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PRACTICAL GUIDE FOR THE USE OF ICT IN AET

This document provides information on the use of information and communication technology (ICT) in agriculture and agriculture educational training (AET). It addresses the use of robotics, drones, mobile applications, and GIS with practical illustrations of applications and their benefits.

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General use of ICT in agriculture – Introduction

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Information and communication technology in agriculture (ICT in agriculture), also known as e-agriculture or smart-agriculture focuses on the use of different ICT technologies, products and services in order to foster and improve this important economic field. The application of ICTs in agriculture is a very broad term and for now there is no its precise definition.

Agriculture has always been characterized by a high demand for information and communication. To answer this demand, farmers and other people have used different means through the history. Mesopotamian farmers used clay tablets with descriptions on watering crops, 3,500 years ago. Many centuries later, agricultural newspapers and books became popular. Then the telegraph, radio and TV programs and weather broadcasting became available in providing valuable information for agriculture sector. However, these more traditional forms of information and communication have limitations, but are still popular. One-way communication is considered as main drawback of broadcasting media like TV, radio and newspaper. In addition, much of the information desired by farmers is highly location-specific and many of these technologies could not address this request.

The personal ICT devices such as computers, smartphones and other electronic gadgets can be very useful for farmers and other end users in e-agriculture. Thanks to fast-dropping prices of connectivity and tools, such personal ICT devices, especially mobile phones are used worldwide, even in the most rural villages of Africa. According to ITU (2017), 3.6 billion people were using the Internet in 2017, out of which 2.6 billion were living in developing countries; 4.3 billion subscribed to mobile broadband, with highest growth rates coming from least developed countries. Table 2 shows connectivity dimension performances for most of Wester Balkan countries regarding different connectivity indicators/technology as well as comparison with EU Avg (average value in EU) [2]. The fast spread of ICT devices has led to a strong interest by public and private sectors to develop ICT applications for farmers and community to access inputs, services and markets and to support farm management and decision-making. Finally, the usage of ICT is unavoidable in supply chain of agro products as well in education and marketing.

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TABLE 1 Conectivity dimension performance

INDICATOR	EU AVG	AL	BA	ME	MK	RS	TR	XK
INDICATORS FOR WHICH DATA AVAILABLE		8	1	8	7	9	5	8
1A.1 Fixed BB Coverage %	97%	13%		90%	98%	72%		100%
1A.2 Fixed BB Take-up %	76%	12%	18%	81%	66%	62%	56%	18%
1B.2 4G Coverage % TK	91%	87%		97%	100%	96%	87%	89%
1B.2 Mobile BB Take-up (per 100 pop)	90	65		75	69	83	75	92
1C.1 NGA Coverage %	80%	14%		71%	50%	68%		97%
1C.2 Fast BB Take-up	34%	4%		52%	21%	44%	9%	33%
1D.1 Ultrafast BB Coverage	57%	0%		61%		67%		9%
1D.2 Ultrafast BB Take-up %	15%	1%		5%	1%	2%	0%	
1E.1 Boadband Price Index	87					57		5

[TK]2017

In last decades, other new technologies in addition to communication emerged, having the potential to address the needs of farmers, both in the developed world and in developing countries. Research and technological progress in fields of big data, satellite systems, computational power and (remote) sensing, artificial intelligence and others significantly contribute to ICT revolution.

From technical point of view Information and communication technologies (ICTs) are devices, networks and applications for collecting, storing, using, and sending data electronically. ICT applications in the context of agriculture offer tremendous opportunities for food security and sustainability but there is no panacea and various challenges remain.

Additionally, ICT applications have the potential to address very specific tasks in agriculture. They include different types of risks, which may become more pronounced with climate change: seasonality and spatial dispersion of farming, high transactions costs, information asymmetry, and the need for highly location-specific management knowledge. The health of the crops can be monitored very intensively and precise.

AREAS OF APPLICATIONS

ICT can be applied along the entire agricultural value chain, as is seen in Figure 1. They can be used to better manage the basic factors of production (land, labour, capital and also soil), to access inputs and services, including extension services, and to facilitate processing and marketing. They can also be applied at the level of the consumers, Figure 1.

In new content the ICT in agriculture is applied in advanced areas as Supply Chain, Industry 4.0, Industry 5.0 services, Education, Research and related fields. Especially in education and research Internet becomes very powerful tool. We have very intensive application of ICT in monitoring environmental conditions in agriculture (weather parameters, micro and macro clime, climate changes etc).

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Recently, the situation requests urgent work on development ICT systems for disaster management as flooding, wild fires, illnesses, COVID-19 pandemics and others.

In one word, there is no field of agriculture where ICT is not applied.

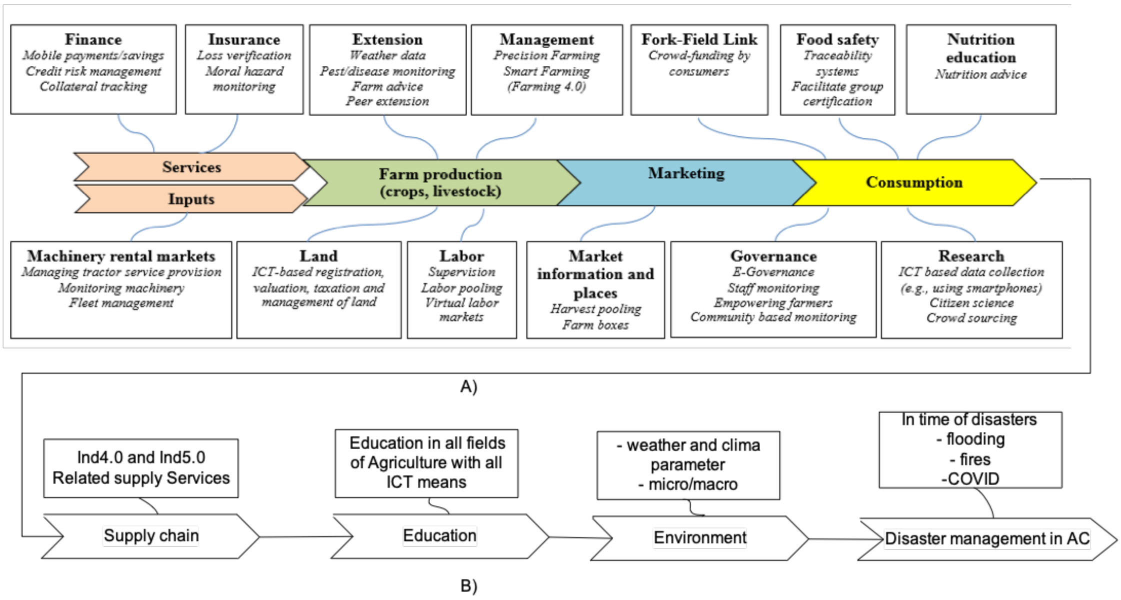

Figure 1: Examples of ICT applications along the agricultural value chain

DESIGN CHALLENGES

In order to develop proper ICT system in agriculture someone should to be familiar with basic tasks and principles which fulfil such design challenge. Infrequently, the smart agriculture is a fashion. Not every ICT solution for agriculture will suit your needs. Almost, the smart solutions are custom based.

First, define what you want? Sometimes, you can lose money and time because you do not know what you want. Have in mind that the time is "non-renewable" resource. The optimization is never solved problem, but we should do our best to be as much as possible near to optimal solution. Overall idea is to find a solution that meets our needs in minimal cost.

As example, Figure 1.2 shows the modern ICT system for monitoring the parameters of the selected crop on the field. As seen, we use: sensors, sensor networks, communication protocols, cloud, server, database, client etc. We can use a drone to capture spectral imagery or other signals. Target application can be vegetation Index mapping. As seen, this is very complex task that require knowledge, technology and resources and can be solved in different ways, all of which apply ICT technology.

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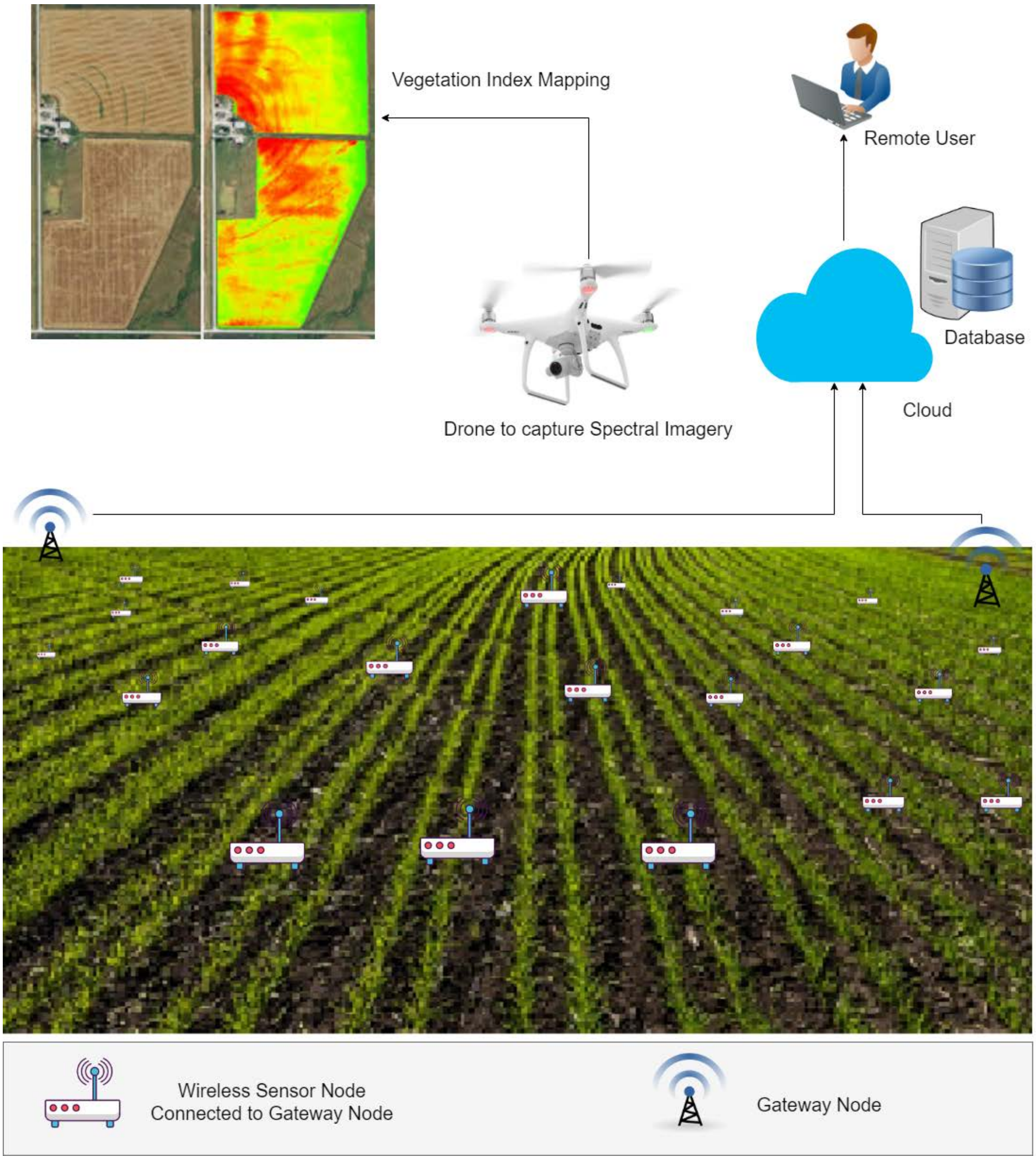

Figure 2: Modern system in precision agriculture [3]

Usually, in practice, there are different ways to solve one problem related to the agriculture? Let's consider an example, determination nitrogen parameter into crop. The basic principle is based on detection colour of the crop. We can do it manually, by using template colours sheets which costs 5 EUR. In this case our eyes are sensor and brain a processing computer. The second method is using hand held meter, as example Minolta SPAD 502, that costs around 1000 EUR. We can perform the same task by using smart phone (Android or iPhone), suited by proper application in a price of 600 EUR. And the last technology is by drone, 5000 EUR. The prices are varying from 5 EUR-5000 EUR. Most frequently, the solution with smart phone is optimal one, because the phone we have is being used for many purposes. In addition to be cheapest, this approach allows us to store, send and receive information.

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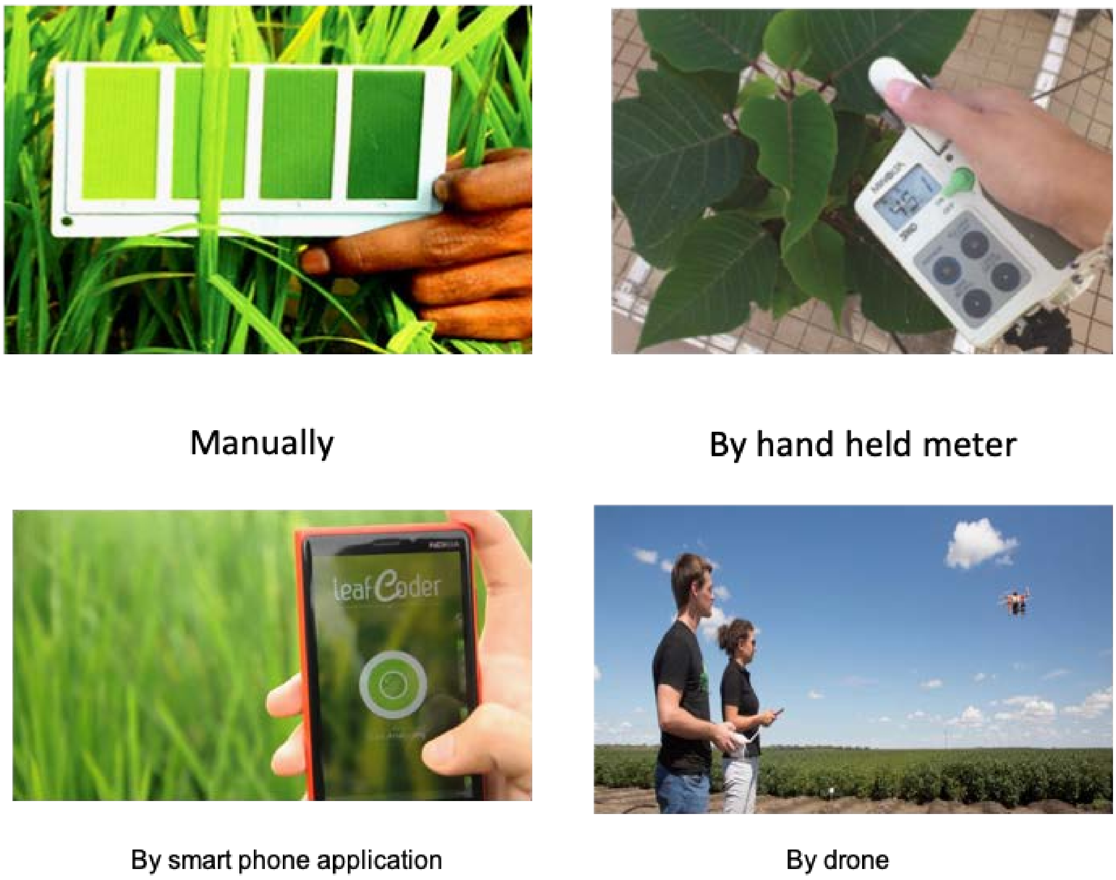

Figure 3: Different techniques and design approaches to measure nitrogen parameters into crop

STEPS IN DEVELOPING E-AGRICULTURE SYSTEM

It is important to follow the methodological steps in process of designing and developing development e-agriculture system:

1. Perform an analysis of whether you really need e-agriculture system for devoted application. SWOT analysis can be used as a tool to point out strengths, weaknesses, opportunities, and threats related to business competition or project planning.
2. Define your goals and purposes. Every farm has priorities. If your farm is in dry climate area then, soil humidity monitoring could be your primary goal. The key goals you want to achieve will ultimately determine the rest of the project – from the sensor's structure to the software architecture. Start from one priority.
3. Decide on the data transfer technology. Transfer automatically or manually. Raw data or rare data. Near, far. Indoor, outdoor. Which technology to use for data transfer, from Serial till WPLAN from wire to wireless.

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4. Determine the power sources. The data travel distance is also important because it directly impacts the sensor's battery life. You can manage power consumption by regulating the frequency of data transfers, or transfer fewer amounts of data. One way or the other, power consumption and power sources will require preliminary estimations.
5. Estimate the frequency of data collection. Power usage and sensor life will also depend on the frequency of data collection. How frequently does the data you need have to be collected in order to deliver value?
6. Consider sensor specification? Select a proper sensor. The selection of the sensor is very expert job from span till housing. Consider that most of measurements are "physiological".
7. Consider self-calibration? Usually, the design skips this point, but how you will know that your sensor is sending proper value. As example, PH measuring.
8. Make mini-model and test the system? Usually in laboratory or "mini garden" condition you should to do mini-test system. System should operate on models.
9. Install system on the spot? It is a demanding work, not only electronics or ICT based, you need mechanical, civil engineering, masters.
10. Test work on the spot? Do testing procedures. Do not skip "the worst case" testing.

Although precision agriculture is challenging job you should to do optimal and feasible design of your business, and your time. For this you need knowledge from economy, agronomy, computers, and quality of life. Have in mind:

"It's really hard to design products by focus groups. A lot of times, people don't know what they want until you show it to them." — Steve Jobs

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Use of robotics in agriculture

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Over the last few years, we have seen many new interesting robotic projects with promising robotic solutions intended for agriculture. The reasons behind this lay in increasing public awareness that mirrors in strategic documents, such as specialization strategies involving aspects like Industry 4.0, digitalization in agriculture, precision farming, ICT use and other. The other reason is the change of paradigm of thinking for new farmers that take over the farms to make them sustainable, with a circular economy in mind and seeing potential in new ways of farming. This includes small, cheaper fleets of autonomous machines, instead of owning one big machine, operated by human workers. And this can go a step further, by maybe not even owning them, but renting or sharing between the neighbouring businesses, making more smaller entities as one, bigger, stronger entity that will compete one the market easier [1].

In the following subsection we investigate different kinds of robots. On one hand we present the robots built to work in an indoor environment, such as greenhouse robots. Then, we investigate the status of the robots that should work outside, like field robots, where we divide them based on their size, purpose, supporting sensory systems and technology they are based on; internal combustion engine (ICE) powered, electrical and hybrid solutions.

ROBOTICS IN GREENHOUSES

Greenhouse production is an intensive production method with high investment and operational costs, therefore permitting only the production of high value fruit and vegetable crops like tomatoes, sweet pepper and cucumber, flowers like roses, chrysanthemums and gerbera's and many types of potted plants. In the past decades, in western societies, this type of production has been confronted with increasing labour costs and increasing problems with the availability of sufficiently skilled labour, health problems of the employees due to heavy and repetitive tasks and growing competition on the national and international markets.

A typical greenhouse growing cycle includes many steps or operations such as:

1. Seeding, grafting and cutting
2. Transplanting
3. Transport of plants to a greenhouse
4. Planting

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5. Plant Maintenance Operations (PMOs)
    a. Attaching plants to a support wire or stick
    b. Sticking support sticks or knotting wires
    c. Side shoot removal
    d. Weeding/plant thinning
    e. Fruit/flower thinning
    f. Leaf picking
    g. Lowering plants
    h. Crop protection/spraying
    i. Harvesting (single/multiple)
6. Internal transport of plants or harvested products
7. Grading
8. Packing
9. Crop removal and cleaning

There are single-harvest and multiple-harvest crops growing in the greenhouses. The first group of crops (lettuce or Chrysanthemum) goes through all production steps only once and the entire process lasts usually only a few weeks. It is more appropriate to apply automation processes and robots then in a multiple-harvest crop (tomato or rose), which has a longer production cycle (one year for tomato and up to five years for rose).

Current state of the art in greenhouse mechanization showed that commercially available solutions exist for seeding, cutting, grafting, transplanting, transporting, sorting, packing, and cleaning of crop production. They consist of automated systems largely based on mechanical engineering solutions, inflexible to variations in the working conditions, containing a small number of sensors and not much "intelligence." The reason is simple. The tasks during these phases are simple and focus on well-defined objects in terms of location, size, shape, and colour [2].

Since the complex working environment constitutes a considerable challenge to robotics, two directions in developing and researching is used in the practice: 1) advancing robotics technology, and 2) modifying the environment to simplify the task. One must have always in mind that robotics for protected cultivation is not only about developing suitable technology. In the end, the machines should closely fit into the production process in the greenhouse. Moreover, greenhouse robotics is faced with a small and very scattered market.

Plant Maintenance Operations (PMOs) comprise more complex operations because they deal with varying position, shape, size, and colour of plants within an unstructured crop. They require specific treatment at the level of complete plants or, even more often, on particular parts of plants (fruits, flowers). The specific treatments also depend on the specific state of the fruit or flower as well as on the specific changing requirements on the market. Furthermore, the objects are highly occluded, with limiting visibility and reachability.

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Therefore, successful execution of PMOs strongly relies on human skills such as intelligence, decision making, adaptation and learning capabilities, and on highly effective eye-hand coordination. However, due to the rising human labour costs these tasks are interesting for high-tech solutions using more advanced manipulation and gripping devices, a wide ranging of sensors, and advanced computing hardware and intelligent software. These challenges have received considerable attention in research on agricultural robotics in the past three decades and produced several experimental robots such as strawberry harvesting robot, cucumber harvesting robot, sweet pepper harvester. At the moment, the most used robots in greenhouse production are spraying robots (24.7%), followed by planting and harvesting (22.2%), packaging (11.7%) and stacking robots (3.7%) [3].

TECHNICAL CHALLENGES IN ROBOTICS

Although protected cultivation provides a more controlled environment than outdoor agriculture production applications, the unstructured crop environment imposes many technical challenges for introducing robotics.

The environment around crops is known to be unstructured and dynamically developing in time and space and thus overly complex. When developing automated technology for these kinds of systems engineers must use advanced technology to deal with the complex environment as encountered in current agricultural practice or by modifying the working environment allowing simpler technical solutions or faster solutions given the current state of technology [4].

DESIGN AND OPERATION OF MODERN GREENHOUSE ROBOTIC SYSTEMS

To achieve fast and robust operation in the complex and dynamic greenhouse environment the robot must be equipped with intelligent sensing, planning and action skills. Sensing is needed for the detection, classification, and localization of objects in the 3D environment. Sophisticated algorithms are required to deal with the high variability and occlusions. Finally, intelligent planning and complex actions is required to decide on the actions and adapt to the changing crop conditions, to reach the objects within a highly occluded environment, and to pick up and transport the object to a container. These actions must be performed effectively but delicately ensuring no damage is caused to the object or crop environment [5].

MODIFYING THE WORKING ENVIRONMENT

Despite huge efforts in developing modern greenhouse robots for harvesting fruits and flowers, it is still much easier (but more expensive) practice to adjust the growing environment to best fit the robot movement before introducing it in a new production environment. This is based on robot's working analysis and crop training systems, so the production is modified to accommodate robotic operation. For instance, a high-wire cultivation system was adopted for cucumber harvester, which assured that fruits were more clearly visible and easier accessible.

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Figure 1. Robot harvesting of cherry-tomatoes [6].

THE FUTURE OF GREENHOUSE ROBOTICS

Robotisation of greenhouse production is not the solution for short-term staff shortages, although horticulture is innovating, the autonomously working applications are still relatively limited and the costs are considerable. Plant breeding with robust fruits and flowers could make it easier in the long term to automate the harvesting process. Looking from this perspective, robotisation is a solution for the shortage and costs of personnel in the sector in the long term.

LAND / FIELD ROBOTS

In comparison to the static robots in industry or robots that work in greenhouses, the development of robots that should work outside, in the elements, regardless of the conditions, proves to be a tougher challenge [7]. This one of the most inhibiting reasons why the development and use of robots is behind the use of robots in other areas. It is followed by obstructive legislation, preventing robots to work unsupervised and without protective fences, with a price tag that could be just too high for majority of middle and small farmers, with a sophistication level, including state of the art sensorics solutions, and immaturity of the technology.

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Different farm robotic producers are competing to reach market readiness to a state where the cooperation between users and producers will stay on a phase of rare occasion, but both know this will happen. One of the first producers of commercially available robots is Naio technologies [8], offering 3 different size farm robots. They cooperate with buyers after the product has been sold to work out the specifics and improve the robustness and usefulness of the robots.

The OZ, DINO and TED robots from Naio [8] are not the only robots that promise to reduce the workload in the future. Solutions like AGROINTELLI [9], AVO [10], Meropy [11], Rhoban [12], ROVITIS [13], Trektor [14], Vinescout [15] and ViTiBOT [16] seem like promising solutions that could soon reach market readiness state. All these are compared on Table 1 where their intended area of use is presented, its size, power source and sensors they use to navigate, detect plants, crop rows and other.

Table 1. A list of agricultural robots and their specifics like area of use, format, power source, and advanced sensoric systems.

Company - Name	Used in	Format	Powered	GPS	LIDAR	Vision
SITIA - Trektor	Vineyards, orchards, row crops	Big	Hybrid	Yes, RTK	No	No
Ecorobotis - AVO	Row crops	Big	Electric	Yes	No	Yes
AGROINTELLI - Robotti	Row crops	Big	ICE	Yes, RTK	Yes, multichannel	Yes
Instar- Trooper	Horticulture, arboricul-ture, logistics	Small	Electric	Yes	No	Yes
Bakus - ViTiBOT	Row crops, vineyards, orchards	Big	Electric	Yes	No	Yes
VineScout	Vineyards	Small	Electric	Yes	Yes	Yes
Naio – TED	Vineyard weeding	Big	Electric	Yes, RTK	Yes	Yes
Naio - Dino	Vegetable weeding	Big	Electric	Yes, RTK	Yes	Yes
Naio – OZ	Row crops, weeding	Small	Electric	Yes, RTK	Yes	Yes
Meropy - SentiV	Scouting	Small	Electric	Yes	No	Yes
Rhoban - E-Tract	Row crops	Big	Electric	Yes, RTK	Yes	No
Ag. Giorgio Pantano - ROVITIS	Vineyards	Big	ICE	Yes, RTK	Yes, multichannel	Yes, visual odometry
Farmbeast	Row crops	Small	Electric	No	Yes, multichannel	Yes, weed control

MARKET READY SOLUTIONS

One of the examples of this change in agriculture, with new smart machines is Naio technologies [8], a French producer that is developing robots for agriculture and viticulture, including a wide array of tools for weeding, hoeing, and harvesting to assist farmers in their daily tasks in order to relieve their workload and increase profitability while reducing impact on the environment.

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Figure 2. Robotic solutions developed by Naio technologies; eeding robot OZ (upper left image), vineyard robot TED (upper right image) and vegetable robot DINO (lower image).

CLOSE TO MARKET SOLUTIONS

TREKTOR from SITIA [13] is an interesting solution for viticulture and / or row crops, built on top of a hybrid powered system. It has an interesting design, being able to adjust its height and width

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to adjust to specific field demands. It can work close to ground for field crop related application, it can rise to work above vineyard rows or can be used in standard size to work in the orchards.

Figure 3: An example of a hybrid robot - Trektor developed by SITIA.

Another example of a bigger robot is the Bakus robot from ViTiBOT [16]. It is 100 % electrical and includes a variety of sensors; 8 infrared 3D cameras, 2 RTK GPS and 2 inertial units. All this is needed to build a robust, state of the art solution, which will be robust enough to work in a natural environment. Beside this, it has to be safe, so the BAKUS includes 8 safety buffers, 4 sensors and 6 emergency stops. The electricity powered platform is ecologically friendly as it preserves soil and air quality and produces low noise pollution.

Figure 4. An example of a fully electric platform - ViTiBOT developed by BAKUS.

The third example is the ROVITIS 4.0 autonomous vineyard robot [13] built with the support of Italian EIP AGRI project funding and led by dr. Giorgio Pantano. The Rovitis 4.0 autonomous

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vineyard robot is in final prototype stage and relays on the data sensor fusion supported by different technologies to make the robot robust as possible and to drive from the garage to the field, do the work and return to garage even with GPS blackouts and environmental interferences to other sensory systems.

Figure 5. ROVITIS by dr. Giorgio Pantano - a completely autonomous platform that drives by itself from the garage to the vineyard, autonomously completes its operation in the vineyard and returns to the garage.

ADD ON EQUIPMENT TO AUTOMATE EXISTING FIELD MACHINERY

The robots are not the only solutions that are being built to automise the workload. An additional add on equipment is being developed to be part of existing agricultural machinery. One example is the Lettuce bot by Blueriver technology [17] that was acquired by John Deer, working to detect and eliminate the weed on the field. The second example of this group is the RowCropPilot [18], developed by Robotmakers GmbH that is offering manufacturers of vehicles the possibility to automate their field machinery with low costs of investment.

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FIELD ROBOT FORMATS

So, what kind of robot should the farmer buys when they are commercially available? According to the overview from Table 1 big and small robots will be available, but in comparison to big farming machinery they are still small and a fleet of smaller field robots seems more reasonable. The size of farming machinery increased over the years so one operator could do more in the same timeframe. As the researchers and producers are working hard to produce autonomous robots, they will not need an operator, which means they can be smaller, less expensive and they can divide the work and work in fleets with no extra operator needed to manage them. In case one or a few breaks down, the others will substitute, not leaving the work uncompleted like it can happen in case of big tractors driven by human operators.

EDUCATION OF FUTURE OWNERS, OPERATORS, AND DEVELOPERS

The survey results [19] show that farmers are looking to accept new robotic solutions, but at the same time point out barriers that should be overtaken before adopting modern technologies. One is the financial burden, as the cost of the new equipment is particularly high and should be supported by subsidy schemes. The second is the complexity of such systems which in majority cannot be repaired by farmers alone, so a good support is needed in the area where these machines will operate. The last are developers that will build these machines. As the subsidy schemes are up to the policy makers and the support is left to the producers, the preparation of future skilled labour force is up to the educational entities.

One interesting approach to the last challenge, important for education of future workforce, is given by a group of teams that meet each year at the international Field robot Event [20]. This is a student event where groups from different universities meet to compete with their autonomous robotic solutions. They build small robots that fit between the crop rows and develop algorithms to make them autonomous, so they drive on the field on their own, build a map of the field, detect weeds or other objects and treat them.

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Use of drones in agriculture

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Unmanned Aerial Vehicles (UAV)/Drones have been widely used in many different domains such as precision agriculture. Nowadays, Precision Agriculture is changing many aspects of agriculture and reducing its impact on the environment. Different applications of drones in precision agriculture such as crop monitoring, biomass estimation, yield estimation, and disease detection have been recently implemented by researchers. In this study, we have identified and reviewed the survey papers published on the use of UAVs/drones in precision farming and synthesized the observations and suggestions discussed in these studies. We have investigated the use of UAVs/drones in precision agriculture, discussed the application areas and the type of devices, and presented the opportunities, challenges, and future research directions. This study not only paves the way for further research in precision farming but also presents novel application ideas that can be applied by practitioners in the future. Also, we presented our drone lab and discussed some of the research projects that are currently being implemented. We observed that this type of drone labs are quite useful for educational and research activities and improve the research collaborations.

INTRODUCTION

Investments in the agriculture sector have increased by 80% within the last five years (Tsouros et al., 2019). Because the world population will continue to increase and the agricultural areas under cultivation will decrease, the productivity growth should achieve at least 70% by 2050 (WHO, 2009). To this end, different technologies such as GIS (Geographic Information Systems), GPS (Global Positioning Systems), variable-rate fertilizers, and yield monitors are used in precision agriculture.

Precision Agriculture (PA) is defined as "a management that gathers, processes and analyzes temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production" by the International Society of Precision Agriculture (ISPAG). Zhang and Kovacs (2012) presented the following stages of precision agriculture practice: data collection, field variability mapping, decision making, and management practice.

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Nowadays, precision agriculture is changing many aspects of agriculture and reducing its impact on the environment. The core ideas in precision agriculture are also helping to improve management decisions and reach higher yield. Compared to traditional agriculture, precision agriculture manages the portions of a field instead of the whole field and this difference might be considered as one of the distinguishing characteristics of precision agriculture. However, it requires investment in technology and knowledge, which is one of the adoption barriers (Shannon et al., 2020).

One of the motivating conditions for adopting precision farming is the variability, which has the following two components: spatial variability and temporal variability. The first one is related to the characteristics over depth and distance such as variation in soil and crop. The second one is related to the characteristics over time such as variation in crop and soil. Precision farming is complex because there are several aspects that need to be considered. For example, crop yield can be represented as a function of Genetics, Environment, and Management (G x E x M). As such, there are several interactions among these components that make the variability complex (Shannon et al., 2020).

Remote Sensing is one of the most critical technologies for precision agriculture and used for more than 30 years to monitor agricultural fields (Mulla, 2013). Satellite images were used in agriculture in the past (Egido et al., 2012; Moulin et al., 1998); however, since they provide low spatial image resolution, they are no longer the best option for agriculture. Also, satellites are not always available for the tasks, which limit the temporal resolutions and environmental conditions. For example, clouds might restrict the reliability of the study (Tsouros et al., 2019). Instead of the satellite images, another option is to use manned aircraft; however, they are very costly and multiple flights are not possible due to this high operational cost. To this end, UAV-based systems are nowadays widely preferred because they can provide ultra-high spatial resolution images and have a temporal resolution because they can be used at any time (Tsouros et al., 2019) with minimal cost.

In this study, we have identified the review papers that presented different applications of drones/ UAV/UAS in precision agriculture and investigated them from different dimensions. These papers are shown in Section RELATED WORK in Table 1. Application areas are discussed in Section APPLICATION AREAS. Sensors used in drones/UAV and the applied communication technologies are explained in Section SENSORS AND COMMUNICATION. Opportunities for the use of drones/UAVs are presented in Section OPPORTUNITIES. The current limitations and challenges of using drones/UAVs are discussed in Section LIMITATIONS AND CHALLENGES. Future research directions are explained in Section FUTURE OUTLOOKS.

The following sections are organized as follows: Section 2 provides the related work and the use of drones in precision agriculture. Section 3 describes the practical aspects on the use of drones in agriculture. Section 4 presents the conclusion. Finally, Section 5 lists the references.

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USE OF DRONES IN AGRICULTURE – IMPORTANCE AND CHALLENGES RELATED WORK

There has been a lot of research on the use of drones/unmanned aerial vehicles (UAV) for precision agriculture. Each of these studies focused on a particular application of precision agriculture such as crop yield estimation, weed management, and disease detection. Recently, several review/survey articles have been published on the use of drones/unmanned aerial vehicles (UAV) for precision agriculture. In these papers, studies have been investigated from several dimensions. In Table 1, we present the survey papers that we analyzed in this article.

Table 1. The identified survey/review papers on the use of drones / UAVs in precision agriculture.

ID	Reference	Publication Type & Venue	Title	Year
1	Panday et al. (2020)	Journal / Drones	A Review on Drone-Based Data Solutions for Cereal Crops	2020
2	Messina and Modica (2020)	Journal / Remote Sensing	Applications of UAV Thermal Imagery in Precision Agriculture: State of the Art and Future Research Outlook	2020
3	Tsouros et al. (2019)	Journal / Information	A Review on UAV-based Applications for Precision Agriculture	2019
4	García-Berná et al. (2020)	Journal / Applied Sciences	Systematic Mapping Study on Remote Sensing in Agriculture	2020
5	Daponte et al. (2019)	Conference / IOP Conference Series: Earth and Environmental Science	A Review on the Use of Drones for Precision Agriculture	2019
6	Mogili and Deepak (2018)	Conference / International Conference on Robotics and Smart Manufacturing (RoSMa2018)	Review on Application of Drone Systems in Precision Agriculture	2018
7	Kim et al. (2019)	Journal / IEEE Access	Unmanned Aerial Vehicles in Agriculture: A Review of Perspective of Platform, Control, and Applications	2019
8	Boursianis et al. (2020)	Journal / Internet of Things	Internet of Things (IoT) and Agricultural Unmanned Aerial Vehicles (UAVs) in smart farming: A comprehensive review	2020
9	Hassler and Baysal-Gurel (2020)	Journal / Agronomy	Unmanned Aircraft System (UAS) Technology and Applications in Agriculture	2019
10	Abdullahi et al. (2015)	Conference / International Conference on Wireless and Satellite Systems	Technology Impact on Agricultural Productivity: A Review of Precision Agriculture using Unmanned Aerial Vehicles	2015
11	Zhang and Kovacs (2012)	Journal / Precision Agriculture	The Application of Small Unmanned Aerial Systems for Precision Agriculture: A Review	2012

In these studies, some researchers prefer the term drone and others use UAVs or other terms such as Unmanned Aerial System (UAS), remotely controlled planes, and low altitude remote sensing. A drone is an aircraft that is controlled by either onboard computers or using the remote control by the pilot who is on the ground (Panday et al., 2020).

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APPLICATION AREAS

Several applications of drones in agriculture were reported. Panday et al. (2020) specified the following major applications of drones in precision agriculture: crop monitoring, biomass estimation, yield estimation, and fertilizers, weeds, pest, and water-stress assessment. They also investigated the use of machine learning methods in cereal crop applications and categorized the applications into the following six categories:
Crop classification (Chew et al., 2020): Deep Neural Network (DNN) algorithm was used.

- Weeds identification (Gao et al., 2018): Random Forest (RF) algorithm was used.
- Disease detection (Zhang et al., 2019): Convolutional Neural Network (CNN) and RF algorithms were used.
- Water-stress assessment (Ge et al., 2019): RF algorithm was used.
- Fertilizer estimation (Näsi et al., 2018): RF algorithm was used.
- Biomass and yield estimation (Näsi et al., 2018; Fu et al., 2020): RF algorithm and ANN algorithm were used.

Messina and Modica (2020) reviewed studies that used UAV thermal remote sensing (RS). The surface temperature can be estimated with thermal sensors and this information can be used for many applications such as plant phenotyping, plant water stress detection, disease detection, yield estimation. The following applications of thermal UAV imagery analysis were presented in detail in their study:

- Crop water stress monitoring
- Plant disease detection, phenotyping, yield estimation, and vegetation status monitoring

They reported that most of the studies addressed the detection of crop water stress and management of irrigation and stated that most of the studies in the literature use other types of sensors such as multispectral and optical sensors instead of thermal sensors.

Tsouros et al. (2019) reviewed 100 papers published between 2017 and 2019. Based on their review study, the most common applications are as follows:

- Weed mapping and management: This application is the most popular one among other applications. Weeds consume the water, take unnecessary space, and cause the use of herbicides over the field. Also, the overuse of herbicides may cause pollution in the environment and evolution of the herbicide-resistant weeds. With the help of UAV images, weed cover maps can be generated and locations, where the chemicals are required, can be determined.
- Vegetation growth monitoring and yield estimation: The progress of cultivation must be monitored systematically to increase productivity. Information collection with UAVs helps to monitor the growth of the crop. Also, crop yield estimation can be performed using the collected data.

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- Vegetation health monitoring and disease detection: Diseases in crops cause the reduction of yield and hence, economic loss is inevitable. Performing this task with human experts is time-consuming. Another approach for dealing with diseases is the application of pesticides, but this may cause groundwater contamination. Using UAV-based data can detect diseases at an early stage.
- Irrigation management: The irrigation of the crops consumes 70% of the consumed water worldwide (Chartzoulakis, and Bertaki, 2015). As such, precision irrigation is crucial for agriculture. Different irrigation zones are defined to manage the water effectively.
- Crops spraying: For crop spray management, UAVs are particularly useful because they can adjust the height and amount of herbicide to spray. Also, this application is not time-consuming compared to the conventional sprayers that require the presence of operators.

In addition to these common applications, Tsouros et al. (2019) also specified the following applications of UAVs in agriculture: assessment of soil electrical conductivity (Křížová et al., 2018), soil analysis (Sobayo et al., 2018), cotton genotype selection (Jung et al., 2018), and mammal detection (Kellenberger et al., 2018).

García-Berná et al. (2020) performed a systematic mapping study (SMS) on remote sensing in agriculture. They analyzed 106 papers that focused on Remote Sensing in Agriculture (RSA) and categorized them into the following seven main research topics:

- Agricultural parameter extraction (e.g., the total biomass, the depth of the roots, height of the plants, the surface roughness, leaf area index (LAI).
- Growth vigor (i.e., temporal analysis of the plant vigor at different growth stages)
- Drought stress, irrigation, and water productivity (i.e., water and irrigation related studies)
- Detection of pathogens, diseases and insect pests (i.e., early detection of them)
- Yield prediction (i.e., predicting the yield before the harvesting)
- Weed detection (i.e., causing a reduction in water and nutrients for crops)
- Nutrient status (e.g., proper use of nutrients)

They stated that agricultural parameter extraction received more attention (i.e., 34 papers), followed by growth vigor (i.e., 26 papers) and drought stress, irrigation, and water productivity (i.e., 21 papers).

Daponte et al. (2019) specified the following applications of drones in agriculture:

- Monitoring of the crop growth, biomass, and food quality
- Precision farming applications such as the detection of weeds
- Harvesting and logistic optimization

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Kim et al. (2019) reported the following application categories: mapping, spraying, crop monitoring, irrigation, diagnosis of insect pests, and artificial pollination. Currently, UAVs are not applied for harvesting, but in the future, there might be this kind of application. They are mainly used for spraying, mapping, and sensing purposes.

Boursianis et al. (2020) performed a survey on the use of the Internet of Things (IoT) and UAV in agriculture. The use of UAV in smart farming was divided into the following key innovation and UAV utilization categories: 3D crop modeling, multi-spectral imagery, multiple-UAV systems, smart sensors integration, weed detection and management, vegetation indices extraction, yield management, field-level phenotyping, and complex agricultural issues.

Hassler and Baysal-Gurel (2020) reviewed studies that focused on the use of Unmanned Aircraft System (UAS) technology in agriculture. The following application areas were reported in their paper: field mapping, plant stress detection, biomass and field nutrient estimation, weed management, counting, chemical spraying, and miscellaneous.

Zhang and Kovacs (2012) reported the following applications of UAS in precision agriculture:

- Yield mapping
- Chemical content measurement
- Vigor mapping
- Vegetation stress monitoring
- Assessment of impacts of fertilizing on crop growth

SENSORS AND COMMUNICATION

Panday et al. (2020) reported the following sensors used for small drones: RGB digital camera, multispectral, hyperspectral, thermal, LiDAR sensors. They stated that while multi-rotor drones have the vertical take-off and landing (VTOL) ability that enables the drone to operate in space-constrained environments, they have lower efficiency compared to the fixed-wing drones because fixed-wing ones can cover larger fields with a single battery.

Tsouros et al. (2019) reported the following very common elements of unmanned aerial systems in precision agriculture: One or more UAVs, a ground control station, a UAV control system, and sensors for data acquisition. The types of the UAVs are divided into the following five categories: fixed-wing, rotary-wing (unmanned helicopter and multi-rotor), blimps, flapping wing, and parafoil-wing. According to their analysis, 22% of studies used fixed-wing UAVs, 4% of them used an unmanned helicopter, and 72% of them applied multi-rotor UAVs. No study used blimps and flapping wing UAVs in precision agriculture and only 2% of the studies applied parafoil-wing. This shows that most of the precision agriculture studies use multi-rotor UAVs. The reason is that areas are mostly not very large and there is no requirement to cover the entire land with high-speed and fixed-wing UAVs. The advantages of rotary-wing UAVs are being low-cost, having slower speeds, easy to operate, and the ability to maneuver (Tsouros et al., 2019). The on-board

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sensors that are preferred can be classified into the following categories: visible light sensors (RGB), multispectral sensors, hyperspectral sensors, and thermal sensors. In addition to these sensors, laser scanners and light detection and ranging (LİDAR) sensors can also be used. The crop features that can be monitored with UAVs can be classified into two categories: Vegetation (biomass, nitrogen status, moisture content, vegetation color, spectral behavior of chlorophyll, temperature, the spatial position of an object, size, and shape of different elements and plants, vegetation indices), Soil (moisture content, temperature, electrical conductivity). The most common methods to analyze UAV images are photogrammetry techniques (i.e., the construction of 3D models using overlapping images of the same scene), machine learning methods, vegetation indices calculation based on the mathematical transformations. The most common crops that are monitored with the help of UAVs are maize, wheat, cotton, vineyards, rice, and soya (Tsouros et al., 2019).

García-Berná et al. (2020) also analyzed the types of spectral information used in the studies and reported that RGB images are the most preferred type (i.e., 46 papers), followed by hyperspectral images (i.e., 28 papers), and thermal ones (i.e., 22 papers). The other used types are near-infrared (NIR), multispectral, red edge spectrum, synthetic aperture radar (SAR), LiDAR, and short-wave infrared. They also investigated the types of capture platforms and reported that satellite-based one is the most preferred one, followed by drone/UAV/manned aircraft.

Daponte et al. (2019) also divided the applications into the following two categories:

- Applications based on multispectral and thermal cameras: Chlorophyll and pesticide absorption, nutrient stress, diseases, water deficiency can be measured using images collected by drones.
- Applications based on RGB cameras: The Digital Terrain Model (DTM) or the Digital Surface Model (DSM) of the area can be extrapolated using images collected by drones.

Mogili and Deepak (2018) reviewed papers that explain the use of UAVs in precision agriculture. The following components embedded to the UAVs together with their purpose were reported in their study: accelerometer, gyro, magnetometer, IMU, GPS, camera, multispectral camera, hyperspectral camera, thermal camera, video camera, laser scanner, altimeter, air pressure sensor, Microsoft Kinect, barometer, digital temperature, humidity indicator, and anemometer. Also, they presented the following controllers used in these studies: Arduino mega 2560, Arduino atmega 328, KK v5.5 atmega 168, FC, Rotomotion`s SR200, Hexa-II atmega1284p, atmega 8 bit AVR, atom board processor, Yamaha RMAX, MSP430, Pathfinder-plus, LLP&HLP, DJIs 900 model, TTA M8A, Z-3, N-3 type, UAV ZHKU-0404-01, and Aero drone PAM-20.

Kim et al. (2019) reviewed studies that focused on agricultural UAVs. They divided UAV platform types into two main categories, namely fixed-wing and rotary-wing. Rotary-wing one was further divided into two subcategories, namely multi-rotor and helicopter. Multi-rotor one was further divided into three main categories, namely quadcopter, hexacopter, and octocopter. For communication, the following categories were defined: Wireless Radio, Wireless Local Area Network, Bluetooth, WiFi, and Xbee. They categorized UAV control methodologies into the following categories: linear control, nonlinear control, learning-based control, and swarm control.

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OPPORTUNITIES

The following opportunities for drone-based applications were discussed in the study of Panday et al. (2020):

- Ultra-high spatial resolution: Drones can provide ultra-high spatial resolution images depending on the flying height.
- Extremely high temporal resolution: Drones can fly at different times and phenological stages of cereal crops.
- Cloud-free images: Clouds were an obstacle for satellite images, but drone-based images are not affected by clouds.
- Potential for high-density 3D point cloud: For the estimation of crop phenology, biomass, and plant height, the 3D point cloud is required. Drones provide good potential for the high-density 3D point cloud.
- High potential for citizens participation: The use of drones and the application of image processing tools such as PrecisionMapper and WebODM on the collected images by farmers are now possible with some training.
- Scalability with a low-cost operation: Cooperative farming helps to reduce the costs and share the resources. Drones are scalable and low-cost in the case of cooperative farming (Neupane et al., 2015).
- The emergence of cloud-based data processing platforms: Big data processing platforms such as Microsoft Azure and machine learning algorithms provide several opportunities to process the collected data.
- The fair and accurate payout for crop insurance: In the case of natural disasters, pandemic, and zoonotic diseases, the accurate assessment for crop insurance payout is necessary and drones can provide useful information.

LIMITATIONS AND CHALLENGES

The following challenges of drone-based applications were presented by Panday et al. (2020):

- Limited payload: Drones have limited capacity to carry sensors, and lightweight ones are expensive.
- Low spectral resolution for low-cost sensors and high cost of hyperspectral sensors: Hyperspectral cameras are expensive, and consumer digital cameras are not sufficient for many applications. In this case, multispectral sensors might help to solve this problem.
- Sensitivity to atmospheric conditions: Haze, strong wind, and precipitation may adversely affect the use of drones; however, proper planning and image preprocessing approaches can help to overcome these problems.
- Limited flight endurance: The use of multi-rotor drones in large fields is not possible, but fixed-wing drones can be utilized in that case.

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- The high initial cost of ownership: Hyperspectral sensors improve the quality of the applications, but they are costly compared to the other sensors used in agriculture.
- The requirement of customized training to the farmers: Confidence and motivation of the farmers are important for the proper application of technologies in agriculture. Therefore, training is needed for farmers.
- Lack of technical knowledge for repair and maintenance, and unavailability of parts: The maintenance of the drones requires expert knowledge and sometimes the unavailability of some parts might be a serious problem.

Although there are many benefits of using the UAVs in precision agriculture, there are also some limitations listed as follows (Tsouros et al., 2019):

1. There is no standardized workflow to process the UAV-based image data.
2. Skilled and expert personnel are needed to process the collected images.
3. High investment costs are needed.
4. Most UAVs have a short flight time (i.e., 20 mins to 60 mins), or the UAVs that have longer flight time are very expensive.
5. Climatic conditions such as rainy or windy days affect the use of UAVs.

The following limitations exist (Kim et al., 2019):

- Battery and flight time limitations: These limitations can be minimized with the help of hybrid battery solutions. Also, swarm control techniques using multiple UAVs can help to operate UAVs more efficiently.
- The user interface limitation: A better user interface will simplify the use of UAVs in the agriculture sector.

Hassler and Baysal-Gurel (2020) specified the following sensors in their study: RGB cameras, multispectral and NIR cameras, hyperspectral cameras, thermal cameras, and depth sensors. The following limitations were discussed:

- Platforms cannot be used for long flight times
- Photogrammetric processing time might take a considerable amount of time for high-resolution images
- An up-front investment cost is required

Abdullahi et al. (2015) discussed the following limitations:

- Difficulties of taking readings in extreme weather conditions
- Insufficient regulations on flying UAVs
- No standardized workflows for UAV image processing
- Sensor payload limitation

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Zhang and Kovacs (2012) explained the following challenges of applying UAS in agriculture:

- High initial costs
- Platform reliability due to engine breakdown and inadequate materials
- Payload weight limitations
- Lack of standardized procedures
- Strict aviation regulations
- Lack of interest from the farmers
- Short flight duration

FUTURE OUTLOOKS

The following future outlooks were discussed by Panday et al. (2020):

- The drone is still considered as a high-tech device in low-income countries. For larger farm sizes, satellite-based images might be better because drone-based data provide local-scale solutions. For an accurate yield estimation, a framework is needed to integrate local scale drone-based data with satellite-based data.
- Citizen science-based data can be used to validate the models. Also, the use of drones by farmers can reduce the costs, improve the technical know-how of farmers, and help to create a sustainable system.
- Most of the studies apply linear regression models; however, machine learning-based approaches provide more opportunities to investigate.

Messina and Modica (2020) discussed the following research outlooks in their article:

- The operational costs of thermal sensors per hectare are more expensive than the cost of multispectral ones. Also, an expert is needed to process the acquired images. As such, this practice can be preferred by farmers who have large agricultural fields.
- More research is needed to simplify the use of collected data because thermal remote sensing needs expert knowledge on thermography.
- It is desirable to combine thermal satellite data with UAV images to improve the quality of the models.

García-Berná et al. (2020) presented the following future outlooks:

- A solution, which integrates in-field cameras and airborne images, is needed to reduce costs, and cover large fields
- Deep Neural Networks have the potential for further research
- For holistic approaches, problems should not be considered in isolation. The integration that considers all the aspects in the cultivation cycle must be considered

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Boursianis et al. (2020) reported the following future research directions in their study:

- Each system addresses a particular cultivation process. However, the integration of a group of cultivation processes can provide more benefits.
- There are still several agricultural issues such as field-level phenotyping and quality improvement of the crop.
- User-friendliness, easy installation, and system scalability should be considered in future developments.

Hassler and Baysal-Gurel (2020) reported the following research directions:

- Agricultural image databases are needed to be shared with the other researchers
- More deep learning-based models can be developed
- The use of UAS in livestock is very limited and UAS with thermal cameras can monitor the health of cattle and discover the lost individuals.
- Limited human intervention is needed for these systems

Abdullahi et al. (2015) reviewed studies on the use of UAVs in precision agriculture. For future research direction, they suggested focusing on the reduction of costs of UAVs.

Zhang and Kovacs (2012) specified the following future outlooks study:

- New camera designs
- Lower costs
- Improved image processing techniques

EXAMPLES OF PRACTICAL USE OF DRONES IN AGRICULTURE

Unmanned Aerial Vehicles (UAV or drones) technology today is one of the most demanding monitoring tools for agriculture and nature conservation. Nevertheless, airborne technology is still very complex, and proves to be a hurdle to non-expert users. There is an eminent need to investigate further on how to bridge the gap between UAV technology and non-expert users, like farmers and crop producers.

A new facility hosted by the Information Technology Group (INF) at the Social Sciences Group of Wageningen University & Research has been opened to address this problem. In this new Social Artificial Intelligent Drones (SAID) Lab or Social Drones Lab for short students, researchers and other (internal and external) stakeholders are working, as shown in Figure 1. Dr. Joao Valente is the Principal Investigator of this research lab, who is also involved in this VIRAL+ project.

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Figure 1. Students visiting the SAID lab for the first time, from left to right: Christos Pantos (Biosystems Engineering, Junior Researcher), Mihai Frangulea (Plant Sciences, Junior Researcher), João Valente (Principal Investigator), Stefan Maranus (former Research Assistant).

SAID Lab envisions to have a research facility that develops Artificial Intelligence (AI) approaches applied to UAVs to leverage the interaction between people and airborne technology. The SAID Lab mission to contribute to research excellence is presented as follows:

- Design AI approaches that translate raw UAV data in practical information that can be understood by non-expert users.
- Explore famer-UAV interaction tools, e.g., combined with Internet of Things (IoT), that ease the usage of UAVs.
- Develop AI data fusion approaches, e.g., multiple sensors, to support farmers decision-making in real-time.
- Leverage multi-robot symbiosis, e.g., A complex task executed by a ground and an aerial robot collaboratively.
- Boost the adoption of off-the-shelf robotic farming systems.
- Boost UAV technology education, e.g., workshops, MOOCs.
- Promote circular economy and engineering with recycled materials.

Currently, there are several projects and activities running in the SAID Lab focusing both in research and education. Some of the projects that are running are shown as follows:

- Robotics Association for Wageningen (RAW) 1.0 – Learning ROS programming drones, funded by European union.
- MARS4EARTH: Modular Aerial Robotic Systems for Sustainable Living on Earth, funded by Netherlands Organisation for Scientific Research (NWO).
- MOOC Drones for Agriculture: Prepare and Design Your Drone (UAV) Mission, funded by WUR.
- FIELDS2COVER: Roads across the fields, funded by Netherlands Organisation for Scientific Research (NWO).

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The SAID Lab is also a sister facility of the Unmanned Aerial Remote Sensing Facility (UARSF) which is hosted by the Laboratory of Geo-Information Sciences and Remote Sensing – Wageningen University & Research (WUR), Environmental Sciences Group. SAID and UARSF complement each other and envision stepping towards the employment of autonomous and more intelligent vehicles for remote sensing the environment. Additionally, further collaborations are running within other chair groups and research centres from WUR, but also with other universities and labs worldwide.

Moreover, several other projects addressing the usage of drones for agriculture and nature management are being developed as part of BSc and MSc thesis studies. These projects focused in TRL up to 6, where the focus is to develop airborne and sensing technology that can be combined to support people with less technical skills like farmers. The projects developed so far have been demonstrated in small-medium scale agricultural companies, but also in large scale agricultural scenarios. Some successful case studies that have been demonstrated are presented as follows:

Agriculture applications:

- Yield estimation tools for orchard management: https://doi.org/10.3389/fpls.2020.01086
- Spinach plant breeding management: https://doi.org/10.1007/s11119-020-09725-3, https://doi.org/10.1109/LRA.2019.2926957
- Disease detection in potato plants: https://doi.org/10.3390/s19245477
- Fruit ripeness estimation: https://doi.org/10.3390/s19020372

Nature management:

- Remote and mobile assessment of greenhouse gases: https://doi.org/10.3390/mi11080768
- Limnology long-term remote sensing: https://doi.org/10.3390/app9010038, https://doi.org/10.3390/drones4030037
- Flood damage assessment: https://doi.org/10.1007/s12145-019-00427-7

The SAID lab has currently five aerial drones from the French company Parrot. Three of them are the AR.Drone 2.0 and the other two are the Anafi models. Both platforms can be programmed using open-source software development kit (SDK), which is also available in the Robotic Operation System (ROS) framework. Figure 2 depicts AR.Drone and ANAFI drones that fly in a greenhouse while detecting and counting plant leaves.

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Figure 2. AR.Drone and ANAFI flying in a greenhouse while detecting and counting plant leaves.

Furthermore, the SAID lab has a water drone, named Striker. This platform was custom-built to support aerial drones in in-land water environment as a backup landing and recharging platform. Striker can navigate in two modes: Autonomous or Remote-piloted. Aerial drones up to 5000 grams can land on his surface. Moreover, this project is 100% open-source. Currently it is being upgraded to be used as a remote sensing platform. In Figure 3, the Strike drone is shown from different angles.

Figure 3. The Strike bottom up where the mechatronic system is enhanced (left) and full assembled (right).

Additional to drones, the SAID Lab has also one 3D printer and high-performance computer, as shown in Figure 4.

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Figure 4. High-performance computer with a Intel Core i9 (3.3 GHz), 2 NVIDIA TITAN RTX, HDD 3TB Samsung 860 EVO, 64 Gb memory RAM, and a Corsair AX1600i board (left) and Creality 3D® Ender-3 DIY 3D printer kit with a 220x220x250mm printing size (right).

The SAID Lab is online, and you can find the latest news and progress in Twitter (https://git.wur.nl/said-lab). Moreover, the SAID Lab is governed by an open-access philosophy, therefore all the researchers are encouraged to make the (non-confidential) data available in a public repository. The SAID Lab public repository can be found in the WUR GitLab (https://git.wur.nl/said-lab). Finally, a webpage is in under development and will be hosted by WUR (https://saidlab.wur.nl/).

From educational perspective, we have observed several benefits opening this drone lab in our university. Also, it helps to collaborate with industrial partners and researchers from other chair groups.

CONCLUSIONS AND RECOMMENDATIONS

These papers were investigated, and the observations presented in these studies were discussed in detail. Based on the identified papers, we have presented the opportunities, challenges, and future research perspectives.

Our recommendations for future research are as follows:

- More research is needed on the use of deep learning-based drone applications in precision agriculture
- A framework and a public repository are required to evaluate the existing techniques in literature
- The cost of devices and platforms need to be decreased for wider acceptance of this technology

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- The data integration is needed to develop holistic approaches in precision agriculture
- The user friendliness must be improved, and the available tools must be simplified
- The battery capacity of drones needs to be improved

We have also shared our new Drone lab that has several drones used in agriculture. We believe that this type of drone labs are very useful for not only agricultural universities but also technical universities that aim to collaborate with industry using drones.

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Co-funded by the Erasmus+ Programme of the European Union

Use of mobile applications in smart agriculture

T. Popović, V. Maraš, S. Čakić, S. Šandi, S. Radonjić, K. Pavićević

ENABLING TECHNOLOGIES, IT MEGATRENDS

Nowadays, we are witnessing the dramatic process of digital transformation in which digital technologies are changing how businesses connect and create value for their customers. Digital transformation is gaining an important role in the agri-food sector in production and in general in agriculture. [1-2] This section focuses on the use of mobile applications in smart agriculture and megatrends in ICT that enable implementation of such solutions.

MOBILE

The use of mobile devices is one of the biggest trends in ICT today. In most countries, even undeveloped ones, the majority of people do have a mobile phone within a 24/7 reach. This is dramatically affecting the paradigm of usage of connected computing devices. With PCs and laptops, the expectation was that people would access them or be available during work hours only. The popularity of mobile devices pushed development and production of better miniature and low-power computer components such as CPUs, RAM and flash memory, batteries, connectivity, etc. Mobile devices are often used as the mean for Internet access [3]. For organizations, the presence of mobile computing and connectivity allows increased collaboration, ability to manage businesses in real time (anytime, anywhere), and provides new ways of getting in touch with customers. Most popular mobile devices are mobile phones and tablet computers. Mobile phones are full blown computers miniaturized and formed to perform the phone function, and equipped with Internet connectivity. Mobile devices are equipped with variety of sensors and computing capabilities that allow for creation and installation of various mobile applications (apps) that can add new and innovative features. Mobile apps can be made as a stand-alone functionality running on the device itself, but more often they are made as a “window” into systems that are installed on remote computer infrastructure (Cloud).

Main benefits are summarized below [4]:

- Powerful devices within small packaging,
- Battery powered with Internet access,
- Easily expanded with addition of new apps,
- Real-time connectivity, anywhere, anytime (24/7),
- Availability of BYOD (bring your own device) paradigm,
- Mobile Apps provide access to systems employing various other technologies (Cloud, Internet of Things, Sensors, Computer Vision, AI).

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INTERNET OF THINGS

Internet of Things (IoT) is an IT megatrend that is a key enabler for precision agriculture. The IoT technology assumes a network of physical objects (devices, vehicles, buildings, equipment, etc) that are equipped with embedded computers, electronics, sensors and networking allowing these objects to collect and exchange data (Ojha et. al. 2015). IoT is necessary technology and very often combined with Cloud setup for data collection and storage, data analytics, and application hosting. The concept of precision agriculture supported by IoT technology is illustrated in Fig. 1 (T. Popovic et a. 2017). Various electronic devices equipped with sensors (i.e. air temperature, air humidity, air pressure, soil moisture, cameras on drones and satellites) allow for much broader coverage of the field with measurements and provide an in-depth insight into conditions in the field. The data is communicated to servers in the Cloud, where it can be processed and analysed in order to extract additional knowledge and implement various decision support functionalities. The users can access the data and analysis results via their mobile devices while on the field, but also from remote locations (office, home). The mobile devices can be used for alarms, notifications and to allow users to initiate or confirm actions (i.e. to remotely activate irrigation).

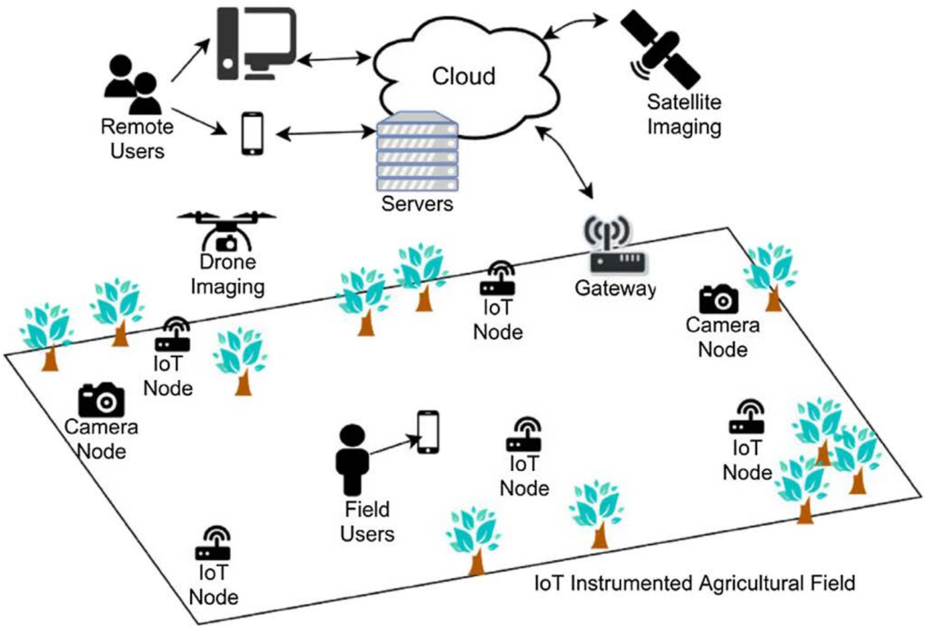

Figure 1. Contextual view of precision agriculture [5]

An illustration of the IoT reference architecture is given in Fig. 1. The architecture assumes the use of sensors in the field used for collection of various measurements about the objects of interest. The sensor measurement, sometimes called raw data, is communicated via network connections and the data is aggregated, preprocessed and stored for further analysis. Depending on the application, the data is put into the context and analysed to create or extract additional knowledge used to augment and improve our decision-making process and the actions. As seen in the diagram, mobile technology and devices can play role in sensor data creation and collection, as

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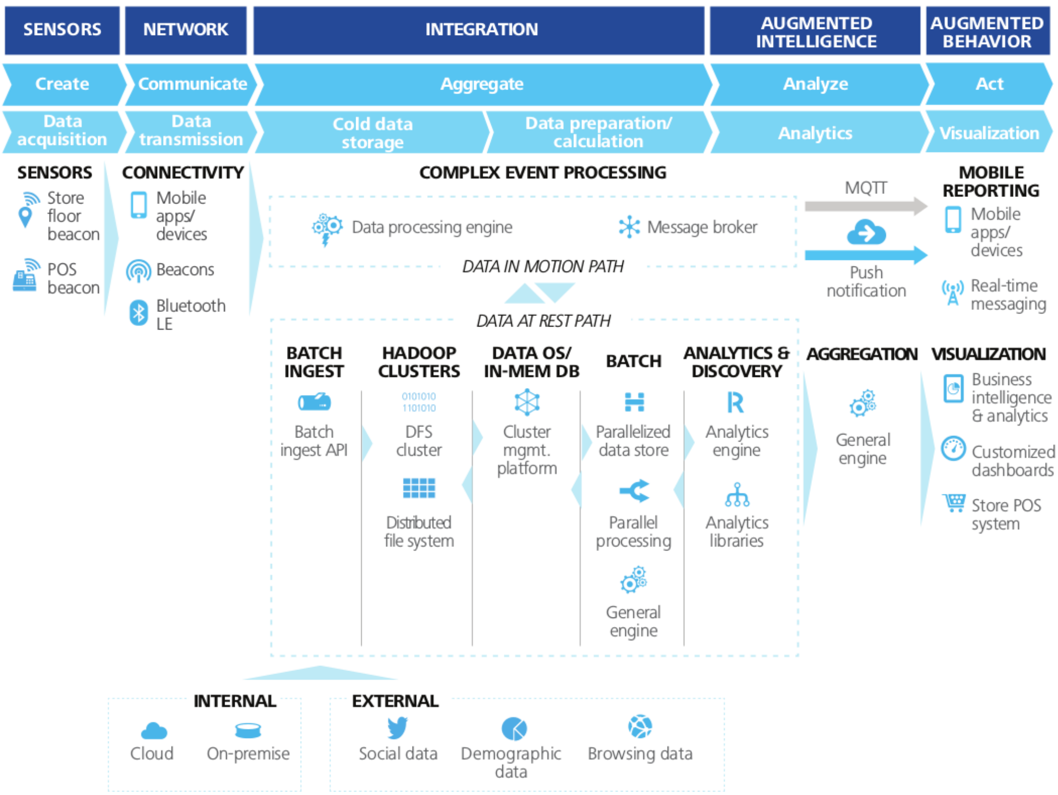
well as in the process of mobile reporting and with or communications back to the actuators in the field (i.e., start the irrigation pump). Finally, the key role is a multi-purpose two-way interaction with the end users. The interaction with the end users may be to collect additional data, to inform them about the augmented intelligence about the process, or to send or receive action commands. The IoT technology is one of the key enablers for creation of advanced smart agriculture applications that involve mobile technologies.



Source: Deloitte's IoT Reference Architecture.

Figure 2. Internet of Things: Reference Architecture, image: https://deloitte.com

CLOUD

Cloud computing technology provides an on-demand availability of computer system resources such as data storage, processing power and operating memory, and connectivity. Cloud relies on the availability of high-speed Internet connection and allows users to utilise the resources without direct involvement in the management (please refer to Fig. 3). There are various service models available, most notably:

- IaaS – Infrastructure as a Service, where users or solution providers use the infrastructure provided by Cloud service providers;
- PaaS – Platform as a Service, where the Cloud offers a platform type service that is used as a foundation to implement a solution;
- SaaS – Software as a Service, where the complete software system installed on the cloud infrastructure is offered as a service.

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As for the deployment, there are various approaches, i.e. deployment models:

- Public,
- Private,
- Community,
- Hybrid.

Cloud technology targets higher reliability of information systems and the back-end of modern information systems including advanced mobile apps is typically installed on a Cloud infrastructure or platform.

Cloud systems are very popular for modern projects. With cloud technology you can use a lot of micro-services that already implement most common functionalities for most common problem. Sometimes, for complex systems infrastructure can be very huge and hard to setup. These cloud systems can help to solve that problem. Also, some of the benefits are reducing costs, flexibility, improved automation, etc. Some of the most popular systems are:

- Azure,
- Amazon web services (AWS),
- Google cloud.

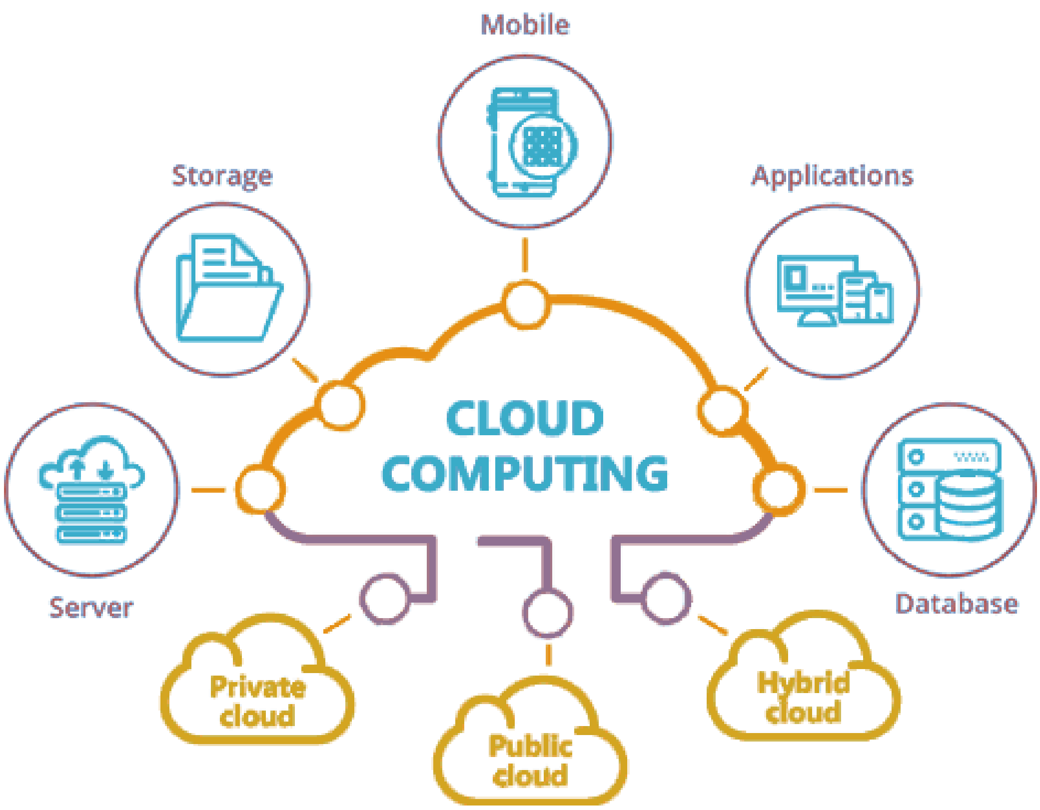

Figure 3. Cloud computing, image: https://networkencyclopedia.com/cloud-computing/

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BIG DATA AND DATA ANALYTICS (AI)

Big Data is an information technology megatrend that addresses the ways to analyse, extract information and knowledge from, or in generally deal with data sets that are too large or complex to be processed by traditional data processing approaches. Data sets are growing rapidly due to the fact that there are more and more computers, mobile devices, and embedded (often inexpensive) computers equipped with various sensors or input devices. There is a wide variety and large volume of data, coming in at different speed (velocity) and with different level of accuracy and reliability (veracity). Volume, velocity and veracity are sometimes called three Vs of Big Data (see Fig 4.) [6]. Users with their mobile devices are also source of Big Data and this data is used or can be used in different ways.

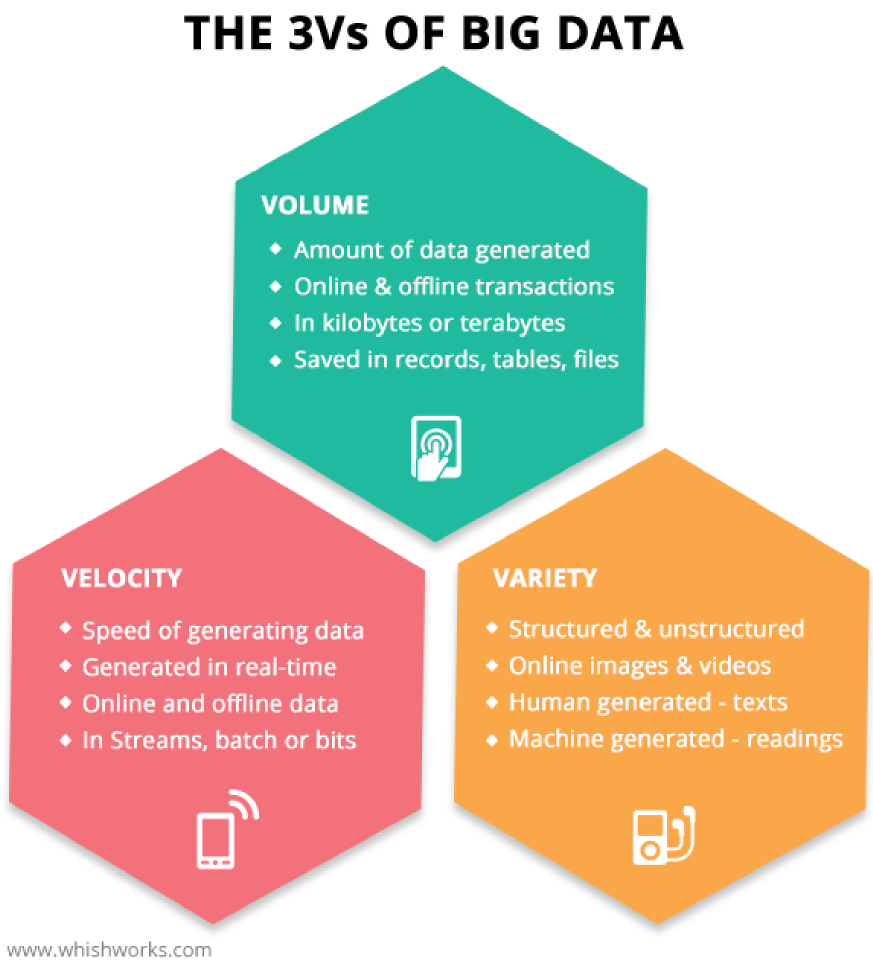

Figure 4. The 3 Vs of Big Data, image: https://www.whishworks.com/

Typically, big data refers to predictive analytics, user behaviour analytics, or various advanced data analysis and knowledge extraction methods that extract value from data. Nowadays, artificial intelligence (AI) is part of everyday routine but most of people does not recognize that. One of the fields where AI can be used very efficiently is agriculture. Some of the main fields of usage:

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- Speech recognition and NLP,
- Understand context from text,
- Translate text from one to another language,
- Robotics,
- Recommendation systems (Amazon, Netflix, etc),
- Search engines,
- Email (spam / not-spam),
- Face recognition,
- Games (chess– IBM Deep Blue, Dota 2 – OpenAI, Go - AlphaGo),
- Diseases detection,
- Autonomous driving,
- Biomedicine, etc.

Two main subfields of AI are especially important: machine learning and deep learning. In those fields data and good models are most important things. Without enough preprocessed data machine learning is almost useless. Machine learning is often classified on supervised and unsupervised learning. For supervised learning, model learns to predict result from labelled data. In the case of unsupervised learning algorithm form some knowledge from data, and can see something that is not obvious if someone analyse that particular problem. Also, one of the fields of AI that have enormous impact on a lot of processes is deep learning (DL). Most people say that DL is machine learning, but with processing more data. Popular concept that is must be mentioned for DL is neural network, which is core of the DL. Neural networks are used to recognize pattern in processes and generate appropriate answers from the given input data. It is a learning process. Figure 5 depicts the relation between AI, ML, and DL.

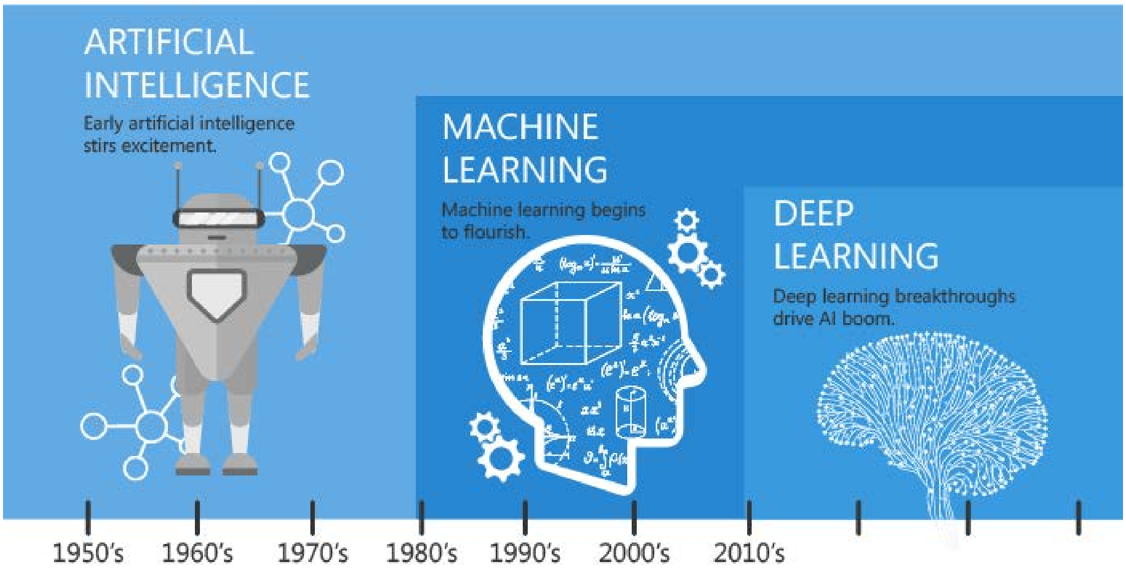

Figure 5. Relation between AI, ML, and DL, image: https://towardsdatascience.com/artificial-intelligence-vs-machine-learning-vs-deep-learning-2210ba8cc4ac

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SOCIAL MEDIA

Social media and social networks are interactive web-based applications that allow users to not only consume the information, but also act as creators of the content available on Internet. User generated content includes textual messages, i.e., posts and comments, digital photos, and videos, as well as meta data that results from these interactions (tags, dates, GPS location, ...). This collective creation of the content and continuous interaction of social media users makes this technology a megatrend that changes the way how we do the business.

Social media and 24/7 connectivity of the end users drives businesses to use social networks as a platform for marketing and sales promotions. Social media also allows companies to collect a feedback from end users, provide support and perform risk management. Being a powerful tool for interaction with users it important to understands that social media may have negative effects to business if not used the right way. Finally, social media is a major source of data that can be combined with the data from other sources and used big data in analytics, as well.

Figure 6. Social media interactions, image: https://www.marketingwitches.com/

MOBILE APPS IN SMART AGRICULTURE

Mobile applications can be very useful in a lot of areas. One of them is their use in smart agriculture. Farmers need information from crop planning to final product sales (Figure 7), and mobile apps could provide that. This information varies according to the crop calendar, however, there are some categories of information that are common to different epochs and independent of the crop type and its location [7]. These categories are divided into three main stages: know-how, contextual information and market information.

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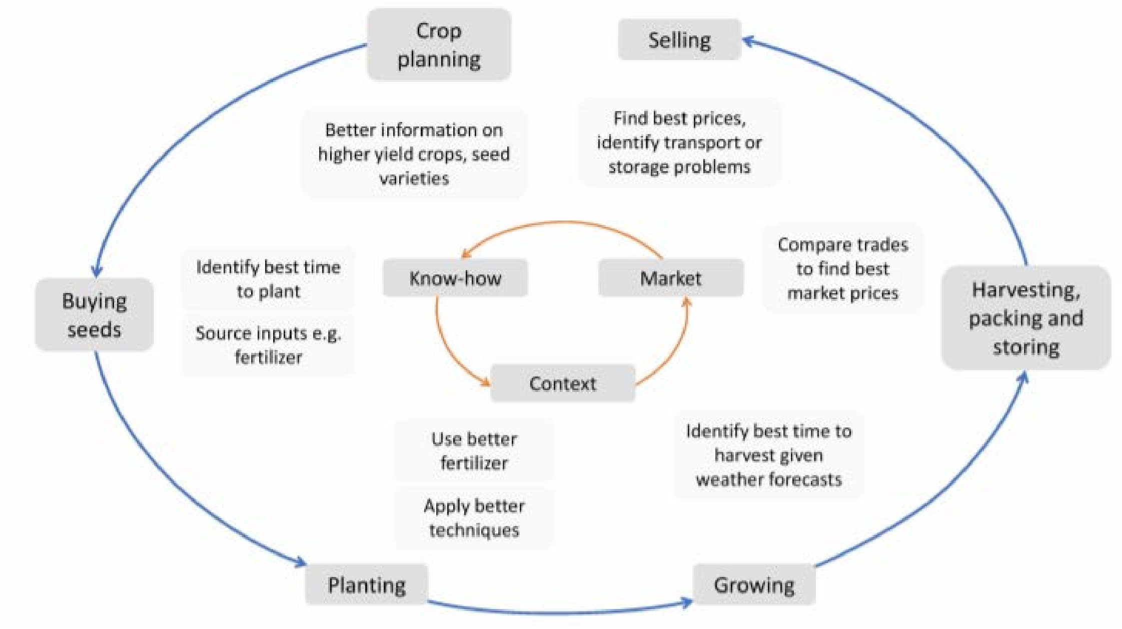

Figure 7. Information needed from farmers through the agricultural cycle [7]

Questions in these stages, like what are the new crop options (know-how), when should I harvest taking climate/soil into account (contextual information) or what are the products prices (market information) can be used to define better production.

Mobile business is based on a set of goods and services offered by a mobile device company, including hardware, operating system and mobile apps offered in app stores. As for hardware, this includes various types of mobile devices, components used to make them, as well as physical add-on components.

Main class of mobile devices widely user around the world is smart phones, i.e., mobile phones equipped with connectivity and computing resources, including system software and capabilities to install mobile apps [7-10]. The use of mobile apps and mobile devices in agriculture is not an exception. There are various mobile applications for agriculture and they can be divided in following groups [7-15]:

- **Crop operations** applications can help farmers in general crop-related activities on their farms [16-20]:
  - Crop protection and diagnosis applications mostly used for:
    - Pest and diseases detection and diagnosis;
    - Weeds identification and treatment;
    - Soil and plant diagnosis.

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    - Crop nutrition and fertilization applications mostly used for:
        - Crop nutrition monitoring;
        - Spraying management;
        - Fertilization application.
    - Crop irrigation applications main functionalities:
        - Crop hydric status and irrigation decision;
        - Support irrigation
    - Crop growth and canopy management applications are used for:
        - Track canopy growth;
        - Calculate LAI (Leaf Area Index)
    - Crop harvest mobile applications are used for:
        - Estimation of productivity;
        - Indicators of quality.
- Farm management category includes applications that help farmers to achieve better management of farm resources and general agricultural activities [20-25]:
    - Field mapping and soil information are used for:
        - Field location and area calculation;
        - Identification of sample collection points;
        - Soils agricultural indicators: colour, pH, NPK (N—nitrogen, P—phosphorus and K—potassium), carbon content, etc.
    - Machinery management apps for:
        - Machinery costs estimator;
        - Real-time field trajectories monitoring;
        - Machinery monitoring: activities, productivity, efficient use, stability, etc.
    - Control of farm activities:
        - Manage field tasks, manage farm workers' activities.
- General information system for providing most relevant facts for the farmers such as [26-29]:
    - Agricultural tips and knowledge;
    - Market information;
    - Relevant news;
    - Chat with experts;
    - Climate.

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On the Figure 8 you can see example of agriculture mobile application PCAPS.

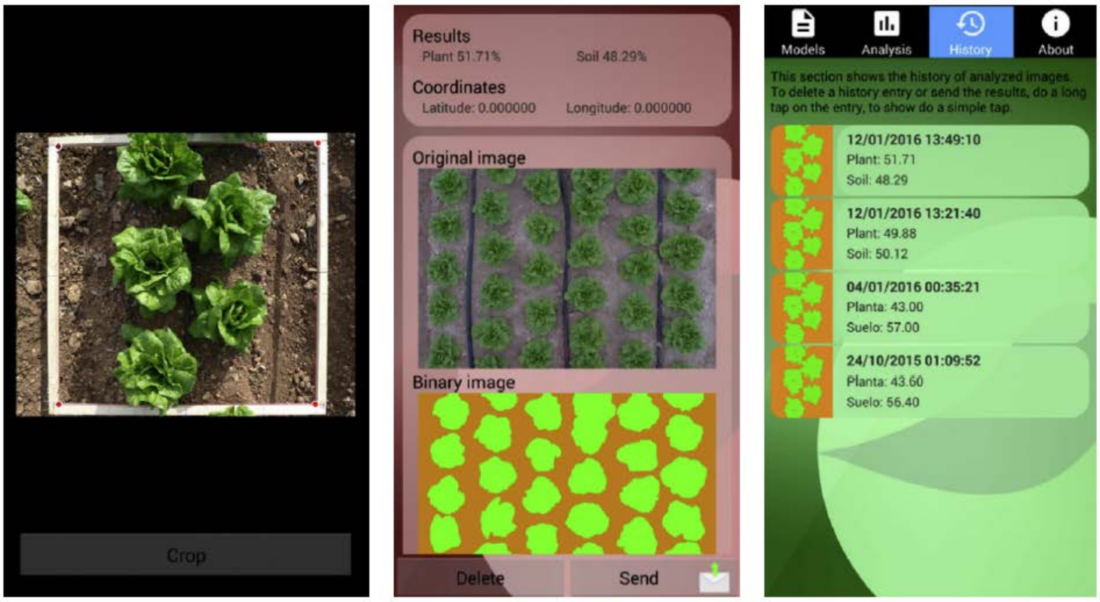

Figure 8. PCAPS [24]

SMART AGRICULUTURE PILOTS IN MONTENEGRO

There are several smart agriculture pilots currently being implemented in Montenegro by University of Donja Gorica and company "13. jul Plantaže" in partnership with technology company DunavNET:

- Counterfeiting prevention in wine industry implemented as food track and trace use case that includes interaction with end-users [31, 32]. This system combines smart tags, IoT, Cloud, and mobile app to monitor each wine bottle and its status throughout supply chain. The solution uses heuristics to determine whether a specific bottle may be a subject of counterfeiting activity (Figure 9).

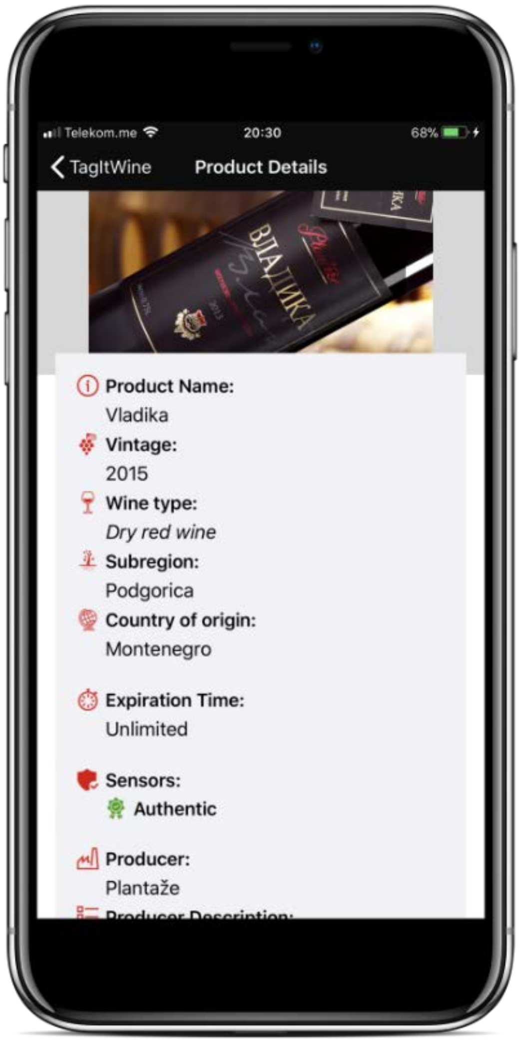

Figure 9. Mobile app for wine tracking and tracing

- Precision agriculture pilots aiming irrigation optimization and disease detection and prevention [32, 33]. These pilots are being implemented in vineyards (precision viticulture) and in orchard settings (apple and peach farms). Typically, they use IoT weathers stations to monitor air temperature, humidity, pressure, atmospheric participation, and IoT nodes with sensors such as leaf wetness, soil moisture, and cameras to capture images inside pheromone traps. The data is used for remote monitoring and for prediction models and decision support in applications to optimize irrigation, insect spraying, etc [32]. User interact with these solutions using web browser on their personal computers or mobile devices (Figure 10).

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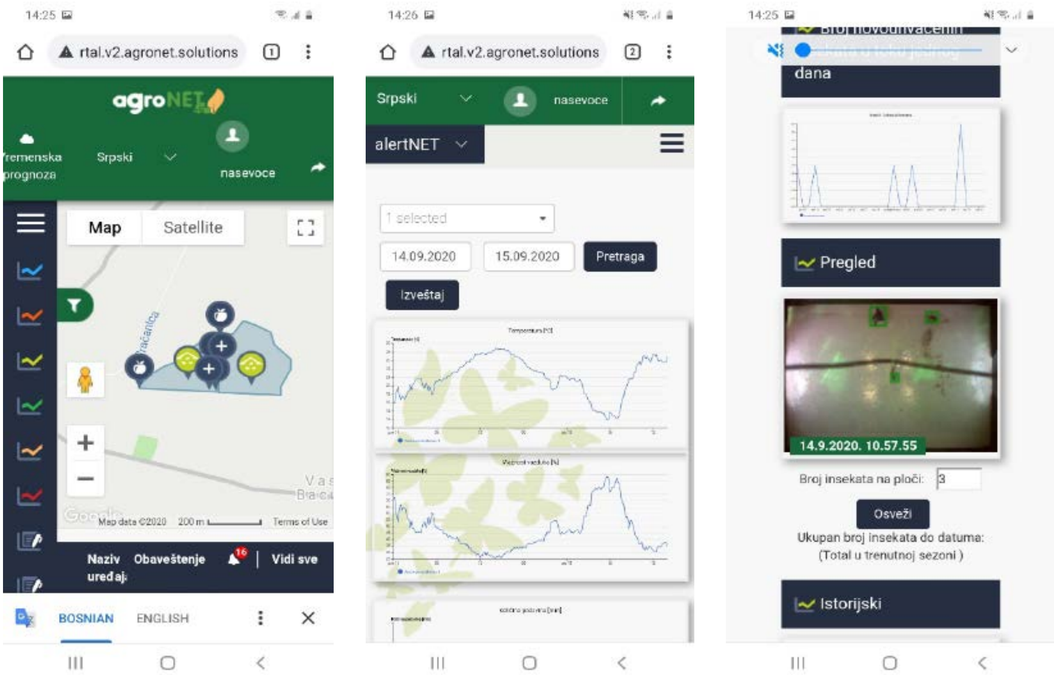

Figure 10. Accessing smart agriculture platform using a mobile device [34]

- Precision agriculture pilot for poultry farms focused on environmental parameters monitoring and health assessment [33]. IoT nodes with sensors for temperature, humidity, air flow, CO2 are used to monitor and control conditions in poultry farm objects (Figure 11).

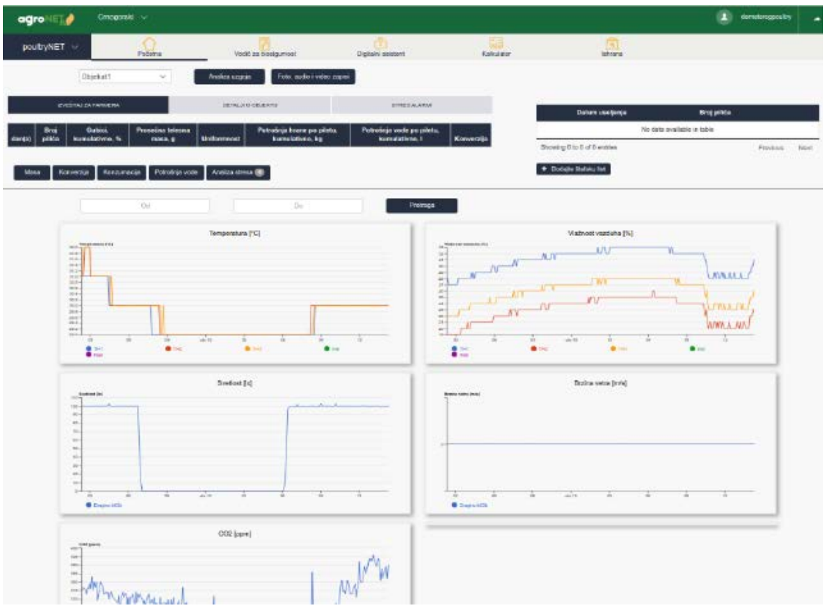

Figure 11. AgroNET patform poultry farm management [34]

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Co-funded by the Erasmus+ Programme of the European Union

Use of GIS in agriculture

M. Šipka, M. Marković

INTRODUCTION

Agriculture is being changed by three fundamental forces: molecular biology revolution, the expanding capacity of personal computers, and developments in information technology like geographical information systems (GIS) [17]. Agriculture is a business sector ideally suited for the application of GIS because it is natural resource based, requires the movement, distribution, and/or utilization of large quantities of products, goods, and services, and is increasingly required to record details of its business operations from the field to the marketplace. Nearly all agricultural data has some form of spatial component, and a GIS allows you to visualize information that might otherwise be difficult to interpret. The value of GIS to agriculture continually increases as advances in technology accelerate the need and opportunities for the acquisition, management, and analysis of spatial data on the farm and throughout the agriculture value chain [64].

Production of food in a cost-effective manner is the essential goal of every farmer, large-scale farm manager and regional agricultural agency. Remote sensing (RS) and GIS used to analyze and visualize agricultural environments has proved to be very beneficial to farming community as well as industry. It plays great role in agriculture throughout the world by helping farmers in increasing production, reducing costs and managing their land more efficiently. GIS has been widely applied and been recognized as effective and powerful tool in detecting land cover and land use change [39]. In the face of decreasing land, degrading soil quality, limiting water resources and rapid climate change, the main challenge for every country is to vertically maximize production in order to provide sustainable food security for all people of the country. Current trend of food demand and production reveals that in next 20 years, it would be quite impossible to feed the increasing population without proper scientific management and planning of the existing natural resources. However, for maximizing the production and for the potential use of land and soil resources considering soil health conservation, water saving in irrigated agriculture, crop adaptation with the climate change, a quick acquisition of related comprehensive information is necessary for decision making, technology generation and scaling up processes. Use of GIS and RS techniques can play active role in accomplishing these processes. However, GIS and RS are not automated decision-making systems but these are tools to data acquisition and analysis, and produce relevant maps in support of the decision-making process [26].

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GEOGRAPHIC INFORMATION SYSTEM (GIS)

Geographical information systems are a special class of information systems that keep track of events, activities and things and also of where these events, activities or things happen or exist [46].

According to Sharma R. et al (2018) GIS deals with spatial data and visualizes the collected information with patterns and relationships using computer-based tools. GIS includes the following components:

- Storage of spatial data in digital form.
- Management and integration of spatial data collected from different sources into the GIS system.
- Retrieval and conversion of the spatial data in the required formats.
- Performing data analytics to convert data into useful information.
- Developing different models based on the information.
- Display of information model and decision making.

Figure 1. Examples of notable commercial and open-source GIS software
source: Sarmah K. et al (2018)

Acharya S.M. et al. (2018) recognize that GIS combines location data with both quantitative and qualitative information about the location, allowing you to visualize, analyze, and report information through maps and charts. When these data are organized in a GIS along with other parameters, they become an important tool that helps in making decisions about crops and agricultural strategies.

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APPLICATIONS OF GIS IN AGRICULTURE

GIS applications play an important role in the agriculture production, both locally and across the globe. Through assisting farmers in increasing production, reducing costs, and providing an effective means of managing land resources, GIS has become an increasingly invaluable resource. Its applications come in a variety of forms, including precision farming, drone and satellite technologies and the capabilities of Geographical Information Systems themselves [1]. According to Hartkamp et al (1999) applications of GIS have grown from primarily hydrological applications in the mid-1980s to the current wide range of applications in agronomy and natural resource management research. Computer programmes, such as GIS, contribute to the speed and efficiency of overall agronomic planning processes [93].

Oshunsanya S. O. and Aliku O. (2016) divide GIS applications in agriculture into the following categories:

- Operational use of GIS in precision farming
- GIS applications in agrometeorological operations
- Operational use of GIS in agroclimatological and agroecological studies
- Use of GIS for agronomic characterization and zonation
- GIS application in soil survey studies
- GIS as an agronomic land-use planning tool
- Operational use of GIS for soil fertility studies
- Spatial yield calculation
- Agronomic impact assessment using GIS

Examples of GIS applications in agronomy and natural resource management research are explained in the following works: atmospheric modelling [42] climate change, sensitivity and/or variability studies [71][87][8], characterization and zonation [5][11], water quality, water pollution [55][73][48][20][30], soil science [15][49] and spatial yield calculation-regional, global [29][37] and precision farming (spatial yield calculation) [10][32][14][17].

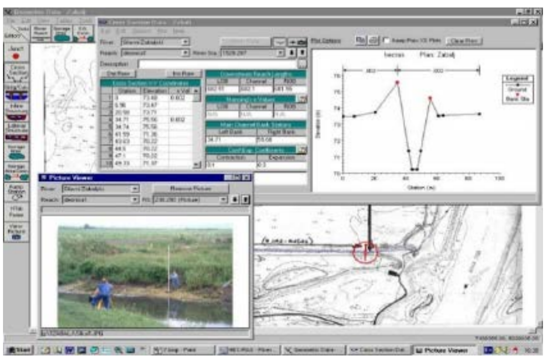

Figure 2. and 3. GIS Workspace of HEC RAS application package tool for hydrology source: (Salvai A. 2004)

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In his paper Hingray B. et al (2009) analyze the use of hydrological models coupled with GIS and large amounts of data relating to contributing factors and conclude that it is an inexpensive and essential tool to implement effective and adapted soil conservation measures.

Hydrologic modelling to estimate surface roughness or friction values, since it affects the velocity of the overland flow of water. Land-use information, coupled with the hydrologic characteristics of soils on the land surface, can provide measures of expected percolation and water holding capacity [57].

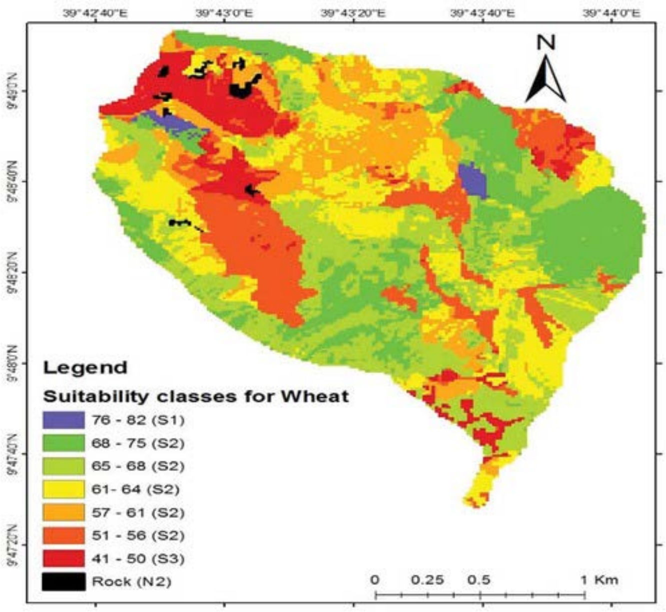

Figure 4. Map of soil suitability for wheat source: Hamere Y & Teshome S. (2018)

The most significant application of GIS used for planning and management is the land use suitability mapping and analysis and they are clarified in [52][43][33][12][19]. Land suitability assessment is a prerequisite of land use planning. It is a process of determining the suitability of a given piece of land for agriculture purposes [6]. Abdelrahman M.A. et al. (2016) argue that land suitability assessment is land evaluation which usually conducted to determine specific land use for a particular location and identify limiting factors for a particular crop production. Land suitability evaluation according to FAO standards has been applied in many parts of the world, particularly in the developing countries [23].

Several studies have been reported on the application of GIS on cultivation practices of various crops [67][21][66][61][4]. In [75], the authors reported the application of GIS to fertility management of soils where digitized maps of the soil pH, potassium, phosphorus and organic matter were prepared using the GIS software. Kokhan S. et al (2013) explain how a geodatabase was developed using GIS mapping to provide soil quality monitoring based on data of agrochemical soil survey in order to monitor land cover/soil quality changes between periods of soil survey.

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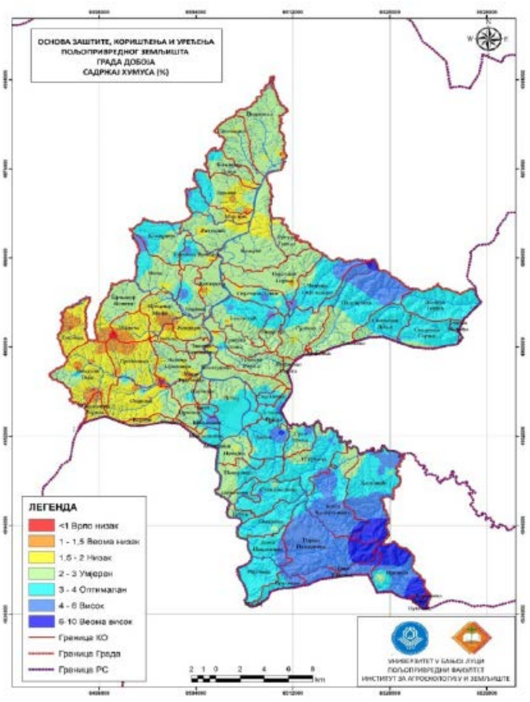

Figure 6. Content of humus in soil
source: The Basis for Agricultural Land Protection, Use and Restructuring city Doboj (B&H) 2020

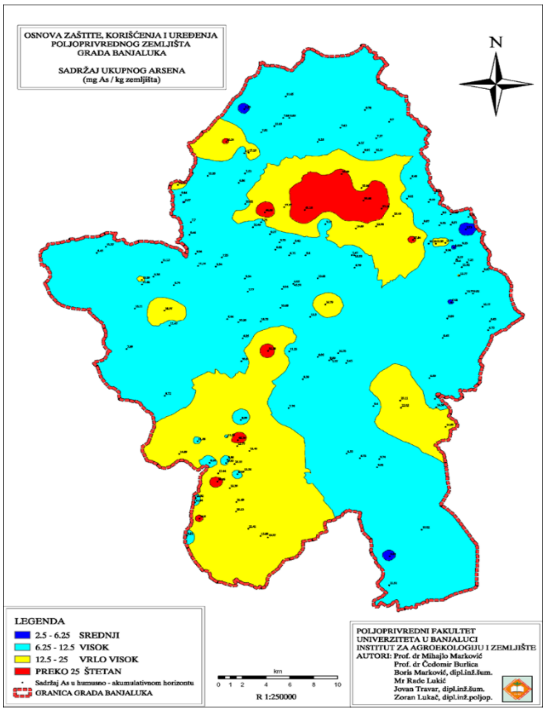

Figure 7. Content of heavy metals (As) in soil
source: The Basis for Agricultural Land Protection, Use and Restructuring city Banja Luka (B&H) 2006

A GIS-based decision support system was used to establish potentials and limitations of different soils for crop production [76], while Gandomkar R. (2009) in his work employed GIS in soil erosion control where the factors and elements affecting erosion were studied by analyzing numerical maps of different parts of a basin. Soil erosion has been accepted as a serious problem arising from agricultural intensification, land degradation and possibly due to global climatic change [91].

In papers [7] [63] [57] use of GIS for Land use and Land classification (LULC) was demonstrated. Knowledge of land use and land cover is important for many planning and management activities and considered as essential element for modeling and understanding the earth as a system. Land cover maps have presently developed from local to national to global scales. The use of panchromatic, medium-scale aerial photographs to map land use has been as accepted practice since the 1940s. More recently, small-scale aerial photographs and satellite images have utilized for land use/land cover mapping [45].

Resource allocation is often used for estimating the utilization and allocation of a resource. For example, groundwater potential and crop yield estimates are described in [53] [70][79]. Few studies [65][31][35][86] have used GIS in the impact assessment of specific events (prolonged activity over a specified period) on the agriculture productivity. Knowledge-based Systems combine diverse information sources and provide insights on a fed information. The outcome is an image which is used to provide solutions to the problem in perspective which are explained in [83][90] [9][44][81].

One of the most important fields where we can opt for application of remote sensing and GIS through the application of precision farming is nutrient and water stress management. Detecting nutrient stresses using remote sensing and GIS are important in site specific nutrient management and thereby can reduce the cost of cultivation as well as increase the fertilizer use efficiency [77].

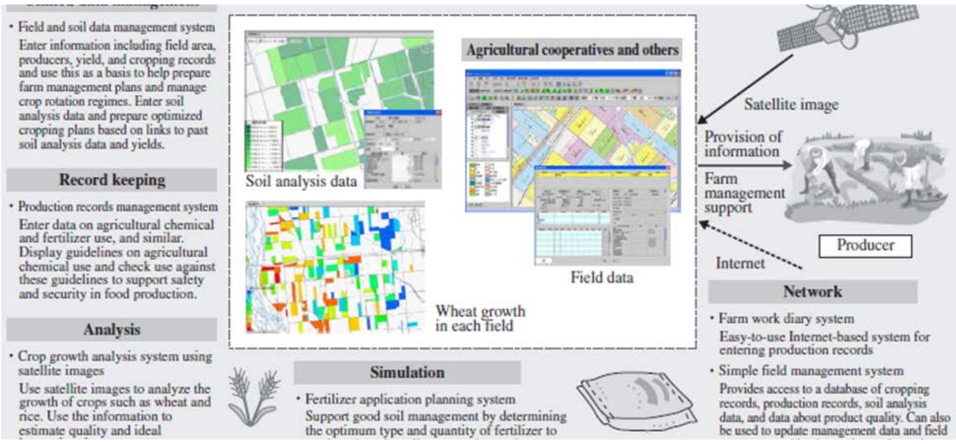

Figure 8. Overview of Agricultural Information Management System with GIS platform. source: Hitachi Software Engineering Co.

Sivakumar M.V.K. et al. (2004) reported that the ultimate use of GIS lies in its modeling capability, using real world data to represent natural behaviour and to simulate the effect of specific processes. Modeling is a powerful tool for analyzing trends and identifying factors that affect them, or for displaying the possible consequences of human activities that affect the resource availability.

One of the most essential functions of GIS and mapping is to be used to raise awareness of such issues as food scarcity, and locating areas that are in a need of assistance. Web mapping tools like the (FAO)'s World Hunger Map provide a unique view of global food production. Though establishing the underlying causes of food insecurity, GIS data and technology are helping to safeguard the areas and communities affected by food scarcity [69].

CHALLENGES

Felicísimo A. and Gómez-Muñoz A. (2008) discussed how GIS can be a useful tool for spatial or land-use planning, but only if several conditions are fulfilled. The key conditions are related to

1. the quality of basic spatial information,
2. and the statistical methods applied to the spatial nature of the data.

Appropriate information and methods allow the generation of robust models that guarantee objective and methodologically sound decisions.

Information is valuable to producers only if it is timely, accurate, and can be (a) easily accessed, (b) straightforwardly integrated with multiple sources, (c) analyzed with software and hardware a

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typical information-seeker possesses, and (d) used with a minimum of training. These challenges are magnified in the case of precision agriculture by the digital size of satellite scenes and the limited bandwidths available to producers in many rural areas [89].

Wanjohi K. (2020) noticed that rise in the GIS workforce poses a challenge since most people who are joining the workforce are only knowledgeable in the front-end of GIS. That is, they can use some of the mapping visualizing tools, but they have no idea how to explain the data in spatial terms. To effectively apply GIS in various industries, the workforce will need to learn the theoretical aspect of collecting and analyzing geographic data.

Further, Lee J.G. and Kang, M. (2015) reported that the spatial data sets exceed the traditional computing capacity, referred to as big geospatial data is receiving high attention from the researchers. With the exponential increase in the amount of big geospatial data, the challenges for managing and analyzing the big data has also increased. Geospatial data represents a significant portion of big data in agriculture supply chains, with its size proliferating at least by twenty percent every year.

Sharma R. et al (2018) emphasize a need for developing novel frameworks incorporating different layers or platforms for efficient collection of data, storage of data, data analysis and information sharing. These frameworks should be based on emerging technologies such as IoT, drones, mobile computing, cloud computing. The various applications of integrating the emerging technologies with the GIS data will help the practitioners to decide on the adoption of appropriate technologies in their organizations. Understanding the importance of real-time data sharing with the different stakeholders in the agriculture supply chain the practitioners will be required to come up with data sharing policies. The policymakers will be expected to design new rules and procedures for the open access of data, maintaining the privacy of the data and the security of the systems. Wanjohi K. (2020) observes that as a result of the open-source mapping, and the numerous GIS applications, a lot of people have access to geographic data. This may be a good thing since now; more industries can take advantage of data to make better decisions. However, there's no effective control over who can access the data and how they can use it. IoT may also lead to the availability of sensitive information, exposing the users to cyber-attacks.

FUTURE OUTLOOK

Over a period, GIS usage has seen a drastic evolution from traditional practices involving land use planning to modern day scientific applications. Big data, IoT, blockchain and other technological advancements have taken over the world with their accuracy and reliability. Big GIS Analytics is expected to play a significant role in shaping up the modern agriculture meeting the expectations of the stakeholders on three main dimensions viz., accuracy, accessibility, and accountability [78]. Also Carbonell I. (2016) and Bronson K., Knezevic I. (2016) expected that the blockchain technology applications is going to bring significant developments in the aspects of accountability and transparency in the agricultural supply chains.

Rymaszewska A. et al (2017) argue that organizations should identify innovative ways to derive maximum value from the possible integration of GIS with blockchain, big data, and IoT technologies.

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It is understood that the IoT applications in agriculture will empower the majority of the agriculture-related industries to extend their value chains to cater their stakeholders resulting in increased profitability. Examples of early integration of the above-mentioned technologies can be found in works od Wu et al and Ye et al. [92] [88].

Use of advanced algorithms can accurately predict and forecast the requirement of fertilizer in fields. Future research studies should focus on developing advanced algorithms for impact

assessment applications. Irrigation planning decisions can also benefit from the deployment of impact assessment measures using GIS. Future studies should focus on developing micro irrigation applications which are found to be more sustainable (Rao M. 2018).

Uchiyama H. (2017) reported that drones can use automated control systems and help in providing the necessary geospatial data for GIS reducing the complexities involved in capturing field data. Drones can also be used for soil sampling, and its integration with GIS analytics can help in the collection of crop growth data and that illustrate related papers [34][36].

There is considerable potential for integrating Big GIS Analytics with other technologies such as LiDAR for improving site search and selection. Such integration of analytical techniques will help in improved simulation, resulting in identifying future risks based on past and current trends of land consumption [25].

Wanjohi K. (2020) presented the following future outlooks and found that GIS's future is most promising when combined with machine learning, but there is much to be expected from a combination of GIS, AI, machine learning, deep learning, augmented reality, cloud computing, IoT, and real-time data collecting and analysis. For instance, they can help in creating predictive models for precision agriculture, predicting extreme weather conditions and their possible effects, and many more applications. GIS computing capability, such as the use of Python and R, makes it possible to handle bulk data all at once. Other useful computer networks for handling data include CyberGIS and cloud GIS.

CONCLUSIONS

In the coming years, use of efficient information technologies will play an increasingly significant role in agriculture production and natural resource management. In this context GIS has a significant role to play in the decision-making process in agriculture at various levels i.e., field, regional, national, and global levels. The GIS is an excellent informative tool that enhances visualization and ease of analysis and handling of spatial data. This spatial information technology allows to examine and analyse a wider range of agricultural related resources such as soil, weather, hydrology, various socio-economic variables simultaneously and accurately. Simultaneous examination of all these variables in a GIS environment leads to a better understanding of how agricultural systems function and interact over space and time. This understanding leads to developing stable and sustainable dynamic agricultural technologies.

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Co-funded by the Erasmus+ Programme of the European Union

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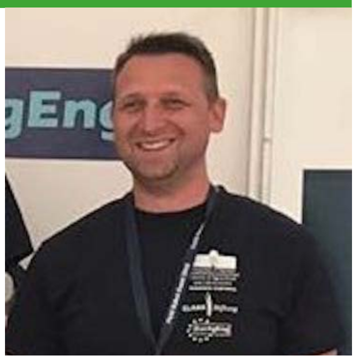

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Co-funded by the
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of the European Union

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Co-funded by the
Erasmus+ Programme
of the European Union

This publication is result of WP2 – Building comeptences in AET (Outcome 2.6)

This publication has been created within the VIRAL project, funded by the European Commission through the Erasmus+ program, KA2, Capacity building in higher education

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Co-funded by the Erasmus+ Programme of the European Union