Operation of unmanned aerial vehicles for the application of pesticides

On the 2nd and 3rd of February 2017 the Julius Kühn-Institute organized and hosted a workshop to discuss open questions about the use of unmanned aerial vehicles for plant protection in steep slope viticulture and forests. The paper provided below summarizes the most important findings and results of the expert discussion groups.

Operation of unmanned aerial vehicles for the application of pesticides in steep slope viticulture and forests (published 21-02-2017)

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Unmanned aerial vehicles (UAVs) are more and more used privately or for commercial purposes in order to fulfill different functions. Also within the field of agriculture UAVs are increasingly used and will play an important role in future. Especially for the application of pesticides in steep slope viticulture and forests UAVs may prove an interesting alternative to helicopters. But before a lot of technical and legal questions have to be answered. For this reason the Institute for Application Techniques in Plant Protection of the Federal Julius Kühn Institute organized an expert discussion on national level. For two days experts from public authorities, the industry and the scientific community presented and discussed the state of the art and addressed open questions.

On February 2nd and 3rd representatives of the companies Rucon and Procow, of the Fraunhofer-Institute for Transportation and Infrastructure Systems (IVI), of the Institute of Flight Systems (DLR; National Aeronautics and Space Research Centre), of the Federal Aviation Office (LBA), of the National Air-Traffic-Control (DFS), the University of Geisenheim and of the Julius Kühn-Institute (JKI) presented their latest knowledge about the utilization of UAVs in agriculture. The event was accompanied by an exhibition of UAVs and projects. This paper summarizes the most important findings and results of the expert discussion.

A) Actual use spectrum of UAVs in agriculture

In agriculture UAVs are actually used as carrier platforms being simple to control. They can also be equipped with different sensor systems for purposes of remote sensing. Based on georeferenced images recorded during the flight in different spectra (e.g. ortho, thermal or multispectral images) 2D or 3D information can be generated. This information, partly enhanced by further data-sources, allows an assessment of the agricultural areas with regard to different tasks. Image data can be used to assess the nutritional requirement of a plant population in order to compile nutrition maps for the precise application of fertilizer. Since this data allows only a relative comparison between good and poor nutrient-supplied areas, there is a need for manual sampling in order to provide an absolute reference data, which is necessary for the evaluation of the actual field situation. Furthermore, orthoimages and sensor data supplied by UAVs can be used to get information about biotic and abiotic damages in a plant population. This includes damages caused by game animals, pest infestation (e.g. mice) or weed spots. Also damages due to winterkill, storm, hail or erosion can be analysed in a cost effective way using UAVs. However, a fully automated evaluation of the situation in the fields made by UAVs is not possible at the moment. But for trained damage appraisers UAVs are a practicable support for the generation of data being necessary for their work.

If UAVs are equipped with infrared cameras they can also support tasks in the area of nature conservation and animal health by detecting fawn before grass mowing on agricultural used grassland for example. For this purpose the area being mowed is scanned by UAVs and the position of present fawns are marked. Before mowing, fawns can be removed from the area to another by hand. So far guided dogs have been used for this purpose. However, the success is not always guaranteed with this method. Also with UAVs there are disadvantages because of the time delay between flight mission, image analysis and manual removal of the fawns being detected. In some cases a detected fawn changed its position in the meantime and cannot be found precisely. For this reason it is planned for future to connect the UAV with the mowing machine by cable in order to have an online detection system, when the UAV flights ahead. This would also solve the energy problem UAVs have momentarily. The capacity of the rechargeable batteries are limiting the net flying time (ca. 10-25 minutes depending on model and capacity of the battery). A practicable solution of connecting the UAV with a ground vehicle was presented within one presentation on the expert discussion. The implementation of this idea is an important step forwards to further interesting approaches for the use of UAVs in agriculture. Besides the use of UAVs as a carrier platform for remote sensing, the use as working machine was also discussed. Today, UAVs are already successfully used to apply *Trichogramma* capsules in corn to control European corn borer. However, the limited net flying time caused by the use of batteries is a disadvantage of the system for such kind of application. In this context, the legal situation was clarified by the experts: the application of *Trichogramma* species is not forbidden due to the general prohibition of aerial spraying within the EU since the insect *Trichogramma* is a macro organism and not a plant protection product with regard to German plant protection laws.

B) Electronics and flight control of UAV

Technique and capabilities of UAVs have made big progress within the last few years and technical development is continuously going ahead. Scientists of the IVI and DLR presented the technical state of the art and the technical challenges which have to be overcome in order to apply plant protection product with UAVs in steep slope viticulture.

In modern UAVs multiple sensors are being used in order to detect the attitude of flight in a correct manner and to operate automatic work flows. This is necessary because UAVs equipped with multiple propellers are in an instable flight condition. Due to this control systems are permanently checking position and attitude of the UAV in order to constantly adapt them. Techniques used for this purposes are 3-axle acceleration sensors, 3-axle rotation rate sensors, barometric sensors, ultrasonic sensors as well as GPS-antenna and camera systems.Acceleration and rotation rate sensors are used in order to avoid uncontrolled pitching, rolling or yawing. Aiming to control flight heights, barometric and ultrasonic sensors are used. They also help to release the pilots because they enable automated landing routines. GPS-antenna and camera systems are able to determine the position in order to control and adapt the flight track. Every type of sensor system is thus used for specialized tasks, but they can also substitute or supplement each other. This is needed, because every sensor can be influenced by different exterior effects. The accuracy of a GPS-positioning can be influenced severely e.g. while flying between buildings, within forests or in front of slopes. This has a negative impact on the reliability of operation of an UAV. In order to solve this problem it is possible for an UAV to identify its position with higher accuracy by using a real-time-kinematic (RTK)-signal. This solution is already widely spread in agriculture and can be found for example in automated steering systems of machines. Another possibility is to detect the position and the environment by using UAVs equipped with stereo camera systems. Both of these systems are able to compensate inaccuracies of GPS-data in difficult environments.

Within premium quality UAVs redundant systems are in use in order to avoid loss of control if one system fails. Furthermore, the challenge for the set-up of a steering system of an UAV is to configure it in a way that data from different measuring systems are permanently compared and checked on plausibility. If a sensor system fails or if data is contradictorily the steering system should be able to identify the correct data and use only this for flight control. In this way it is possible to operate in "high-level operating mode" in order to release the pilot from ordinary tasks. Examples for such operating modes are flight operations where the UAV is keeping a constant distance and/or position to the ground or an object. Likewise, automated flights along prior to this defined waypoints and different "follow me" routes[1] are examples of these flight modes. With these specialized flight modes it will be possible to keep an UAV in constant position before or over an object, even if this is moving by itself. One promising application would be the forward flight in front of agricultural machines for data detection e.g. for the already mentioned location of fawns or online detection of the nutrition status of plant population.

If UAVs are used for the application of PPP the technical requirements are raised significantly against requests from actual tasks done by UAVs within agriculture. This is especially true talking about the environment of steep slope viticulture, where UAVs could be an alternative to the pesticide treatment actually done by helicopters or hand held sprayers. But, besides systems for flight control, in this scenario UAVs have to be equipped with additional systems for avoiding collisions and for the detection of objects. On one hand side grape-vine rows have to be detected and being flight over precisely, one the other hand side collisions with trees, buildings, operators, bystander, vehicles, rock faces and transmission lines have absolutely to be avoided. The high weight of sensor technology being able to fulfil these requirements at the moment is limiting the net load of the UAVs, that such a fully automated flight operation is not feasible. Due to this reason it is not thinkable, even in a medium-term, to abstain from a pilot, who can control the flight track and intervene at any time in an emergency if the UAV is flying automatically.Moreover, it has to be taken into account, that there is a need for more dynamic manoeuvres in steep slope viticulture when applying PPP. In these areas the flight is done under difficult topographies and at very low altitude close to the grape-vine compared to mapping tasks done by UAVs in remote sensing. There will be higher acceleration forces, which will put much more mechanical stress onto the structure and power unit of the UAVs. In order to assure the safe and faultless operation of UAVs in such an environment further experiments and additional technical development is needed.

Interim conclusion:

At the moment low net loads and very short flying times when using battery powered vehicles are limiting parameters for the utilization of UAVs in agriculture. The state of the art is not sufficient in order to realize automatic flight modes without any active control of an additional pilot to apply plant protection products (PPP).

C) Air law and air traffic control

Besides technical challenges which are especially connected to the application of PPP by UAVs multiple aspects of air law and air traffic control have to be considered for the operation of UAVs. Up to now the classification of commercially and privately used UAVs is insufficiently regulated. For this reason the draft of the amended German air traffic regulation was presented on the expert discussion. This regulation is supposed to clarify the rights and duties when operating UAVs. Furthermore, it contains provisions on the permission-free ascend, on hazard control for third parties on ground, on air traffic and on safety of sensible objects as well as on better protection of privacy. One reason for the amendment of the regulation is the rising number of conflicts concerning privacy. Moreover, there had been a lot of dangerous approaches of UAVs in air traffic as well as disturbance during operations of police, fire and emergency services. At same time the new regulation should give more possibilities for commercial activities and should release the authorities from certain duties concerning administrative decisions. The following table 1 gives an overview of the legal situation.

Table 1: Rights, Duties and limitations for UAVs depending on their weight (Source: https://www.bmvi.de/SharedDocs/DE/Artikel/LR/151108-drohnen.html?nn=12830, 15.02.2017).

	≥ 0,25 kg	≥ 2,0 kg	≥ 5,0 kg	≥ 25 kg
Labelling requirement	Yes	Yes	Yes	Yes
Obligation for evasion	Yes	Yes	Yes	Yes
Knowledge proof	No	Yes	Yes	Yes
Obligation for permission	No	No	Yes	Yes
Operating out of sight	No	No	With permission	With permission

Operating ban	• operating out of sight for UAVs < 5 kg; • within and above sensible areas, e.g. operation sites of police, fire and emergency services, crowd of people, industrial plants and prisons, federal and regional authorities, nature conservation sites; • above certain traffic routes; • within control areas of airports (also landing and departure areas of airports); • in flying heights more than 100 m above ground. This ban does not count for model flight airports; • above private properties, if UAV > 0,25 kg or it is equipped with devices being able to receive, transmit or record optical, acoustical or radio signals. Exemption: If the affected persons on the private property give their permission; • the operation of UAVs >25 kg is forbidden in general.
Use of video eyewear	• permitted, if flying heights is < 30 m and the UAV < 0,25 kg or if another person is permanently intervisible with the UAV, in order to instruct the pilot about existing risks. This is comparable to an operation in sight.

One of the most important aspects of the amendment is the introduction of a knowledge proof for pilots of UAVs from 2kg take-off weight. In case of the general operating ban of UAVs from 25kg there shall be exemptions especially for operations in agriculture and forestry, because in this area a big potential for the commercial utilization can be seen (Carsten Konzock, LBA). Due to these exemptions it could be realistic that UAVs > 25kg can be used for the application of PPP in future if permission is applied and given. The amendment of the German air traffic regulation, where all these frame conditions are included, will only be an interim solution. It is already known that the utilization of UAVs will be regulated on EU-level (expected in 2018).

Interim conclusion:

The answer to specific technical and legal questions (concerning plant protection laws and air traffic laws) will decide about the future utilization of UAVs for the application of plant protection products.

D) Application of plant protection products with UAVs

Within the last section of the expert discussion the proper application of PPP with UAVs under consideration of technical aspects was presented and discussed. First, however, it was pointed out clearly that the actual legal situation does not permit the utilization of UAVs for application of PPP! One simple reason - besides others - for that is the fact that there is actually no authorised plant protection product on the market for this purpose.

The operation of UAVs for the application of PPP is not sufficiently analyzed in Europe up to now. There are first trials, e.g. done in Switzerland, which give indications about the expected drift potential when UAVs are used. But, these trials had been done in flat areas, where the UAV was completely manually operated by a pilot. The results show off, that under these circumstances drift and leaf covering is comparable to a conventional application done with vertical sprayers commonly used in viticulture. Trials done in USA under similar topographic conditions show that the flying heights above the grape vine rows and the way of flying over the area[2] has a significant impact on the drift potential and the resulting leaf coverage. These results are also proven by tests done in China, where the commercial application of PPP with UAVs is already widely spread. Together with experts from the JKI a first draft for a method under reproducible conditions was worked out there and presented on the expert discussion. The experts agreed that there is a big need for such methods and that there is still a lot of research demand to realize such methods, in order to determine leaf coverage, drift potential and biological efficiency of the treatment with UAVs. There was a critical discussion about the question how far the existing standard test report (JKI-Guideline 7-1.5) can be used for drift measurements concerning the application of PPP in steep slope viticulture with UAVs. This was due to the fact that the UAVs are flying along the grape vine row during the application, whereas the helicopters in the steep slope viticulture at the Mosel area apply diagonally to the grape vine rows. This procedure makes it very difficult to find appropriate steep slope fields with an open area in the direct neighbourhood for the measurement as well as having "wind from the right direction". For this reason it was discussed how far an adoption of the test report to the special characteristics of application with UAVs in steep slope viticulture is meaningful.

Interim conclusion

The workshop-participants concluded that an exemption for the operation of UAVs in steep slope viticulture as well as in forestry is manageable, provided sufficient data is available for the risk assessment during the authorisation process for PPP. There is however a need for a coordinated course of action between the federal and regional authorities as well as the producers/dealers of UAVs. The auditorium agreed that the technique of UAVs for the application of PPP should be brought to practical use by conducting further trials and implementing new research projects.
