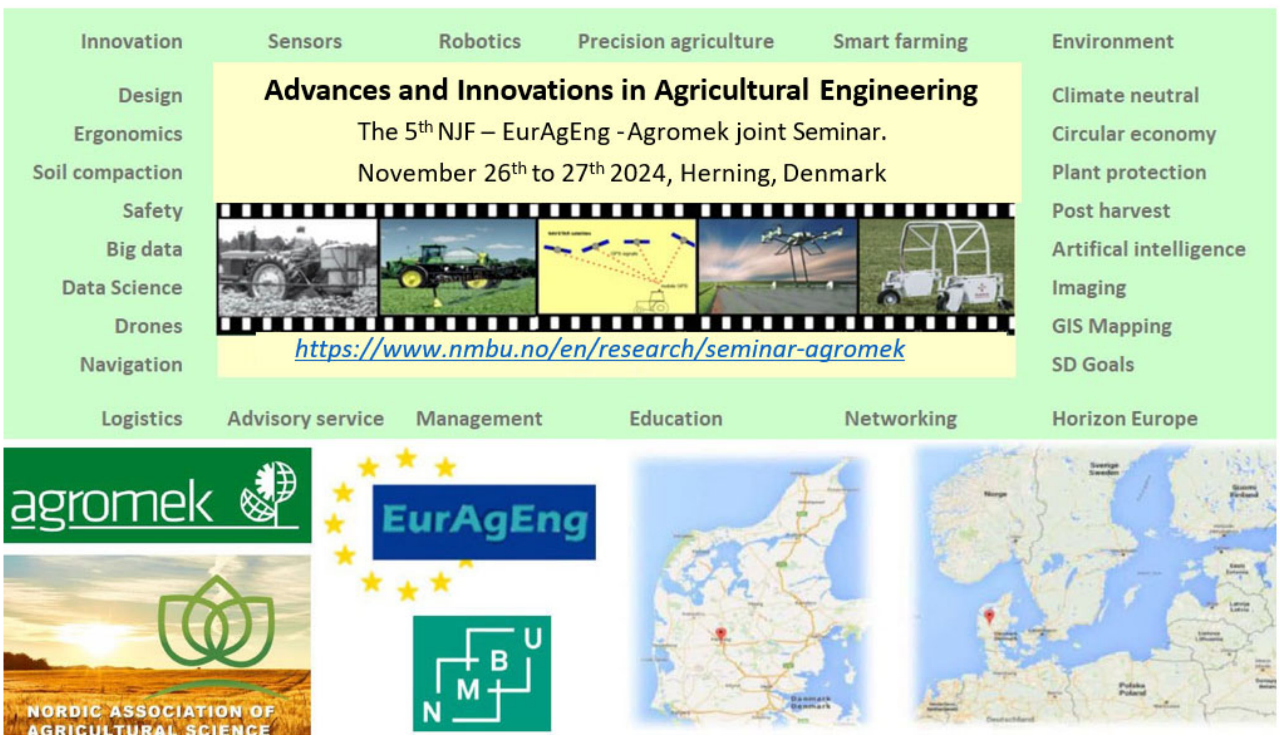
BOOK OF ABSTRACTS

NJF seminar

Advances and Innovations in Agriculture

The 5th NJF - EurAgEng - Agromek Joint Seminar



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CONTENT

TOWARDS A KNOWLEDGE HUB FOR DIGITAL TECHNOLOGY IN AGRICULTURE

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Keywords: Digital technology, agtech, knowledge hub, AKIS, innovation diffusion.

The emergence of a knowledge hub for digitization can be said to have two backgrounds. One is the enormous digitization that has taken place in agriculture since the 1970s. See example in fig. 1. Another background is that, according to several assessors, Europe has lost competitiveness against the USA and Asia in innovation and advanced digitization. The latter is evident from Draghi (2024), who, however, believes that precisely agriculture in Europe belongs to the sectors that still hold the positions:

”On the other hand, the EU outperforms the US in mid-technology sectors like manufacturing of transport equipment, agriculture and in the wholesale and retail sectors. The latter reflects catching up effects to key innovations that had been introduced in the US in the previous decade...” (p. 23)

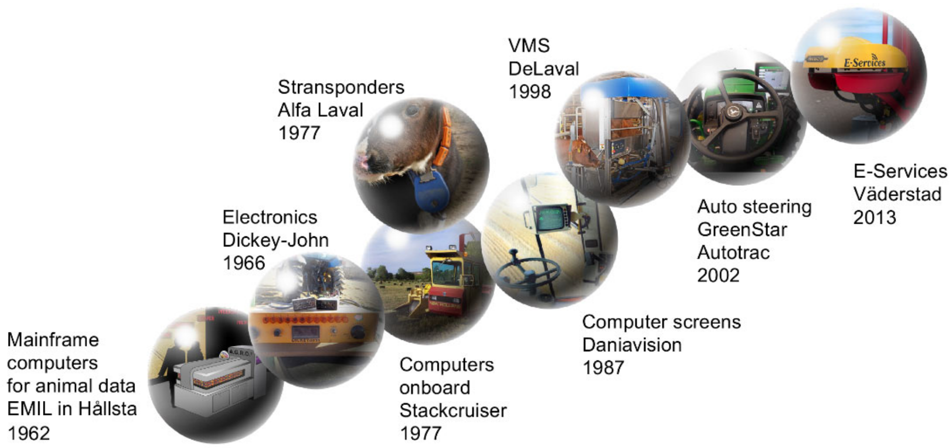

Fig. 1. Digital technology milstone examples in agriculture

In connection with a new program period for the common agricultural policy, the Swedish Agency for Agriculture made a review of which activities should be carried out within the support for skills development. The support should be part of the strategic plan for the common agricultural policy. One result of the review was the perceived need to expand the precondition-creating activities at the national level, with a focus on compiling and making knowledge available. In these discussions, the idea of developing a knowledge hub in digitization came up and the authority chose to announce a procurement of this hub in order to expose various actors to competition. The procurement was for a pilot hub of 3 years and the purpose would be to work with solutions to the perceived shortcomings such as lack of collaboration among the actors of the knowledge system, lack when it comes to compiling and making available knowledge, lack of interaction between research and practice, and lack of common view of needs.

Examples of what the authority means by digitization were, automation in the field (precision farming, autonomous vehicles), Smart stables (digitalized "furnishings"), decision support (digital technology and data sharing to be able to measure, calculate more, and monitoring of animal herds (digital technology for monitoring the welfare and development of the animals.) They underlined the importance of demo farms.

The budget was defined as SEK 20 million so that the procurement would not be about price. No, it was quality and the ability to establish the pilot hub in the best way that constituted the criterion.

The innovation platform Agtech Sweden at Linköping University decided to enter the game and in the fall of 2023 began extensive work to do research, write the application and, not least, form a consortium of actors, which came to be called an expert network. It was important to have nationally important advisers in agriculture, academia and trade associations. But we also decided to try to bring in two of the leading technology companies in Sweden as well as various "tech actors". The consortium behind the procurement response from Linköping University was Gård och Djurhälsan, Lovang Lantbrukskonsult, Ludvig & Co, Växa Sverige, SLU, LRF, DeLaval, Väderstad, AI Sweden, Sweden Secure Tech Hub, IoT World, Linköping Science Park, and Agtech Sweden.

At the beginning of 2024, it was clear that Liköping University won the tender. Among the first things we did then was to supplement the consortium as well as the expert network by inviting the Rural Economy and Agricultural Society (Hushållningssällskapet) and RISE, who agreed to be involved. The knowledge hub's office is located at Linköping University. The hub is led by the undersigned together with a strong team at Linköping University. The hub also has a steering group and a reference group. This includes farmers, technology companies, member organizations and advisors such as knowledge organizations. Furthermore, there is an accompanying researcher.

In summary, the hub is a national effort to raise the possibilities of digitization for Swedish agriculture. An important part is refining, packaging, and conveying knowledge to the industry. The knowledge hub's goal is to increase knowledge, strengthen cooperation regarding digitalization with relevant actors and for more farmers to see the possibility of using digital equipment. This is intending to improve the competitiveness of Sweden's primary producers. The increase in knowledge must be aimed at everyone, regardless of previous knowledge level (digital maturity and use). Na-vet's mission can be summarized in the following 5 blocks: External world surveillance, Needs analysis, Coordinate cooperation and dialogue, Test and evaluate new technology, and Package and spread knowledge.

Fig. 2. One example of external world surveillance made by the hub: Radical agronomics. Fig. 3. Agtech Dashboard (AGDA) including 37 different digital technologies (presented by the hub at Borgeby Field Days 2024).

The effect of the investment is expected to be a stronger agrarian knowledge system that contributes to efficient, profitable, and sustainable primary production and a competitive food chain. Already during the hub's first half year, extensive activities took place, which included exhibitions at Borgeby Fältdagar and Elmia Lantbruk. We have also received delegation visits from e.g. The Netherlands and the Nordic Council of Ministers network for test beds. The official opening took place on 23 October with a large conference and display of examples of digital technology in the form of the Mac Trac Robot and John Deere's route optimization system, and right now is ongoing technology surveillance at the fair Eurotier in Hanover.

The knowledge hub focuses on collecting, packaging, and disseminating information and knowledge about new technology. It is an important complement to efforts to drive forward new innovative concepts, which is the focus of Agtech Sweden (see further Frankelius & Muhrman, 2023).

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UAV SPRAYERS IN SWITZERLAND

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In 2019, Switzerland became the first European country to approve the use of unmanned aerial vehicles (UAV) for pesticide applications. The first step in the approval of a UAV sprayer, known as "homologation", must be carried out once for each UAV sprayer model. Parameters such as lateral spray distribution, pumps, tank, pressure gauges, built-in strainers, accuracy of flight path and lateral wind generated by the UAV are tested. Each individual UAV sprayer is entered into the national UAV register upon notification. However, each individual UAV sprayer must pass a sprayer test before it can be put into service and every three years thereafter. The sprayer test covers the same requirements as the homologation procedure with two exceptions: (i) lateral wind speed measurements are not performed and (ii) the accuracy of the flight path is not measured.

The results of over 200 measurements on the patternator show that the UAV sprayers used in Switzerland achieve homogeneous transversal spray distributions with coefficients of variation below 15%. Effective swath widths are typically less than those quoted by UAV manufacturers.

A study comparing patternator, water sensitive paper and tracer for transversal distribution showed no significant differences between these three different methods. This confirms the use of the patternator for the sprayer tests.

In addition, the lateral wind speed generated by the UAV sprayers, measured at distances of 10 m and 20 m respectively, is not significantly affected by the size or weight of the UAV. Wind speeds remain low for all UAVs measured. This is confirmed by drift measurements showing that spray drift is lower compared to standard air blast sprayers.

A survey we conducted to gain insight into agricultural practices under the current regulatory framework suggests that up to 11.5% of the total Swiss vineyard area was treated with UAV sprayers in 2023, corresponding to about 1500 ha. Other uses, such as the application of slug pellets, also appear to be gaining in importance. Finally, efficiency trials in Swiss vineyards showed that UAV sprayers achieve limited control of powdery and downy mildew at high disease pressure. This is due to the relatively low amount of spray deposit around and on the bunches. This can be explained by the fact that the lower leaves are covered by the upper ones, which act as an umbrella, preventing droplets from reaching the lower leaves.

The experience gained with UAV sprayers over the past 5 years has been very positive. Today, UAV sprayers are a standard tool for spraying steep vineyards. However, the small size of the spray tanks and the low spray deposit on the grapes in the vineyard limit their use.

UAV SPRAYERS AND DRIFT MEASUREMENTS IN NORWAY

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Spray drones (UAV) have been growing rapidly during the last decade worldwide and in particular in Asia and North and South Amerika where the equipment has replaced the use of knap sack sprayers and/or aircraft sprayers. However, the European Union, made in 2009 a framework for sustainable use of pesticides (Directive 2009/128/RC) that explicitly prohibit area spraying with aircrafts including UAVs. Derogations may be allowed, where the use of UAVs can document reduction in the use of PPP and a low hazard of drift. This could be the fact when spraying in steep areas and voluminous crops which are difficult to threat by the use of conventional ground sprayers.
In 2024 a pilot study was conducted in Norway in order to;

- Get a literature overview of methods of spray drift and in particular when using UAVs sprayers
- Evaluate possible methods for a pilot study measuring spray distribution and drift
- Perform some experiments with the most suitable method
- Evaluate the results due to distribution and spray drift by using this method

There are ISO standards regarding field drift measurements for conventional sprayers (ISO 22369 1&2; ISO 22866; ISO 222401; ISO 22856) and similar standards for UAVs in progress (ISO 23117 1, 2, 3 & 4). However, following such procedure is very labour and time consuming which also may result in fewer replicates and major changes in metrological parameters like wind size and direction compared to quicker methods. There are also several parameters influencing the results, thus a quick method for evaluation of distribution and drift is very much highlighted. During the literature study, a new method in use in the US, the Gobbler Swath width analyser, especially made for spray drone evaluation, has been developed. By rolling out a suited length of paper perpendicular to the flight direction and adding an ink into the spray, the deposit on the paper may quickly be analysed by the device after the spraying application is carried out. The paper may be stored for a while before the analysis is performed, making it possible to execute several experiments during a short time in the field. The analyser measuring the deposit on the paper by an imaging system. Several hundred images, each of a length of 35.5 mm are analysed in few minutes continuously along the paper stream. The distribution pattern may be expressed as percentage of coverage and hits of droplets per cm^2 as single values or as automatically generated graphs as a function of the length of the paper roll. The equipment was originally meant to measure the horizontal distribution of a single swath on the ground. However, in these experiments, we also fixed the paper vertically at a certain distance from the end of the swath in the wind direction, in order to measure the airborne vertical drift in the same manner.

Figure 1: Use of the Gobbler swath analyser; a) set up of paper, b) drone c) paper roll and analyser, d) graph generated on the computer.

This is preliminary studies only. And the following may be concluded.;
The use of 110 01 nozzles seems to give a high risk of drift. Additionally, the distribution curve is narrow and steep, which makes it difficult to get an even accumulated distribution and also demands a short working width that results in a low area capacity in ha sprayed/hour. Other experiments were carried out using a drone with rotating discs where the rpm could adjust the droplet size. By using lower rpm and larger droplets, the drift may be reduced. The spray pattern was also improved compared with a spray drone using flat fan nozzles. However, still the distribution was not appropriate.
The Gobbler swath width method makes it possible to run several experiments and replicates in short time. This is important due to quickly changing conditions and several influencing parameters to be considered and evaluated by using spray drones. A main issue is to obtain a proper distribution curve suited for good overlap and not too short working width. At the same time the drift has to be kept at a low level. When setting up the paper vertically, this made it possibly to estimate the drift potential. However, there are important to;

- Ensure that the drone follows the planned routh for the set up (follow the centre line).
- Position the vertical sampler at a sufficient distance (at least 5 m) in order to avoid experimental disturbances caused by minor deviations
- Use vertical samplers with a minimum height of at least 3 m (recommended 5 m) in order to catch the whole drift profile.
- The Gobbler system is only practical to use for spraying equipment using a similar volume rate

After the adjustment is optimised by the use of the Gobbler swath width analyser, the absolute and exact level of deposit and drift should be controlled by a final analysis following the ISO drift standards. A use of a Gobbler system or similar method should always be used in advance of the first spraying operation in order to calibrate the sprayer and ensure a proper distribution and coverage. Then vertical poles also could be added in order to control the hazard of drift.
These studies included only few experiments in order to test the Gobbler analysing method. More studies have to be carried out in order to define optimal set up when using spray drones. This is of high importance to ensure a proper deposit and low level of drift. Generally, and also shown by other research, the accumulated distribution of spray can never be better than a proper adjusted field crop sprayer. Thus, using a spray drones may only be recommended for spot spraying in fields or for hilly terrain with 3D crops that are difficult to treat due to spray quality as well as drift and operator safety by conventional equipment.

Standards regarding drift measurements
ISO 22369-1 Crop protection equipment — Drift classification of spraying equipment Part 1: Classes, 2006
ISO 22369-2: Crop protection equipment -- Drift classification of spraying equipment -- Part 2: Classification of field crop sprayers by field measurements, 2010
ISO 22866: Equipment for crop protection -- Methods for field measurement of spray drift, 2005
ISO 22401 Equipment for crop protection — Method for measurement of potential spray drift from horizontal boom sprayers by the use of a test bench, 2015
ISO 22856: Equipment for Crop Protection – Equipment for crop protection — Methods for the laboratory measurement of spray drift — Wind tunnels, 2008
ISO 23117-1 Agricultural and forestry machinery — Unmanned aerial spraying systems Part 1: Environmental requirements (2023)
ISO/CD 23117-2 Agricultural and forestry machinery—Unmanned aerial spraying systems –Part 2: Test methods to assess the horizontal transverse spray (2024)
ISO/WD 23117-3 Agricultural and forestry machinery —Unmanned aerial spraying systems —Part 3: Field measurement method of spray drift for UAV chemical application (in progress)
ISO/PWI 23117-4 Agricultural and forestry machinery —Unmanned aerial spraying systems —Part 4: Measurement method of droplets deposition into crop canopy for UAV chemical application, (in progress

SMART FARMING SUSTAINABLE ARENA ACTVITIES IN NORWAY

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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 now 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 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 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.

The arena got funding for 2021-24, however, the research and education within smart farming will continue and further develop due to the wide established network, the running and upcoming projects as well as the common efforts for a cross-disciplinary educational program within smart farming and student innovation.

The following presentations from NMBU show results from some of the projects within the NMBU sustainable arena Smar Farming and Green Innovation:

- Robotic and AI solutions for field phenotyping
- Wheat head counting using robots
- Adaptive Sensing in Agri-Food
- Image processing in fruit and berries
- AgriSun – cooperation between solar power and grain production

Several other project and activities are also included. To get an updated information about our sustainable platform Smart Farming and Green Innovation, please visit;
https://www.nmbu.no/forside/en/projects/smart-farming

ROBOTICS AND AI SOLUTIONS FOR PLANT PHENOTYPING

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Robotics and Artificial Intelligence (AI) are revolutionizing plant phenotyping by enabling precise, efficient, and high-throughput analysis of crop traits. Traditional phenotyping methods, which are often labor-intensive and time-consuming, are now enhanced by robotics that automate data collection and sensor deployment across agricultural fields and greenhouses. Robots and UAVs equipped with high-resolution cameras can capture critical data on plant morphology, physiology, and health at scale. AI-driven algorithms then process this data, providing insights into plant growth, stress responses, and yield potential. At the Norwegian University of Life Sciences (NMBU), researchers are integrating UAV imagery, robotics, machine learning, and deep learning models for grain yield (GY) prediction across various plant species. Their study gathered high-throughput phenotyping (HTP) multispectral data in a large-scale, multi-environment field trial. By comparing genomic (G matrix) and multispectral-derived (M matrix) data using best linear unbiased predictor (BLUP) methods, they found that models combining G and M matrices achieved higher accuracy and lower error rates than models using G or M alone. Additionally, M matrix data proved robust across environments, with optimal data capture during grain filling and high-heritability camera bands crucial for GY prediction. Even a single RGB camera capture session yielded useful predictive data, underscoring multispectral data's value in crop modeling and offering a cost-effective framework for genomic selection.

Deep learning models such as YOLO5, YOLO8, and CNN were also tested for object detection and seed phenotyping. YOLO5 outperformed CNN and YOLO8 with 90% accuracy in detecting wheat heads and 58% accuracy in identifying spikes infected with fusarium head blight (FHB) in close-up images captured by robots and UAVs. In a separate experiment, CNN classified infected wheat seeds with 98% accuracy using RGB imagery in the lab. These findings demonstrate that machine learning, including deep learning, is highly effective for analyzing complex datasets, recognizing patterns, and predicting traits under varying environmental conditions. Overall, machine learning tools are accelerating breeding programs, enabling precision agriculture, and supporting adaptive crop management by providing real-time, data-driven insights.

ON THE GO WHEAT HEAD COUNTING USING ROBOTICS AND AI

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Keywords: wheat head detection, wheat head counting, wheat phenotyping, autonomous robots, agri- cultural robots, agricultural navigation, deep learning, convolutional neural networks

Wheat is an important crop worldwide, and in wheat breeding, spike number is a key indicator of yield. How- ever, manual counting is time-consuming and labor-intensive, making it ideal for automation. This study presents advancements toward an autonomous robotic system for wheat head counting and data recording. The Thorvald vineyard model, a multi-functional crab-walking robot, was used to capture videos of wheat in fields. To navigate these fields, a navigation model was developed using a convolutional neural network (CNN) segmentation architecture in Keras, specifically a modified version of DeeplabV3+. The model gen- erates two outputs: a line to guide the robot's path and a mask that highlights drivable areas. Trained on annotated images from a camera mounted above the wheel, it enables precise, real-time navigation adjust- ments. For head counting, the YOLOv5 deep learning model was applied to detect wheat heads on the go. Captured images were tested at resolutions of 840x840, 1000x1000, and 1200x1200, with the largest reso- lution yielding the best F1-score of 94.7%. A distance-based algorithm processes images at two frames per second, ensuring unique counts of detected heads. Testing across seven wheat plots revealed mean absolute percentage errors (MAPE) of 3.9% for the highest resolution, 6.53% for the middle resolution, and 14.39% for the lowest resolution, compared to human counting, while completing the task 17 minutes faster than manual methods. Overall, these results demonstrate that robotic systems can count wheat heads with near-human accuracy, providing a faster, reliable alternative for researchers and farmers, with reduced bias from human fatigue or distraction.

ADAPTIVE SENSING IN AGRI-FOOD

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Digital Food Quality (short named DigiFoods) is a center for research-based innovation (SFI) with the purpose of developing smart sensor solutions for food quality assessment directly in the processing lines, throughout the food value chains. The obtained food quality information will be used for optimization of both processes and value chains and make the food industry more efficient and sustainable.

As a part of this center, we have a project (MobileSense) to develop fully autonomous robots for automatic collection of large-scale quality data in the field. Current robotic systems mostly operate in controlled environments such as factory floors or structured outdoor environment. There are few or no autonomous mobile platforms that can carry a wide variety of sensors and perform intelligent data collection in the field, bringing advanced biological sensor systems to new areas.

Foods can be extremely complex and heterogeneous, and precise interaction between the sensor and the sample could vastly improve the performance of the sensors. Robotics can be used to operate sensors in processes and field, for automatic sampling and sample preparation. In this project, we aim to combine mobile robots with manipulators to not only collect optimal data in agriculture, but also to locally prepare the sensing field for the robot. Adaptive Sensing is the outcoming system that is capable of detect sensing targets, autonomously move to target location, optimally place the sensor, and clear the sensor view.

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

CHALLENGES AND EXPERIENCES FROM THE HANDS FREE FARM PROJECT

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Keywords: Autonomous farming, Hands Free Farm, Autonomous crop robots, Data insight

Agriculture is facing a range of substantial challenges including population increase, urbanisation and both mitigating and managing effects of climate change. Agricultural automation and robotics are foreseen as potential solutions beyond precision farming, to move agriculture through sustainability towards system regeneration. The Hands Free Hectare (HFH) and Hands Free Farm (HFF) collaborative projects founded at Harper Adams University (HAU) have been demonstrating autonomous farming system development since 2016 and have conducted multiple autonomous field crop production cycles, challenging perceptions, since a world first in 2017. Noted as a milestone in the advancement of precision agriculture (Lowenberg-DeBoer and Erickson, 2019) many lessons can be shared from the HFF project which has shown the technical possibility of crop production with small-scale autonomous agricultural machines.

Two key project organisation components led to the rapid development and successful dissemination of the Hands Free (HF) work. The first of these being an integrated and honest collaboration between academic and commercial partners, members of different organisations working as the same entity, being clear and frank about progress towards key milestones. This reduced time slip as resources were pulled to where effort was most required avoiding milestone delays. The second component was openness of the project to third party interest (i.e. funders, sponsors and media). Clear time lines were communicated to third parties along with progress against those time lines through regular updates via press releases and social channels. This built a momentum of external interest, from which pressure kept the team highly motivated and performing.

The HF projects started by utilising opensource drone/UAV technology for both the navigation hardware and software, fitted to the small-scale agricultural machinery, namely Erle-Brain and Mission planner respectively. Despite these being highly successful for the rapid development process the performance achieved with this system was limited. Tuning of the opensource system was limited within the project and GNSS stream variance resulted in wavering during autonomous field runs. To counter this commercial grade signal smoothing IMUs were employed to reduce variance and therefore, field run linearity.

When the project progressed to HFF in 2019 the incorporation of a further commercial project partner to develop a proprietary autonomous field navigation system allowed a growth in size and scope. The autonomously farmed area expanded to 35ha using a total of four autonomous vehicles, with enhanced capability such as headland and in-field static obstacle rout planning, specific for each vehicle/implement combination (Gill, *et al,* 2022) and vehicle to vehicle communication for co-ordinated operations. Where possible simple solutions were implemented to reduce development times and improve reliability. A key example of which is where possible creating space between cooperating vehicles to prevent collisions, this being applicable when vehicles are in communication or operating independently.

When considering agronomics, small-scale lighter machines have been hypothesized to improve soil health by reducing compaction, therefore improving yields and reducing farm energy requirement by reducing need for compaction mitigation tillage, as well as enabling increased resolution precision farming, although specific economic hypothesis was limited. The Hands Free Hectare Linear Programming model was developed based upon the HFH experience to calculate the economics of small-scale autonomous crop production. The results show reduced cost of production in the order of £30/T of wheat using the HFH system over the conventional systems tested, due in part to reduced labour and capital requirements (Lowenberg-DeBoer, *et al,* 2021).

The volume of data produced from the HF projects is extensive and has only been integrated in a very limited way. Deriving any meaning from the data has been a considerable challenge with a team that is focused on problem solving, project delivery and dissemination rather than in depth analysis although undoubtedly valuable insight is held within the captured data. Examples of this potential value are presented in a linier analysis of predicted field operation time vs recorded, field times which shows strong correlation and therefore, opportunities for farm management and planning.

Further consideration of the HFF system performance and scale highlighted a potential for autonomous machines within agro-ecology regenerative cropping systems. The small-scale autonomous precision machines lend themselves to strip cropping at 2m row widths creating synergistic benefits between crops. The HFF system has shown capability of establishing and then repeatedly returning to individual crop rows, including at harvest, within a multiple cash crop field. Each crop has routing plans to call upon when needed and individual nozzle control on the HFF crop sprayer can apply to 2m strips from a standardised set of tramlines. Autonomous crop robot technology in the form of the HFF system could enable a move to agro-ecology strip cropping, improving in-field biodiversity and agronomic performance as agriculture moves to regeneration.

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ENHANCING PRECISION WEEDING WITH YOLOV11 OBJECT TRACKING FOR ROBUST EARLY CROP DETECTION AS A FOUNDATION FOR FUTURE ORGANIC PRECISION SPRAYING TRIALS

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Keywords: Precision Agriculture, YOLOv11, Early Crop Detection, Organic Weeding, Object Tracking, Sugar Beet, Multi-View Imaging

This study presents a novel approach to enhancing early-stage crop and weed identification in precision agriculture through the application of YOLOv11 object tracking. Our primary objective is to improve detection and classification accuracy of newly emerged dicotyledonous sugar beet plants, which are particularly challenging to identify due to their small size and stress induced by autumn seeding conditions, including lower temperatures, reduced sunlight, and increased soil moisture. By leveraging the state-of-the-art YOLOv11 algorithm, we aim to address these challenges and provide a robust solution for early crop detection.

The field trial was conducted in a sugar beet field seeded off-season in autumn 2024 near Vejen, Denmark. The field featured sugar beets planted with 0.5 m row spacing and approximately 0.18 m plant spacing. To challenge the detection model, seeding occurred in two temporally shifted operations, resulting in a range of seedling sizes. Various weeding treatments were applied, including unweeded sections and mechanically intrarow and interrow weeded rows.

The imaging system utilized a 16-megapixel global shutter camera with flash assistance, which was crucial for ensuring consistent illumination, stabilizing white balance, minimizing ISO noise, and reducing motion blur during image capture, especially under varying and low-light conditions typical of autumn seeding. Images of 0.9 m × 0.56 m were captured approximately every 0.1 ml, with an approximate ground sample distance (GSD) of 6.3 pixels per mm, allowing each sugar beet and potential weed to be imaged 5-6 times during the traversal of the FarmDroid FD20. This multi-view approach improves detection accuracy by providing multiple viewing angles and reducing the chances of misclassification due to occlusions or variability in plant appearance.

A key objective of this research is to enable precise weeding in the 4 cm radius surrounding crop plants at the earliest possible growth stage. The 4 cm radius is critical because it represents the immediate vicinity where weeds directly compete with crop plants for nutrients, water, and light. Effective weeding within this area ensures minimal competition during the vulnerable early growth stages, thereby promoting healthier crop development.

In organic farming systems, conventional selective herbicide applications are not viable, necessitating the use of organic non-selective contact herbicides such as horticultural vinegar, Avenger®, Matran® 2, and

Homeplate®. These herbicides are non-selective because they do not distinguish between crop and weed species, impacting all plant tissue they contact. As a result, precise targeting is essential to avoid damaging crop plants and to minimize herbicide use, thereby optimizing the weeding strategy.

The combination of multi-view imagery and advanced object tracking is expected to address the challenges associated with early-stage detection, particularly for stressed seedlings in autumn-seeded fields, facilitating more efficient and sustainable crop proximity precision weeding. This approach lays the groundwork for future organic precision spraying trials planned for spring 2025, which aim to reduce chemical inputs further and enhance sustainability in crop management practices.

INTERPRETING AND ADAPTING REGULATORY STANDARDS FOR COMPLIANCE OF DISRUPTIVE AGRICULTURAL TECHNOLOGIES: A CASE STUDY ON HIGH-PRECISION HERBICIDE SPRAYINGROBOT

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The agricultural sector is witnessing transformative advancements with the advent of precision technology, and Kilter's latest innovation, the AX-1, is at the forefront of this revolution. AX- 1 is a robotic system designed for precision herbicide application in vegetable crops, utilizing a state-of-the-art nozzle to deliver single droplets of herbicide directly onto targeted weeds. Unlike conventional sprayers that broadly disperse chemicals, AX-1 minimizes herbicide usa- ge, reducing environmental impact and promoting sustainable farming practices. However, the disruptive nature of AX-1 poses significant challenges in aligning with existing agricultural equip- ment standards and regulatory frameworks.

To address these challenges, Kilter has actively collaborated with The Norwegian Food Safety Authority, the Norwegian University of Life Sciences (NMBU), and the Julius Kühn Institute (JKI). This collaboration focuses on interpreting current laws and regulations and developing new standards specifically tailored to evaluate and approve disruptive agricultural technologies like the AX-1. This presentation will outline the innovative capabilities of AX-1, detail the regulatory hurdles faced, and share insights from our cooperative effort to establish testing protocols that ensure both efficacy and safety. Attendees will gain an understanding of how industry and regulatory bodies can work together to pave the way for future advancements in precision agriculture.

UAV-BASED VEGETATION BIOMASS ANALYSIS WITH RGB, THERMAL AND MULTISPECTRAL IMAGERY

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Key words: UAV, 3D model, cereals, oilseeds, grain legumes

Drones are versatile tools for data collection, offering the ability to carry a range of sensors such as thermal and multispectral systems. Many researchers have explored different applications of drones in agriculture. For example, thermal cameras have been employed to assess soil moisture levels and water balance of crops, while multispectral imaging and 3D modeling have been used to estimate crop yield and biomass (Crusiol et al. 2020, Li et al. 2022, Viljanen et al. 2018). Additionally, drones have been used in research for detecting and identifying various weed species in fields (de Camargo et al. 2018). The data gathered by these sensors can be further processed to generate field-specific maps, which farmers can use for planning plant protection or fertilization.

The aim of this research was to investigate how different cameras installed on UAVs can be used to estimate the amount of crop biomass. The key advantage of the study is the wide variety of crops and the use of multiple types of cameras to capture images from the crops during the growing season.

The study involved experimental plots from the Leg4Life STN project's field trials, which were in Haltiala, Helsinki, Finland. The area under study contained two different field trials, with a total of 72 experimental plots, each measuring 1.5 x 15 meters. The crops included wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.), rapeseed (*Brassica napus* L.), pea (*Lathyrus oleraceus* Lam.), and faba bean (*Vicia faba* L.). The data was collected during the 2021 growing season.

Aerial imaging of the crops was carried out using four different cameras: a RGB camera (DJI Phantom 4 Advance), a thermal camera (Flir Duo Pro R), and two different multispectral cameras (Micasense Rededge 3 and Mapir Survey3W RGN). Two different drones, the Tarot T960 and DJI Phantom 4 Advance, were used in this study to collect data. The aerial measurements of the crops were done seven times during the growing season. In the same time, crop biomass samples were collected. UAV flight missions were conducted at altitudes of 50 and 20 meters, with an 80% overlap between images. Orthomosaic images of the study area were created from all the images taken by the cameras and a 3D model was created from the RGB images. Various vegetation indices, such as the Normalized Difference Vegetation Index (NDVI) and the Modified Soil Adjusted Vegetation Index (MSAVI2), were calculated from the data produced by the multispectral camera.

The results explore how the values derived from spectral bands, vegetation indices, thermal values and 3D models correlate with the biomass measurements from the experimental plots. The 3D models height model showed better performance than the volumetric model, achieving a maximum correlation of 0.81 (R^2) for spring wheat, compared to 0.55 for the volumetric model. For the thermal camera, the highest correlation was observed with spring wheat, with an R^2 value of 0.8.

When comparing the correlations of individual spectral bands and vegetation indices between the two multispectral cameras, the results varied. Micasense showed the highest correlation with the Green, GNDVI, and RedEdge ($R^2 = 0.74$), while Mapir demonstrated the strongest correlation with the GRVI index ($R^2 = 0.89$). When combining spectral band data, the Micasense camera achieved higher correlations than the Mapir, with some models reaching $R^2 = 0.96$ through multiple linear regression. This is likely due to Micasense's greater number of spectral bands compared to Mapir. These findings align with previous research, suggesting that integrating data from multiple wavelength ranges and camera systems can improve the accuracy of models used for estimating crop properties.

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LOW-COST TELEMATICS SYSTEM FOR SMART FARMING

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Keywords: CAN bus, data measurements, data transfer, field operations, Node-RED, telematics

Aim of research

The primary goal of this research was to develop a cost-effective telematics system for agricultural tractors, featuring efficient and secure data transfer and processing methods. The system was designed to: 1) Measure operational data from agricultural tractors, 2) Transmit this data in real-time to a server computer, and 3) Enable data storage, monitoring, and subsequent analysis.

The development of this telematics system offers several benefits:

Systematically collect operational data from agricultural field operations

Enable operational analysis of fieldwork

Generate valuable input data for informed decision-making in farming

Provide data for modeling and simulating agricultural machinery and field operations

Research background

The increasing use of automation technologies in agriculture has resulted in a substantial increase in data generated from field operations (Paraforos et al., 2017). This data, produced by modern farm machines, has the potential to revolutionize farm management practices (Backman et al., 2019). Utilizing this data can contribute to the development of more sustainable and energy-efficient food production (Wolfert et al., 2017). Modern agricultural tractors, for instance, generate standardized operational data, which remains largely underutilized beyond tractor and implement control (Boland et al., 2021). Various farming implements also continuously gather and generate information about field conditions and crops (Steinberger et al., 2009).

Smart farming methodologies leverage this information from various sources, including tractor and implement data, precise tractor location, and field-specific information. Integrating weather data and enabling real-time analysis can further enhance the capabilities of smart farming applications in tractor operations. The ISO 11783 communication protocol plays a critical role in facilitating data exchange between tractors and implements (Boland et al., 2021), (Smart et al., 2022).

Experimental design and methods

The measurement system was developed by utilizing readily available, low-cost components. A raspberry Pi 3B+ single-board computer was used as the data logger and was selected for its compactness, affordability, and compatibility with add-ons and open-source software. The tractor data was recorded from CAN bus by using RSP-PICAN2 CAN measurement board which enabled the Raspberry Pi to connect to the tractor's CAN bus and provided access to operational data such as fuel consumption, engine load and draft force. The tractor location data was tracked with GPS-RTK2 Board and U-blox Multi-band GNSS antenna. The location and operational data were collected with the Raspberry Pi, processed with a python program, and send further with Node-RED program via Tosibox 175 remote connection device which created a secure 4G LAN connection for transmitting data to a server. The server machine is a Linux computer in which the received data was stored in a MySQL database and the server hosted a user interface for real-time monitoring of tractor's operation.

Open-source programming tools were employed to develop the measurement and data transmission system. Data collection and transmission were handled through a program created using Node-RED, which also facilitated the creation of the system's user interface. A MySQL database hosted on the server stored the collected data which was transmitted in real time over the network to the database server. The CAN bus data was processed with a python program that reads the CAN bus and decodes its messages. The output, a decoded CAN message in JSON string format, was forwarded to the json-node in Node-RED program, converting it into a JSON object. A function node was then used to add a timestamp and other variables to the message. Since each CAN bus message contained only a subset of parameters, multiple messages were consolidated into a single JSON object using a join-node, ensuring that each transmission to the server included all the necessary measurement data.

Field measurements

Field tests were conducted at the Viikki Research Farm of the University of Helsinki to evaluate the measurement system's performance. Data collection was done in different fields and operational data was recorded from two different tractors (Valtra N141 and Case Puma 160 CVX) during silage harvesting operations. Measurements were done successfully, and data was collected from both tractors across various tasks, including mowing, baling, and transporting silage. The implements were Krone Easy Cut 3210 CV mower, Welger Lely RPC 245 Tornado baler, and Krone RX 400 GL forage wagon. With the user interface, operations could be followed in real time by using the same local network that was created for sending and receiving the data. The recorded data stored in a database is easily available for different analyses. The operation of the tractor and forage wagon combination on one field is presented in Figure 1. The presented power corresponds to the engine power that was calculated from the measured engine data.

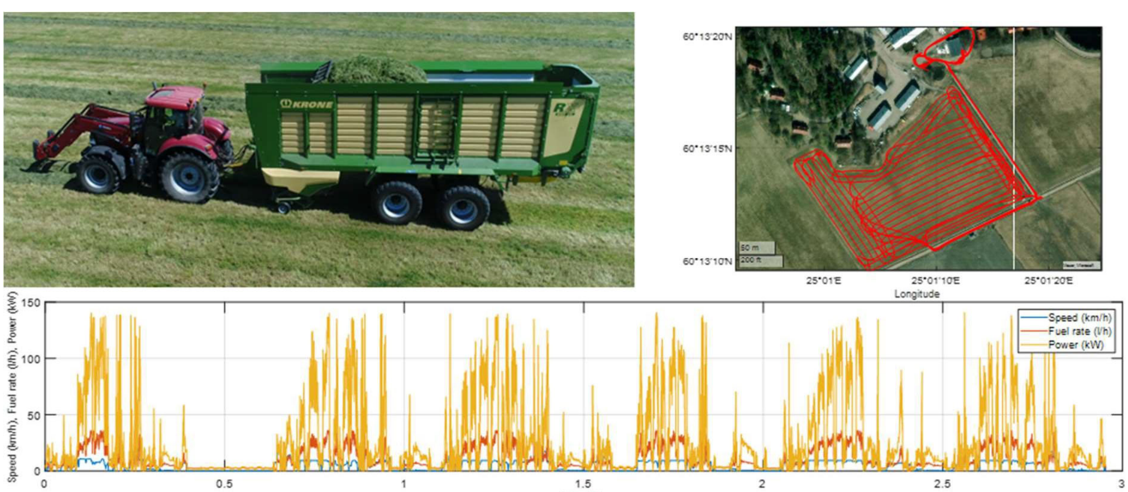

Figure 1. Puma 160 CVX tractor with Krone RX 400 GL forage wagon and operational data.

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INNOVATING SMART AGRICULTURE: HOW FINNISH FUTURE FARM IS SHAPING THE FUTURE OF FARMING

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Key words: smart farming, testbed, digital twin, virtual pedagogy, business accelerator

The Finnish Future Farm initiative, based within the Bioeconomy Campus in Saarijärvi, Central Finland, seeks to create a cutting-edge hub for smart agriculture by integrating advanced technologies, networks, and innovative solutions. This initiative aims to demonstrate economically viable and ecologically sustainable farming practices. Its key focus areas include the development of testing platforms for data generation, implementation of digital twins for processing agricultural data, education on data-driven management, and the creation of networks to foster innovative bioeconomy startup ecosystems.

Key initiatives within the Finnish Future Farm include the BioBoosters business accelerator, which supports the development of biobased businesses and agritech innovations, promoting international startup networks in these critical sectors. The FarmGuard project addresses the increasing importance of cybersecurity in farming, providing practical models to enhance farms' resilience against cyber threats. The Data Economy Incubator establishes a national center of expertise, fostering digital and innovative solutions for rural small and medium-sized enterprises (SMEs). Additionally, the Data Field Pioneers project focuses on overcoming challenges related to data transfer, storage, and ownership in the agricultural sector.

This abstract presents the ongoing results of these initiatives, providing insights into the innovative technologies and frameworks driving the future of smart agriculture.

The physical Tarvaala Smart Farm has been in action for three growing seasons and has joined the Nordic Testbed Network in 2022. The smart farm has been instrumented heavily including e.g. wireless soil sensors, drone measurements with three camera types, satellite images and soil scanning. Ground truthing has been done with extensive manual measurements. Yield and its quality have been measured with yield and NIR mapping.

The data has been stored in a dedicated Farmers Data Storage. Fair data economy has been demonstrated in connection of data intermediation to experimental data spaces.

Tractor navigation tests where the tractor was either fully equipped with navigation features or without them have been done. The effects of using the navigation have been evaluated in terms of compaction, fuel consumption, and economy mapping. Driver´s fatigue during the workday using the different equipment setups has been measured using heartbeat sensors.

The Tarvaala Digital Twin has been developed. Open access data from National Land Survey, Forest Centre, and Finnish Meteorological Institute have been utilized together with local measurements to build the basis of the DT. It is used for e.g. Precision Agriculture, scenario simulations, cybersecurity testing, and technology testing. For different users it is used for virtual training, e.g. to train farmers and students in advanced farming techniques through simulations. Environmental impact analysis is also done.

ENERGY CONSERVATION AND ENERGY EFFICIENCY IN AGRICULTURE AND SMART FARMING

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Keywords: Energy conservation, energy efficiency, smart farming, measures, 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. A large part of these emissions can be traced back to agriculture´s energy use.

The primary objective of this project was to identify and compile measures that can be used together with smart farming to reduce energy use in agriculture and/or increase yield, and therefore increase the yield per unit of energy input, and because of this 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.

Smart farming, i.e. that you digitally measure various constituent parameters in a system in agriculture and then with computer power analyse and control the processes with the aim of minimising energy use as well as the use of means of production to produce different types of food, has a very great potential to become very significant in agriculture. In agriculture, large amounts of energy are used both directly on the farm and indirectly to produce inputs such as fertilisers. It is therefore important that this energy can be used as efficiently as possible. Direct energy use on the farm includes e.g. fuel for field work and energy use in buildings and animal stables.

Energy conservation is usually defined as actions to reduce the end-use of energy. Energy efficiency is usually defined as using the supplied energy as efficiently as possible, i.e. using less energy to do the same work or produce the same product. This together means, in a first step, mainly behavioral changes, i.e. things that do not require an investment, such as e.g. improved planning of the logistics around field work, the use of traction power, the use of lighting and ventilation in animal stables as well as the cleaning of ventilation devices, radiators/elements and other things where heat or cold is transferred. In a second step, it means that new technology is put into use, such as e.g. for the optimisation and control of processes that use energy in such a way that they are only in use when they are needed. Processes are controlled to use only the energy needed for the work to be done, and this applies to precision control in both crop cultivation and animal production. It is in this last step that smart farming comes in.

Smart farming has a very large potential for making agriculture's energy use as efficient as possible in a number of areas. During fieldwork, tractors and harvesters can be controlled with GPS so that the working width is used optimally, engines and gearboxes can be controlled for the lowest possible fuel consumption, and the supply of fertilisers and pesticides can be controlled according to the potential and needs of the soil and crops in each part of the field. In irrigation, the water supply can be controlled according to the needs of the plants, the soil's water saturation and water-holding capacity in each part of the field, and that the water supply and spreading times can be controlled according to weather forecasts and their certainty. When drying grain, the dryers can be controlled by the moisture content of the material, the temperature and humidity of the outdoor air, as well as weather forecasts and crop forecasts, for optimal use. The boilers can be controlled according to the needs of the dryers. In animal production, feed distribution and feed composition can be controlled according to the needs of each individual animal. The animals' health status and feed consumption can be recorded and abnormalities, such as signs of illness, reported. During milking, milk quantity and milk

composition can be recorded and form the basis of each specific animal's feeding. Heating and ventilation of stables can be controlled according to the needs of the animals, usually piglets or broilers, weather conditions and weather forecasts. If there is underfloor heating with separate loops, e.g. for the sows and each piglet stall, the temperature can be optimised for each type of animal according to its needs. The heating can also be controlled in a similar way for agricultural homes and farm workshops with underfloor heating so that the heat supply is as optimal as possible. The lighting in animal stables, farm workshops, homes and more can be controlled according to attendance, needs, access to daylight and 24-hour rest. Logistics software can be used to optimise agricultural transport.
There are thus a large number of different areas of use for smart farming in agriculture to conserve energy and make farming more energy efficient. Together, they have great potential to really make a difference.

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AGRISUN – COOPERATION BETWEEN SOLAR POWER AND GRAIN PRODUCTION

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Keywords: Renewable energy, solar energy, grain production, arctic agriculture

Three rows of ground-mounted solar panels have been set up in an area at NMBU, Ås, Norway. The goal of the installation is to investigate whether such ground-mounted solar panels can work together with grain production.

There is a worldwide need more renewable energy and solar power is one of the fastest growing energy sources. Solar panels can be scaled up and down, from small installations on private homes to huge installations for large-scale electricity production. The question is where these large facilities will be built, when we are not going to destroy untouched nature. Cooperation between solar power and other industry or production is an attempt to solve that dilemma. Ground-mounted solar cells are coming full circle in large agricultural nations such as Germany. Such solar panels are also on their way to Norway, but here we have other challenges related to both area and solar conditions. There are special challenges related to frost and snow and the solar position on the sky is high in the summer and very low in the winter. We have few developed areas where solar systems can be incorporated, we have a lot of untouched nature and we have little agricultural land (about 3% of arable land). In addition, we have a national regulation that you cannot use the land for anything other than agricultural production if the production is negatively affected by it.
In the present project we will test whether the solar panels negatively affect grain production in the installation in Ås, Norway.

The solar panels that are now being installed are vertical. It is the very latest technology with functioning solar cells on both sides of the panel. The panels absorb the sun's rays from the east in the morning and from the west in the afternoon. In the middle of the day, when the sun is highest in the sky, production will be somewhat lower. Then the shadows will also move, so that the arable field does not remain in shadow for too long in one place. The panels are now being tested in an area for grain production. This is partly because grass and grain are not as sensitive to such so-called wandering shade as other plants.
This knowledge of plants is very important when the solar system is to be tested. The panels have been set up in collaboration with NMBU's sustainability arena Smart Farming, and REALTEK works closely with the Center for climate-regulated plant research (SKP). The research here will involve many of NMBU's areas, and will benefit from the university's expertise in grain, grass, soil research, sensors and technology.

The solar panels are to be included as part of NMBU's laboratory teaching for students. There is already great interest in the project among the students, who are planning master's theses in the field. Several master's theses from NMBU have already modeled how the solar panels will affect plant production. In a simulation of grass production, it was found that grass production is expected to be 90-97% (4m – 20m row distance) compared to area without PV (100% including uncertainties). This will now be tested in practice. If it succeeds, it will be an additional source of income for the farmers and an important source of more renewable energy in Norway - without destroying untouched nature.

SMART FARMING RESEARCH AT AU

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Key challenges facing the agro-food system include improving production efficiency, coping with climate change, ensuring sustainability and resilience, providing ecosystem services, empowering rural areas and supporting policies, and sustainable and competitive agri-food industry along the value chain, and development for bio-based products and processes (circular economy). This must be addressed by sustainable intensification, including embracing smart farming technologies and methods. By definition, Smart Farming will extend the current Precision Agriculture concept enhanced by context, situation and location awareness, data-rich ICT services, data integration, data communication, standardization, signal processing, automation technologies, high-level automation planning and control, path/operations optimization, etc. Specifically, the concept will extend to real-time assisting features to include intelligent assistance in implementation, maintenance and use of the technology.

Key is the paradigm shift from scaling of technology items to intelligent optimization of technology items in agriculture with mobile/cloud computing, location-based monitoring and management, IoT, Big Data, etc. reaching Smart Farming/Farming 4.0 equivalent to Industry 4.0 and cyber physical systems. Smart Farming research at AU involve linking advanced information and communication technology with high level control of automation and smart processes, specifically planning, operations optimization, and system evaluation. A key challenge in Smart Farming involves valuing the large amount of data acquired in digital farming as means to increase adoption. The Smart Farming research also include facilities like an automation and mechatronic laboratory, livestock and field experimental facilities and wireless sensor network systems for field monitoring. Examples of specific research activities and projects include:

- ***EU ET4D: Development of a practical data management system with embedded sensors for improved environmental management and transparency of dairy farming.*** Validate and expand a data management system (DMS) with embedded sensors for on-farm use to collect and process data from diary barns.
- ***AgroRobottiFleet: Agricultural robotic fleet communication and collaboration for complex arable operations.*** A fleet collaboration system, enabling & allowing multiple autonomous agricultural robots to collaborate with each other as well as human operated tractors & machinery.
- ***EU SPADE: MULTI-PURPOSE PHYSICAL-CYBER AGRI-FOREST DRONES ECOSYSTEM FOR GOVERNANCE AND ENVIRONMENTAL OBSERVATION.*** Developing an Intelligent Ecosystem to address the multiple purposes concept of deploying unmanned aerial vehicles (UAVs alias drones) in sectors of agriculture, forestry, and livestock.
- ***EU COMMECT*. *Bridging the digital divide and addressing the need of Rural Communities with Cost-effective and Environmental-Friendly Connectivity Solutions.*** COMMECT develop a green, purpose-driven digital infrastructure, addressing the needs of multiple end-users, while minimizing energy consumption and maximizing ICT resource utilization in the green and digital transformation targets.
- ***H2020 PATHWAYS*:** Pathways for transitions to sustainability in livestock husbandry and food systems. The implications of agro-technologies, specifically digitalization and smart technologies.
- ***EU LivestockSense - Enhancing environmental sustainability of livestock farms by removing***

barriers for adopting ICT technologies. Economic and environmental viability of livestock farms through application of advanced information and communication technologies and to identify/remove social barriers for technology adoption to achieve a wider use of ICT on farms.

- ***SOLGRAS**: **Optimization of field traffic to ensure soil protection and efficiency: the case of grass harvest***. Decision support system (DSS) for optimizing traffic during grass harvest operations that will make full use of available topography, soil, climate, and machinery data at the field scale.
- ***EU Internet of Food & Farm 2020, IoF2020*,** Deployment of IoT solutions in European agriculture through integration of advanced IoT technologies across the value chain, demonstration of multiple IoT applications at scale and in a usage context.
- ***SqM-Farm (Square Meter Farming)*** Artificial Intelligence and Automated Big Data for Location Specific Decision Support for Agriculture.

POSTER

GIS-BASED ASSESSMENT OF OPERATOR STRESS: HART RATE ANALYSIS IN SMART VS. MANUAL FIELD OPERATIONS

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Keywords: heartrate, smart farming, ergonomics, GIS

As automation becomes increasingly prevalent in agriculture, the well-being of operators has emerged as a central consideration in the design of tractor cabs. Modern tractors are equipped with advanced features that reflect the fact that operators are spending long hours in the cab and are subjected to various stress factors. Maintaining optimal working conditions can significantly assist the farmer in keeping pace with the demands of extended workdays.

Achieving optimal conditions requires improvements in working environments as well as a thorough understanding of the related stress factors and their causes. A good indication for stress is heart rate since the human heart rate can increase within 1 to 3 seconds in response to provocation. However, the time delay in stress response is influenced by multiple factors.

At the Jamk Institute of Bioeconomy in Tarvaala, Finland, we had the idea of mapping heart rate as an indicator of differences in Smart Farming practices. The goal was to correlate heart rate fluctuations with specific field locations and operational tasks, such as working in the headland area or managing complex actions like looking backward while adjusting the implement simultaneously.

To achieve this, we equipped an operator with a heart rate monitor to observe how heart rate (HR) and heart rate variability (HRV) fluctuated during the sowing season. The observation period spanned one week prior to sowing and one week afterward to establish baseline HR and HRV values during rest, exposure to stress, and to assess the effects on recovery. In this presentation, our analysis is focused on the changes in HR at specific locations within the field.

The test field was divided into two equally sized and shaped areas, each measuring 4 hectares. On one side, the operator had access to a full suite of smart farming applications, including automated steering, headland turning, and variable rate technology. On the other side, the operator performed all tasks manually, using the same equipment.

Initial observations from the heart rate maps indicate that the plot equipped with smart technologies resulted in lower stress levels for the operator. Some distinct patterns of elevated heart rate were observed, particularly in the headland areas and near forested islands where the operator had to reverse and adjust the implement manually. However, further analysis of the combined HR, HRV, and ISOBUS data is needed to identify the specific causes of stress accurately. This will be further investigated in future research.