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Faculty of Tropical AgriSciences

Use of drones in agriculture and rural development

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this Thesis entitled "Use of drones in agriculture and rural development" independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 15. 4. 2019

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Prokop Laichter

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Abstract

Information is playing a key role in the modern agriculture. Introduction of the drone technology created a new way for farmers and researches to not only gather information but also interact with the environment. The goal of this Thesis was to analyse the current usage of drones in agriculture as well as for the development of rural communities, and to look into the future scope and possibilities of the drone technology. The Thesis is based on a literature review done trough the snowball effect method. As the main areas where drones are used was firstly identified monitoring, specifically monitoring of the environment, forests and plants, secondly spraying and thirdly protection. Analysed were also the impacts on the communities as humanitarian and health operations, and the legislative aspect of the drones' usage. Moreover, at the last part of the Thesis were mentioned the areas in which the drones could find further application. It was concluded that drones are promising technology, which may due to subsequent automation of agricultural production be implemented on a significant scale. The drones will be mainly useful in the collection of data and possibly even in conduction of all the farming practices without human overlook. The main contribution of the present Bachelor's Thesis is the summarization of information related to this yet very young technology.

Key words: automation, crop protection, environment monitoring, remote areas, technology evolution, unmanned aerial vehicle

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List of abbreviations used in the Thesis

UAV – Unmanned Aerial Vehicles

GPS – The Global Positioning System

RGB – Red Green Blue

LiDAR – Light Detection And Ranging

C/N – Carbon/Nitrogen

NDVI – Normalized Difference Vegetation Index

PRI – Photochemical Reflectance Index

AED – Automated External Defibrillator

AGL – Above Ground Level

ATZ – Aerodrome Traffic Zone

ARP – Airport Reference Point

LAD – Leaf Area Density

LAI – Leaf Area Index

1. Introduction

The introduction of modern technologies in recent time, especially information and communication technologies, has changed agriculture. Today, information exchange, transactions, and movement of knowledge are vital for almost every aspect of agriculture production (El Bilali & Allahyari 2018). One of the most valuable inputs in agriculture is knowledge about the land, soil, crops, and their management across time. This transformation has been taken into account by governments as they acknowledge the fact that investment into research and development are essential for maximization of the potential of agriculture production (OECD & FAO 2018). Improvements in information and communication technology are indisputably a part of the solution for the upcoming hurdles in the agricultural sector. These improvements will play arguably a major role in innovation and sustainable agriculture (G20 Agriculture Ministers 2017).

One of the more recent technologies which has been used in agriculture worldwide are drones. Drones are generally referred to as UAV – Unmanned Aerial Vehicles. This is not entirely correct as drones do have a degree of autonomy. An UAV requires a permanent attention of the pilot (Giones & Brem 2017). Therefore, all drones are UAVs, but not all UAVs are drones. In this thesis I will be using either names, because in most of the articles the terms are used without clear distinction, if the vehicle used was with a degree of autonomy or not. Due to this fact, they must be accounted for differently in the eyes of the law, as they can operate without human oversight (Freeman & Freeland 2014). Another reason why they are not synonymous with UAVs is that they do not have to be airborne. Their ability to operate independently made them an important aspect of modern warfare. Even though drones have been here for more than 100 years in different forms, the hype around the drones is fairly recent. The use of drones begun as a military invention to carry attacks without the need to endanger the pilot. In recent years, the use of drones has broadened as the technology improved. They began to be used not only as the military tools but as well as tools in agriculture, industrial inspection and security. The introduction to civilian use has been much faster. The miniaturization of electronic components, the increase in the computational power, and new materials made them more affordable and suitable for the open market (Giones & Brem 2017). The innovation which has made them available to the public could mean an opportunity for faster and more extensive development of technologies used in professional drones.

Furthermore, agriculture is adopting an increasingly technology centred approach. As farmers need to manage larger swaths of land and they are losing their traditional farming practices. Evolution of technology is taking everyone further from the nature. People are closing themselves more and more in the cities as the urbanization raises. As well the technological improvements are distancing farmer further from natural processes and the contact with the environment. Farmers when operating on the large scale more often must rely on the information gathered by integrated systems, sensors and machines (El Bilali & Allahyari 2018).

Summarization of the drones' applications for different agricultural purposes as well as for rural development is the focus of the present Thesis.

2. Aims of the Thesis

The aim of this Bachelor’s Thesis was to analyse the working operation of the drone technology and the areas of agriculture where it is already used as well as its effects on the rural communities and possible future applications.

3. Methodology

In my literature research, I used the snowball method. First, I conducted a search of scientific databases: Scopus and Science Direct. As key words, I used: drone, agriculture, and UAV. For the search, I used a Boolean operator to exclude unwanted results. From the results, I excluded all the mentions of bees, as I was not interested in drones as male bees. By further excluding articles unrelated to the topic of my thesis, I chose about 30 articles fitting the search query. On the basis of these first articles, I looked further in the sources of these articles to find more relevant sources. I have also researched a most recent application of drones by watching videos and reading popular scientific articles because many of the use cases of agricultural drones are presented as promotional videos from companies which are currently manufacturing, researching, and developing the usage of drones in narrow cases.

4. Literature review

4.1. Drone description

Giones & Brem (2017) refer to drones as an Unmanned Aerial Vehicle (UAV) with some degree of autonomy. There are two types of UAVs: fixed wing and rotary wing. The fixed wing type relies on its wing to fly while the rotary wing is lifted and propelled by a set of rotors. There are multiple variations of each type, however, in the rotary wing type, we distinguish among different types depending on the number of rotors. The helicopter has two rotors: the main, big one is on top of the helicopter and one smaller is on the tail. Tricopters have three rotors. Quadcopter has four rotors while the less usual are hexacopters with six rotors, as visualized in the Figure 1 (Anweiler & Piwowarski 2017). There are even octocopters with eight rotors (Mogili & Deepak 2018). The usual configuration consists of the (X) shape which is more popular for its stability in contrast to the (+) configuration. The quadcopter does have two rotors turning in the clockwise direction and two turning in the opposite direction (Mogili & Deepak 2018). This setting permits the quadcopter to move on three axes: tilt axis, roll axis, and yaw axis, as shown in the Figure 2.

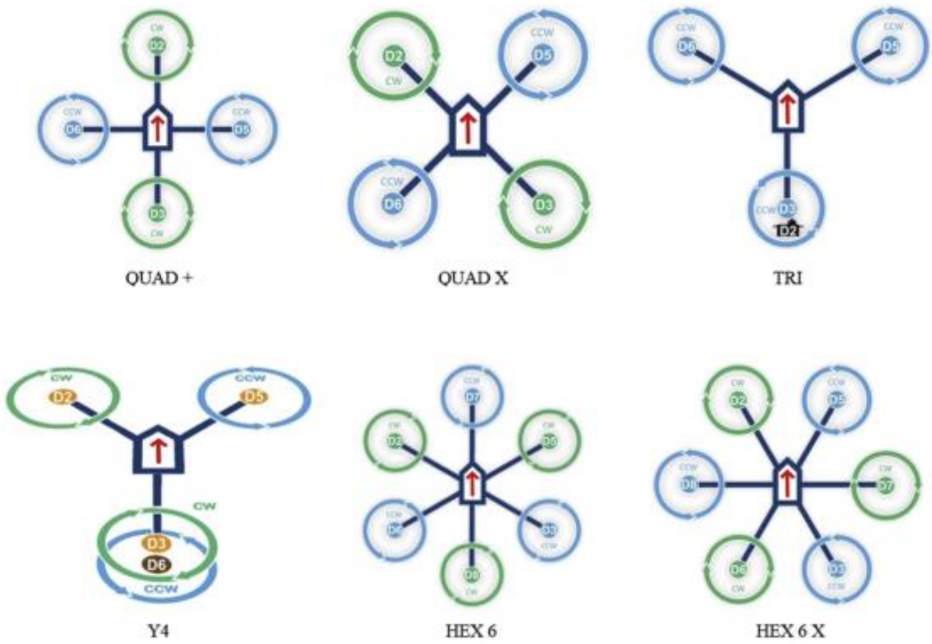

Figure 1 Types of rotary wings UAV (Anweiler & Piwowarski 2017)

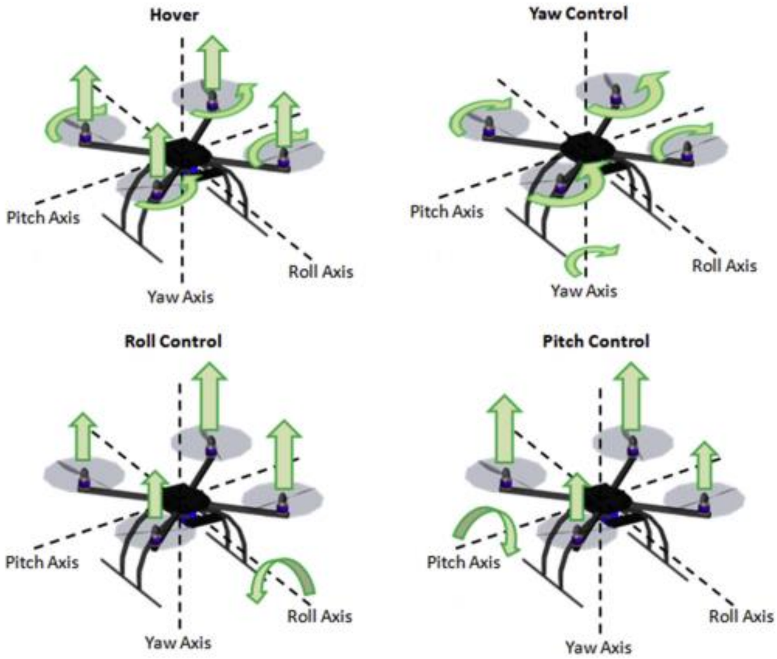

Figure 2 Multi-rotor UAV ways to achieve stable and controlled flight (Anweiler & Piwowarski 2017)

The UAVs operation is relying on multiple sensors and an onboard computer. The pilot is controlling the UAV through a wireless controller. The types of sensors varies depending on the type and use-case of the drone (Anweiler & Piwowarski 2017).

The flight is controlled by the computer onboard which is responding to the pilot on the ground or is guiding all the drone operation autonomously. The computer is gathering the data from the sensors to be able to control the flight of the drone. The computer is controlling the speed of rotation of each rotor and changing it to ensure its flight. The pilot on the ground is connected to the onboard computer through the controller to be able to communicate with the drone. There are multiple options for the instantiation of the connection, some of which include the use of Wi-Fi or radio waves (Mogili & Deepak 2018).

There are multiple sensors and peripherals on board of the drone which are gathering information about the drone and its surroundings. Their purpose is to give drone and its pilot the relevant information to ensure safe flight or to get insight on the conditions of the environment. Examples of such sensors include accelerometers, gyroscopes, magnetometers, GPS, altimeters, or air pressure sensors. These sensors are used for spatial orientation and surveillance of the surrounding environment. They can also include an RGB camera, a thermal camera, a multispectral camera, or a laser scanner (Mogili & Deepak 2018).

4.2. Usage of drones in agriculture

4.2.1. Monitoring

The most frequent use of drones in agriculture pertains to their ability to give a farmer more information about the plants, the environment, and the overall situation. There is a number of different data we can obtain from a drone. The data obtained may be used for further studies or directly used by farmers in the form of data compatible with machinery and technology already in use.

4.2.1.1. Environment monitoring

Drone technology is showing promising results in understanding the environment. For example, it allows for a better understanding of soil and its components. From data captured by drones, farmers may be able to cut their expenses on location scouting, soil sampling, or better expect future farming conditions.

For establishing suitable C/N ratio is very desirable to know the previous crop residue. Kavoosi et al. (2018) compared the use of the satellite multispectral imagery and a drone with an RGB camera. Their study showed that spectral analysis is more accurate than a drone RGB camera. The correlation was acceptable between the satellite, already in general use and drone-based observation.

A major advantage in comparison to satellite imagery is much lower cost of drone imaging technology and the ability to operate on smaller patches of land. Also, a disadvantage of the satellites is that they are able to operate just in the good weather, on the other hand, drones are able to operate even on cloudy days (Kavoosi et al. 2018).

Huuskonen & Oksanen (2018) in their study brought together remote sensing and the use of the augmented reality. In this study was a drone used to gather pictures of bare soil after ploughing. By creating an RGB map of the plot pictures El Bilali & Allahyari (2018) determined the locations for soil sampling. To determine differences in the soil type they used colour difference of the segment. The number of extraction points was reduced through the mapping of the plot and a person was guided through augmented reality glasses to the soil sample collection spots.

In a different study, a drone was used to create a map of copper contamination with the goal of reduction of real samples needed (Capolupo et al. 2015). The drone was used to create the prediction of hydrological models and the hotspots where the concentration of copper was high.

As an advance, Capolupo et al. (2015) have stated that the acquisition of the images was rather quick, as the drone is able to fly much more close to the ground which resulted in higher quality of images than from an airplane.

Drones does not have to be used only on the ground. As the study of Ventura et al. (2016) shows drones can be a handful tool to map the coastline. The drone used in this study was a homemade drone, which price was less than $100. The imagery was used for the creation of the 3D model of the seabed and of a map of its composition, which can be seen in the Figure 3. The study suggested that this technology may be suitable for a number of ecological applications. For example, it can be used for monitoring of coral reefs, salt marshes, mangroves and estuaries.

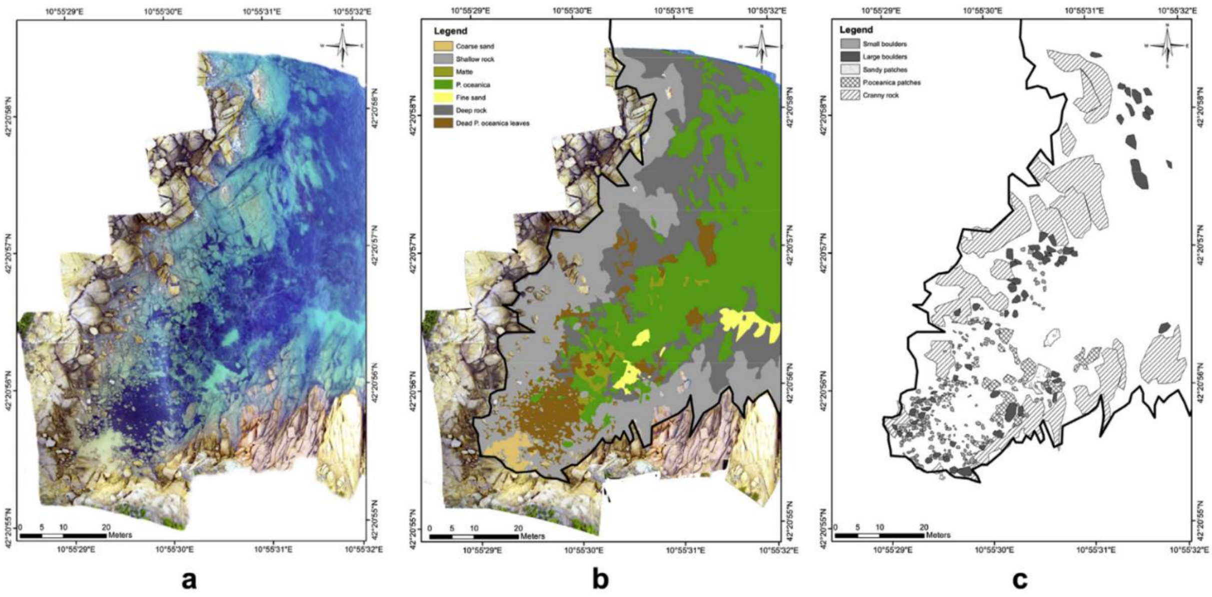

Figure 3 a) Aerial ortophoto of studied area b) Main seabed cover classes c) Five subclasses identified in the study site by manual classification of high resolution aerial images (Ventura et al. 2016)

Ventura et al. (2016) describe the main highlights of the drone use like their ability to be automated, their low-cost and their capability of producing high quality aerial images which can be transformed to maps with quality superior to the airborne and satellite imagery.

4.2.1.2. Forest monitoring

Drones may also become a technology to replace a Light Detection and Ranging (LiDAR) in the mapping of the forest or technology which could highly improve the way we take care of the health of agricultural forests.

The LiDAR is a method used for measuring distance by shining a laser beam to an object and measuring the time till it reaches back to the sensor. Such information can be used to create a 3D model of the environment. The LiDAR is rather expensive and usually requires large aerial vehicle to be used, as presented in the Figure 4 (Kamoske et al. 2019).

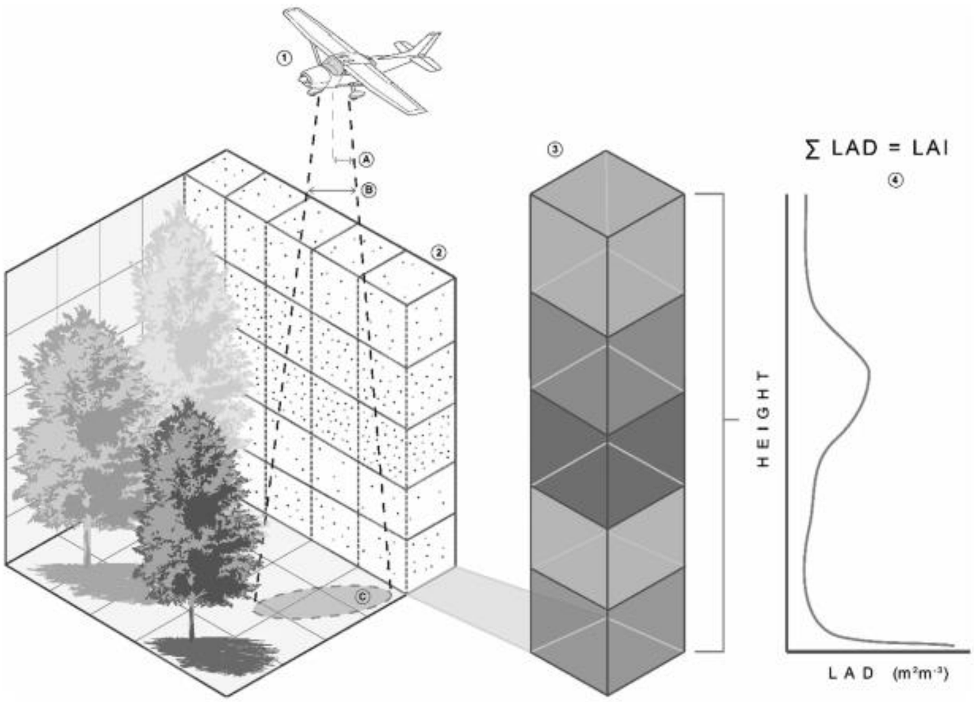

Figure 4 LiDAR pulses from the airborne sensor measuring distance between airplane and objects to measure their spatial dimensions (Kamoske et al. 2019)

Zahawi et al. (2015) conducted a study of the possible use of a drone to monitor rainforest recovery in southern Costa Rica. In this study, they used a hexacopter with a consumer grade point and shoot camera. Subsequently, using a program called Ecosynth, they processed large set of overlapping images to create a 3D map of the vegetation. The map enabled them to estimate the amount of the above-ground biomass, the carbon accumulation and the height as well as the structure of the canopy. These metrics are hard to obtain from normal field observation. The map also showed to be useful for estimating the number of avian frugivores, comparable to the estimations by using field-based metrics.

Dandois & Ellis (2013) and Zahawi et al. (2015) stated that the advantage of this approach is that in comparison to the LiDAR mapping this technique can be used on a much smaller patch of land. Where LiDAR is used on missions covering ten to thousand square kilometres, the Ecosynth can be used on a smaller scale (for example tens of hectares). Another advantage is that the equipment is way more affordable than the LiDAR mapping.

Zahawi et al. (2015) admits that the disadvantage of this approach is that there must be a prior map of the terrain which is not always available. Furthermore, the UAV used in the study required a degree of knowledge about flying and processing of the data. This obstacle could be avoided by the improvement of the programming of the UAV.

Another possible implication of the UAVs' use is in the monitoring of the health of the forests. Dash et al. (2017) have stated that UAVs may play a significant role in detecting and monitoring the state of the trees. Until now, monitoring of trees had to be done by either on ground inspection or by a skilled observer from an airplane or based on satellite imagery. For this study multispectral camera was used to obtain five narrow bands (blue, green, red, red edge and near infrared). These data were used to calculate multiple spectral indices. From the indices, the most useful was the Normalized Difference Vegetation Index (NDVI), because it was most accurate in identifying infected trees.

Dash et al. (2017) suggested that the results should be compared to the usage of satellites to record multispectral images. Nevertheless, UAVs do have a place in the monitoring of the health of forests, occupying the space between expensive and large scale airborne appraisal and infrequent ground analysis.

4.2.1.3. Plant monitoring

Another field in which farmers can take advantage of the drone imagery may be the use of aerial imagery to monitor the welfare of plants. The data acquired can be used for a number of applications, such as pest monitoring, estimation of inputs as is water and fertilizers.

Andújar et al. (2019) compared the on-ground detection and the aerial solution for measuring the area of a vineyard. The generation of a 3D model allows for a more precise use of inputs as are fertilizers and additional water. Reduction in the use of inputs would reduce the costs and the possibility of over usage of the fertilizers. The data were acquired by using three different sensor setups: two on the ground setups and one airborne. Both of the on-ground solutions were set up on a Renault Twizy, a small car with an electric engine. The first of on ground solutions was equipped with the Kinect based system which has an RGB and infrared camera. The second was equipped with a LiDAR system. The airborne solution was a UAV (quadcopter) with an RGB camera.

The results of the studies show that all three sensors' setups are viable. Nevertheless, the RGB sensor results provide less accurate data than the other two because they are not able to render small branches. From the economical point of view, the aerial solution was the most cost effective. It is the easiest to operate, as it can cover more surface, therefore, reducing the cost of labor. In addition, the study states that the resolution for agricultural operations is sufficient even without the terminal branches. The automatization in both ground and aerial platforms would reduce the cost's of production (Andújar et al. 2019).

4.2.1.3.1 Water stress

Maes & Steppe (2019) described a UAV system equipped with a thermal camera for estimating the drought stress. As the transpiration is a demanding process, the article used the temperature of the plants' surface to determine if there is significant water loss.

The paper states that it is a viable option for orchards where the data can be implemented in the drip irrigation planning. The data are less usable in fields with sprinkler irrigation which cannot be really adjusted for precision agriculture.

Robbins (2018) described different methods. Apart from thermal imaging, he talked about infrared camera and off-shelf RGB cameras. From the RGB camera he created Photochemical Reflectance Index (PRI) and which he compared to other biological indexes. For example, the NDVI which did not indicated a lack of water. On the other hand, the thermometer showed accurate data which were useful for determining the water stress on single tree level.

4.2.1.3.2 Plant health

Maes & Steppe (2019) described the usage of UAV with RGB or multispectral camera to assess the plant health. The predicament here was the change of NDVI of plants when attacked by disease, fungi, or pests. The multispectral imaging can also differentiate between various species of fungi.

This approach is in the article identified as yet needing further research. The potential is seen mainly in merging the data from RGB, multispectral and hyperspectral cameras to distinguish the most common diseases. The further research is also needed to reduce the number of false positives, which is leading to pesticide overuse.

Similar information was gathered in the Robbins (2018) review. It states that there is a lot of research already done on this topic. The multispectral or hyperspectral sensors were used to early detect changes in the plants and fruits. The review mentions also a comparison of aerial measurements made from airplane in 580 meters above ground versus an UAV at the height of 100 meters. The conclusion was that the UAV based data were better than the data obtained from a manned aircraft, mainly because of the ground reflectance.

Robbins (2018) also mentions the usage of UAV to monitor the nutrient status of the plants, trough color-infrared imagery. By usage of different indexes we can estimate the amounts of various compounds, however, this review also provides some of the research resulting in information not suitable for such estimations.

4.2.1.3.3 Weed detection

Interesting is also the ability to use remote sensing for identification of weeds. Maes & Steppe (2019) used RGB camera to either distinguish weeds from the plants based on the color difference or by object-based analysis. Both methods will be benefiting from further research, as machine learning and improvements in the resolution of cameras can yield more accurate results, even as far as recognizing the species of the weeds.

To a similar finding arrived also Robbins (2018) in his review. He describes two steps in distinguish one of weeds from row crops. First destringing the plants with weed from the ground and then by using object based analysis separating the weeds and the desirable plants. This information was used both in herbaceous and woody crop fields, to create a map of infestation by weeds.

The data from such sensors can be used for generation of spraying maps that reduce the amount of herbicides used. The challenge here is the state of the sensor technology for acquiring a sufficient quality of images.

4.2.1.4. Wildlife monitoring

The other very possible application of the UAVs is the counting of wild animals. As the Rey et al. (2017) describe in his study, this process is rather long and require a lot of financial resources and specialized personnel. The counting of wild animals is usually done through estimation based on restricted area monitoring via photo traps or via helicopters with experts on board. The UAVs even without specialized cameras may be able to detect and count the number of wildlife in an area. The technique used in this study is described as semi-autonomous. Volunteers did identify animals in pictures that were taken by the UAV, and the results can be seen in the Figure 5. By identifying the animals, a machine learning model was trained to be able to distinguish animals automatically. In case of uncertainty regarding the input, the program returned data to the user to re-evaluate its content and therefore to improve the recognition.

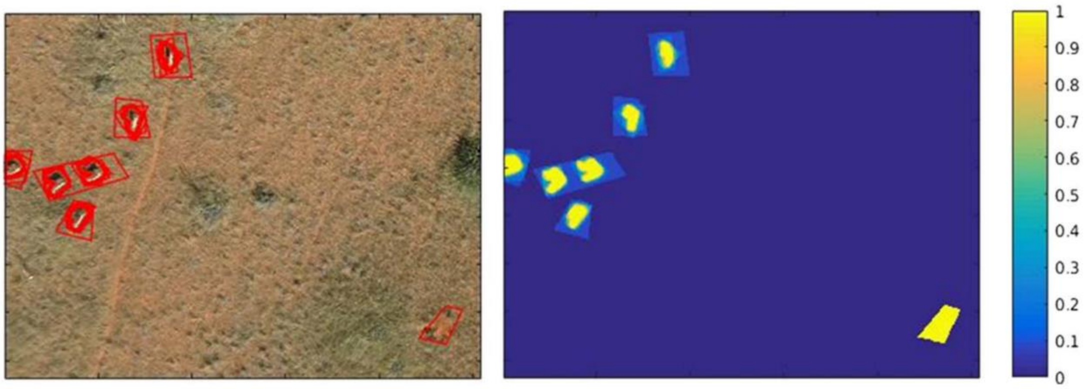

Figure 5 Example of crowd sourced identification of animals. Animals identified by volunteers (left). Each polygon represents on volunteers identification of animal. Confidence map of identifications (right) (Rey et al. 2017)

In this study, the program was trained to detect the presence of an animal, however, it might be able to distinguish different species in the future too. The main benefits from such technology would be the capacity to manage large protected areas.

The study states low cost, time efficiency, and the ability of drones to cover large areas even the inaccessible or remote areas, as the main advantage of the usage of drones. Even further the ability to monitor the animals from the distance is safer for the observer and also for the animal. As future improvements were identified that the program could not distinguish two animals close to each other, therefore it counted them as a single animal. Second problem was that the program identified the same animal on multiple photographs as a different animal and lastly the active learning of the program required active participation of a person dealing with false positives.

4.2.2. Spraying

One of the very promising uses of drone technology is to employ them in precision agriculture. The promise is to be able to cover large plots of land at low cost, reach remote fields, get to places unreachable by on ground vehicles, autonomy, and the ability to address each part of field accordingly to needs of every plant.

Xue et al. (2016) in their study created a drone able to carry a tank of 25 kg of spray solution. The drone was equipped with multiple sensors enabling it to fly close to the ground and to spray control system monitoring the spraying output, therefore applying the spray solution very efficiently. The whole operation was remotely conducted on a test field 10 km away from the ground control console. The precision of flight path was with maximum deviation of 1 m. The test flight was conducted during crosswinds of speed 3 – 4 m/s. The spraying test was conducted as well. The minimum variation coefficient was 25% which is way under the limit for ultra-low volume spraying, as set at the time and place of the study.

The study of Qin et al. (2016) was using the drone to reach otherwise hardly reachable parts of the rice plant. This study was testing the drone use for reaching the lower part of the plants, to battle the plant hoppers. The size of the droplets was rather favorable therefore there was not a major drift. This was supported by the airflow under the drone.

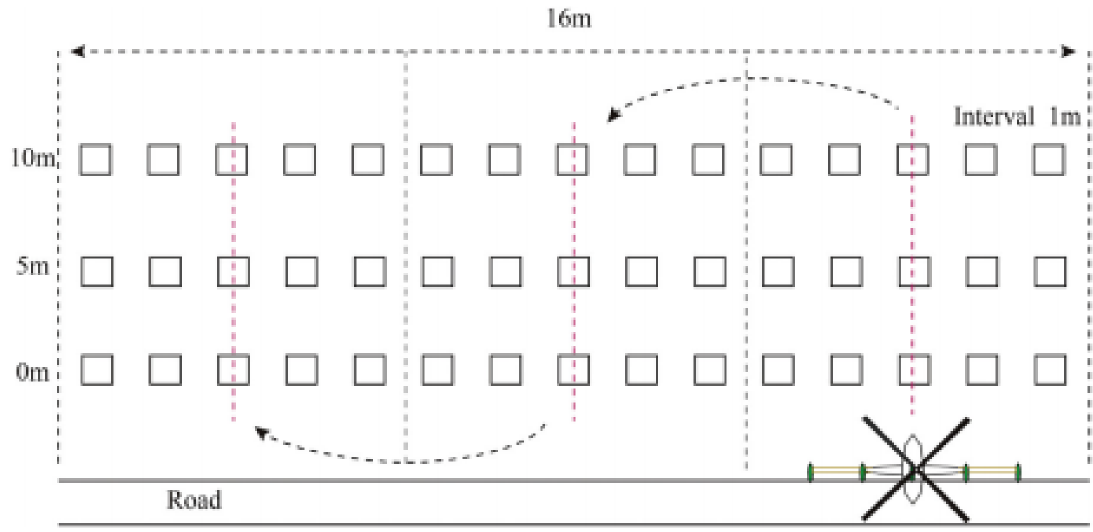

Figure 6 Layout of droplet sampling cards in a multi swath (top view) (Qin et al. 2016)

The use of the drone, in this case, showed as fairly superior to conventional ways of spraying. As a comparison was chosen a stretcher sprayer. The effect of pesticide was stronger and lasted longer time without overdosing and runoff to the soil. Example of method of spraying is illustrated in the Figure 6.

The drones can be used as well on the trees as on the cereals. Tang et al. (2018) used a UAV to spray citrus trees to determine the ideal shape and flight height for optimal droplet distribution. The importance of this study is that it proves that the drones can be used in a difficult situation as flying around trees in hilly areas. The use of a drone, in this case, shows that the drones are able to substitute the labor-cost of the spraying of small trees.

4.2.3. Protection

There is wide range of the pest able to damage the crops. The drones may be used as a non-lethal tool to protect the hard-earned yields. The imagery from the drone can be also used in the field of poaching. The ability to be deployed on site and effectiveness of use may be a great resource for the people protecting wildlife.

The study by Wandrie et al. (2019) has investigated the usage of different UAV for the protection of crops by hazing the red winged blackbird. This approach was suggested also for protection of different sites than just the field. By using UAV, we can protect the airports or land fields. The study concentrated on finding the most efficient way by comparing the fixed wing UAV and rotary wing UAV. The difference was also in the height and style of flight.

The conclusion is rather interesting, as the horizontal approaches from a bigger distance did not trigger an escape. Therefore, the usage of UAV may also be very well used in conservatory manner for observation of animals. When the aircraft approached vertically, the blackbird behavioural response fleading was 80%. The problem is that both of these solutions are not meant for disturbing the wildlife. Both of them were powered by electricity therefore much quieter than for example fuel powered motors (Wandrie et al. 2019).

4.3. Impact on the rural communities

The drone usage is not advantages of drones makes the very reasonable solution to other problems appearing in the rural areas. As these areas are in many countries quite remote and the road network is not reliable the drone may be a solution to carrying a needed medical equipment/goods. They could be as well used in the times of natural catastrophes to help with the search and rescue, and later to carry out the humanitarian help. Their mobility may be also a key for improving a connectivity by means of electronic communication.

4.3.1. Humanitarian and relief operations

In the times of disaster, the humanitarian organizations are often combating not only the impacts but also a lacking transportation infrastructure, in some case disrupted by the floods or blocked. The major problem often does not lies in the transportation from an affected area but in the last few miles to the victims. Drones may be a key component in the last mile distribution of the relief operations (Rabta et al. 2018). In the same manner as they are thought to be used in a delivery services (Yoo et al. 2018), they can be used in a conveyance of the relief supplies to concrete victims of the disaster. Drones are in most of the cases running on the electricity provided by the battery and therefore they need to recharge after some time in flight. For this reason a recharging station need to be set up prior to the disaster or to be delivered on site operationally. Their impact can be much broader in the time of disaster as they are also capable of number of different operations. Their purpose can be delivery of supplies, mapping of an area, searching for victims, damage assessment and path planning (Rabta et al. 2018).

4.3.2. Health operations

Ability of drones to carry packages is also used in the times of peace. In the areas with lack of transport infrastructure drones are used to deliver medical equipment. The drones are used routinely, to deliver the medicines, blood or tools. Sub-Saharan Africa is actually leading the path to adoption of the technology. This phenomenon is called leapfrogging. It happens when developing country skip a technological evolution and directly uses the technological improvements (Haidari et al. 2016). The first national wide drone delivery service was adopted by Rwanda. The company Zipline is currently supplying 19 different hospitals around the country with medical equipment, mainly vaccines. Rwanda is aiming to have universal healthcare coverage and as the country stand up to its name "country of thousand hills" the delivery can be rather tricky (McCall 2019). Van de Voorde et al. (2017) have studied the possibility of the drone ambulances.

The premise is that in the case of cardiac arrest is time the most important factor. Even though that many countries have first response services they are in general unable to achieve the needed swiftness. Drones may be besides the trained voluntaries one of the most effective solutions. They can be stored in various locations, and can operate exactly when they are called and possibly they can save countless lives by arriving in the time close after the cardiac arrest when the resuscitation is most effective. The drone would carry AED and the statics suggest that bystanders/voluntaries are far more likely to use the AED when the patient is near to it (Van de Voorde et al. 2017).

4.3.3. Impact on the labor force

The impact on the labor force are maybe one of the most significant affecting the rural populations. Drones are aiming at reducing the costs of production, by rising the efficiency of usage of inputs. This will mean that some of the jobs will be reduced, mainly the high skilled labor will be substituted. On the other hand, some jobs will be created because drones need the skilled technicians. The positions created will be most likely about maintaining, repairing and operating drones as well as about the interpretation of the data gathered by the drones (Krishna 2017).

Very possibly the impact on the labor force will not be uniform. Rotz et al. (2019) interwieved the farmes about their predicion on the labor market and impact of the digitalization of the agriculture. In their point of wiev the most impacted will be the temporal workers. The reason is that in general there is number of obstacles for indigenous people, as a residue of the colonial era. The problem will only grow as there is less people in agriculture.

Price is a key factor for many farmers. Distinction betweenee large companies and small scale farmers will only grow. As the technoligical advancement will dictate the farmers life, trough the ability to produce at reasonable price. The improvments will raise the bar at which farmers will be able to produce at fair and reasonable prices. Prices of the technology will decrease by time very possibly, yet the change of the agricultural sector may be too fast to be sustained by small scale farmers (Rotz et al. 2019).

4.4. Law and regulations

The drone technology is facing many hurdles as it is not yet reasonably solved in many countries around the world. From the legislative point of view, it is not from the beginning easy to define a drone. The question of differentiation between remotely operated, autonomous and anything in between is a possible to be used for legislative definition. The problem of the drone, in the point of view of the law is that they pose in case of malfunction a substantial threat to the people and to the environment in which they are operating. This threat depends on the size of the drone and on the amount of the fail-safe systems (Rao et al. 2016). The fact that the amateur used drones are smaller, therefore they don't have such destructive impact. Problematic is that in many dangerous situations the actual operation or the rapid response is not on the pilot but on the computer on board. There is a problem of responsibility for the action. The ability to react on its own can bring a lot of benefits, but also a lot of complications (Clarke 2014).

Major reason for regulation is a fact that the drones can be used as a tool for compromising other people's privacy. The ability to enter private owned space and to record images without the knowledge of the owner is problematic (Rao et al. 2016).

According to Rao et al. (2016) the complicated line is between a professional usage and the amateur usage. The amateurs or the vehicles do not have to be registered in multiple countries around the world. There is a clear logic behind forcing the owners to register in the same way as with cars. The cars can do physical damage as well as drones.

The regulations that are posing a serious problem to implementation of the drones in agriculture are not yet covered in the Czech Republic or are not that serious as there is a clear legislative system to professional usage of drones (Ministry of Transport 2017), as shown in the Figure 7. The cost of such legislative procedure is not that big if we consider the price of a drone usable in agriculture. Nevertheless, this is not the case around the world. For example in many states of USA, the drone operators are limited in their use of drones. Even though the potential of usage of drones is acknowledged it is not yet legally regulated in many countries around the world.

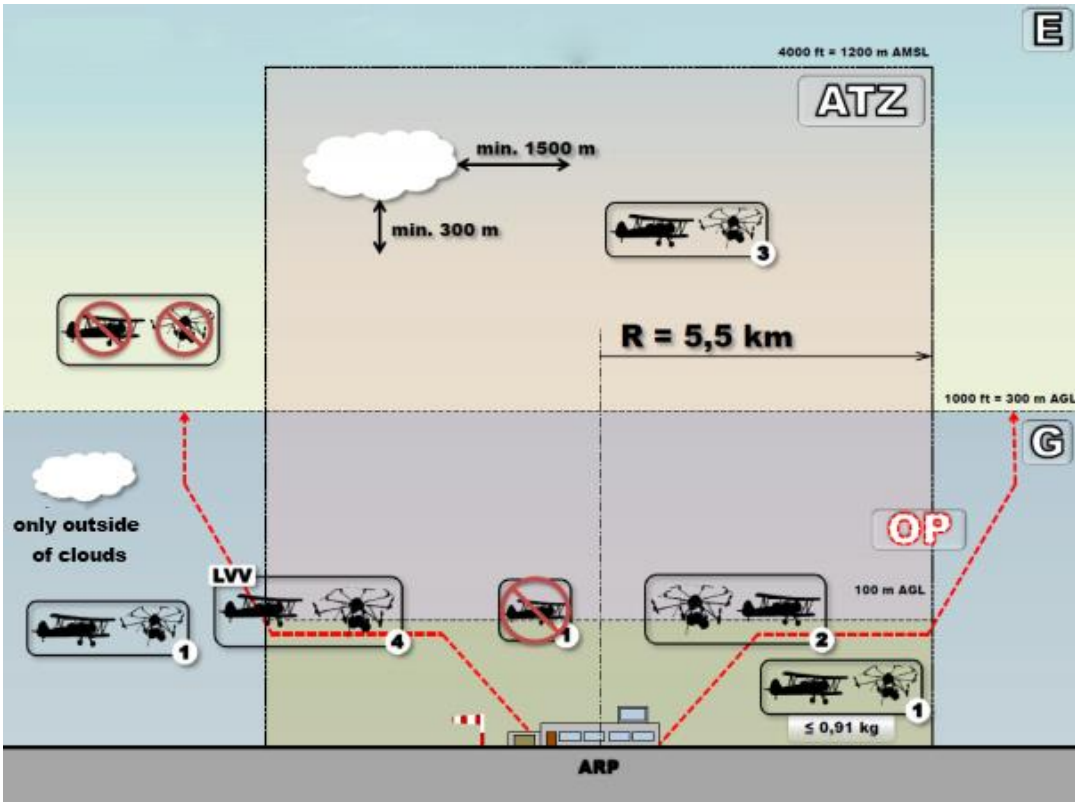

Figure 7 Diagram of legal operations of drones in the Czech Republic (Ministry of Transport 2017 edited)

4.5. Future scope

There is a lot of possible implications of the drone technology which I find underutilized. The major potential I see in the area of interaction with the environment and as second, I think is that the definition of the drone as an aerial vehicle is very restrictive. The word drone in entertainment has already moved from simply a flying vehicle to also a vehicle which is operating under water, on land, or even changing from airborne to underwater operating (Diez 2017). As very underused application of drone is their cooperation. There is research done on the swarm like movement (McCune & Madey 2013) or in cooperation on single task as mapping (Albani et al. 2017). Yet there are to my knowledge no cooperative usages of drones when each has a specific task cooperating on a complex operation in agriculture. By combining many capabilities of drones, we could achieve an unprecedented improvement in production without the need to increase the number of people taking care of the process (Hands Free Hectare 2018).

The usage of autonomous vehicles in the Internet of Things could mean an entirely new way of herding animals. The amount of required labor on a pasture needed for protection, location and looking after animals could be reduced. I can imagine a usage of drones to crate geofenced areas, where every animal is being traced. The aerial drone is able to distinguish each animal by an appearance. They are able to substitute for a human inspection, in which case they are even effective because it is impossible for farmers to take observe each animal individually if the animal is not showing signs of disease already. The drones on the other hand may be using thermal cameras or other sensor pinpoint an animal with higher risk of being infested before full manifestation of a disease.

The swarm technology could mean autonomous farms. The same as in the case of a Hands Free Hectare, the future of fish farming is autonomous (SINTEF 2018). Autonomous sea vessels capable of communication in between themselves and each of them having a crew of drones at disposal to carry out everyday task. The monitoring, feeding and the risk management could be all carried out by autonomous vehicles. The need of human on board would be eliminated, with the humans being just on the shore without the need to be the part of the process till the end.

The important aspect in the future scope discussed as well is the loos of jobs to automation. The drone technology is one of the technologies, which will affect the job abundance in agriculture as other technologies will affect different industries. The jobs at risk are mainly the high skill jobs, requiring the knowledge of the crops and animals. Never the less the adoption of this technology will as well create new jobs. The drones are sophisticated tools which need a skilled operator and skilled technical support. Drones need to be maintained repaired and the data from them must be interpreted so they can be used (Krishna 2017). This may relate as well to the agriculture itself as well as to the connected industries.

The automation is a major aspect of any modern production industry. Drones and automation of transportation process will mainly threaten the low skilled employees. The usage for the drones in the beginning possibly will be more in the monitoring of the transportation (Hadiwardoyo et al. 2018). The aerial drones could be used for the transportation of the production on their own. Yet the public opinion is still that drones are threat to the privacy; therefore, this will not happen in near future (Yoo et al. 2018). The drones are now a days are as well in general too small to carry larger quantities of products, therefore they are not yet feasible to be used as large capacity caring vehicles. Their advantage is mainly in their potential to accurately deliver goods to a specific consumer (Yoo et al. 2018).

5. Conclusions

In the always changing environment of agriculture, drones are already playing a key role in obtaining the information as well as contributing to the field operations such as spraying and protection against pests. The technology behind them is still evolving. The rising number of scientific articles suggests that there is definitely more for what they can be used. Their power in substituting the work which would otherwise occupy humans is major benefit of their usage. They may as well replace big and expensive technologies as are satellites and planes in monitoring the environment or distributing the materials. The regulations in place are in many cases prohibiting the industry from further evolution. Yet the threats as loss of privacy and other inappropriate uses is undeniable, and therefore the regulations cannot be dismissed. Automation is an ever present opportunity and threat as well. The loss of work positions is very much possible as drones are capable of many tasks done nowadays by human workers. There are numerous potential use cases that are yet unprecedented in large scale. As the fully autonomous operation, operation in different environments or usage of the latest sensors to better asses their use. There is a number of potential applications to be scientifically evaluated. There is a lack of the articles looking into swarm technology, cooperative applications, or connection and automation of farm processes. Overall worth investigations also the aspect of the social impact of drones on the farmers.

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