International Conference of Agricultural Engineering
AgEng 2014 Zurich 6–10 July
Ref: C0298

Autonomous Unmanned Aerial Vehicles for Agricultural Applications

Bastiaan A. Vroegindeweij. Sjoerd W. van Wijk and Eldert J. van Henten, Farm Technology Group, Wageningen University, P.O. Box 317, NL-6700 AH Wageningen, The Netherlands

Abstract

Drones or Unmanned Aerial Vehicles (UAVs) receive a growing interest in media and literature, not only for military and surveillance applications, but also as toys and for agricultural purposes. In this research, we reviewed the current state of art of UAV technology, and found that most current applications are based on remotely piloted observation. Next, we define potential agricultural applications where autonomous UAVs can be used, like monitoring of crops and animals, but also controlling field robots and performing management actions. Before this becomes reality in the complex agricultural domain, significant work has to be done both by research and technology providers, especially in the field of autonomous decision making, so as to allow safe and reliable autonomous operation.

Keywords: drones, unmanned aerial vehicles, autonomous control, agricultural applications, precision farming

1 Introduction

Nowadays, drones or UAVs are in the news almost every day, suggesting that they will become one of the technologies for the future. MIT technology review even listed it as one of the 10 breakthrough technologies of 2014 (Anderson, 2014). Still, the number of applications they are really used for is limited. In this research, we will investigate where they originate from, and what their applications were. The next step is discussing the advantages of UAVs for agriculture, in terms of tasks, and system capabilities. From this, we define possible use cases, which lie mainly in the field of mapping and observation but also can contain management actions, both on a field and a plant/animal level. All point in the direction of precision farming, and possible task examples are the gathering of maps of weeds or animal activity (with more detail than current methods), sending out ground-based robots for manure scraping or weed removal, or even activating animals by actively approaching them. As these tasks have specific requirements on execution and from their complex environment, we review these and indicate which developments are required to make UAV technology successful in agriculture. Thus, specific attention is required for data processing, advanced control, safety and legislation, which in turn creates opportunities for production methods.

2 Background

Before we will investigate the future of UAVs in agriculture, we look back to see what UAVs are and where they come from. Also their functioning, current applications and possible limitations in their usage are discussed here.

What is a drone or UAV

The word ‘drone’ is the common name for an Unmanned Aerial Vehicle (UAV), and originates from remotely piloted DeHavilland aircraft that were called Queen Bees in the 1930's.

In this paper, we will use ‘UAV’ and ‘AUAV’, for (Autonomous) Unmanned Aerial Vehicle. The most common definition of UAV is: ‘*a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload*.' (Office of Secretary of Defense, 2005). The most important categorization of UAVs is based on control and autonomy, which ranges from full remote control at level 1 up to fully autonomous swarms that only need activation at level 10 (Office of Secretary of Defense, 2005).
Several different categories of UAVs can be identified, that can be of relevance for agricultural purposes. In military, several other types like stealth or jet-powered UAVs are used as well, but they have limited use in agriculture:

1) Fixed wings and flying wings are similar to conventional planes, which use wings for lift and a propeller or jet engine for thrust (forward movement). They can cover long distances but have limited manoeuvrability.
2) Vertical take-off and landing (VTOL) using a rotor system to provide both lift and thrust, like heli- or multicopters. They are very manoeuvrable and can even hover, but have a limited range.
3) Micro UAVs differ mainly in their size, which is in the range of centimetres. This allows exploration of areas with limited space, but comes at the cost of a short radius. Lift and thrust can be generated in many ways, like with rotors or even flapping wings.
4) Parafoils and airships, which use parachutes or balloons to stay airborne. This allows longer flight periods, but comes at the cost of lower manoeuvrability and a larger size.
5) Combinations and concepts, which combine several of the previous principles to get benefits from both sides.

What is the origin and application of a UAV?

In the beginning of aircraft development, UAVs were already used to test ideas and plane principles, which finally led to the development of man-carrying aircraft. The first conscious idea of a UAV started with Nikola Tesla, who described it as a remote controlled aircraft that ‘… could change its direction in flight, explode at will, and … never make a miss’, and led to the development of his ‘Telautomaton’ in 1889. The invention of gyrostabilizers for airplanes by Elmer Sperry, led to new interest in the possibility of UAVs, and initiated the development of unmanned flying bombs from 1915 onwards. As a result, a lot of development in this field was done in the army for military applications like bombing and artificial targets for anti-aircraft training, and fast-forwarding to assault drones in WWII (Newcome, 2004). During the Cold War, this attention shifted to reconnaissance for two major reasons: keeping an eye on the other party without risking pilot lives and enabling observation of locations were nuclear weapons might be used (Sosa, 1997). In 1958 a new reconnaissance UAV program started, resulting in a versatile UAV with the possibility to spray chemical or biological fluids, but proved a step too far at that moment. As flight times were also limited, research focussed on this as well, leading to flight durations of 28 or even 51 hours in the 1970's. As result of all these developments, several military UAVs are sold for surveillance and even combat applications, like the Global Hawk and the Predator (Newcome, 2004).
Currently, many different UAVs exist for military applications, using all kinds of flying concepts, but their level of autonomy remains limited to flight stability control with real-time feedback using remote control. Commercial applications extended from the fluid-spraying UAV, to make this applicable in agriculture as well. For example, Yamaha is selling (since 2001) a remote-controlled helicopter-UAV that can be used to seed, spray rice, or spread granules. Another application that got wide-spread in recent years is mapping of areas like crop fields and civilian areas or the observation of large crowds of people. Also, UAVs are fequently used as flying cameras on a movie set. A number of other applications has been proposed, like surveillance of roads, waters and borders, and the search for causualties, criminals, forest fires etc. However, although a lot of applications are discussed and mentioned, only a very few of them have been worked out on a commercial scale, and the applied level of autonomy is limited to assisting the pilot on stability control or following waypoints.

How does a UAV work?

UAVs operate similar to regular aircrafts, with the only difference that the pilot is no longer present on-board. However, the same tasks remain and are performed either by a remote

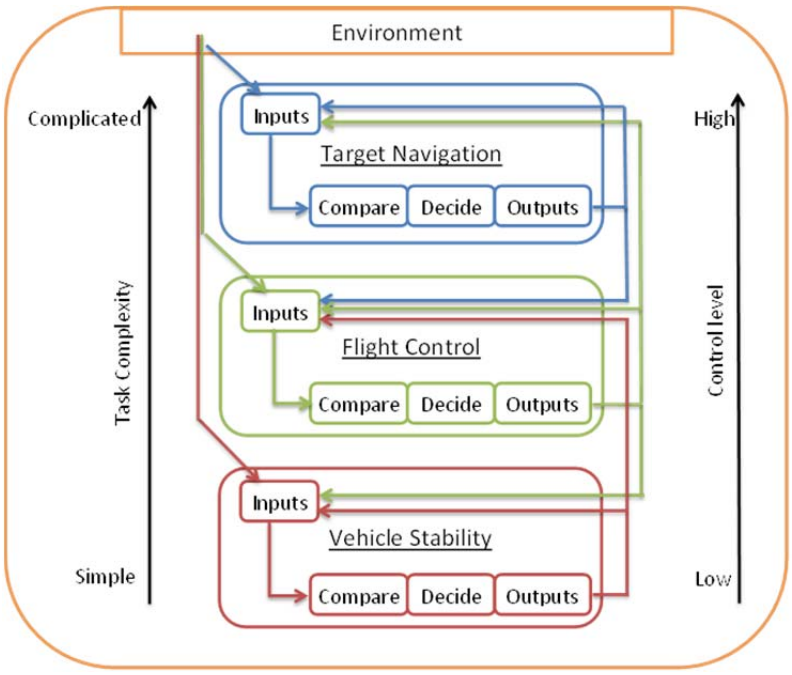

Figure 1: Simple overview of aircraft control, consisting of 3 main tasks: providing vehicle stability, flight control and performing navigation. Complexity and control level increase when moving from stability to navigation.

pilot or computers (Newcome, 2004). These tasks can be classified in 3 interacting groups, as shown in Figure 1, with increasing complexity from bottom to top.

A regular airplane has three surfaces that provide direct control of vehicle stability, being the elevators, the ailerons and the rudder. For helicopters, the rotor speed and blade angle or rotor tilt are adjusted to control lift, while the tail rotor is used to control the yaw. Multicopters stabilize through the distribution of power to the different rotors. Lawrence Sperry developed a gyroscopic stabilizer to apply such control automatically, and the same principles is currently used, although sensors are replaced with modern varieties.

Development of remote aircraft control started with Tesla's 'Telautomaton' that used radio frequencies linked to specific actions. This method is (in a more advanced form) still in use for the remote control of many UAVs. The downside is that line of sight to the vehicle or on-board camera feedback is necessary for adequate control. Beyond the line of sight, other systems are required, like following a pre-programmed route based on waypoints, or capturing position and environment information and offering this to the remote pilot (Geer & Bolkcom, 2005; Miasnikov, 2005; Newcome, 2004).

In general, navigation requires to have an estimate of the position of the UAV, either in a global frame or with respect to its surrounding. For the first situation satellite navigation systems like GPS or Galileo can be used, whereas radar, ultrasound and machine vision are common methods for the second situation. Information about the status of the UAV, like rotor speeds or velocities can be added to improve the accuracy of localisation and navigation. If the location is known, target locations can be selected (either a priori or online) and a path towards this location is planned and followed by issuing control commands, either manually or with help of computer software.

A human pilot imposes a number of constraints on design and operation, like an increase of weight and required space. Thus, when a pilot is no longer necessary on-board, a number of other components can be omitted as well, like the cockpit with all its related components as seats and flight controls (Sosa, 1997). Furthermore, this also allows greater tolerances in the operation of the UAV, so sharp turns, unexpected movements and longer flight duration become possible.

Several parts are essential to allow operation of an aircraft or UAV. Thrust is required for forward displacement and for plane-based design also to generate sufficient lift to carry the weight of the vehicle. For other vehicle types, the lift can be offered by rotor systems or flapping wings. In all cases, some form of energy supply is needed to power these components. Next, also suitable gears need to be installed to allow take-off and landing of the vehicle, as well as to control in during flight. An overview of this can be found in Table 1.

Table 1: Three types of aircraft that occur as UAV with the different components that provide the lifting, steering, and landing of the specified vehicle (Ratti & Vachtsevanos, 2011)

	Fixed wing	VTOL	Bird and insect
Lifting device	Wings produce lift Engine and propeller produce thrust	Rotor systems Engine	Flapping wings Engine
Steering device	Primary: Elevator, Aileron, Rudder, Secondary: Flaps, Spoilers, Other systems	Cyclic pitch control, Turning blades and Tilting rotor Tail rotor	A vehicle with flapping wings can manoeuver through distribution of power to the wings
Landing gear	Equipped with wheels for taxiing, take-off and landing	Equipped with a damper to smooth the landing	Equipped with a damper to smooth the landing

Which problems occur using UAVs?
Besides the advantages, also several problems occur when using UAVs. Performance of current UAVs is still limited in terms of payload, range and/or accuracy. VTOL-vehicles can be well-positioned and even hover, but have limited payload due to the power required for lift. Fixed-wing vehicles can carry more, but cannot be positioned exactly as they have to keep flying. With respect to autonomy, current models usually can at most autonomously follow waypoints, but still need an operator to intervene if problems occur, and online mission planning is still hardly available.
Furthermore, several ethical problems need to be addressed when applying UAV in commercial applications. Especially when using UAVs for observational tasks, questions arise on ownership and security of data and violation of privacy. These have to be clearly addressed or sorted out. As with all new technology, there is the discussion on replacement of human labour, which is probably desirable for reasons of efficiency and reliability, but also takes away people's jobs.

What are the regulations concerning the use of UAVs?
The use of UAVs is relatively new to the commercial sector, as until recently only the army used them. As a result, only immature legislation is present, which can be very different among countries, and a number of countries currently even limits or prohibits the use of UAVs. Sometimes, it is possible to get a permit to fly, if a number of prerequisites have been met like having a flight plan and permission, a proof of experience and/or flying within a line of sight with a height restriction. Furthermore, only a few frequency bands are allowed for remote control of UAVs, making reliable control difficult at increasing numbers of UAVs in the same area, being another reason to prohibit their usage.

3 Why use an agricultural UAV?

After having seen the current State of the Art in UAVs, the question arises why they might be useful in agriculture. By reviewing several related questions, we provide an answer to this.

Why machines?
From the beginning, machines are designed for tasks that are Dull, Dirty, Dangerous or Dependable. Observational tasks are frequently long and monotonous actions which put the endurance of a human being to the test, and can thus be regarded as dull, while the outcomes are also dependable on the observer. Dirty and dangerous sometimes overlap, as dirty tasks are those, which jeopardize human health, like in areas with hazardous conditions from dust, gasses or even nuclear radiation, and may also be dangerous (Miasnikov, 2005). In these cases, machines can offer much higher endurance, objectivity, repeatability and availability, making their results less dependable on the worker. The task classification of Dull, Dirty, Dangerous or Dependable, do apply to every application of a robot, so also with a UAV and in agriculture. Two major differences with common agricultural machinery are: they fly, and they are unmanned. A third one is autonomous operation, which becomes also more common in other machinery.

Why flying machines?
An aerial vehicle has several advantages compared to ground-based agricultural vehicles. UAVs are very agile, especially the VTOL versions which can hover and have good manoeuvrability, thus having more freedom in approaching crops or animals. Aerial vehicles also have the advantage of not touching the ground, and thus suffer less from difficult terrain conditions compared to wheeled or tracked vehicles. Compared to satellites, their main advantage is that they can approach the target and collect information on a much more detailed level (Rango et al., 2009; Xiang & Tian, 2011), while also being capable of high-level observing to get a field overview. As flying removes the need for wheels and tracks on the field, more space becomes available for crops and the available soil is less compacted. Crop cultivation and field usage can change, as constrains on accessibility for wheeled vehicles are removed. Thus, planting patterns do no longer need to be in rows and crops can be mixed, such that the available resources can be used in the best possible way. Finally, access to fields or others objects can be easier and with less constraints through the air, so also steep or irregular fields being hard to exploit with current technology can be used.
A disadvantage is the limited payload of aerial vehicles, making them mainly suitable for observational tasks and maintenance activities. For planting or harvesting, other machines might still be necessary.

Why unmanned and autonomous flying machines?
Leaving the human out of a vehicle saves a lot of space and weight, and enables the creation of smaller or more powerful vehicles. As a result, they can be cheaper to produce and easier to implement. Furthermore, smaller means in general also more versatile, as obstacles induce limitations, and accidents will cause less damage to external objects, although the UAV itself might get lost in the accident. The step to Autonomous UAV (AUAV) is made, because flying or controlling an aircraft will become a dull task, especially when actions like monitoring are required daily or hourly. Autonomous activities can be executed with a higher frequency with lower costs, thus making such frequent observations possible, and in turn providing a better understanding of the situation and probably a better plan to react. Thus, an autonomous vehicle will be more reliable and offer greater benefit.

4 Which tasks can be performed by an AUAV?

As already indicated before, AUAVs can perform or take over numerous tasks, also in agricultural applications. They seem to be especially useful in the context of precision farming, where frequent (detailed) observation and tailor-made control is desired. In this section we will discuss several applications of AUAVs in agriculture with increasing complexity of the systems required, going from Monitoring, via Control & Coordination, to (re)Acting.
Techniques of operating military UAVs for mapping and surveillance tasks are also useful for agricultural applications. Mapping can be used to gather one-time data about crop yield or field status, to make a cultivation or harvest plan. Surveillance goes a step further and deals with repeated observations to get a stream of information over time on objects of interest, like crops or animals in the field or the occurrence or spread of diseases and plagues. This kind of observation tasks is dull and time-consuming for the farmer, making them ideal for replacement by AUAVs. In addition, the level of detail may increase, together with the quality and objectivity of the information collected, also compared with satellite-based observations. Furthermore, in some environments these tasks can affect farmer's health, for example by dust present in animal housings. Possible applications at this level are creation of a weed map in arable farming, or monitoring distribution and activity of animals in their environment. UAVs in research and commercial applications already perform such tasks, but lack autonomy as a remote pilot is still required to control the vehicle and define flight trajectories.
The next step is making use of the gathered information when performing actions, which is currently the job of the farmer. After processing and comparing the information with other data and history, control actions can be planned and executed. When this processing, planning, and acting is automated, relevant features can be selected, faster and more objective. If this is achieved, not only attending the user is possible, but also new options emerge, like autonomous tractors or field robots performing tasks based on the information collected by or with direct feedback from the AUAV. An example here is the use of field robots that remove

weeds, which are detected by an AUAV flying over the field, and that also provides directive information to the robots. In livestock production, this can be used to add additional information and control to already existing automation, like sending out a manure scraper to a location with a certain amount of faeces on a slatted floor. It can even extend current inspection functionality, as it becomes possible to send the AUAV out to perform more thorough inspections on areas of interest in already collected information, like specifically checking the status of a calving cow or whether spots on plants are mud or a disease. In-flight detection, processing, and re-planning of tasks is required to perform such activities.
A similar, but slightly more complex activity from an AUAV point of view, is performing actions through the AUAV itself, instead of by commanding ground vehicles. The simplest option here is to perform a herbicide spraying action on weeds, although mechanical weeding can be done by an AUAV as well. In animal husbandry, it can be that AUAVs are used to search for cows that have not visited a milking robot in due time, and send them to the robot by actively stimulating them. A similar thing might be done in broiler farms, to assure the animals have sufficient activity over the day. Also specific harvesting of fruits is an option, possibly at a faster rate as transportation speeds can be much higher through the air, although the limited payload of a UAV might be an issue here.
In fact, eventually all kind of management and control actions can be performed by a AUAV. Thus a complete, interacting system that can also learn over time can be created, that assist the farmer in all kinds of tasks on observation, tracking, management, control, and action.

5 Where do these tasks have to be executed?

Every task subscribed in the previous part has its own specific environment. The direct surroundings of an AUAV that has to map a couple of arable fields differ from the surroundings of an AUAV that observes animals inside a livestock house. Some general properties that hold for each application will be discussed. Although it is frequently mentioned that agricultural environments are complex (comparable with those in space and the army), heterogeneous and constantly changing with a large variation in size and shape (Edan, Han, & Kondo, 2009), only very few explicit descriptions are given. Bac, van Henten, Hemming, and Edan (2014) do this for harvesting horticultural crops, and they describe it by three parts: 1) the variation within crops, 2) the variation between crops, and 3) the variation in the environment. Their description will be repeated shortly, and expanded to other agricultural domains like arable and livestock farming.
The variation within a single crop is caused by the natural variation in pheno- and genotype, as well as the individual history of the plant or animal and their parts: position, size, shape, colour, sensitivity, and conditions differ and change over time. Extending this to livestock, this will also include differences in behaviour and character of the animals. All of this becomes more and more relevant with the current trends of precision farming, in which no longer whole fields, crops or herds are treated, but attention is paid to individual plants and animals and their properties. As human labour is expensive and cannot do this on a large scale, this is an excellent opportunity for the use of automated systems, and thus also AUAVs, which should then be able to handle such variation.
The variation between crops is, similar to the variation within crops, also caused by natural differences in the pheno- and genotype, and so the same issues will emerge here. Since different crops are usually grown separately, this is only relevant when moving from field to field or greenhouse to greenhouse. However, when intercropping becomes more common, this issue also has to be taken into account when applying AUAVs for agricultural tasks. Furthermore, redesign of the environment as a result of disappearing constraints will most probably lead to less structure in the system.
The most common way of growing crops is arable farming or open field cultivation, where the outdoor environment causes challenges by the lighting conditions, the weather, and the infinite space. The amount of light present highly influences the settings required in the use of cameras, to obtain similar information under different conditions. Weather is also influencing here, but even more important when dealing with vehicle control, as wind, rain and weather changes might affect the control of the AUAV. Finally, the infinite space in open fields can be an advantage, because UAVs can approach the object of interest from above, but also offers

problems as no physical boundaries are given, and thus artificial ones need to be derived to aid in determining location and controlling behaviour.
In indoor environments, either used for growing crops or housing animals, these challenging conditions are less dominant, as most of them can be controlled and thus help to optimise production results. Still, also indoors significant variation in temperature and airflow can occur, which might influence the control of a AUAV. Furthermore, as greenhouses are covered with glass or plastic, they have huge variations in light intensity, and thus influence the use of camera systems. Light is less of a problem in livestock buildings, but in turn the presence of dust and gasses like NH_3 and CH_4 can also complicate the use of AUAVs. On the other hand, this is also a good reason to have AUAVs take over tasks in these environments.
More problems are expected from the use of 3D space in indoor environments, which is much more densely filled compared with field crops. They contain numerous structures that provide support or offer facilities to plants or animals living there, and to humans performing activities. Although these can be an advantage or requirement for efficient production, and might aid in localising the AUAV, they also complicate the use of AUAVs here, as these structures have to be taken into account in controlling the AUAV. Furthermore, for each plant or animal species different structures are used, which complicates this problem. Finally, the presence of moving vehicles, people and animals and makes the environment more dynamic, so also coordination between vehicles is required.

6 What is needed to realize this?

Although UAV technology is developing rapidly, also for autonomous applications, still significant work has to be done to make the previously described applications reality. In this work, the indicated properties and requirements of (autonomous) UAVs and the agricultural environment should get clear and specific attention. We therefore define several areas of interest that have to be addressed in order to realise this:

1) The development of advanced control with artificial intelligence, so that full autonomy is reached on application level to limit the amount of manual labour required. This includes autonomous start/stop decisions, task and path planning, localisation and navigation through the field or the house, handling obstacles and other conditions in-flight, as well as automatic error handling and recovery;
2) Assuring safety and reliability of such AUAVs, so that unsafe conditions are detected in time and the AUAV responds accordingly so that safety to environment and vehicle is guaranteed, but task completion is achieved as well. Furthermore, task completion should also be reliable, in that it is executed according to the specified standards, and deviation of these standards should be detected and corrected during execution, or if this turns out impossible, notified to the system supervisor;
3) Suitable data processing methods have to be selected and/or developed, so that all the data collected can be analysed properly and automatically. This includes data analysis, world or feature modelling, and machine perception to provide only relevant features and information either to the system supervisor or other system components. Only then, it is possible to increasingly automate tasks;
4) Legislation should be well-suited to the use of AUAVs for agricultural purposes, not only allowing their use but also defining suitable standards for safety procedures and other operational guidelines. Furthermore, ethical issues related to their application, for instance on privacy and ownership of data, should be resolved so that all relevant data can be collected without risking any legal claims, and will remain accessible for the farmer. This might be achieved by actively including privacy in the design and development process;

If this point is reached, new possibilities and extensions will come up, like:

5) The development of new actuation methods: as the skills and working environment of AUAVs differ from current methods, new or adapted technology is required to perform actions. Furthermore, new activities will also require new actuation methods;
6) If constraints from current production methods no longer apply, agricultural production methods can be redesigned to take advantage of the new situation. Irrespective of this, redesign can be desired as the capabilities and requirements of AUAVs demand different environments than current technology. A clear example of this is the high-wire cultivation

system in cucumbers, being developed to ease the construction of a harvesting robot and now being common practice while the robot itself never became a commercial success.

These developments can only be achieved, if both research and industry join their forces, by developing new theory, principles, and approaches, which can quickly be deployed to practical applications. Also governmental institutions have to contribute, by creating suitable legislation and guidelines pro-actively and in cooperation with industry to enable a fast and successful growth of this technology.

7 Discussion & Conclusion

Drones or UAVs are mainly developed for the military, to be able to use the advantages of planes without risking pilots in dangerous situations. They currently exist in many different versions and a wide range of applications is mentioned. However, most of them are still manually controlled by a remote pilot and mainly used for mapping or observational tasks. This has to do with the fact that controlling a UAV's flight status can be automated, but that sufficient technology is lacking to allow higher level control, for example in the area of target determination and autonomous navigation. Furthermore, ethical issues on privacy and data ownership together with lacking regulation currently limit the use of these vehicles.

However, they contain several aspects that can be of a great benefit when applying them in agriculture, especially in the field of precision farming. They can take over monitoring tasks, and have the potential of performing much better than current systems that are based on satellites or human observation, in terms of repeatability, accuracy and timeliness. If suitable processing technology becomes available, this will also allow coordination of actions taken by humans, machines or robots in the field, as well as developed of manipulation methods by AUAVs themselves. Possible examples are the gathering of maps of weeds or animal activity, sending out ground-based robots for manure scraping or weed removal, or even activating animals by actively approaching them. However, before such advanced applications become reality in the large variation within the complex agricultural environment, a significant amount of development has to take place in fields like Data Processing, Advanced Control, Safety, and Legislation. If this is achieved, it will also open up new possibilities for the development of new technologies and production systems.

8 References

Anderson, C. (2014). Agricultural Drones Retrieved 8-5-2014, from http://www.technologyreview.com/featuredstory/526491/agricultural-drones/

Bac, C. W., van Henten, E. J., Hemming, J., & Edan, Y. (2014). Harvesting robots for high-value crops: state-of-the-art review and challenges ahead. *Journal of Field Robotics* (to appear).

Edan, Y., Han, S., & Kondo, N. (2009). Automation in Agriculture. In S. Y. Nof (Ed.), *Springer Handbook of Automation* (pp. 1095-1128): Springer Berlin Heidelberg.

Geer, H., & Bolkcom, C. (2005). Unmanned Aerial Vehicles: Background and Issues for Congress (pp. 62). Washington.

Miasnikov, E. (2005). Threat of Terrorism Using Unmanned Aerial Vehicles: Technical Aspects. MIPT, Dolgoprudny.

Newcome, L. R. (2004). *Unmanned Aviation: A Brief History of Unmanned Aerial Vehicles*. Barnsley: American Institute of Aeronautics & Astronautics.

Office of Secretary of Defense. (2005). Unmanned Aircraft Systems Roadmap, 2005-2030.

Rango, A., Laliberte, A., Herrick, J. E., Winters, C., Havstad, K., Steele, C., & Browning, D. (2009). Unmanned aerial vehicle-based remote sensing for rangeland assessment, monitoring, and management. *Journal of Applied Remote Sensing, 3*(033542).

Ratti, J., & Vachtsevanos, G. (2011). Inventing a Biologically Inspired, Energy Efficient Micro Aerial Vehicle. *Journal of Intelligent & Robotic Systems, 65*, 437-455.

Sosa, A. J. (1997). Unmanned Aerial Vehicles-Promises and Potential. Carlisle Barracks, Pa.

Xiang, H., & Tian, L. (2011). Development of a low-cost agricultural remote sensing system based on an autonomous unmanned aerial vehicle (UAV). *Biosystems Engineering, 108*, 174-190.