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Master Thesis

Precision Agriculture with Unmanned Aerial Vehicles for SMC estimations – Towards a more Sustainable Agriculture

Gjennomgang av presisjonslandbruk med bruk av droner for jordfuktighet estimering

– Mot et mer bærekraftig landbruk

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Master in Sustainable Agriculture

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Preface

As Immanuel Kant formulated in the book Critique of Pure Reason (1998) “All our cognition starts from the senses…” this master thesis will review the latest published research on advanced remote sensing technology in the agricultural sector. As we now have modern sensing technology that expands our sensing capabilities along with the birds view perspective, we thrive to utilise the possibilities it gives us. In this literature review, I would like to outline the potential use of the upcoming technology of UAS within the agricultural sector. This is an exciting field of study with several unanswered questions regarding its, potential and practical use.

The introduction of precision agriculture (PA) has changed the way of Western farming. Mulla (2013) states that “Precision agriculture generally involves management of farm inputs such as herbicides, fertilisers, seed, fuel (used for, planting spraying and tillage) by doing the right management practice at the right place and right time”. This shows the various aspects this technology is involved in. There are several different ways to use this technology and there has been much research undertaken in this field. Precision agriculture has been and is contributing to a more sustainable way of farming. With PA, farmers are slowly improving the application of input variables on the fields, as technology improves. The agricultural method of managing a field uniformly to variable-spatial could not be happening without improved PA.

Abstract

This master thesis is reviewing the latest published research on remote sensing technology in the agricultural sector, for soil moisture estimations towards a more sustainable precision agriculture. Modern, exciting new technological innovations will also be presented, along with the sustainable aspect of conventional agriculture with more precise agricultural practices. The synergy between UAS, SMC and sustainability are the focus of attention for this review thesis, as the possibilities and opportunities this can open for us can be of significant advancement in profitability and precision agriculture.

As precision agriculture evolves and grows, the potential and opportunities also follow. The new field of unmanned aerial systems demonstrates this. There are several sectors the unmanned aerial vehicle is being welcomed with open arms, only within the agricultural sector, it has shown to be of great value for crop yield and biomass estimation. It takes little energy to run and operate and it can be from a green power source. As we all should move towards a more sustainable and eco-friendly lifestyle, industries, businesses and corporations are no exceptions. Agriculture is a major contributor to the climate change and environmental destruction, we should make a change to a more sustainable method of farming, with precision agriculture we are making this shift. The objective of this thesis is to contribute to the fundamental research for future implementation and introduction of remote sensing technology with a UAV.

This thesis highlights these areas, to assist in closing the gap between researchers and end-users. By increasing the precision and applying inputs like artificial fertiliser and pesticides/herbicides at a correctly variable amount and time, a reduction of the inputs and the environmental disruption should follow, which results in an increase in the profitability for the farmers, and less environmental damages.

Sammmendrag

Denne masteroppgaven gjennomgår den siste publiserte forskning av fjernmålings teknologi i landbrukssektoren, av jordfuktighets beregninger for ett mer bærekraftig presisjons jordbruk. Moderne spennende nye teknologiske utviklinger vil også bli presentert, sammen med det bærekraftig aspekt av konvensjonelt landbruk med mer nøyaktig jordbrukspraksis. Samarbeidet mellom UAS, SMC og bærekraft er i fokus i denne avhandlingen, som diskuterer mulighetene dette kan åpne for.

Ved at presisjons jordbruk utvikler seg og vokser, følge også nye muligheter og metoder for utførelse av arbeidsoppgaver. Det nye fagfeltet av ubemannede luft systemer (UAS) demonstrerer dette. Det er flere sektorer som ønsker UAS velkommen, bare innenfor landbrukssektoren har det vist seg å være av stor verdi for vanningsanlegg planlegging og inspisering, avling og biomasse estimering. Det tar lite energi å operere og betjene systemet, energikilden kan være fornybar. Vi skal alle bevege oss mot ett mer bærekraftig og miljøvennlig livsstil, bransjer, bedrifter og selskaper er ingen unntak. Landbruket er en stor bidragsyter til klimaendringer og miljøskader, vi bør ta et skifte til en mer bærekraftig utvikling for landbruket, presisjon landbruk kan bidra med dette. Målet med denne avhandlingen er å bidra til grunnleggende forskning for fremtidig implementering og innføring av fjernmåling teknologi med en UAV.

Denne oppgaven belyser disse områdene, og bidra i å lukke gapet mellom forskere og forbrukere. Ved å forbedre presisjonen på midler som kunstgjødsel eller sprøytemidler, på riktig tidspunkt med riktig mengde, vil resultere i en redusert menge utførelse av midler som vil igjen gi bonden større profittmargin, og mindre konsekvenser på miljøet.

Nomenclature

SMC	Soil moisture content
UAV	Unmanned aerial vehicle
UAS	Unmanned aerial system
PA	Precision agriculture
SCD	Stepwise chemical digestion
NIR	Near infrared
SOC	Soil organic carbon
NIRS	Near infrared reflectance spectroscopy
EC	Electrical conductivity
CIR	Colour-infrared
NDVI	Normalised different vegetation index
GNDVI	Green normalised difference vegetation index
TDR&FDR	Time and frequency domain reflectometers
ANN	Artificial neural networks
RVM	Relevance vector machine
SVM	Support vector machine
IR	Infrared
VI	Vegetation indices
SWIR	Short-wave infrared
SWHC	Soil water-holding capacity
LAI	leaf area index
PGR	Principal components regression
PC	Principal components
VTOL	Vertical take-off and landing

Content

Background

1.1 Agricultural paradigm

Since the beginning of agriculture, the big paradigm shifts are caused by newly developed techniques and tools to cultivate arable land with. To mention a few, the ard, plough and the tractor have changed the way we cultivate our land (Chambers, Altieri, & Hecht, 1990). We are constantly improving and changing our methods of farming according to new studies and technologies. In the last two decades, we have seen an exponential growth in these two fields. The rapid improvement with the increasing exploration of applied science and the large-scale team-based research; the development of new tools in agriculture is happening rapidly. Precision agricultural technology has and will still shape the way we are moving into this new paradigm of precision agriculture. By improving the surveillance and application of inputs on the field, we are shifting from a traditional conventional, uniformed treatment of each agricultural field to a tailor-made treatment for as small as possible areas.

1.1.1 Precision agriculture

Precision agriculture had its beginning in the middle of 1980´s with sensors for soil organic matter and is currently developing exponentially. It has quickly evolved to include satellite, aerial and tractor mounted or handheld sensors. It was not before the 1990s that precision agriculture became commercially available. Precision agriculture had several milestones during its progression to where it is today. It began with farming by soil and has progressed to site-specific crop management based on grid sampling and management zones. Later, there has been increasing emphasis on real-time on-the-go monitoring with ground-based sensors. The accuracy of the images has become greater which allows evaluation of soil and crop properties at a fine spatial resolution at the expense of increased data storage and processing requirements. Precision agriculture tends to offer increased farm profitability by improving the crop production (Larson & Robert, 1991; Zhang, Wang, & Wang, 2002), and through improved management of farm inputs leading to less environmental pollution (Tian, 2002).

The large amount of data and information that is being collected gives us more accurate and precise application of the inputs on a farm. This leads yet again to improved crop productivity and environmental quality (Harmon et al., 2005). There has also been a shift from spatial data analyses and management alone to a spatial-temporal data analyses and management (Mamo, Malzer, Mulla, Huggins, & Strock, 2003; Miao, Mulla, Randall, Vetsch, & Vintila, 2009; Varvel, Wilhelm, Shanahan, & Schepers, 2007). The PA involves several steps of information management, processing and analysing of the data that is collected, technological advances in computer processing, yield monitoring, field positioning as well as sensor design and remote sensing (Mulla, Schepers, Pierce, & Sadler, 1997)

Precision agriculture involves several different new technologies and spreads over many management inputs for the farmers. Sensors and cameras can be mounted to any platform that can carry them such as tractors, equipment's and satellites, which are commonly used. Following the rapid development of technology; cameras and sensors are getting smaller and lighter, with higher resolution. Along with these advancements, the introduction and development of unmanned aerial vehicles give us the possibilities of combining these to an unmanned aerial system (Sánchez et al., 2014).

This thesis will give an introduction to the field of precision agriculture (PA) and surface soil monitoring methods. The sustainable aspect of this technology and the opportunities for application will also be discussed. Also, the alternative use of UAS and potential advances will be discussed which may help facilitate their use and attract farmers' interest in their application within PA.

1.2 Research area

This review thesis will outline the established methods of remote sensing technology with a UAV in the agricultural sector. Different research areas and theories will be discussed and reviewed. Soil moisture estimation methods with remote sensing technologies will be examined. The sustainability in general around these topics will also be described, to shine the light on a more sustainable farming practice. Also, the potential advances and alternative uses of UAS will be discussed. As well as recommendations for further research and usage of the UAS technology. My hypothesis is that this field of agricultural technology have great potential for further development and make precision agriculture more sustainable.

1.2.1 Objectives

The primary goal of this thesis is to contribute to the fundamental research for future implementation and introduction of remote sensing technology with a UAV. Furthermore, it will explore the research conducted on UAS for soil moisture estimation methods, and link it towards sustainability.

This study aimed to examine the relationship between UAS, SMC and sustainability, as the development is rapidly increasing and becomes more complex, the opportunities for a network of modern technology from different areas cooperating, resulting in a more sustainable agriculture.

The sub-goals are:

- Analyse and review various sources critically to gain information and use it to structure and formulate a thesis as well as arguments.
- Create an independent research project.
- Communicate my research and other significant scientific results to researchers as well as students, farmers and the general public.
- Analyse relevant research and ethical problems.

2. Materials and Methods

2.1 Research design

The present thesis is a literature review that aims to the standard of a master thesis at Hedmark University for Applied Science. The purpose of this paper is to get an overview of this new field of PA that is emerging with the focus on the soil moisture estimating techniques with aerial remote sensing technology.

2.1.1 Literature review

The literature that has been selected for this thesis is decided upon reading and understanding them to the best of my ability. Articles and journals that have been reviewed and used are from open sources and they are available to the public. Some of the literature that has been examined is also accessed through Hedmark University's database.

2.1.2 Data collection

The data for this research were collected from the Internet, with the use of several search engines. The search engines that have been used are Google Scholar, Web of Science, Science Direct, Scopus and Springer link. Some words have repeatedly been coming up in articles and reports such as UAV, agricultural soil, topsoil, moisture, remote sensing. Searching further with these keywords and looking at relevant references in the literature that have already been established, has been the methods for finding relevant and up-to-date research.

2.1.3 Limitations & delimitations

There are also some limitations on this thesis. There had been no experiments undertaken of soil moisture estimation methods. Only a literature research and an evaluation of those researches are conducted. Sometimes related secondary data could be unavailable or accessing available data could be difficult or impossible as it is paid-access only. Time and background knowledge together was sometimes not as sufficient enough to explain complex issues and detailed procedures. Other limitations that are present are the sampling method and the time that was set aside.

By focusing the thesis on to a particular topic and area of research, some information has been excluded and omitted. The delimitations that are deliberately present here are the field of SMC estimation. This area was chosen because of the potential that lies in it, and to raise the public and political awareness of the subject. Even though there are many interesting fields of PA. A further delimitation is the remote sensing technology used for acquiring the images/data. The focus is on remote sensing technology for a few reasons such as the high resolution of the images, varied fields of use and growing marked for UAS.

3. Results & discussion

3.1 Unmanned aerial systems

Unmanned aerial systems have in recent years been available to the environmental and agricultural application (Laliberte & Rango, 2011). The advantages with a drone up in the air, it the shift of perspective it gives us. We can by getting a birds-view look precisely down at the wanted objects, whether it is biomass or soil. Today there are several different UAS and they can be grouped in fixed wing aircraft, helicopters, and the most recent one is a quadrocopter with vertical take-off and landing (VTOL). The fixed wing aircraft usually have longer fly time and it can cover more acres. However, they are less user-friendly.

The development of quadrocopter with attached cameras in the last five years has been progressed a lot. The cameras can detect light waves, which are invisible to the human eye. This enables researchers and scientists to explore the possibilities of this new spectre in agriculture. There are several established methods of using UAS in the agricultural sector, such as finding potentially yield-limiting problems in a timely fashion, reduction of time on scouting the crops, crop health image, integrated Geographic Information System (GIS) mapping.

Currently, the use of UAS is mostly to support some of the farm operations where it is utilised. It is used across the world. In Japan, China and North America there are commercial players who offer this technology. While in Europe, the UAS are mainly used for research purposes. There has been an increase in the use of UAS technology around the world and it is becoming an important part of the agricultural practice, whereas in Norway there is little or no use of this technology except some research projects. One project that has contributed to the field of PA is on the mineralisation patterns from NIR spectroscopy, by the Nordic Joint Committee for Agricultural Research. They found that using NIR to predict the C and N in plants is a much less laborious and cheaper analytical method compared to the traditional stepwise chemical digestion (SCD) or C/N ratios (Bruun et al., 2005).

There are some limitations that come along with the UAS application to agriculture. The drone and sensors are sensitive to precipitation but on the other side, they can retrieve higher pixel quality and operate under the clouds without the restrictions that satellites have.

3.1.1 UAV technology

The UAS technology is modern and experiencing exponential growth in development and marked. The physical parts such as the UAV and the payload (camera/sensors) are steadily becoming lighter and cheaper. This is not only creating better aircraft's but also increasing the user market. Another essential part of the UAS technology is that there is an exponential growth of possibilities as the data-driven methods for analysing the data are explored. This method is where most of the previous research in this field has been focussed on. All the analyses, processes and calculations that a UAS needs to operate are executed in the data driven models. The technology becomes more sustainable and brings new areas of usage. However, the rate of users is still low.

With the development and improvements that we see today and the opportunities that this offer us, is, and can be life changing for many people. This technology can save time and improve productivity on certain operations, like input management. An open-source community sometimes develops UAS, this crowdsourcing and communal approach will continue to develop in a highly efficient and low-cost manner. There are a few factors that will determine the widespread usage like, the cost, user-friendly, flight abilities (i.e. fly time, payload) sensors technology, pixel resolution and more accurate and time-consuming analysing methods.

3.1.1.1 Platform

The platforms that have been tried out are ranging from planes to 4 or more rotor drones. The planes have proven to be quite functional for vast areas with many acres to cover. The development of unmanned aerial agricultural planes has gone from pilot controlled to fully autonomous flight, with a more user-friendly application (Ollero & Merino, 2004). This has given rise to the establishment of several companies in the large plains of United States of America. The flight time is usually longer on a plane, as the object glides smoother through the air than a multi-rotor drone. The planes are therefore well developed to acquire images over large areas.

The multi-rotor drones are well designed to cover smaller and harder to get to fields. They usually have four, six or eight rotors, this gives the platform a lifting power that has proven to be useful for UAS spraying, and for experimenting with sensing technology that is still too heavy for planes, like hyperspectral sensors. Some disadvantages that the multi-rotor drones have is the limited flight time, the most efficient drones today can fly approximately 25 minutes. The limited flight time results in a smaller area covered, and therefore not suitable for large fields like the plane. As technology improves and becomes lighter and more effective, the development of UAV platforms will enhance and give rise to new opportunities for application. There are many drone producers but there are only a few for the agricultural marked, like AggieAir, AgDrone, eBee AG, Lancaster, Crop Mapper, AG550, Quad Indago, AgEagle, DJI Inspire and AGRAS MG-1 (Cheslofska, 2015).

3.1.1.2 Sensors & cameras

The UAS have sensors and cameras that can capture images and other inputs, like temperature, depending on the sensor and its purpose. Some sensors specifically look at certain areas of the electromagnetic spectrum, out of the human eyes capability. The area of infrared light rays is widely used for different purposes, like measuring temperature and biomass. The visible light that humans can detect is also used, and this is called the visible light rays. An area that some believe holds a great potential is the ultraviolet light rays. This provides a large set of data and a 3D-model, which can be hard to interpret. Combining the different spectres and sensors have become more and more common as better results and estimations are made, like Zhan, Dongjian, & Yongliang (2013) demonstrated in their report. Sensors and cameras are becoming smaller and lighter, and this allows for more stability in the air and longer flight time. The pixel size is also improving and an essential part of a precise reflection of the reality. Sensors that are commonly used for agricultural purposes are capturing light in different areas like Red/Green/Blue, near-infrared, red-edge, multispectral, thermal infrared.

3.1.1.3 Agricultural application of UAS

The established methods of using UAS for agricultural practices are diverse and they depend on the area and the desired outcome. There are several different lightweight multi-spectral cameras that can be attached, for the particular desired result. This gives the operator a wide range of aerial imagery to choose from. These images will be analysed and processed for further use. The cost and availability of high-resolution satellite imagery often limits the application in PA (Wu, Wang, & Bauer, 2007). The research that has been published on PA for agricultural application is diverse and spreads across a variety of agricultural production systems. Most areas of use can be put in these categories for an organised and structured overview (Stark, McGee, & Chen, 2015).

- Soil properties (moisture, organic matter, clay content, salinity & pH)
- Crop yield and biomass
- Plant nutrient and water stress
- Infestations of weeds, insects and plant diseases

The application of UAS in agriculture has had an exponential growth in the last years and has focused on a broad range of endeavours (Adamchuk, Hummel, Morgan, & Upadhyaya, 2004; Moran, Inoue, & Barnes, 1997; Pinter et al., 2003). The application of hyper-resolution vineyard mapping based on visible, multispectral and thermal images has been demonstrated (Turner, Lucieer, & Watson, 2011). Estimation of vegetation indices derivation, vegetation canopy mapping, soil and crop temperature, crop nitrogen estimation among others have shown to be affordable, precise and feasible (Al-Arab, Torres-Rua, Ticlavilca, Jensen, & McKee, 2013; Berni, Zarco-Tejada, Suárez, & Fereres, 2009; Haboudane, Miller, Pattey, Zarco-Tejada, & Strachan, 2004; Hall, Louis, & Lamb, 2003; Hassan-Esfahani, Torres-Rua, Jensen, & McKee, 2014). There are still few problems that continue to challenge us such as the sensor capacity, platform reliability, and image processing and final products dissemination. It is suggested that a successful application of UAS supported image capture could reduce the time frame needed for agricultural practice adjustment and that the results of this remote sensing monitoring could exceed those from traditional control treatments (Beeri & Peled, 2009). As artificial neural networks and more user-friendly software's are becoming more and more popular, some are offering these services commercially like Dronedeploy (Van Rees, 2015).

Even though the technology of UAV has been around for approximately thirty years, the development and opportunities are continually expanding. The result of this is an exponential growth in the field of use for UAV. There are several different methods an unmanned aerial vehicle system (Sánchez et al., 2014) can be implemented in the farm operations. The following section describes the most shared and relevant methods that soil moisture is estimated today.

Soil properties

Soil properties like moisture, organic matter, clay content, salinity and pH can be measured using direct techniques such as field measurements and sensors. These direct techniques are reliable and accurate but also, time and energy consuming, expensive and laborious. Today there have been great improvements in how we are measuring these soil qualities and collecting the data. Using on-the-go and near infrared (NIR) measurement have shown to be an inexpensive tool for mapping soil texture and organic carbon (SOC) (Bricklemyer & Brown, 2010; Christy, 2008). Other soil attributes like PH can also calculate from an on-the-go spectrophotometer for in situ measurement of reflectance spectra using near infrared reflectance spectroscopy (NIRS) like Christy demonstrated (2008). The salinity level of agricultural soil is also interesting to look into. Depending on the area the salinity of the soil can clearly limit the productivity of irrigated land. This can be measured with a soil electrical conductivity (EC) like Corwin & Lesch showed in their report (2003). Remote sensing of soil moisture, using a UAV with high-resolution multispectral imagery have proven to be of great value for the UAS technology (Hassan-Esfahani, Torres-Rua, Ticlavilca, Jensen, & McKee, 2014).

Crop yield and biomass

The research of Bradford, Everitt, Escobar & Yang (2000) showed that a UAV can be a useful platform for detecting plant growth and yield variability. Crop yield can be a valuable indicator for farmers who want to estimate their predicted harvest and income. This can be done with a few different methods but the most efficient and cost effective way would be to use a UAS. The process of acquiring these estimations consists of a few steps, like georeferencing the images and classifying them into zones of homogeneous spectral response using unsupervised classification procedures. A correlation analysis shows then the correlation to the NIR, red, and green bands of the colour-infrared (CIR) images and the normalised difference vegetation index (NDVI). There are several similar methods of estimating the crop yield and biomass, but most of them are along these lines. There have been several important research done in this field and one that showed the potential in the 1990ś, are one where they showed that green normalised difference vegetation index (GNDVI) could be used to produce relative yield maps depicting spatial variability in fields (Shanahan et al., 2001). Predicting crop yield and grain quality with multispectral field radiometers and a hyperspectral airborne imager was proven (Øvergaard, Isaksson, Kvaal, & Korsæth, 2010). There is also done research on estimating yield of irrigated potato fields, using aerial and satellite imagery (Sivarajan, 2011).

Crop nutrients

Researchers from around the globe have studied the course of freshwater in the last decades. The depletion of lakes and groundwater, several places are showing us the trends. Although research is time after time telling us, freshwater is becoming a scarce resource (Bastiaanssen, Molden, & Makin, 2000) we seem not to change the way we manage it. Irrigated agriculture is a major contributor to this. Crop nutrient and water stress are indicators that can tell us something about the plants health and the quality of the crops. There are also a few different methods of estimating the crop nutrient and water stress. Remote sensing indices like NDVI, GNDVI, NDWI. (Clay, Kim, Chang, Clay, & Dalsted, 2006). There is also a successful research done on thermal imagery and spatial analysis (Alchanatis, Cohen, Meron, Saranga, & Tsipris, 2005) for estimation of leaf water potential. Thermal and visible imagery have also been used for estimating crop water stress in irrigated grapevines (Möller et al., 2007). Additional nutrients are usually added to the agricultural fields, these are costly for not only for the farmer but also for the environment**,** as the result is runoff and massive dead zones around the globe (Crookston, 2006; Diaz & Rosenberg, 2008; Rabalais, Turner, & Wiseman Jr, 2002; Tilling et al., 2007).

Infestations of weeds

Weeds, insects and plant-disease infected agricultural fields can be highly devastating for a farmer. A mono-cultural agricultural field will always be exposed and threatened by the surrounding ecological systems. The field of pesticides in agriculture is conducted widely by researchers for several decades (Thorp & Tian, 2004). The use of genetically modified species, pesticides and herbicides are commonly used for eliminating the unwanted intrusion. With continuing application of pesticides and herbicides, some plant and insect species can build up a resistance, which usually results in an increase of the pesticides usage on the farm. The normal practise of managing the application of pesticides is by normal/variable rate pesticides application, rather than precise weed location with a UAS. There are some advantages with remote sensing of weeds and plant diseases like virtually instantaneously generated maps showing the status of the field (Lamb & Brown, 2001; Torres-Sanchez, Lopez-Granados, De Castro, & Pena-Barragan, 2013). Plant diseases are something every farmer is faced with. Fungicides are conventionally used to prevent plant diseases and their value has been demonstrated several times (Seelan, Laguette, Casady, & Seielstad, 2003).

3.2 Soil moisture

The SMC portrays an important role for soil chemistry, agriculture and groundwater recharge. Four of the states` soil moisture is routinely described are saturated moisture content, field capacity, permanent wilting point and residual moisture content. Soil moisture content (SMC) can be divided into two main components, root zone soil moisture (top 200 cm of soil) and surface soil moisture (top 10 cm of soil). Soil moisture is a good way to identify the water and energy exchange at the land surface/atmosphere interface (Zhang & Kovacs, 2012). There are different techniques and methods to estimate the SMC.

3.2.1 Practical value

Without a practical adoption of this new information that we get with SMC estimations, the purpose would be defeated. It is, therefore, important to mention a few of the methods this new information is incorporated into some farmer's management decisions. Irrigation management has taken a new turn with the values of SMC estimations, more precise and accurate irrigation decision is taken from these SMC estimates, either in managing the irrigation systems more efficiently or in planning and designing one. Not only farmers are affected by the SMC. Saturation and permanent wilting point of the specific soil texture and structure will affect extreme weather conditions such as floods and droughts (Rodriguez-Iturbe, D'odorico, Porporato, & Ridolfi, 1999). Also meteorology and climate change research are looking into SMC (Heathman, Starks, Ahuja, & Jackson, 2003; Sandholt, Rasmussen, & Andersen, 2002) the possibility that we will find other fields of use is also present.

3.2.2 Soil moisture estimations

The SMC can be measured by in situ measurements such as gravimetric measurements, time and frequency domain reflectometers (TDRs and FDRs). Covering a large area and measuring the soil moisture with methods mentioned are time-consuming and laborious. Other methods that have become more popular in the last couple of decades are remote sensing technology, as thermal imagery, visible and near-infrared (NIR) reflectance data, optical and thermal remote sensing techniques, passive and active microwave sensors and meteorological satellites. All these different methods of measuring SMC are also used together to measure and estimate SMC. These sensors are addressing some issues that the in situ measurements are facing. For example, the soil condition, vegetation and topography can all vary greatly when taking local measurements (Hassan-Esfahani, Torres-Rua, Jensen, & McKee, 2015). The SMC information can be used for different purposes, depending on the goal. The reports that will be assessed are concerning the SMC and mostly related to the remote sensing technology. Lately, data-driven modelling tools have been introduced for analysing the data, and this method addresses some of the issues connected to estimating SMC.

Data-driven modelling tools such as artificial neural networks (ANN), relevance vector machine (RVM) and support vector machine (SVM) are changing the way we are measuring and estimating SMC (Beale & Jackson, 1990). These models have shown that with training they can predict better and more precisely. There has been several successful research done, with using methods like, SVM (Gill, Asefa, Kemblowski, & McKee, 2006; Kashif Gill, Kemblowski, & McKee, 2007; Yang & Huang, 2008), ANN (Atluri, Hung, & Coleman, 1999; Chang & Islam, 2000; Jiang & Cotton, 2004; Song et al., 2008) and higher-order neural networks (Elshorbagy & Parasuraman, 2008) for estimating SMC. However, the SVM model has some issues that result in a too much wasteful use of both data and computation. The RVM model does not succumb under these limitations and is the Bayesian treatment of the SVM. Another interesting area of remote sensing technologies is the hyperspectral field. This is a little-known area that some researchers are exploring. Some work that has been done with this technology is by Sánchez et al. (2014). One essential improvement to using hyperspectral optical, thermal, and microwave L-Band observations is to retrieval soil moisture at very high spatial resolution.

3.3 Sustainability

Even though sustainability is a widely spread and used term, it should be given serious consideration. We are one of many species on this planet, living in symbiosis with nature (even though most people feel very distant from it). Behaving as a virus, polluting and damaging the environment around us are diminishing the resources we as human species are depend on. As agriculture is a major contributor to the increasing environmental destruction, we need to change towards a more sustainable way of farming.

Demand on soil recourses are greater than ever and will only continue to increase with the growing population and rising demand for higher quality diets with living standards, as more people are climbing out of poverty (Lal, 2009). The agricultural sector is responsive for a large portion of the environmental disruption and damage that has been done to this planet (Leontief, 1970). Cultivated areas on land and in water provide important habitats for several wild plants and animals. When these areas are sustainable managed they can help preserve and restore critical habitats, protect watersheds, and improve soil health and water quality. When we do not care about the sustainability and manage our land in a conventional method, agriculture presents a great threat to these species and ecosystems. There are several factors that drive the sustainable agriculture forward, the fact that we are more aware of the importance of a healthy and functioning ecosystem. Also the fact that we can now measure the effects of our established methods of farming faster and easier makes the consequences clearer to us. The ability to produce food year after year, with little to no interference is essential for our civilisation. It is, therefore, vital to make sure we can continue, and not destroy the ecosystems we depend so much upon.

3.3.1 Agricultural consequences

Agriculture has been and still is an essential part of how our societies are build up and works. Even though we have made considerable progress on the production side, the paradox is that many of the unfavourable effects of farming are increasing (Homer-Dixon, 1991). The ability to produce food is so essential for us, the intensification that has been going on has some side-effects that damage the environment and ecosystems we depend so much upon. Some side-effects of agriculture can be devastating like the dust bowl (Schubert, Suarez, Pegion, Koster, & Bacmeister, 2004) or the dead zones in Mexico (Robertson & Vitousek, 2009), and around the world. The biodiversity around the globe is also reducing, and agriculture has a direct impact in some places. Land conversion & habitat loss are two factors all farmers are having an impact on, directly thorough their land and management practises and indirectly as a part of an ecosystem. The weaker and smaller an ecosystem is the less resistant it is to changes as we see in the environment today, and will see more of. The recourse that already is scared in several places and increasing is water (Wallace, 2000). The intensified and large yielding crops we have around the globe today are demanding a high amount of water. The pressure on irrigation water on the planet today is greater than ever. As a result, the groundwater level around heavily pressured areas are sinking (Viala, 2008). This has an adverse effect on the growth of plants and crops witch will contribute to soil erosion and degradation. Pesticides and artificial fertiliser inputs are the biggest environmental polluters from the agricultural fields. These are inputs that can be reduced significantly with detailed yield maps along with PA (Seelan et al., 2003). To minimise the negative consequences of agriculture we need to be aware of all these aspects and work towards a higher consumption and use of all produced food. The food that goes to waste and dumps are having the most negative effects, as all the resources and time use to handle and produce the food will not end up eaten, but converted to something less useful.

3.3.2 Sustainable technology

Technological progress and developments have and are still changing our methods of farming and managing our agricultural land. Precision agriculture can be explained as the last paradigm shift in modern agriculture. PA can be defined with the goal for a tailor-made treatment down to as close as possible to the individual plant level. New and modern technology is an essential and necessary method to achieve this. As the agricultural drones will revolutionise spatial ecology (Anderson & Gaston, 2013). Some will say the dawn of drone technology is coming upon us and the agricultural sector is its first target (Koh & Wich, 2012). We are not able to treat each plant individually and specifically today, even though great progress has been made in the last ten years (Mulla, 2013). PA is changing the way we are farming from a uniform treatment of a field to a more variable treatment according to the plants and soils needs (Bongiovanni & Lowenberg-DeBoer, 2004). Some of the many different technologies that are being used to acquire soil moisture estimation are sensor technology, machine-learning software, multispectral sensors on UAV, satellite images and ground bases data (Aubert, Schroeder, & Grimaudo, 2012).

4. Discussion

This thesis focuses on a few different, but very related topics in precision agriculture (UAS, SMC and sustainability). The findings from this study suggest that by combining the ability we have of acquiring quality information and transform that data to useful knowledge for humans and machines, we can take better and more precise management decisions, that again will lead to a more sustainable agriculture. The increase technological development in every aspect of the agricultural industry is and will continue the exponential growth of precision in precision agriculture, and the adaption of more sustainable agriculture.

4.1 Unmanned aerial systems

The introduction of UAV has provided a platform that is very suitable for acquiring images for agricultural purpose, from a birds view. There are several different UAV producers and their products can vary considerably, with only a few that are producing products for the agricultural sector. The use of UAS can save a lot of manpower by just lifting the perspective to a birds view and cover more hectares in a more effective manner. The rapid development of new UAVs is contributing to better and more improved technology, adapted to the agricultural sector. This development is present in both drones & sensors. The development of sensors and cameras are also declining in size, weight and price, with an increase in accuracy and pixel quality, results in a broader field of use. The application of UAS in the agricultural sector can be divided into two areas, the established commercial usage and the research that are done with them. The established commercial use of UAS is mainly in irrigation management of fields, crop and yield estimations, and plant chemical content estimation by various methods.

The quality and composition of the soil are factors that the plants are first interacting with, and important for an optimal result. By using a UAS to generate a map of SMC and take this new information into account when making management decisions have shown to be effective and reliable (Hassan-Esfahani et al., 2015). Also, Chen, Zhang, Chen, & Yan demonstrated in their study (2015) how the appropriate utilisation of SMC monitoring along with integrated geospatial sensor web, can substantially increase the efficiency of farm operations. However though there are areas where improvement is needed to make better estimations. Fernández-Gálvez mentions the errors induced by uncertainties in the effective soil dielectric constant (2008). Other shortcoming areas connected with UAS are the initial cost, platform reliability, sensor capability, and lack of standardised procedure to process large volumes of data (Zhang & Kovacs, 2012). Fortunately, these shortcomings have the last decade decreased. Agricultural field operations consist of heavy and energy demanding tools and equipment. By introducing a light, small and energy effective technology like UAS, we are taking one more step towards a more sustainable and environmentally friendly agricultural practises. Further research is needed to develop better and more adapted UAS for the agricultural sector, with less human intervention. By improving flight time and payload the application of UAS could expand and become more suitable for agricultural purposes.

4.2 Soil moisture

This thesis presents and reviews the established methods for estimating soil moisture content. The development of new methodologies and analytic methods are increasing and improving in accuracy, leads us towards a more detail knowledge based agriculture. SMC can provide us with valuable information on the growing conditions. By knowing the SMC and the plants needs, we have the knowledge to apply more precisely inputs, like minerals. The more we know, the better we can supplement the needs. SMC estimations are increasing in accuracy as the development of sensors is enhancing. By generating an informative image about the soil moisture content and other valuable factors for a grow bed, we can move towards a more tailored and detailed growing managing practises.

The importance of soil physical properties and the effect it has on the plants is well established, but monitoring them has been expensive, time-consuming and laborious, until now. Like Pignatti, Simoniello, Sterk, & de Jong mention (2014), a remote sensing system today is almost able to provide near-laboratory-quality information from every pixel in an image very quickly. The use of machine learning approach for soil moisture estimation from remote sensing data was successfully demonstrated by Ali et al., (2015). However, with only one input, the thermal imagery is proven to be the most relevant information in surface soil moisture estimations (Hassan-Esfahani et al., 2015). The effect of precise knowledge about SMC in an agricultural field, have demonstrated its improvements in irrigation fields and will increase doing so in other areas of agriculture. This is contributing to a more detailed and informative base for agricultural practices, like, irrigation, artificial fertiliser, pest and herbicide application, which again leads to a more sustainable agriculture. Some limitations to this are the gap between SMC and operational management. The acquired data need to be transformed and processed for the next step, for this, the knowledge gaps between different technologies need to be reduced. Further research should be focused on more detailed and precisely estimations of SMC from UAS technology, and transforming this new knowledge to farm operation management decisions and applications.

4.3 Sustainability

Farming is and has always been an interaction between humankind and natural processes. We can tweak and turn some of these processes to the likings of our desired direction. By doing this, we are also affecting the surrounding and connected ecosystems, altering their natural state. Unfortunately, this has resulted in a negative and sometimes directly destructive on the environment. As we depend on upon them, their downfall and destruction will eventually bite us in the back. Therefore, it is important to have an agricultural practice that takes this into considerations and preservation. Soil organisms are considerably affected by mineral fertilisers, organic amendments, microbial inoculants, and pesticides (Bünemann, Schwenke, & Van Zwieten, 2006). A precise and accurate application of inputs could contribute to moderating the unfavourable effect on the soil organisms. Abdullahi, Mahieddine, & Sheriff mentions in their study (2015) that remote sensing technology is playing a key role through precision agriculture. The application of UAS in farm operation is demonstrated by Zhang, Walters, & Kovacs (2014), the issues related to post-processing of images along with cost and training to operate and analyse were still present.

With reduced inputs in fields by more precise and variable application of artificial fertilisers and pesticides, would boost the productivity and not at least the sustainability. For this to take place, the gap between researchers, end-users, and different technological innovations need to diminish. Like mentioned by Anderson & Gaston (2013) the opportunities that recent technological innovations offers, was almost unimaginable a few years ago. Further research is needed to acquire more knowledge about the web of agricultural life, and the implementation of UAS towards a more sustainable agriculture.

5. Conclusion

Soil moisture estimation methods are developing rapidly with great complexity. By building on previous research and with newly innovations of technology, smarter and more accurate methods are created. Farmers and other potential users should be more aware of the opportunities that UAS technology offers. It has been demonstrated that estimating the soil moisture in an agricultural field can help with the input decisions of some farm operations. It can also have a positive impact on the environment such as reduced fertiliser and pesticide runoff from agricultural fields. More organised "toolbox" of inputs and user-friendlier approaches, would improve the user-friendliness and attract more consumers. Networks of modern technology acquiring key information and collaborating with others have great potential to improve the precision in precision farming. It is concluded from the above that technological application like remote sensing holds a great potential for a more sustainable agriculture.

Further research is hence needed to improve the use of UAS in operation on agricultural fields and link the technology closer to input management operations, where the potential for reduction is prominent. Artificial fertilising and weed spraying are two areas that that should be focused on first, as the resulting benefits are greatest there. Are we to trust that history will repeat itself as it does in most cases, these issues will be resolved and improved in the future.

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