ABSTRACT

Precision agriculture aims at providing ICT tools that allow farmers to micromanage and make detailed plans for the work to be done. Solutions have existed since the 1980s but have not found widespread adoption. With the rapid development of low-cost open-source drones and advances in camera technology the last couple of years, we propose a system for monitoring crop development by taking pictures and planning agricultural activities using drones that can be controlled beyond visual range using a standard web application. The system was evaluated in terms of its perceived usability and a comparative measure on the time it takes to cover an area by foot comparing with using drone captures. We found usability of our system to be high and calculated the coverage time of the drone to be 3 times faster than manual effort. This will allow the farmers to schedule activities in a more informed way, saving time first and resources.

Author Keywords
drones, aerial photography, precision agriculture, precision farming, crop specific site survey, UAV, decision support system

INTRODUCTION

Using drones or unmanned aerial vehicles (UAVs) in agriculture initially started back in the early 1980s for crop dusting[3]. Since then the UAVs have proliferated in applications of aerial photography to imaging of crop fields to assist with crop production management [7, 1]. The agriculture industry has grown and is seeking advanced ways to control and monitor crops, thus the term Precision Agriculture/Farming (PA/PF) has emerged as a farming management strategy. PA was initially used as synonym for automatic steering systems in the early 1990s. Current PA applications collects and process data from multiple sources for improving the understanding and management of soil and landscape resources in order to handle crops in a more efficient way.

Even though solutions for PA exists today, widespread adoption has not been catching on. There can be numerous reasons for this including that PA is not equally suited for all types of crop [2], but also that the systems available are too complex or more advanced than needs to be for the utility of the farmers in their day to day work.

We propose a low cost, low entry barrier system for monitoring crop development and planning agricultural activities which can be used as part of a larger PA framework. This will be achieved by using drones to take pictures of farm parcels.

The problem of proficiently monitoring crop development in modern industrial agriculture increases with the size of the farmland. For this reason we established a partnership with Ryegaard og Trudsholm Godser[1] which operate an area of 1000ha with a yield of 850ha per year. Their main crop is wheat and by their own needs they are already trying to develop ways to detect and respond to crop threats in more efficient ways.

For planning and crop-development purposes we think drones could be useful within organic agriculture and permaculture as well.

RELATED WORK

The usage of UAV is not new, it have been in production since the early 1900’s. The technology was initially driven by military applications in World War I and expanded by World War II. The military UAV applications are more advanced than the civilian applications. [5]

The civilians applications are likewise evolving in the same directions, due to their rapidly utilisation in various applications such as firefighting assistance, police observations of civil disturbances and scenes of crimes, reconnaissance for natural disaster response, border security, traffic surveillance and precision agriculture [4, 5, 8].

Primicerio et al utilises unmanned UAV (“VIPtero”) equipped with camera for site-specific vineyard management. Normalised Differential Vegetation Index (NDVI) values acquired by the Tetracam ADC-lite camera mounted on “VIPtero” were compared to ground-based NDVI values measured with the FieldSpec Pro spectroradiometer to verify the precision of the ADC system. The vegetation indices

1 http://www.ryegaard.dk/
obtained from UAV images are in excellent agreement with those acquired with a ground-based high-resolution spectroradiometer.[6]

Merz et al addresses the design of an autonomous unmanned helicopter systems for remote sensing missions in unknown environments. Focuses on the dependable autonomous capabilities in operations related to Beyond Visual Range (BVR) without a backup pilot by providing flight services. Utilizes a method called Laser Imaging Detection and Ranging (LIDAR) for object detection which are applicable in real world development.[5]

Barrientos et al. utilises a team of UAVs to take pictures in order to create a full map, applying mosaicking procedures for post processing and automatic task partitioning management which is based on negotiation among the UAVs, considering their state and capabilities. Thus they combine a strategy which encompass multi robot task planning, path planning and UAV control for the coverage of a crop field for data collection. [1]

Table 1 compares the industry UAVs with the research-based projects. It emphasise on product costs and survey speed. See the table on page 3.

The parameters mentioned in the table description:

Project Name Identification name of industry or research project.
Frame type The type of UAV — fixed or and rotary wings
Retail Price The real product price. How much the product will cost from the beginning to use stage.
Control interface Is it controlled by a remote, pilot, autonomously or continuous trajectories, and what systems is utilised to control them.
Imaging specification Is utilised with photogrammetry that analyses images providing information regarding the recognition and identification of objects and their significance with respect to the particular application. And hardware which describes cameras in hardware level.
Coverage per trip How long it takes to cover a specific area.
Storage The type of storage used to store the data (images). 2

The parameters in “Price” and “Survey speed” are not completely up-to-date, accurate or comparable. There are four factors that affect the survey speed: 1) Camera angle of view, 2) Drone height, 3) Requested image overlap and 4) Drone cruise speed.

Most companies (except Trimble) did not provide information on the value of the factors used for calculating the survey speed. In Denmark authorisation must be gained to fly above 100m.

Regarding price it should be noted that we are not including development costs for AgriDrone. One of the main advantages of the commercial UAVs compared with our Open Source UAV is the camera specification and the survey specification. As the table shows, the commercial UAVs are superior in those categories, but comes with an expensive price compared to our UAV which is more cheaper and adequate to carry out the essential tasks as the commercial products.

Another notable difference is that most of these other products are using a fixed-wing design. This implies that they have to be pushed into the air on launch, either by hand or by catapult, and do a ‘crash landing’ at the end of the mission. Conversely in our prototype we have a rotary wing frame which enables us to do vertical take-off and landing (VTOL). VTOL enables the user to initiate multiple aerial missions without low-level user involvement in takeoff or landing.

**Main Contributions**

As it will be stated in the interview section, farmers have numerous tasks of routines to carry out in their daily activities. The farms are really huge, thus it takes time to plan for the tasks. However the solution presented enables the farmers to monitor and investigate the area in a sufficient way compared to current solution where they have to accomplish the tasks manually by going out and checking each place, which consumes a great deal of time.

Below we list some of the main features that our solution contributes which none of the other projects offer.

**GSM** Our solution provides communication over the GSM data network. This allows for true remote control beyond visual range.

**LPIS** Our solution integrates with the Danish implementation of the EU Land Parcel Information Systems to present a custom overlay of the fields belonging to the farmer. In Denmark more than 300,000 fields are registered in LPIS. 3 In all of EU this figure is 135 million fields belonging to 8 million farmers. 4

Our systems contributes and facilities the farmers daily work. It enables farmers to operate the UAV on the different devices that have internet access thus providing flexibility.

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<table>
<thead>
<tr>
<th>Project Name</th>
<th>Frame type</th>
<th>Retail Price [EUR]</th>
<th>Control interface</th>
<th>Imaging specification</th>
<th>Coverage per trip</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>QuestUA V200</td>
<td>Fixed Wing SkyCircuit autopilot</td>
<td>18000</td>
<td>Custom made laptop and RC</td>
<td>Hardware Modified Lumix LX5 10MP</td>
<td>100Ha (1km²) in 7-15 min</td>
<td>SD card</td>
</tr>
<tr>
<td>QuestUA 300</td>
<td>Fixed Wing SkyCircuit autopilot</td>
<td>20000</td>
<td>Custom made laptop and RC</td>
<td>Hardware Tetracam MCA 6</td>
<td>100Ha (1km²) in 7-15 min</td>
<td>SD card</td>
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<tr>
<td>eBee</td>
<td>Fixed Wing</td>
<td>8800</td>
<td>eMotion 2 software for desktops and NoteBooks</td>
<td>Hardware 16 MP Camera Sony NEX5R Photogrammetry Postflight Terra 3D-EB powered by Pix4D</td>
<td>100-1000Ha (1-10 km²) in 45 min Resolution: 3 cm/pixel</td>
<td>SD card</td>
</tr>
<tr>
<td>Swinglet CAM</td>
<td>Fixed Wing</td>
<td>7800</td>
<td>eMotion 2 software for desktops and NoteBooks</td>
<td>Hardware 16 MP Camera Sony NEX5R Photogrammetry Postflight Terra 3D-EB powered by Pix4D</td>
<td>150-600Ha (1-6 km²) in less than 60 mins Resolution: 3 cm/pixel</td>
<td>SD card</td>
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<tr>
<td>CropCam</td>
<td>Fixed Wing</td>
<td>5200</td>
<td>Custom made software for windows 98</td>
<td>Hardware 12MP Pentax Optio A40</td>
<td>64Ha (0.64km²) in 20 min</td>
<td>SD card</td>
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<tr>
<td>Trimble UX5</td>
<td>Fixed Wing</td>
<td>33100</td>
<td>Mission Planning</td>
<td>Hardware 16.1 MP mirrorless APS-C</td>
<td>100Ha (1 km²) in 31min Resolution: 2.4cm/pixel</td>
<td>SD card</td>
</tr>
<tr>
<td>Trimble X100</td>
<td>Fixed Wing</td>
<td>less than UX5</td>
<td>Mission Planning</td>
<td>Hardware 10 MP compact</td>
<td>100Ha (1 km²) in 41min Resolution: 3.3cm/pixel</td>
<td>SD card</td>
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<td>AgEagle (early 2014)</td>
<td>Fixed Wing Piccolo autopilot</td>
<td>5100</td>
<td>Piccolo Command Center</td>
<td>Photogrammetry with Ag-Pixel</td>
<td>240Ha (2.4km²) in less than 60 mins Resolution: (up to 65 kmph) 3cm/pixel</td>
<td>SD card</td>
</tr>
<tr>
<td>MetaVR</td>
<td>Fixed Wing APM2.5 autopilot</td>
<td>MissionPlanner for Windows</td>
<td>Hardware Canon EOS M Photogrammetry MetaVR Terrain Tools extension to ESRI ArcGIS</td>
<td>Resolution: (40 kmph) 1cm/pixel</td>
<td>SD card</td>
<td></td>
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<tr>
<td>Aeryon Scout</td>
<td>Rotary Wings custom autopilot</td>
<td>2200-3600</td>
<td>custom tablet</td>
<td>Hardware Photo3S-NIR Photogrammetry Optional supplementary product powered by Pix4D</td>
<td>(up to 65 kmph)</td>
<td>on-board and sent to base station by radio link</td>
</tr>
<tr>
<td>MicroDrones</td>
<td>Rotary Wings custom autopilot</td>
<td>from 8000</td>
<td>GPS Waypoint navigation system</td>
<td>Photogrammetry powered by Orbit GT</td>
<td>Resolution: 1-7cm/pixel</td>
<td>SD card</td>
</tr>
<tr>
<td>VIPtero (modified Mrokopter Hexa-II)</td>
<td>Rotary Wings custom autopilot</td>
<td>4000</td>
<td>koptertool</td>
<td>Hardware Tetracam ADC-lite camera</td>
<td>0.5 ha. in 7.5min 5.6 cm/px ground resolution at a flight height of 150m.</td>
<td>micro SD card</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Rotary Wings</td>
<td>custom navigation computer</td>
<td>Hardware RICOH GX200 digital camera with zoom leRICOH GR Digital III digital camera RICOH GR Digital III camera mod. for NIRFLIR Photon 640 thermal imaging camera GNC System (LIDAR)</td>
<td>Resolution:</td>
<td>SD card</td>
<td></td>
</tr>
<tr>
<td>AR100 Platform</td>
<td>Rotary Wings</td>
<td>custom backstepping+FST controller</td>
<td>Hardware commercial zoom digital camero be tilted up to 100 deg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AgriDrone</td>
<td>Rotary Wings APM2.5 autopilot</td>
<td>600</td>
<td>web-application</td>
<td>Hardware AeduCAM next 25mn Photogrammetry NDVI capable with DroneMapper or Ptx4cloud 75% image overlap</td>
<td>22ha in 12-20min (at 36 to 20 km/h) Resolution: 2cm/pixel</td>
<td>web-application (radio link)</td>
</tr>
</tbody>
</table>

Table 1: Comparison of commercial industry UAVs with research based UAVs based on the costs and the survey speed. The last 4 projects have been used in research projects on precision farming specifically.
METHOD
Work in the agriculture sector is very much a situated experience and the work required at one farm might not be the same as the work required at another farm at a given day. Because of this nature of situated variability, we found it important to select some research methods that allows us to catch some of this situated variability in a feasible way.

To gain an understanding of the domain, we initially made a literature survey and brainstorming session. Based on this we were able to formulate an interview guideline that we used and made telephone interviews with farmers to get more information about what work scenarios play out in their domain, what factors influence their work and how they envisioned the use of drones could be a part of their daily work days.

Grouping together some of the things we found out during our interviews, we quickly proceeded to make a low-fidelity prototype — a paper prototype that simulates the software running in a browser on a tablet device. Experience prototyping was used to evaluate our paper prototype together with contacted farmers, and we filmed the session to catch the subtle interaction taking place. This feedback was then used to refine and implement our prototype into an early product design.

Final evaluation was done as a usability study together with a quantitative measure, namely a measure for the time it takes to do an aerial survey compared against the time it would take the farmer to make the reconnaissance by foot and direct observation.

THE DESIGN OF THE PROTOTYPE
Our design process was iterative and comprised around 8 weeks in total. In this period we gained a broad understanding of Precision Agriculture, Arduino-based drones and we were able to design and evaluate a prototype system.

Semi-structured Interviews
With the domain in hand, we prepared a short interview and then got in contact with different people involved in Agriculture in Denmark and located within 100km from ITU. This geographic restriction allowed us to visit the farmers and try out our prototype in a situated context.

One of the first things we noticed was that everyone we asked, knew and were enthusiastic about the potential of drones for agriculture. This perhaps reflects the position of this category of technology on the Gartner Hype Cycle5.

The interviews were designed to give us some key information about current working procedures, determining main challenges, and general conditions for work. While talking over a telephone was not enough to get a full picture of the scenarios of the farmers, it provided us with a starting point for scenario analysis. Second part of the interview was designed to be a brainstorm on how they perceived that drones could be applied within their work.

The farmers seemed to be in consensus that the development of drones within agriculture should start with large farms (> 500ha) since tenant farmers of small farms usually will be able to maintain an overview of the state of the farm individually.

In Agriculture, not one day is the same
A common answer we got to the question “What is a normal day for you?” was that they all replied that not one day was the same. In Agriculture, the season, climate, growth states, nutrient levels as well as human and facility resources all played together and affected the required work and ultimately the crop-yield. Examples of this include: 1) If wind is strong, spraying with pesticides is prohibited, therefore spraying usually takes place 05.00 to 11.00 and 16.00 to 20.00; 2) If ‘quickspots’6 develop on the field, they must be detected and removed quickly to protect the crop; 3) If crop is mature and climate conditions are dry, sunny and windy, then harvest can take place; 4) If parts of a field are covered in snow, then spraying with fertilisers is prohibited; 5) When a tractor has been loaded with pesticides, fungicides, herbicides or fertilisers, it has to run until tank is empty, it is not advised to keep remains in the tank for next run; 6) If grasslike weed have developed to two leaves, then they have to be sprayed to avoid nutrient loss from the desired crop; 7) If wheat have developed four leaves, then it has reached high maturity and can soon be harvested.

Another thing that came out of the interviews was that in relation to the planning and accounting/documentation work that takes place on the farm, being able to use maps with the proper ‘Markblok’ field parcel overlay was crucial to the usability of the system. The Danish Markblok database is a national implementation of the EU regulated Land Parcel Information System (LPIS) initiative.7

We identified following application areas for drone-based ICT systems within Agriculture based on our interviews:

- Biomass estimation
- Weed detection
- Nutrient estimation
- Farmland aerial monitoring, task management and communication
- Facility monitoring and management

Aside from these, application areas such as detection of nitrogen stress, water stress, pests and crop diseases have also been mentioned in literature [1]8 and researchers from KU are currently working on a project on weed detection and drones9.

Paper Prototyping

5 http://diydrones.com/profiles/blogs/where-drones-sit-on-the-gartner-hype-cycle
6 quickspots are small areas of weed on the field that is expanding quickly
8 In Denmark, the Danish AgriFish Agency under the Ministry of Food, Agriculture and Fisheries is the agency responsible of implementing the LPIS nationally.
http://ing.dk/artikel/droner-spotter-ukrudt-i-danske-marker-161076
We designed our system so that a web interface is the main point of interaction. The drones base stations, battery recharging requirements and image transfer and post-processing should happen ‘behind the curtains’ by the system requiring little user involvement. To lower the entry barrier (increasing the rate of technological adaptation), we decided to mimic the interface to something that the user is already familiar with - Google Maps. Figure 1 shows our initial mockup of a Google Map interface.

![Google Map mockup](image1.png)

Figure 1: Google Map mockup used for early paper prototype

Then we printed and used scissors and pencil to create a paper-based mockup of the UI and all the interactible elements down to 3rd level of interaction. See figure 2

**Experience Prototyping**

We used experience prototyping as an evaluation method of our paper prototype. This was carried out over the course of an hour in which the user was given the prototype and told to imagine that this was a browser window on a touch-enabled tablet computer. We assumed the role of silent facilitators of interaction giving the user the space to conceptualise the system in his own words. See figure 3

**Evaluation**

The user found the UI pretty intuitive and easy to utilise. We had forgotten to draw the Markblok boundaries on the map and that was a point of critique because this is a necessity to be able to select which farmland to perform an action on.

Based on the feedback we also decided to deprecate our concept of Task Management from the GUI. We had originally conceived this as a task management component for planning human resources, but during the experience prototyping it quickly became apparent that this was not a use case. The argument is that rather than trying to augment the captured data with a layer of task management logic, it would be better to remain transparent to the captured data and provide APIs that can be utilised in tractor GPS computers, boomspray controllers or other peripheral computer-controlled farm equipment.
The Final Design
The system consists of a web-based application that provides all the information that is needed to carry out the drone operations on the field via its web-interface. The web-based application provides a communication link between drones and user via GSM/GPRS connection to the web interface.

Figure 1 illustrates the main idea behind the implementation. We have 6 main parts in the application. The drone which is equipped with an APM2.5 Arduino board, uBlock GPS module, RC telemetry link, GSM/GPRS module that implements the necessary Mavlink communication protocol\(^\text{10}\) and a Sony NEX5R modified NIR for NDVI\(^\text{11}\). The second layer is the Web application which controls the communication between the integrated web-based application and the flying drone. Using GSM module, the drone sends the status information via the GPRS connection to the web application, then the web application gathers and process the information it gets and do other steps according to the tasks (e.g. sends HTTP post with the data to the interactive web-based map). The third layer we have is the web-based interactive interface from which the stakeholders can monitor everything. The fourth layer is database, where we store all necessary transaction information. The fifth layer is the integration with opensources.com API to provide a base map for our interface, together with an overlay map of all danish farm parcels (provided by the Markblok database of Danish Agri-Fish Agency\(^\text{12}\)). The sixth layer integrates a cloud or dedicated server based app for photogrammetry converting our drone captures into orthomosaics that can be used for analysis.

Flying the Drone
The drone model: 3DR DIY Hexa Copter. It was pre-build with main features: camera, gps, telemetry, autocontrol board, arduino APM board. To this concept we added a GSM module with the SIM card, which extended the possibilities for the drone. On the arduino based GSM module we implemented and integrated a service, which can communicate with our main web application on top of Google (We found two similar but currently defunct projects\(^\text{13}\)). The connection was made through GPRS and HTTP json based commands. The flow of the drones operations are illustrated by this sequence:

1. The drone receives the GPS coordinates from the web-application and a trigger to start mission
2. Starts the motors/engine
3. Fly to specified GPS coordinates
4. When reaching the coordinates, drone starts taking pictures at the user-specified setting
5. Drone goes home to base station
6. Captured images are sent to web application over WiFi link for post processing

The same workflow applies to the Scheduling mode as well as the instant-command mode.

Web Application
The web-application in this project takes the most valuable position. It controls the communication between web interface and the flying drones. All requests and responses are

\(^{10}\)https://pixhawk.ethz.ch/mavlink/
\(^{11}\)Open Source Single Camera NDVI http://flightriot.com/vegetation-mapping-ndvi/
based on JSON. The request is sent through the HTTP protocol. The application is hosted using Google app engine, it gives us 99.9% system up-time, and ensures minimum response time. We provide small API in the application, which allow us to connect our application to another third party applications like periphery farm equipment. It stable and recognises (response) only due to predefined commands: get status, send gps coordinates, get pictures, get biomass index at coordinate, check battery and etc.

**Interactive web-based map application**

After the interviews and the evaluation of the paper prototype we decided to change the following:

**Status page** The status page is the main page and allows user to instantiate new missions quickly. Either as a scheduled event to be executed later or an instant event to be executed now.

**Schedule page** Our implementation provide the functionality where you are able to schedule drone to fly to specific place at certain date and time.

**Concept of Task** We changed this from our original post-flight human-centered notion of task planning to a pre-flight drone-centered notion of task planning.

**LPIS/Markblok** Integrating with the national database of farmland boundaries allowed us to provide a way of user interaction where the could just click to select a given field instead of drawing custom polygons.

**Multiple fields and actions** We enabled user to specify multiple fields and actions for single missions.

The system is compatible with multiple devices. So the system can be accessed from smartphone as well as from computer or tablet. Nowadays mobile phones are one of the most widely used devices in the world, this is the main reason why we decided to make a browser-based system. Figure 5 shows the final design of the web interface.

**Challenges encountered in development**

Below we list some of the challenges we encountered in the process of developing our system.

**Calibration** We had to perform a live calibration on our compass. It was difficult to find the compass calibration position because no positions were shown the same applies to calibrate accelerometer.

**Compassmot** This part came us a surprise. It was an onerous task to carry out. It required us to disconnect the propellers, flip them over and rotate them one position around the frame. And simultaneously we had to push the copter down into the ground while the throttle is raised i.e. the propellers are rotating.

**Propellers** During first assembly we didn’t know that propellers of the drone are different and they have to be assembled in special way, thus we encountered take off issues because of the propellers pulling down the wrong direction, while we thought that it is a calibration issue.

**Battery challenges (charging problems)** We had to manually replace and solder the connection cables on the battery because they weren’t compatible. And had difficulties with charging the batteries.

**GSM/GPRS module** To fully accomplish communication between APM2.5 board drone and web-application we suppose to connect and integrate GPRS shield on APM2.5 board. We did Arduino UNO communication channel with GPRS shield and web-application, but it was challenging to move everything on APM2.5 board. Firstly, GPRS shield requires 5V to work with. It was difficult to find the 5V pin also on APM board. Moreover we had problems connecting to the internet using some GSM providers SIM cards. Also we could not figure out how to transfer Arduino UNO based implementation code to APM2.5 board, the compilation were failing due to missing different libraries.

**EVALUATION**

The challenges that we encountered during this project meant that we could not in effect implement the fully working system as per our design. In order to do the evaluation anyway we used a version of the ‘Wizard of Oz’ method in which we asked the user to imagine that interacting with the web interface would control the drone.

One of our goals was to have an intuitive interface so that the barrier of entry could remain low. Based on the evaluation from our test person, this goal appears to have been achieved. Another of our goals was to integrate a communication link between the GSM module and our web server. As mentioned before we could actually get this to work in testing with the Arduino UNO board, but porting it to the APM2.5 wasn’t successful. The third goal that we wanted to show was that utilising a drone can be a big timesaver for the farmer. Our test person informed us that, if it should be very thorough, then inspecting a 20ha field would take him 3 hours. By calculations based on an altitude of 100m and image overlap of 75%, then it would take the drone 12min at top speed (36kmph) and 20 min at a cruising speed of 20kmph. After capturing the data we estimate another 30 min in post-processing of the images on a server to produce the orthomosaic maps at 2cm/pixel resolution which the user then can inspect. This means the drone-based solution is approximately 3times faster than the current method. The bottleneck is likely to be the rate at which we can transfer the images off the drone to the cloud for processing and this processing time increases when the number of images increases.

Now, because we have only evaluated the system with one test person we do not have enough data to make a very strong and compelling argument. At Ryegaard there are 12 fulltime all-year employees. Our test person was one of these employees. Their organisational structure is very flat meaning that they are all involved in field inspection tasks when needed. That they are all exposed to the same type of field inspection tasks is a good indicator that they will all find our system equally user friendly as our main test person did.

As part of a more general discussion, it is also worth noting, as our test person commented. That the real difficulty faced
is in knowing how new measures of biomass or weed density should be translated into actual measures of the amount of chemicals to use on the fields. With precision farming and the ability to look at the field with greater variability, then we are also able to spray chemicals in matching variability, but initially this does not necessarily entail that less chemicals will be used - only trial and error will lead to an understanding of how chemical usage can be reduced in the long run. This is important because, in light of the interviews, the value of the drone system is proportional to the value that the farmer can save by adopting the drone system. Saving human resources is one thing, but being able to use the information captured in a way as to save costs on chemicals is probably what is going to be the crux of the argument.

In Denmark the rules and regulations for flying with drones are governed by Trafikstyrelsen in §BL9-4[^13]. Specifically it mentions that operation must be more than 150m away from residential areas and main roads, 5km away from aerodromes and military areas, and at a maximum height of 100m with full pilot control override at all times during flight. Exemptions can be granted for research and commercial applications. We think that as imaging technology becomes more advanced, the desire to go above 100m in altitude is going to increase because people would want to capture bigger areas faster.

**FUTURE WORK**

During the research and the user-participation, many ideas came to us. We will list them here.

Suggestions for improvements based on Farmer:

1. Place multiple waypoints on map
2. Integration with Trimble GPS control system on tractors

**Copter**

The 3DR Hexa-C Copter that we are using has a maximum speed of 36kmph. The performance of a drone has a lot to do with the aerodynamic properties caused by the physical design of the drone. 3DR has since we started this project, deprecated the HexaCopter model and replaced it with the Y6 model which is a tricopter frame with rotors on both sides. They have also provided a guide to do this modification oneself[^15]. Use the 3DR Iris QuadCopter[^16] or some of the mini-UAV quadcopters available.

**Photogrammetry**

Dronemapper.org[^17] allows us to upload our photos and turn them into orthomosaics which will be a much nicer way to present to the stakeholders. Pix4uav Cloud

In the open-source world, maybe there will be possibility to use the frameworks GRASS[^18] or ImageJ[^19] to integrate the photogrammetry features within our own web framework.

To improve precision of measurements, it might be necessary to introduce ground control points on the fields or maybe just at the base station.

**Data Management**

As the geospatial image data grows we need better ways of control and optimizations. The tools provided by the PostGIS[^20] project allow easy hookup with a PostgreSQL database.

**Integration with Danish Agro ICT**


[^14]: Iris QuadCopter: [http://store.3drobotics.com/products/iris](http://store.3drobotics.com/products/iris)


[^20]: PostGIS [http://postgis.net](http://postgis.net)
PlanteIT\(^1\) offers a mobile application that registers when users enter and leave a farm and prompts user to do time-tracking of activities. Extending this solution with the information gathered via AgriDrone will allow us to push information to the user in a location-aware context.

**Camera System**

Aside from the TetraCam option mentioned in [6]. In the ConservationDrones project they use cameras that do NDVI in one camera. These cameras are modified by the company LDP LLC\(^2\) and they offer conversions of many consumer cameras.

**Integration with Agricultural Products**

In our usecase the farmer had a Fendt tractor with Trimble GPS system. It would be very beneficial to provide a method of sending the data (tables of GPS coordinates and corresponding biomass index and other measured parameters) to the Trimble system that the farmer already brings with him into the field.

**Crowd Sourcing and User Submitted Readings**

In an article from IBM Research\(^3\), they mention another use scenario which we have not yet explored. The scenario they propose is to allow users to, with their mobile device, take pictures in the farm of that is uploaded to the website and can be analysed by distributed experts. It bears some resemblance to Trimbles ConnectedFarm platform\(^4\).

**Manual Override**

Even though various failsafe parameters are already in place, to increase safety, disaster management and user control further, there should be an option of manual override to force the drone to land. One way to do this could be to have a ‘Abort Mission’ and a ‘Emergency Halt’ button available as part of the webinterface. But that would only work with internet access. A better way would perhaps be to use the GSM module directly. Where placing a call to the drone would invoke the ‘Emergency Halt’ behaviour and land the drone instantly on ground.

**Authentication and scaleability**

We didn’t implement any kind of authentication in our system which means that anyone on the internet could in effect trigger a drone to start flying a mission. To be a useful system for farmers each tenant farmer needs to be secured exclusive drone operation rights and data-access to the fields belonging to him. To allow for collective drone-sharing, it might make sense also to allow farmers to create groups in which they share operational access to a shared set of drones with base station between their properties.

**Integration with wireless sensor networks (WSN)**

Our interviews showed that another important parameter for farmers is to know about the microclimatic variations across the fields - soil moisture levels, soil nutrient levels and crop local temperature conditions. These kinds of data would not be feasible to acquire using a drone flying at 100m altitude. Instead we propose a solution that involves a WSN of WASP-motes using Libeliums Agricultural sensors\(^5\) as a starting point.

**CONCLUSION**

Modern industrial agriculture is a very highly coupled system with dependencies on many uncontrollable components. This is in general why introducing a system that can facilitate early detection early response is a good idea.

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