicle (Traxxas TRX-4 Sport, Traxxas, USA) itself is already targeted at all-terrain driving. The rigid frame is suitable to mount additional equipment at, like for example a weeding tool. The size and weight of the robot without any load is ca. 56x25x24 cm and ca. 3 kg, respectively. By using mostly off-the-shelf components the overall price of one robot is around 1500 €.

To evaluate the robot, several field experiments were carried out. Those included traction, speed, and incline tests under different ground and load conditions. The energy consumption for all conditions were measured to allow easier comparison to other systems. In addition, a field trial will be conducted with the mechanical weeding tool for early-season inter-row weeding.

Our results show that the presented robot platform can be a highly efficient complement to other vehicles for selected agricultural tasks while minimizing energy consumption, and avoiding soil compaction, as well as fossil fuels.

In the future, it is planned to extend weeding experiments to a setting with multiple robots. That work will focus on the task planning and how the robots are coordinated on the field. It might be interesting to use drone imagery to generate weed maps which will be input data for the swarm controller.

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SMART FARMING AND GREEN INNOVATION -A PLATFORM FOR SUSTAINABLE AGRICULTURE ESTABLISHED AT NMBU

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Keywords: Sustainability, student innovation, education

Smart Farming and Green Innovation is a platform for sustainable agriculture established and founded by NMBU (2021-2024). The main goals with this platform are to gather all the interdisciplinary research areas at the Campus within smart farming and together increase our activities within especially networking, education, research and innovation. At NMBU (Norwegian University of Life Sciences) we have 7 faculties and especially the faculty of Science and technology, the environmental sciences and natural resource management and the faculty of biosciences are strongly involved. At the Faculty of Science and Technology, we have 5 years master studies in geomatics, applied robotics, physics (imaging and energy), engineering and data science, approx. 70 PhD students and several related research projects to smart farming. Additionally, we have education and research activities within plant and soil science at the other mentioned faculties who also are joining the smart farming research group. Cooperation with agricultural advisory service as well as manufacturers are important, as well as international cooperation.

In order to create a better working space for student active learning and innovation, we have established an own field, a pilot area, where interdisciplinary students can come together, test out, prototypes and innovations ideas, named Green Innovation and Student Lab. We have also put together a special trailer in order to move the classroom outside also in the field with facilities like robots, drones, sensors and PC's in order to test in situ.

Figure: Mowing classroom trailer

We have also set up a farmbot www.farm.bot , where the students may measure the state of art of plant growth, plant health and soil properties with different sensors as well as develop simple tools for e.g. harvesting of vegetables and test out tools for mechanical weeding.

The university has approximately 300 ha of farmland close to the Campus. The agricultural machinery is equipped with sensors and navigation systems which will improve the quality of the production as well as make the data available for education and research.

At this seminar some of the researchers will show their activities, especially within phenotyping, imaging, use of drones and robots as well as point out important means in order to avoid soil compaction of heavy machinery.

To get updated information about our sustainable platform Smart Farming and Green Innovation, please visit; https://www.nmbu.no/forside/en/projects/smart-farming

IMPACT OF SUN ELEVATION ANGLE AND TYPE OF SENSOR ON MULTISPECTRAL UAV IMAGERY DATA

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Keywords: Multispectral imaging, Unmanned Arial Vehicle, Sun elevation.

Remote sensing technology overcomes the disadvantages of poor timelines and low accuracy in estimating physical and chemical parameters of crops using field sampling and laboratory analysis and has become an important technical means of measuring physical and chemical parameters in plant phenotyping and agriculture more generally. As simple and effective proxies of surface vegetation conditions, vegetation indices (VIs) are widely used in vegetation monitoring via remote sensing (Liu et al, 2012). The absorption and reflection of solar radiation are the results of numerous interactions with plant material, which vary considerably with wavelength. VIs are constructed from reflectance values for two or more wavelengths to analyze specific vegetation characteristics such as leaf area or chlorophyll content. UAV imagery has been successfully used to measure VIs and predict numerous important crop traits (Shafiee et al, 2020). Many factors could be considered when choosing a camera or a UAV platform since VIs are influenced by environmental conditions such as illumination. For example, time of flight or sun elevation angle can significantly affect data gathering flexibility and quality of the data. Our main study objective was to experimentally evaluate two fundamentally different multispectral cameras (the newly released end-to-end phantom 4 multispectral (P4M) and Micasense RedEdge-M) and compare them in terms of their performance for VIs generation under different sun elevation angles, and grain yield prediction.

A collection of 24 historical and current spring wheat cultivars were planted in Vollebekk NMBU Research Station (Ås, south-eastern Norway, 59º39'N, 10º45'E) in the 2021 season. To study the effect of sun elevation angle, the angle was calculated based on trial location, date, and time of flight according to the data from a Solar elevation angle Calculator (https://keisan.casio.com). The missions were conducted during a period of clear sky and low wind on 27 July 2021 (grain filling stage) at the following time points and corresponding solar elevation angles: 09:00 (28.59°), 10:00 (37.75°), 11:00 (42.04°), 12:00 (46.78°), 13:00 (49.23°), 14 (48.92°), 15 (45.89°). Various processing steps for the UAV images including geometric correction, image mosaicking, and radiometric calibration were conducted in Pix4D. QGIS software (QGIS 3.4, Open-Source Geo-Spatial Foundation Project. http://qgis.osgeo.org) was used to extract median spectral values for each experimental plot in the trial (Shafiee et al, 2021).

Based on our results, red, green, and blue bands have less variation with sun elevation angle than red edge and NIR values. Some vegetation indices calculated from RedEdge-M camera are more variable with changes in sun elevation angle, however, P4M is less sensitive than RedEdge-M. While the two cameras yielded very similar reflectance values for the red, green, and blue bands, the mean difference (MD) values of the red edge and especially NIR reflectance values varied with sun elevation angle with the smallest difference around local noon between 12 PM and 13 PM and greater differences in the morning and afternoon. A similar, but less pronounced trend was also visible for red edge reflectance values indicating different spectral responses of the two cameras.

Following a similar pattern, the NIR and red edge values of the two cameras were less correlated compared to the other bands, and the correlations were lowest in the morning. Most of the calculated VIs showed similar patterns with camera differences being most pronounced in the early morning and the VIs from the two cameras becoming more correlated from 11 AM onwards. This can be explained by the much larger NIR reflectance values of the RedEdge-M camera compared to P4M in the morning, and a declining trend in the NIR values from morning to afternoon for the RedEdge-M camera, while P4M showed less fluctuation in the NIR reflectance due to sun elevation angle. The sun sensor on P4M might compensate for sun elevation and zenith angle effects more efficiently than the sensor on RedEdge-M that we studied in this research or Parrot Sequoia that has been studied by other authors (Franzini et al, 2019).

As shown by many studies, the accuracy of normalized VIs was higher than for single bands due to robustness against variable light conditions when measurements from different sensors are compared with ground truth measurements (Di Gennaro, et al 2022).

In conclusion, the type of sensor can affect the multispectral band reflectance measurement data. A sensor such as P4M camera can compensate for the strong shadow effects due to different sun angles while the RedEdge_M camera is not capable of doing so. However, some vegetation indices can compensate for the effect of sun angle, thereby compensating for the deficiencies of the camera.

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SPECTRAL IMAGING IN CROP FIELDS – RESEARCH ACTIVITIES AT NMBU

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Keywords: phenotyping, plant disease, multispectral imaging, UAV, machine learning, deep learning

An ongoing collaboration between plant science, technology and image analysis has led to new methods for characterization of plant health and for genomic prediction. Since the collaboration started with a pilot field project in 2016, extensive field work has been conducted every year which has resulted in a unique times series data set with plant traits both from manual measurements and from multispectral images. In addition, some laboratory measurements have been carried out for detection of plant diseases with hyperspectral camera.

The idea of applying spectral imaging in crop fields is that reflectance of electromagnetic energy by the crop canopy at different wavelengths is predictive of important physiological traits, such as leaf nitrogen content, photo-synthetically active biomass, leaf chlorophyll and plant water status. Manuel direct measurements are closely associated with grain yield, but destructive and time consuming. Canopy reflectance may therefore replace traditional methods to screen large numbers of field plots in a fast and cost-effective manner. Even a simple RGB camera can be used to extract parameters related to biomass and plant physiological status, but more information can be obtained by multispectral and hyperspectral cameras that include a larger proportion of the electromagnetic spectrum. Some wavelengths contain more biologically relevant information than others, and several spectral indices like the NDVI (normalized differential vegetation index), EVI (enhanced vegetationindex) and MTCI (MERIS terrestrial chlorophyll index) are widely used.

The largest project for this collaboration is focused on phenotyping of wheat based on field trials in Ås and at Staur research station in Stange, both in Norway. In addition to evaluating agronomic traits and grain yield, multispectral images from UAV (Unmanned Aerial Vehicle) were taken repeatedly at weekly intervals from emergence to maturity. The multispectral cameras have 5 discrete wavelength bands: blue, green, red, red-edge and near infrared. The red-edge band is capturing the transition from red to the near infrared which is closely related to the cholorphyll in the plants. Orthophotos of the crop fields in all the five wavelength bands are derived from the UAV images, providing layers of five images for each field and each date. The spectral measurements from each of the trial plot are retrieved for analysis together with the manual measurements. The use of machine learning-based variable selection methods has resulted in promising grain yield predictions from the multispectral drone images (Shafiee et al., 2021).

The goal of phenotyping is to not only predict grain yield, but also to be able to improve the genomic prediction, in order to facilitate a more precise selection of new plant varieties. This will give the plant breeder access to more precise data on the growth and development of the plants. NMBU in collaboration with CIMMYT in Mexico have developed efficient and quite reliable statistical models for use in genomic selection that combines phenotypic data with marker data and multispectral information from drone images. Several models that incorporate correlated traits, genotype-by-environment interactions and weather data have been tested out and published. Testing of these models on field trial data from the project shows promising results of improving prediction accuracy by integrating multispectral vegetation data in the genomic prediction models. Recently, they have also compared these classical statistical models with models based on deep learning and artificial intelligence. Results so far show that these models require more data to achieve the same reliability and robustness as the simpler statistical models (Montesinos-Lopez et al. 2022).

In 2020 and 2021 we performed parallel testing of two different multispectral cameras at weekly intervals during the field seasons to compare their data quality for yield prediction. These results show that a much cheaper and user-friendly drone with an integrated multispectral camera provides comparable data to the more advanced and expensive camera we used at the start of the project. This was documented in a scientific publication that will contribute to make multispectral imaging more accessible to plant breeders with limited experience in drone flying (publication in review).

In addition to UAV images, RGB images have been captured from the Thorvald robot (sagarobotics.com) for close-up studies of wheat plots. The main goal for these images is to develop deep learning models to automatically detect and count wheat heads. This work is part of an international initiative to create a labelled database for benchmarking wheat head detection on images (Serouart et al., 2021). This is an ongoing effort that will be continued in 2023.

Another collaboration project between the plant scientist and the image analysis laboratory focuses on detection of rust and leaf blotch, two common diseases on wheat. An investigation in laboratory was carried out by picking healthy and sick leaves from the field trial in Ås and scanning them with hyperspectral camera. Machine learning models were established for disease discrimination and classification. The first overtone of water (1300-1600 nm) was used for an aquaphotomics model (Kristoffersen 2021, Shafiee et al., 2022).

So far, the interdisciplinary research combining technology and plant science has led to new techniques both in image analysis and genomic prediction that can facilitate a more precise selection of new plant varieties. This will give the plant breeder access to more precise data on the growth and development of the plants. Moreover, hyperspectral imaging has proven powerful for detecting plant diseases in laboratory settings. In future work we will explore the possible added benefits in capturing hyperspectral images directly in the field. We have during these years experienced that multispectral and hyperspectral time series form crop fields results in a huge amount of data. During the last two years we have focused our resources on systematization and automation of the processing of the massive amounts of data generated by the drone images and made solutions that enables pre-processing and quality check of the imaging data on the same day as they are being gathered.

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EXPLORING SOLAR ENERGY COMBINED WITH A FLEET OF ELECTRICAL VEHICLES AND PRECISION AGRICULTURE FOR REDUCED GHG- EMISSIONS

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keywords: Precision agriculture, solar energy, autonomous navigation

There are two areas which may be considered as 'low-hanging fruits' in terms of greenhouse gas mitigation options for food and feed production: reducing the emissions from tractor work on the farm, and reducing the emissions related to low nitrogen use efficiency. In this presentation, we present the results of a 4 year research project that addressed these two areas by developing a concept of innovative technical solutions and methodologies applicable at farm level, the SolarFarm. The SolarFarm concept is about utilizing available roof area on farm buildings for solar energy capture, and to use this energy along with state-of-the-art precision agriculture technologies to produce food and feed in a more sustainable manner. To shorten the time span from concept to implementation, SolarFarm comprises a set of approaches, ranging from relatively simple solutions, e.g. for farmers with low motivation for investing in advanced technology, to more comprehensive solutions, e.g. for farmers/early adopters devoted to technology, who want to utilize the full potential. In more detail, the concept involves energy carriers and storage capacity, tailored for the annual and highly dynamic pattern in renewable energy production and demand. It also opens for a system change in farm machinery composition, moving from one or two large and heavy diesel tractors to a few and partly unmanned electrical tractors. The concept integrates the idea of demand-based nitrogen fertilization, in which unmanned aerial vehicles for data acquisition play a central role, along with a system for steering and communication. Moreover, the concept represents a base-case for renewable energy use in a farm setting, enabling assessments of energy aspects, sustainability, environmental impact, cost- efficiency and consequences for policy-makers.

SENSOR TECHNOLOGY FOR OPTIMAL HARVEST IN STRAWBERRY

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Keywords: autonomous, product quality, robot, table-top, tunnel

In Norway, strawberry is the most valuable berry crop produced commercially, accounting for more than 70% of the total berry fruit production. The main strawberry production on Norway is with the use of seasonal flowering cultivars planted in the ground in open fields on raised planting beds. Environmental conditions are highly affecting several factors during strawberry production, like frost tolerance, plant growth, flower initiation and -development, dormancy, flowering and pollination, fruit development and -quality (Rivero, 2022). The most severe during strawberry fruit development and -maturation is rainfall and moisture, which in some years can lead to severe rotting and great fruit losses due to grey mold. Also, with the ongoing changes in climate, with more intense rainfall and unpredictable temperatures during winter in Norway, higher losses are registered in strawberry production. Therefore, alternatives to open field strawberry production are of high interest.

A PVC-based high tunnel system placed over the strawberry plants is an attempt to overcome some of these challenges. The tunnel system can be set up over the existing plants planted in the ground, or in other planting systems, e.g. in a table-top system. In a table-top system, plants are grown in various substrates (peat, coconut coir etc.) in trays placed in gutters on high poles above the ground. Another production system for growing strawberries is in greenhouses but this is not used in commercial strawberry production in Norway today.

Using alternative production systems compared to strawberry field production have increased the past few years and require a change in techniques on how to produce this berry crop. Often, more specific technology systems and a change in strawberry plant types with an everbearing fruiting pattern adapted to the cultivation system, are needed.

With the use of high tunnel systems in strawberry production, some climatic factors are changed. The most important is temperature, where an increase during production may extend the growing season and improve yield and fruit quality.

The interest of using everbearing strawberry cultivars in these systems is increasing, although the knowledge in the environmental control of growth, flowering and fruit quality is still limited. Research on the physiological regulation of vegetative growth, flowering and dormancy in everbearing strawberry in Norway has been done recently (Rivero, 2022), but there are still not many commercial producers of everbearing strawberry cultivars in tunnels in Norway.

Strawberry production in general is labour intensive, especially during harvesting (Xiong et al., 2019). An interest in developing a strawberry picking autonomous robot and testing this in practical field work and develop it further was the base for a collaboration between two faculties at the Norwegian University of Life Sciences - combining technology and plant science.

For this experiment, a Haygrove polytunnel (Hayrove, UK provided from Myhrene AS, Norway) was established at the Norwegian University of Life Sciences, Ås (59°66´N) in 2019. The everbearing strawberry cultivar 'Murano' was planted in coconut coir (NORGRO, Norway) in 50 cm length plastic trays (8 L) with three plants per tray placed in a table-top system. An automatic irrigation and fertigation system was applied (Elceta, Norway). For plant protection, predatory mites (Amblyline, Bioline AgroSciences Ltd, UK) were applied. Bumblebee hives were placed in the tunnel for pollination (BOMBUS AS, Norway).

An autonomous strawberry-harvesting robot was designed and tested in this tunnel (Xiong, 2020), with results as basis for further development of this technology for more efficient work. An interdisciplinary project was funded, as a base to understand how to develop this robot further. The goal of this project was to develop sensors measuring correct maturity stage for autonomous strawberry picking.

Several challenges have been investigated, but the main issue has been to combine robotics to biology and plant physiology, where the plant material and berry quality in the field varies greatly. How to use deep learning for object detection and tracking berries in clusters has also been a practical challenge for the strawberry-harvesting robot (Xiong, 2021). Chemical analysis has been performed together with testing sensors for detecting various quality assessments. Preliminary results are promising with the use of multispectral sensors to assess maturity stage in strawberry fruits. The research is still ongoing, and results from this project will be published later.

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SAFETY CONCEPT FOR ROBOTIC SILAGE HARVEST SYSTEM

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Keywords: Safety, Robotics, Functional safety, Silage

Introduction

Silage harvest can be a hectic activity where large areas must be harvested in short period of time. The harvest chain consists of several machines and operators that must coordinate their work. A crew of several operators and machines handles the harvest. The work is managed by a supervisor, who usually also participates to the work as an operator. One typical harvest chain consists of a mower, a harrow that gathers the mowed grass into windrows and a pick-up wagon or baler that picks the grass from the windrows. The time that the grass spends in the field before harrowing and the time that the grass spends in windrow effects the moisture of the silage when it is picked-up.

The FexiGroBots -project develops a platform for flexible heterogeneous multi-robot systems for agricultural robotics and pilots agricultural robotic solutions. In the FlexiGroBots silage harvesting pilot uses a robotic harrow as a part of the harvesting chain. The robotic harrow receives the track of the mower and utilizes that to create a trajectory for windrowing operation. The time between mowing and windrowing can be adjusted according to the conditions. The windrow is then picked-up by a manually operated machine. The aim is to ease the harvesting operation and enable larger harvesting operations. The robotic harrow consists of an ISOBUS equipped harrow and an ISOBUS equipped tractor with auto guidance system and cruise control system. The robotic solution utilizes tractor's resources. The tasks to the system are given in a standard ISOBUS format. The concept is designed so that only low additional investment and that minimal support infrastructure for the operation is needed. The tractor used can be used as regular tractor in another task and transported by driving on-road.

As the system is highly autonomous and operating in an environment, where also manually operated machines work and there is a high chance of humans being present, the safety of the system is crucial. In this paper a safety concept of the system is presented and evaluated to functional safety and systems safety requirements.

Methods

To define the safety concept a hazard analysis was performed, and safety concept was defined based on the hazard analysis and design principles presented in Tiusanen 2008. The concept is then analysed according to systems safety principles in Tiusanen 2008, ISO 18497 and ISO 17757. Functional safety requirements are evaluated according to principles of ISO 25119.

Results

The most significant risk is for any part of the robotic tractor harrow combination to come in to contact with a person or another working unit, which is occupied by a person. The safety concept has several layers to reduce the risk. The lowest level is to inform the persons around the robotic tractor. This is done by signalling light tower. The robotic tractor has emergency stop function available at the machine. The tractor has a remote controller, through which a supervisor can control the working unit or perform an emergency stop. The tractor carries laser scanners and stereo cameras, that detect obstacles. The overall operation is supervised by a drone monitoring the robotic tractor from above. The drone follows the robotic tractor and identifies hazards. The drone system can halt the unit if an obstacle is too close.

The signalling and emergency-stops alone cannot provide enough risk reduction according to the EN ISO 12100 and the machinery directive. The drone supervisor system is a complex system that has many sub-systems and communication pathways whose performance is difficult or impossible to validate according to current functional safety standards, like EN ISO 25119. The laser scanner-based obstacle detection system is therefore the system to which most of the functional safety performance requirements are allocated. The system would have to be evaluated and validated to the requirements of EN ISO 25119 and be able to pass the obstacle detection test described in ISO 18497.
The remote controller, which in its current state is an industrial safety controller to which systems current safety guarantee is placed. However, the final objective of the system is to operate independently, without full supervision the final safety solution cannot rely only on this system.

Discussion

The signalling from machines to persons in the vicinity is an important part of human-machine interaction (Ronkainen 2013). Various concepts using signalling to better interact with autonomous machinery have been considered, there is currently no means to estimate risk reduction by this. The ISO 25119 considers persons possibility to avoid a hazard and it can reduce the requirements, but this is not well recognized in other functional safety standards, like IEC 61508. Also, there are questions how well different signals are noted and understood by the people around the machine.

The safety supervision by the drone is an interesting development. The overhead drone would allow monitoring a safety zone around the autonomous working unit. The safety zone could also be determined dynamically as proposed by Tiusanen 2012. However, the complexity of the system makes it difficult to validate the system. The system also relies on some machine vision components, which usually are non-deterministic and cannot be validated to the current functional safety standards. There are some methods in automotive industry for estimating the reliability of such systems, such as ISO 21448 The current Machinery Directive does not recognise such systems. The new draft proposal for regulation on machinery products does recognize the AI, but the validation is still unclear.

The supervision as implemented now is not feasible for the final product. The vision is that the operator of the mower could also supervise the harrowing operation. For this to be possible the work of the mower operator would need to be assisted so that supervision is possible.
The current functional safety standards do not provide tools for evaluating risk reduction by several safety layers. The ISO 17757 for earth moving machinery identifies such layered approach for work sites but provides no tools to evaluate the overall risk reduction quantifiably.

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DATA INFRASTRUCTURE REQUIREMENTS FOR ROBOTICS AND SMART FARMING RESEARCH

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Keywords: smart farming, data infrastructure

Introduction – Data infrastructure requirements

Modern Smart Farming research relies on data. Data is utilized for example in modelling, decision-making and continuous monitoring. The amount of data is continuously increasing, hence ways to collect, manage and share data automatically and systematically are needed.

Project FlexiGroBots (Flexible robots for Intelligent Automation of Precision Agriculture Operations, n.d.) aims to create robotic missions and combine those together to automatized larger operations. FlexiGroBots needs data sharing between partners who are implementing the robotic missions. In addition, performed task and situational sensor data are needed. The other example project TwinYields is a digital twin of smart cereal production. The digital twin monitors the field in real-time and links them with a simulation model. The system requires data from sensors, remote sensing, FMIS and ISOBUS tasks and stores simulated crop and field state and forecasts.

Example projects need storing and sharing of farming data. For a while, data infrastructure requirements, like storing and sharing, have been handled case by case with independent implementations. However, data infrastructure requirements will continue in the future, project applications demand prepared infrastructure and smart farming development in practice is dependent on existing infrastructure. Luke's farm would produce historical farming data and maintain Smart Farming practices if infrastructure enables it. In the future also farmers need data infrastructures to build up modern farming systems. For these reasons Luke started developing permanent Smart Farming data infrastructure for research. Some technology choices are derived from our prior research data infrastructure Cropinfra (Backman et al., 2019).

This paper presents data infrastructure requirements from research projects, status of data infrastructure development in Luke and discussion on technology choices and challenges. The aim is to generate discussion on data infrastructures and best practices.

Materials & Methods – Current data infrastructure development and plans

Data infrastructure development began by defining existing farming data sources at Luke's farm in Jokioinen. Additionally new data requirements were listed to acquire or connect to data sources providing that relevant yet missing data.

In the next currently ongoing phase database was considered. Data saving format should be flexible. For example, ISOBUS tasks have their own ISOBUS standardized format. On the other hand, IoT data storing is optimal in formats like JSON or time serialized table. Document database MongoDB was chosen based on its data format flexibility, easy implementation, and usage in ongoing projects. MongoDB database was installed to Azure virtual machine for the development period. Later, the production version of database will be probably launched as Azure's CosmosDB which is a database as a service. It will be combined with CosmosDB API for MongoDB, which provides Mongo commands and functionalities to CosmosDB. Azure is used since it is Luke's default cloud service provider.

In the next phase, data interfaces in and out from the database will be implemented with website user interfaces, REST APIs and data space connectors. Data space is an environment for data sharing. Data spaces are under development and commercial data sources do not support data space connectors yet. REST APIs are hoped to be a relevant basis for implementing data space connectors on the top of them. Besides already mentioned interfaces, IoT data collection methods and techniques need to be considered.

Raw data storage will be separated from the database. Data lake will store the raw data and only necessary data will be transferred to database. Necessary data might mean summarized, analyzed, or periodically picked data. All interfaces will be connected to the database. Planned architecture of data infrastructure is visualized in Fig. 1.

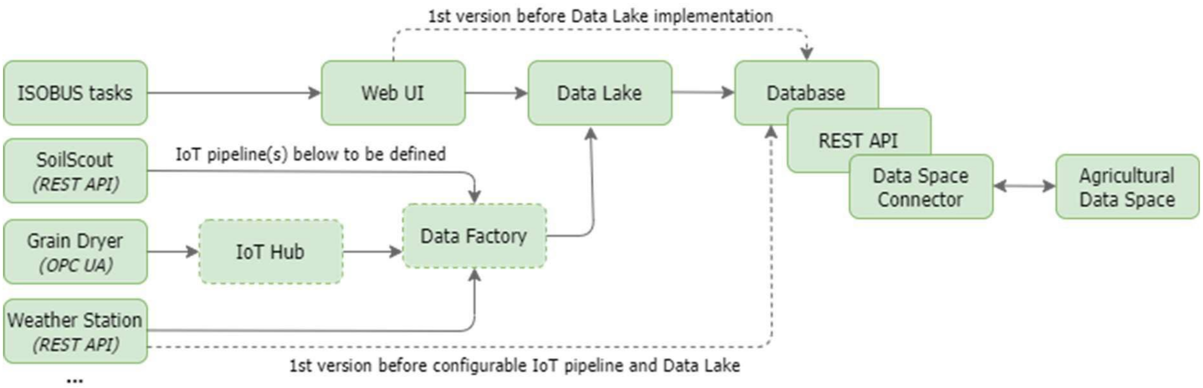

Fig. 1. Architecture of Smart Farming data infrastructure in Luke

Results & Discussion – Discussion on implemented and planned data infrastructures

Farm's own database is partly problematic. In research it works well but when taken into practice to farmers, farm's own database might not be possible due to required ICT-skills and time needed for setting up the database and connections. Even though own databases and data lakes will keep their position in research, the commercial and practical alternatives must be developed to agricultural entrepreneurs.

Like discussed, there is a need for easily sharing the data between multiple data providers and users. Data spaces are promising key to this problem. Luke's data infrastructure must be compatible with data spaces even though data spaces are not mature enough to manage all data pipelines. Other stakeholders must attend data space to create functioning data sharing environment. Using data space should not lead to a vendor-lock and the same components should be compatible with other data spaces.

While data space is built up, REST APIs are existing and general interfaces to multiple data sources and those connections bring large amounts of data to Luke's smart farming database. Organized way to store the raw data seems to be a data lake, which will be tested at Luke during the next year.
The need for collecting, analyzing, and sharing the farming data is evident. Currently the best practices are pondered, and Smart Farming data infrastructure pilot projects are on-going at Luke.

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EXPERIMENTAL STUDY OF LASER WEED CONTROL APPROACH WITH FULL CANOPY AREA TREATMENT

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Keywords: laser, weed control, agricultural robot.

Robotized laser weed control is one of perspective approaches for decreasing ecological impact of farming. Although current level of technology development allows robotized laser weed control to be economically reasonable only in specific applications – mostly in biological farming, it is only a matter of time to introduce them in full-scale industrial farming.

Depending on wavelength laser radiation has different effects on weed canopy and its parts. Blue light has better absorption in chlorophyll. This allows to apply thermal effect directly to chlorophyll and not waste time and power to burn down entire plant. However, in order to affect as much green mass as possible laser radiation should be applied on entire surface of canopy, not only on weak spots – meristems. Theoretically it is possible to slow down development of plant or even eliminate it as it will not be able to synthase nutrients. Real life scenario in this case would be relatively fast multiple treatments, when weeds are still in development stage.

Our study focuses on experimental evaluation of canopy area treatment approach using blue wavelength semiconductor laser. The properties of laser treatment process evaluated in this study were treatment speed, energy required to limit or stop growth of plant and laser beam moving patterns. Semiconductor laser module PLH-12000 with 12 W optical output power and 445 nm peak wavelength was used. The module was mounted on an industrial robot manipulator Universal Robots UR10. Area with weeds was treated individually by applying specific laser movement pattern and varying its size and movement speed. The laser was always operated at constant maximum optical output power therefore irradiation energy per square unit of area in a pattern was affected only by laser head speed. The pattern was applied starting at the centre of a plant canopy without taking into account plants size and individual form. Patterns were generated and sent from PC custom written software; pre-defined spiral drawing algorithm was used. The experiments were performed on plants grown under controlled conditions in a research greenhouse with day temperature 21ºC and night temperature 19ºC, relative humidity 60%, with natural and artificial lighting for 16 h. Watering of plants was done by immersion method – every working day vegetation pots were immersed in a tap water 2 cm deep for 1 hour. Plants with fully emerged cotyledons or emerging first true leaves were used in experiments. Plant species for each experiment – quickweed (*Galinsoga parviflora*); pigweed (*Chenopodium album*); cleavers (*Galium aparine*).

The key findings of the field test were the following:
A clear tendency was observed that proposed laser treatment approach limit weed growth. As expected, an increase in treatment time and thus in total treatment energy gives better result in limiting weed growth. Spiral pattern over a plant resulted in 88.2% biomass reduction with energy effectiveness of 0.221 joules per reduced mg of plant biomass 7 days after treatment. Laser beam moving speed was 22 $mm \cdot s^{-1}$ over 100 m2 area, 6.04 total treatment time and 72 J (or 0.725 $J \cdot mm^{-2}$) applied energy (Osadčuks et.al., 2022). Processing speeds can be easily increased by increasing laser beam optical power. Energy amounts used for area treatment in our experiment are comparable to lower end values in other similar research with precision spot treatment: 0.6 to 5.9 $J \cdot mm^{-2}$ with green 532 nm laser (Mathiassen et.al., 2006) and 0.4 to 20 $J \cdot mm^{-1}$ CO_2 10600 nm laser (Heisel et.al., 2008). Authors in these studies focused on achieving lethal outcome on plant during single laser treatment. Although there were only few lethal cases for plants after area treatment, mass reduction achieved in our experiments can serve as basis for further study with area treatment using laser patterns with presented methodology.

To summarize:
The proposed weed control approach has proven to be effective and was successfully adopted in laser weeder technology developed by WeedBot company (High precision…, 2022). Such laser weed control systems can be equally used on both autonomous and manned tractors.

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CAN AGTECH INNOVATION DISSOLVE GOAL CONTRADICTIONS?

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Keywords: Goal conflicts, innovation, agtech, critical thinking, electrification, battery swap

During the 19th century, it took approximately 4,200 minutes to harvest and thresh one ton of grain thanks to the invention of the knife bar, steam engine and threshers. Today, a combine harvester, such as the John Deere X9, can harvest and thresh one ton in 2 minutes. It illustrates a fabulous productivity development in agriculture. According to Economic Research Service, U.S. Department of Agriculture, the level of U.S. farm output 2019 was about 2.7 times its 1948 level. See fig. 1.

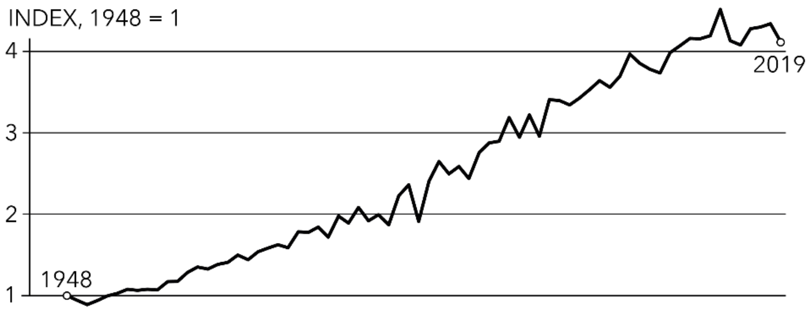

Fig. 1. Total factor productivity 1948–2019. Source: U.S. Department of Agriculture.

But despite all progress in agriculture, there is cause for concern. David Beasley, UN World Food Program, declared 6 May 2022: 276 million people worldwide are already facing acute hunger at the start of 2022 (World Food Program, 2022). The world faces huge challenges regarding food needs in relation to food supply. The expanding food needs relates to population growth, but also with changing food habits in Asia and elsewhere (Silva, 2018). At the same time food production needs to be boosted, there are many other kinds of challenges for agriculture, like threatened biodiversity, sealing of arable land, climate change, soil compaction, lack of manpower, spreading of animal diseases and profitability. To conclude, agriculture has many challenges to cope with at the same time, and these include contradicting goals.

One can argue that there are three possible pathways forward: evolution, imitation, and innovation. Evolution and imitation are much needed. But neither evolutionary changes nor imitation will be enough to cope with the contracting goals. We probably need more revolutionary changes. In other words, we need innovation. But what kind of innovations, and how can we secure innovation success?

If focusing on the possible contradicting goals of more food production and less negative climate emissions, one can discuss the option of "mission impossible problem solving", but there might be an option to dissolve goal contradicting problems rather than solve them. One example: One problem can be to bring down emissions from a tractor cultivating the field. However, the problem might be dissolved if we skip cultivating the field (compare conservation agriculture). Another example: One might try to solve the problem of bringing down the soil compaction of a big combine harvester and might end up in solutions such as tracks. However, one can question the idea of having a large combine in the first place and for example exchange it with two smaller ones. Still another example: One problem can be defined as decreasing the charging time of an electric tractor as much as possible to increase uptime. However, it might be possible to instead just change the battery. This was the basic idea behind the modular battery swap system used in the Drever robot concept. See fig. 2.

For electrification of work machines, the big question is how the machines will get access to electrical energy. The other technology needed for electrification is available to a large extent and can be applied in the machines. For work machines that have regular breaks and work close to the electric grid the machines can be charged easily. But machines in agriculture and forestry that a) mostly work far from the grid and b) tend to work intensively all year, as in forestry, or intensively when in season, as in agriculture, charging is not an option.

In the project coordinated by RISE the goal is to develop and demonstrate a modular battery swap system for electric work machines in different industries. The modular battery swap system is an enabler for fossil free, electric, mobile work machines especially in agriculture and forestry, aiming to drastically reduce the working machines environmental and climate impact.

The battery system is demonstrated in an autonomous electric agricultural machine. The machine is articulated and has four hub motors and one motor powering the hydraulics. The machines performance can be compared to a conventional 100 hk tractor and is large enough for large-scale agriculture, but significantly smaller than today's machines. The prototype is designed and built by start-up Traktorarvid AB and RISE with control system from RISE, hydraulics from Hydraspecma and electric components and battery system from Regal and Micropower. The machine has an advanced control system with RTP-GPS, but a rather simple mechanical build-up.

In the project also an electric forestry machine using the same battery system is built, based on an electric converted diesel machine from Malwa Forestry. The Malwa machine is probably the first electric harvester in world. The project is financed by the project partners and FFI Sweden’s Innovation Agency Vinnova.

Fig. 2. The Drever robot including two packages of batteries.

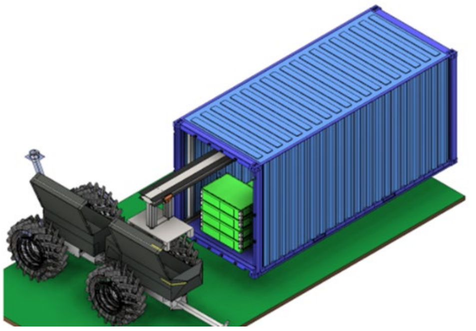

Fig. 3. The automatic battery swap station.

The modular battery swap system can be used by many machines and in many applications. The main feature is that the machine and the battery system are decoupled. A farmer or a machine owner could in the future rent batteries when needed - for example in the spring and thus get high instantaneous capacity at a lower cost. An individual machine manufacturer would not need to develop their own battery system. Another advantage is that it would also be easier to utilize state-of-the-art battery technology.

In the project the next step is to develop an automatic battery swap station that will make the whole system autonomous and with the advantage that the battery can be charged at the same time as the machine is working. See fig. 3.

What, then, are the learning points regarding innovation? First, it is important to question present lines of thinking, just as the small child did in the Hans Christian Andersen's fairy tale "The Emperor's New Clothes" published 7 April 1837. Second, such critical thinking can be boosted if working in teams alongside experimental facilities. In these contexts, critical thinking can transfer into creative thinking and end up in innovative concepts. Our conclusions, therefore, is that societies should invest in collective innovation environments including experimental facilities.

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MEASURES FOR REDUCTIONS OF GREENHOUSE GAS EMISSIONS IN AGRICULTURE

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Keywords: Measures, reductions, greenhouse gas emissions, agriculture

The agricultural sector (farming, forestry, horticulture, etc.) is a major contributor to global warming. According to the IPCC the agricultural sector accounted for 13% of global carbon dioxide emissions, 44% of methane emissions and 81% of nitrous oxide emissions in the period 2007-2016.

The primary objective of this project was to identify and compile measures as a basis for future work in the agricultural and horticultural sector that can reduce greenhouse gas emissions and thus climate impact in the Swedish agricultural sector. This project is part of the larger Mistra Food Futures research program.

In order to reduce the climate impact per unit produced, it is important to produce as resource efficiently as possible. Measures that can contribute to this include plant breeding, efficient livestock breeding and optimised use of inputs such as fertilisers, energy, fossil fuels and feed. Peat soils can also be rewetted to reduce carbon leakage. Animal husbandry can contribute by choosing feed with a lower climate impact and improving feed use efficiency. In addition, animal health and welfare is important for more efficient production.

Negative emissions can be obtained, for example, through increased soil organic carbon. Several measures related to soil carbon storage were identified such as improved management of organic fertilisers, manure, digestate, increased cultivation of grassland as well as the introduction of more perennial crops and cover crops.

In order to make production more efficient in agriculture, a large number of energy saving measures were identified which individually have a rather small significance, but which together have a greater potential.

ENSILING OF STRAW AS A PRETREATMENT AND STORAGE METHOD FOR BIOGAS PRODUCTION

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Keywords: Biogas, straw, silage

Biogas production in Denmark is expected to reach 25-27 PJ in 2023 (Nielsen, 2020) and 40-50 PJ in the longer term (Danish Energy Agency, 2018). However, it has been estimated that potential is >100 Pj if biogas is better integrated into the entire energy supply system, including heat, electricity, gas, and biofuels, and with methanation of biogas CO_2 to CH_4 using surplus renewable electricity (Wenzel, 2020). The cost of biogas production from animal manure alone is often greater than the income (Hjort-Gregersen, 2015), so cheap co-substrates are required. In Denmark, an annual average of 2.44 million tons of straw are available but not utilized. The main reason for the limited utilisation of straw is the need for costly pretreatments, which both increases methane yields to a profitable level and to avoid problems with pumping and mixing and the formation of floating layers in reactors.

Ensiling is a promising biological treatment method that ferments water soluble carbohydrates to organic acids, thus reducing pH, which aids in preservation of wet straws and digestion of the straw fibres. A variety of wet residual products such as brown juice, a byproduct of the biorefining of grass, can be added to aid the ensiling process and increase the energy content. However, wet straw alone can potentially ensile due to natural enzymatic activity and thus the value of moist second-class straws can be increased.

The work presented is under the EUDP funded StrawSilage project. The main project aims are:

- Increasing the methane yield by at least 30%.
- Increasing the possible straw loading to reactors and increasing dry matter content without forming floating layers.
- Optimization of moisture content, particle size, additives and ensiling duration.
- Increasing flexibility of the straw value chain by directing wet straw to biogas and dry straw to combustion.
- Developing dense stacking and airtight wet bale wrapping using the POMI Wrap8 system.
- Analyzing the economic concept of straw ensiling from field to biogas production.

Wrapping of bales has shown some variability in silage quality. Bales wrapped individually have been of good quality with just a little surface fungus and break open easily when the wrap is removed, whereas comparable bales wrapped in a combined wrap have shown a lot of heat development and rot throughout the bale. Investigations into why this happens are continuing.

Ensiling with brown juice lowered initial pH as juice concentration was increased (up to 250 kg juice per ton straw) but pH stabilized at pH 4.5–4.9 after 6 months. Work is continuing regarding the feasibility of adding such large amounts of juice at full scale. Straw with potassium hydroxide is also being tested. So far, lower silage dry matter has been correlated with methane potential increases, from ca. 250 mL/g volatile solids (VS) to up to ca. 310 mL/gVS following 6 months ensiling and depending on the additives used.

Analysis of the degradation and fate of cellulose, hemicellulose, lignin, nitrogenous and sulphurous compounds during digestion has been assisted by a new analysis technique where silage can be placed in porous bags in continuous or batch reactors and removed after specific digestion time intervals for analysis. The method allows washing of the bags to remove most of the contamination from the microbial inoculum.

Regarding straw handling optimization, two scenarios have been examined: for short distances to a biogas plant, the straw can be chopped in the field and potential additives added before ensiling takes place in traditional silage clamps. For transporting to more distant biogas plants, ensiling in wrapped bales is being developed with the POMI Wrap8 system and a new bale grip system.

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ENERGY EFFICIENT GRAIN DRYING PROCESSES

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Keywords: Energy consumption, grain drying, efficiency, Economy

Grain drying is an energy consuming process in the agricultural industry. Furthermore, fossil energy as natural gas or oil is used. This create an incentive for changes. Today a variety of grain storage and drying technologies used, such as silos with fans and heaters, flat storage, continuous flow drying and drum dryers.

It is costly to handle and dry grain. In northern Europe the price pr. ton of grain usually is highest around January. Grain (depending on the type) need to be below ≈ 14% moisture content to be stored safe [Lyngvig 2, 2020]. Uncertainty in measuring the moisture content pushes the farmers to dry the grain to a lower level of humidity, resulting in higher energy consume and lower price for the batch of grain.

Therefore, it is of beneficial for the farmers, to handle the grain as little as possible, dry it efficient with a reliable and fair price energy source, and store the grain until they get the best price.

To converter from fossil fuels as primary energy source to electricity in form of electric heaters have two major drawbacks. The electricity normally is more expensive that other energy sources and the electric installation normally cannot supply the required amount of energy. Even if an air-to-air heat pump is used for heating the drying-air the electric installations at the farms usually is inadequate. Therefore, a drying technology using only electricity within the limitations of the existing installations is interesting.

To handle this challenge new equipment have been developed. This new equipment is based on a significant more energy efficient grain drying method. Test performed to compare this drying method with traditional methods show a reduction of the energy consume by more than 90% [Lyngvig 1, 2020]. The method also reduces the need for grain handling and have potential to improve grain quality.

Figure 1: The prototype at the test site.
1: Direct attachment to existing silo by replacing the fan.
2: Filter and smaller internal fan
3: Dehumidification

Equipment for this new concept for grain drying, is developed for silos. The equipment uses a heat pump and a heat exchanger to dehumidify and re-heat the drying air. Since approximately twice as much water pr. m^3 air is removed from the grain by using dehumidified air, the amount of air can be reduced to the half, which reduces the need for fan power to approximately ¼. That again allows this drying concept to adapt to existing installations limitations in the electric power supply. The drawbacks are larger investments and the machinery is more complex and need more maintenance. A 0-serie of 3 units with capacity of drying a 1000 silo was manufactured and tested to investigate opportunities for cost reduction.
Figure 2: 0-serie at manufacturing site.

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SOIL COMPACTION FROM USING AGRICULTURAL ROBOTS IN COMPLEX ARABLE OPERATIONS

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Keywords: soil compaction, repeated wheeling, robotics

The size of today's agricultural machinery is one of the major contributors to the soil compaction problem (Schjønning, van den Akker et al. 2015). As agriculture adopts new technologies and advances towards automation, lightweight agricultural robots have been suggested as a possible solution to minimize soil compaction (Bluett, Tullberg et al. 2019, McPhee, Antille et al. 2020). Lighter and smaller machinery imply less capacity and as a result, less efficiency. To compensate for it, agricultural robots are being developed to work collaboratively in fleets. More vehicles on the field and narrower working widths will inevitably increase the area affected by traffic and repeated wheeling. Whether, it is less damaging to pass once with a heavy machine or multiple times with a lighter machine is still not clear and fully understood (Pulido-Moncada, Munkholm et al. 2019).

In this project, the ROBOTTI 150D (Agro Intelligence ApS) is being used as a lightweight autonomous field robot in different field experiments related to soil compaction and repeated wheeling. The objectives of the project are (i) to understand and characterize the stresses from the robot at the soil-tyre interface, (ii) to assess their impacts on soil structure and soil physical properties and (iii) to evaluate the influence of time and environmental factors on those impacts.

The ROBOTTI 150D (2020) is equipped with 320/65 R16 tires. It has a total mass of 3100 kg and it can carry 750 kg of extra load. It has two modules each of them having two wheels and one 55 kW diesel engine. The two modules are joined by a boom, which also serves as a suspension by using a revolute joint in one of the extremes. This type of suspension, although simple, differs substantially from traditional tractors and influences how the load is distributed among the wheels, especially when moving while loaded.

An initial experiment was conducted in April 2021 at Foulumgård (Denmark). Stress transducers were installed on a loamy sand soil close to field capacity at 10 cm depth. The robot was driven 10 times over the transducers while measuring the stresses. Penetration resistance down to 30 cm and 100 cm^3 soil cores at 10 cm depth were respectively measured and excavated after one, five and ten passes to assess the effect of repeated wheeling on soil properties. From the stress transducers, we obtained the maximum vertical and horizontal stresses and the dynamic mean ground pressures. In the laboratory, we measured air permeability and air-filled porosity on the soil cores after equilibrating them to -100 hPa matric potential.

Due to the use of relatively small tires, mean ground pressures were found around 100 kPa which are similar to those from light and medium size tractors. For the same reason, mean maximum vertical stresses at 10 cm depths were close to 200 kPa, also similar to maximum stresses found on larger machinery. The high ground pressures resulted in topsoil compaction. After ten passes with the robot, air permeability and air-filled porosity were reduced to 8 μm^2 and 0.14 $cm^3 \cdot cm^{-3}$ respectively. These values although low, are not critical for crop growth but might be worth considering in terms of risk of erosion or gas emissions. No changes were observed in penetration resistance below 25 cm depth for the different number of passes. Thus, showing the potential of using lightweight machinery to protect subsoils.

A second experiment was held on sandy loam soil at Flakkebjerg (Denmark). In October 2021, the robot was equipped with a sowing implement to establish a winter wheat crop on a fresh seedbed (prepared by a tractor) close to field capacity. In May 2022, under dry conditions with water contents close to the wilting point, mechanical weeding was conducted using a weeder attached to the robot. The same wheel tracks were followed for both operations. Before and after each operation, 8 x Ø10 cm soil cores were excavated from the middle of the wheel track starting at 10 cm depth. The samples were equilibrated to -100 hPa matric potential and air permeability and effective air-filled porosity were measured. After the laboratory measurements, the samples were X-ray CT scanned on a medical scanner. The voxel size of the resulting images was 0.3 x 0.3 x 0.5 mm. The images were segmented and analyzed with the software ImageJ to obtain, among other parameters, the total number and volume of macropores larger than 1 mm^3.

The preliminary results show a significant (non-critical) decrease in macroporosity and air permeability from 0.09 $cm^3 \cdot cm^{-3}$ and 200 μm^2 to 0.025 $cm^3 \cdot cm^{-3}$ and 100 μm^2 respectively, as a consequence of passing with the robot on a moist seedbed (low soil strength). No changes were observed on the wheel track from the first to the second operation using the observed parameters. Thus, suggesting no effect from the environmental factors after 7 months. Due to the dry conditions (increase in soil strength) during the mechanical weeding, passing with the robot had no significant effect on the wheel track. These results highlight the importance of considering soil strength for timing field operations.

In conclusion, lightweight autonomous robots might help to avoid subsoil compaction but can potentially cause considerable topsoil compaction. Despite the light wheel loads, the number of wheeling events and operations should not be disregarded. Monitoring and estimating soil strength is still a key aspect to minimize the risk of soil compaction, even when using lightweight machinery.

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PREVENTION OF SUBSOIL COMPACTION: TECHNOLOGIES AND STRATEGIC PLANNING

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Keywords: subsoil compaction, risk assessment, prevention, wheel load, tyre size, tyre inflation pressure, soil strength

Soil compaction is defined as the densification and the distorsion of soil by which total and air-filled porosity are reduced. This caused deterioration or even loss of one or more soil functions. Soil compaction reduces root growth, soil aeration, water drainage and filtering, and activity of macro- and microorganism. Therefore, soil compaction reduces crop yields and constricts time windows to perform optimal agricultural operations. The density of the topsoil (the soil above the tillage depth) will always be affected by traffic. However, natural processes (wetting-drying, freeze-thaw, soil biota) and tillage will be able to mitigate topsoil compaction rather quickly. In contrast, results reported by a range of studies indicate that compaction damages to the subsoil (soil beneath the tillage depth) are lasting for decades and might therefore be considered as permanent. Mechanical loosening of the subsoil is a very problematic solution: efficient subsoiling has to be performed when the soil is friable to avoid smearing, and as the soil is weaker after fragmentation severe recompaction will take place when re-trafficked.

The persistence of the effects of subsoil compaction advocates for efforts toward prevention of this process, and not only limitations of the volume of compacted subsoil.

Soil compaction takes place during field traffic when the mechanical stresses from machinery exceed soil mechanical strength. It means that soil compaction can be prevented if the mechanical stresses transmitted to the subsoil are kept beneath soil mechanical strength. Therefore, risk assessment should be based on a comparison of the stress applied to the subsoil and its strength. The most up-to-date decision support tool for risk assessment of subsoil compaction, Terranimo®, is freely available for farmers, contractors and extension services. Farmers are generally concerned about the state of their soil and are willing to engage in sustainable soil management. However, the use of Terranimo® in its current online form by farmers to plan field operations is still limited. Technologies that could help to minimize the risk of soil compaction exist already: wide tyres able to carry high loads with low inflation pressure, central tyre inflation systems, tracks, offset steering machinery to reduce repeated wheeling, GPS steering to reduce trafficked area. Despite these highly relevant technological advances, soil compaction problems have aggravated during recent years and decades. Subsoil compaction is invisible to farmers and often immediate concerns such as fulfilling delivery contracts, economic considerations, access to labour and time, are prioritized over long-term concerns such as prevention of soil compaction. Furthermore, although farmers are an important decision-maker in relation to subsoil compaction, a range of other actors influence farming practice, including machinery manufacturers, external contractors and political regulation of other management practices. The aim of this presentation is to present and discuss the opportunities and barriers of using the available technical solutions to prevent subsoil compaction.

DRAWBAR PULL TESTING FOR MACHINE-SOIL INTERACTION CHARACTERIZATION

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Keywords: Terramechanics, Mobility Performance, Slip, Traction, Drawbar Pull, Simulation, Testing

When writing specifications for a new machine, designing the machine to meet the specifications and to plan the operational use of the machine, communicating its expected performance characteristics is crucial. The interaction of the machine with the soil is the focus of the discipline terramechanics. Understanding expected machine/ground interaction in a variety of soil types, and conditions influenced by factors such as compaction and tillage state, moisture content, surface vegetation and more is a complex task associated with high variability and uncertainty. Methods for predicting a terrain interaction element whether it is a tire or a track link are numerous. In recent studies these are characterized as simple versus complex terramechanics models (Wasfy and Jayakumar, 2021 and McCullogh et al, 2017). Simple terramechanics models rely on empirical relations between pressure-sinkage and shear-displacement for running gear in soil sinkage and drawbar pull versus slip. Complex terramechanics account for 3D flow and deformation of soil material in contact with any machine component, tines, tires/tracks and underbody etc.

The calibration, verification and validation of both models applied to machine systems requires testing. This presentation describes a test setup designed at Aarhus University for steady state soil interaction to populate the full drawbar versus slip curve guided by a principle of constant speed, slowly varying slip test followed by pull to stall.

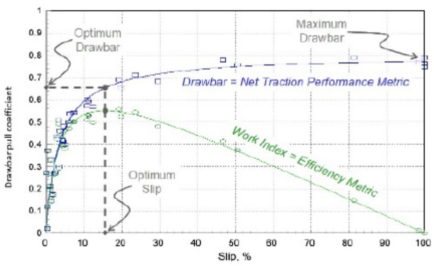
Simulation models created for terramechanics modeling requires specific and clearly defined test conditions to be satisfied to demonstrate simulation maturity. The drawbar pull test of a vehicle traditionally consists of a test vehicle and a hold-back vehicle as illustrated in the left figure below. The right figure shows the new test system based on a stationary hydraulic controlled winch mounted on a tractor.

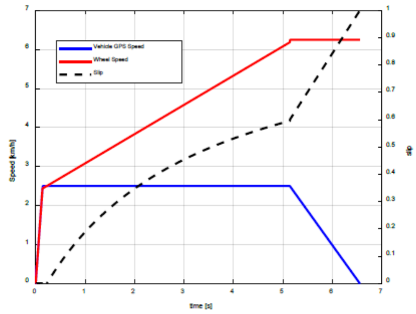
The ideal results from a drawbar pull test is illustrated in the left figure below. However, conducting such

a test with two vehicles and two drivers is difficult without introducing undesired dynamics in the test from the application of throttle of the test vehicle and braking from the hold-back vehicle. This introduces inertial forces that pollute the drawbar pull results. Furthermore, the soil machine interaction includes transients that is not possible to reproduce in the simulation being validated.

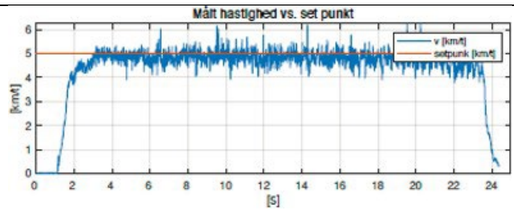
This motivated the development of the “constant speed – slow varying slip and pull to stall” controlled test which leads to an improved population of the drawbar slip cruve from 0 to 100% slip with slip defined as: $slip = 1 - \frac{GPS\ Speed}{Tire\ or\ Track\ Speed}$

The test is defined by keeping the test vehicle at a constant low global speed (GPS Speed) while slowly increasing the wheel or track speed. When the drivetrain is not capable of producing higher wheel or track speed in the selected testing gear, the vehicle is decelerated at a constant low deceleration till stall. This ensures that the drawbar pull curve gets fully populated while keeping the inertia forces from the fore-aft acceleration low, constant, and most importantly: known. The intended speed and slip results of the test is illustrated in the right figure.





The machine has undergone initial testing with wheeled and tracked vehicles as illustrated below.



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