INTRODUCTION OF UNMANNED AERIAL VEHICLES INTO AIRPORT GROUND OPERATIONS

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Abstract

This paper describes a concept of unmanned aerial vehicles (UAV) or rather unmanned aerial systems (UAS) to support airport processes. Three areas of application with potential for an implementation will be presented: Runway inspection, bird control, and a tactical component for future Surface Manager Systems.

The paper starts by identifying airport processes, which could benefit from automated services that an unmanned and preferably highly automated aerial vehicle could provide. For that purpose, usable UAV technologies, design of vehicles, and payloads were assessed. Among several basic layouts, electric multirotor technology turned out as a simple, agile, and safe platform for possible airport support functionalities. Limitations for this kind of applications exist in the battery technology, but improvements are likely in the next years to overcome these constraints.

The first area of application analysed is the runway inspection. For the UAV application, the scanning of the runway for lost objects possibly harming aircraft was considered in the concept. The second UAS application is an alternative method for controlling bird populations on airports. In combination with payloads of droppable pyrotechnical cartridges and strong lasers, the birds could sustainable be scared off.

The third application described is a tactical component of a high-level advanced surface movement guidance and control system (SMAN). To support pilots during the taxiing process, an UAS can be used to guide the aircraft along the taxi route. Based on requirements derived from this application, a sample UAV configuration is described with a signalling LED matrix device mounted to the vehicle through a folding mechanism.

Keywords

UAV; UAS; airport; runway inspection; bird control; tactical surface management

1. INTRODUCTION

For the next years a continuous increase in air traffic is predicted [1][2]. The expected growth rates vary slightly, but the positive effects of an advanced transport system are clear – better and faster connection of the societies on different sides of the planet. Higher absolute numbers of flights have to be counteracted by lower relative numbers in terms of noise, emissions, and ecological impact to keep the acceptance of air traffic in the society high. Efforts are necessary to keep safety at the current level. This becomes more critical, when different parts of the system are congested.

Besides the effect, that optimization will bring to manned air traffic, it is also a necessary basis for the successful, widespread deployment of unmanned air systems (UAS) in the international airspace. The mobile parts of the systems, the unmanned aerial vehicles (UAV), are predicted to play an important role in the air transport system for various functions from freight to surveillance operations [3].

For the use on airports, we developed a wide list of possible applications for UAVs on airports:

- Follow-Me applications for aircraft and ground vehicles
- Tactical 4D-trajectory guidance in combination with a Surface Manager (SMAN)
- Reconnaissance at CAT II/III conditions
- Guiding Remotely Piloted Aircraft Systems (RPAS) on apron
- Runways inspection
- Monitoring passenger movements on apron
- Fire brigade support
- Locate and secure lost luggage on apron
- Bird control

For this paper, we concentrated us on the three areas of runways inspection, bird control, and tactical 4D-trajectory guidance in combination with a Surface Manager (SMAN).

The first area of application analysed is the runway inspection. Currently carried out manually by personnel from a car driving along the runway up to several times a day, a friction test of the runway is sometimes performed in parallel. For the UAS application, only the scanning of the runway for lost objects possible harming aircrafts is considered. Based on specification of lightweight and the commercial availability, laser scanning and image processing technology are described. The solution relies on fast datalinks and precise positioning of the scanning UAS. Deployment of multiple UAS for this task would bypass some limitations like transmission rate or overall time needed for one inspection process.

The second UAS application is an alternative method for controlling bird populations on airports. Investigation of the current situation shows, that there is no single superior solution to prevent bird strikes around airports. Several different methods are currently carried out by bird control staff on the airport areas [4]. A variation of these methods over time provides satisfactory results due to habituation effects. To takeover this task by an UAS only, the vehicle is not sufficient to scare the birds permanently alone. However, in combination with payloads of droppable pyrotechnical cartridges or strong lasers, the birds could sustainably be scared off.

The third application described is a tactical component of a high-level advanced surface movement guidance and control system (SMAN). Congested airport infrastructures require the implementation of enhanced supporting systems to relay speed and routing information generated by air traffic control support systems to pilots for a time-based taxi process [5]. In this case, the challenge is to meet exactly the planned roll speed on the way from the gate to the runway and vice versa. Furthermore, feedback to pilots about their actual taxi speed is limited in most aircraft. To support the pilot an UAS can be used to guide the aircraft along the taxi route. For this task, the UAS have to be equipped with a lighting system and will be used like a follow-me vehicle.

Finally, based on requirements derived from the three described applications, a sample UAV configuration is described. For flexibility, a frame with a signalling LED matrix device always mounted to the vehicle through a folding mechanism is recommended. It offers a secondary function as landing gear and structure for mounting of inductive charging equipment. Runway inspection and bird eviction payloads should be designed as separate modules.

2. MULTIROTOR TECHNOLOGY

Different layouts or rotor configurations are possible and may be studied for reasons of safety or efficiency [6]. The blade theory provides an analytical proof that smaller numbers of larger rotors are more efficient than a set of small rotors of the same footprint. However, the applications considered in this paper should follow safety standards that may not be reachable with a single main lifting rotor.

2.1. Categories and Characteristics of Unmanned Aircraft

UAS are categorized today using various metrics [7]. The classification is based on several parameters defining the structure of the aerial vehicle. For the use on airports, fixed wing UAS will not pose a practical solution since they do not offer hovering abilities. Special configurations like tilt rotor vehicles or hybrid platforms combine hovering with longer endurance of a fixed wing, but may require complex mechanics. Additionally, they do not offer longer hovering endurance compared to rotorcraft at all. Classical helicopters are the most efficient of the rotorcraft due to their large and slow-rotating wing, but also require mechanical aids for flight. Vehicles featuring multiple rotors known as multicopters do not require mechanical parts besides the motors themselves. Stability is achieved through computational evaluation of sensors and control loops that steer the rotors' speed in a suitable manner. The simplicity of this design makes it interesting for businesses that want to utilize an UAS without the unwanted side effect of complex mechanical maintenance.

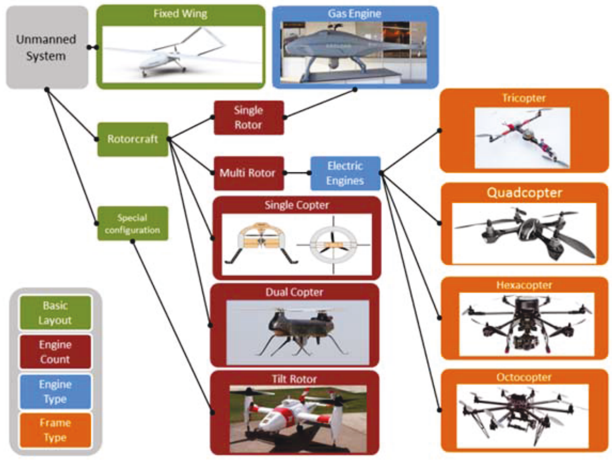

Fig. 1 Classification of UAS by configuration (sources: Fixed Wing: Unmanned Systems Group Discoverer; Gas Engine: Saab: Skeldar V-200; Tricopter: http://goo.gl/uHrwZS; Quadcopter: Hubsan X4 (H107); Single Copter: Ardupilot; Dual Copter: Dragonfly Pictures DP-6; Hexacopter: DJI S900; Octocopter: DJI S1000+; Tilt Rotor: Bell Eagle Eye).

UAV operations on airports will require the vehicle to be capable of carrying different payloads. Some preliminary estimations of weight, hovering, and payload capabilities are provided for various classes of multicopters. The powertrain of an electric multirotor is responsible for a relatively big proportion of its weight. Weight is also the main factor that drives the selection of motor and battery sizes during a design process. The lower boundary of the UAV size was determined by the consideration, that payload capabilities under 100 g might not be sufficient for any practical use at airports. On the other side, UAV larger than 25 kg MTOM are not deemed manageable by a single person. Additionally, larger UAV require more complex and thereby more expensive certifications in most European states and the United States under current regulations. For the deployment at airports, we suggest unmanned vehicles with four rotors, a propeller-diameter of 38 cm, and the MTOM of around five kilogram. Basing on actual technologies, the UAV would allow a flight time around 20 to 25 minutes with a payload of nearly 1.5 kilograms.

Due to their efficiency and power-to-weight ratio, Brushless Direct Current electric motors (BLDC) are usually the choice for multirotor vehicles. For the energy supply, rechargeable lithium-ion batteries are in use, which are capable of several hundred charge-discharge cycles[1]. This number can be significantly raised, if the limits of the capacity during charging and discharging are not stressed.

Without the option for automatic charging of the batteries, continuous operation will be challenging. Due to the characteristics of today's battery technology, the time needed for charging is significant when compared to the flight

[1] Compare Panasonic Lithium Ion Battery UF103450P: http://na.industrial.panasonic.com/sites/default/pidsa/files/uf103450pn_1.pdf [accessed August 31, 2017]

time. In the consequence, either the battery is changed every time the vehicle arrives at a designated base. Complex mechanics may be necessary for the physical detachment of the battery. In return, an automated process may only need seconds for switching a battery. The vehicle is ready to fly almost immediately, while the battery can be charged separately. Alternatively, the battery may be recharged internally through wireless power transfer.

For internal charging, the complete vehicle has to rest in the base station until charging is completed. This increases the necessary number of vehicles for continuous operation. Wireless charging stations require no complex mechanics. If a vehicle's receiving side of an inductive couple is near its bottom, the transmitter can essentially be implemented as a flat surface coil that a UAV needs to land on for the charging process to start.

2.2. Safety Aspects and Coping with Adverse Weather Conditions

The safety of a multirotor can be assessed by identifying its subsystems and evaluate their safety respectively. The main features found on a multirotor prone to malfunction are its structure, the electronics, and the motors. The structural design should be based on an assessment of loads acting on the vehicle. These may include external influences like strong winds or vibrations due to imbalances of the motors and propellers. For a system that has to lift its own weight all the time it may be deemed most efficient to design a structure as light as possible, but safety aspects dictate sufficient margins in the process of the design. For vehicles operating in harsh environments, it may be necessary to consider material deterioration over time like corrosion of metals in rain or in maritime settings.

Electronics are necessary to keep an inherent unstable system like a multirotor flying safely. They need to be shielded against environmental impacts. Redundancy of electronics should be considered for robustness against failure; the small form factors and weight penalties introduced by adding a backup flight controller are negligible, as current implementations of flight controllers only weigh several grams.

The only parts moving within a multirotor platform are the motors and their attached propellers. When operated within the specifications, the only parts affected by wear are the bearings connecting the stator and rotor of the motor. Research has shown that through understanding of the physical model, it is possible to control and navigate a multirotor with only two propellers working, if they are located opposite of the central structure [8].Thus, a quadcopter with each motor capable of lifting half of the vehicle's weight is robust against malfunction.

Quadrotor vehicles of the described sizes are highly agile, but due to their little mass also susceptible to wind. Strong, steady winds may have an effect on the system's performance. Besides the gravitation, it has to counteract the force applied by the wind. Some concepts incorporate aerodynamic hulls, which may even benefit the total lift produced by the system. For systems where aerodynamic hulls may not be applicable, energy storage systems should be sufficiently large to accommodate the desired endurance.

Operation in non-predictable gust situations concludes that high-quality components and especially high-bandwidth actuators (speed controllers for the motors) need to be incorporated in the multirotor design to act against disturbances [9]. In general, lighter vehicles are easier affected by gusts due to their small mass and lower inertia. Sufficiently responsive control algorithms and motors producing enough trust must be chosen in the design process of the vehicle for operation in severe winds.

3. THE REGULATORY ENVIRONMENT

While UAS technology is advancing fast-paced, the legal situation in Europe and Germany is not as clear as operators wish for. More and more businesses are emerging that plan on utilizing UAS as their main source of revenue. On an international level, some guidelines for UAS operation have been established by the ICAO [10][11]. In many aspects, they refer to legislation of the country involved with the operation.

Today, regulations across Europe are not harmonized [7]. UAS with a MTOW higher than 150 kg are subject to European Aviation Safety Agency (EASA) regulation. For vehicles with a MTOW of less than 150 kg, the national authorities are responsible. So far, UAS subject to EASA regulation need to follow the same design and certification principles as manned aircraft do. Depending on factors like the size of a vehicle, its speed, height of operation above ground, vicinity of the operation to other aviation or population, different levels of regulation may be put in place regarding training of pilots, technical requirements, and operational constraints.

Similar to the situation in Germany, US authorities (Federal Aviation Authority, FAA) distinguish clearly between leisure and commercial operation. Additionally, the authorities distinguish between public and civil entities operating the UAS. Concerning non-governmental, business-oriented operations, remote pilots may fly UAS with a MTOW not higher than 25 kg within visible line of sight and up to an altitude of 400 ft. and only during daytime. No-fly-zones exist at circular areas with a radius of 8 km around major airports, near governmental and public facilities, and also over private property, if declared so by the owner.

For commercial applications, pilots are currently required to hold a valid commercial pilot's license [12]. Since it is not easy to obtain such license, the barrier to enter into UAS business is set higher compared to Germany. In general, currently remotely piloted aircraft are heavily sanctioned and unmanned, automatic operations are not yet considered at all. The changes in legislation that are currently discussed usually concern the operation of remotely piloted aircraft together with manned aviation in a non-segregated airspace. Small UAVs may be considered in the future, when proportionate rules for different sizes of vehicles and different types of operations are set up. Businesses that want to apply UAVs, on the other hand, are waiting for a clearer set of rules before they invest in researching technologies that may enable these interactions.

4. EQUIPMENT AND CURRENT APPLICATIONS

This section provides insights into different categories of payloads. These will be considered later for the application cases. The factors to be reviewed besides the core functionalities of the systems are weight and power requirements.

4.1. Sensors

Sensors are a prerequisite for UAV operations. Whenever a human is involved in the operation of a machine, he unconsciously and consciously controls it by comparing system parameters with desired values. Sensors replace this human component by giving feedback to a system in order to enable it to control itself. In some aspects, artificial sensors surpass humans.

4.1.1. Optical Systems

Many of today's commercially sold UAVs are or can be equipped with high-resolution cameras. A forward-looking camera usually works as a "first person view" (FPV) to provide the pilot with a "cockpit feeling" while steering the vehicle. If the camera can be moved independently from the vehicles direction of flight, a greater range of applications is possible. Depending on the intended usage and required image quality, a camera's weight ranges from only several grams to several kilograms for professional grade movie cameras. While the high-end cameras draw significant amounts of power, a typical power consumption of several watts is negligible in comparison to the powertrain.

The data gathered by camera systems can be interpreted easily by humans. If the evaluation has to be automated, image-processing techniques are applicable. Like a human eye, optical systems only work under sufficient lighting conditions and they may not work satisfactory during night or in reduced visibility conditions like fog.

A different category of optical systems is light detection and ranging (LIDAR) systems. They emit, detect, and analyse beams of light to measure the distance between the unit and the reflecting target. In the last years, different designs were developed for different purposes from terrain mapping to wind shear detection [13]. A small, commercially available system weighs less than 20 grams and can measure distance up to 40 metres with an advertised accuracy of 2.5 centimetres and a scan rate up to 500 Hz. Infrared proximity sensors are based on a similar principle to LIDAR systems.

Infrared systems were not taken into account as they exhibit various disadvantages, including a considerably shorter range and susceptibility to interference from other light sources.

4.1.2. Acoustic Systems

Ultrasonic rangefinders work similar to LIDAR. The small systems are very light and draw little power, but they are also limited to short ranges. Additionally, they show low effectiveness for non-perpendicular targets, targets with non-solid surfaces (e.g. fabrics or fur), and the detection can be significantly obstructed by other sources of sound and vibration like propellers.

4.1.3. Radio Detection and Ranging (RADAR)

While optical systems detect electromagnetic waves that are visible to the eye, radio detection and ranging (RADAR) emits and detects electromagnetic waves of lengths from centimetres to several kilometres. These are less obstructed by atmospheric conditions and do not depend on daylight. For scanning of an area, synthetic aperture RADARs (SAR) offer high-resolution capabilities. A small system weighs roughly 1 kg and consumes 25 watts of power.

4.2. Signalling

There are two options when considering a signalling device to be mounted to a UAV: a complete screen or a set of a relatively small number of light emitting diodes (LEDs). A monitor has the advantage of a wide variety of information displayable. Thus, it might adapt to applications that are not considered initially easier. The versatility is contrasted by many disadvantages. A solid surface like a screen is a potential target for wind, yet wind susceptibility should be avoided to ensure safe and steady operation of the UAV. Additionally, the weight handicap to the system is significant and reduces flight time considerably.

In comparison, an array of a small number of LEDs is much lighter and less susceptible to wind, but is limited in the information it can display. The number and configuration of the LEDs has to be considered when designing the display unit. Signals from these units might not be as intuitive as images that can be displayed on a real screen. A documented convention of what the unit might display to the person addressed should be incorporated.

4.3. Commercial Applications

The legal state of UAS operations is not yet clear in all aspects and subject to changes in the near future. These depend greatly on advances in sense and avoid technologies and their approval by the authorities. Since manually operated vehicles are already accepted under certain circumstances, short-range operation proved simpler to set up and appeared as the precursor for more complex operation. Commercially, UAS play in three fields already significant roles.

Although being feared as "privacy intruder" tools by the public, the use of unmanned vehicles for imagery or videography is already widespread and not only limited to the media industry. Besides the media industry, other private and official areas are employing the capabilities previously not affordable or practical to them: UAS are used for real estate to provide a bird's eyes view. In science and ecology, the scenarios range from mapping archaeological sites to wildlife counting to automate three-dimensional mapping of uncharted territory. Police and firefighting use live video feed of unknown situations to enhance decision-making and the optical inspection of large or hardly accessible industrial complexes like pipelines or wind turbines a another field of UAS use.

Since 1990, farmers in Japan used unmanned helicopters for crop dusting, well before UAS became relevant in filmmaking or other mentioned areas [14]. The relatively small size of Japanese farms made manned aviation unfavourable for this application even though it was practiced since the late 1950's.

Several businesses are conducting research to enable UAS for mail or package delivery. The most prominent are online commerce companies like Amazon and Alibaba, as well as logistics companies, for example DHL and Swiss Post. The projects differ in the targeted capabilities of the system.

5. THE AIRPORT ENVIRONMENT

The growth of air traffic has to be encountered by enhanced concepts of air traffic control and enhanced traffic throughput, among others. Thus, new approaches to maximise the use of given infrastructures are necessary. Assistance systems to avoid overloading the authorities coordinating the traffic flow with work become crucial.

5.1. Controller Support Systems

On a local level, controller assistance tools like arrival and departure managers (AMAN & DMAN) were developed and introduced since the 1990s [15][16].

They support the controllers in the process of sequencing and scheduling incoming and outgoing flights. Since a few years, it became apparent, that optimization methods are required for the taxiway system as well [17][5]. The coordination of surface management (SMAN) together with the runway system provides a better concept towards the goal of capacity increase. Thus, research was conducted into coordination of departure and surface management [18], arrival and departure management [19], and the optimisation of all three areas together – arrival, departure, and surface management [20].

In parallel to these improvements, other investigations were undertaken to improve information sharing between aircrafts, air traffic control, and other stakeholders involved in processes on airports. The concept of “Collaborative Decision Making” (CDM) [21] was first developed in the US to improve management of ground delays. It was later expanded to include every party involved in a turn-around process and subsequently called “Airport Collaborative Decision Making” (A-CDM) [22]. The collaborative approach with its focus on sharing all necessary information in the needed form with every involved stakeholder on an airport contributes towards the goal of better predictability of events in the turn-around process. The pre-tactical Airport Operations Plan (AOP) is considered as part of a larger, centralised data handling system; this is studied as the System Wide Information Management (SWIM), as described in the “SESAR Concept of Operations” [23].

5.2. Surface Manager within A-SMGCS

While arrival and departure management systems are in operation for some years now, an optimised use of taxiways and the apron is still within the scope of research [22]. Advanced Surface Movement Guidance and Control Systems (A-SMGCS) provide by definition of ICAO [24] four functionalities for ground traffic: Surveillance, control, guidance, and route planning.

While under the right circumstances it is theoretically possible to implement these functions into a fully automatic system, is this not the scope of ongoing research. State of the art of A-SMGCS focuses rather on consolidating available information on the current and planned traffic situation to enhance ATCOs decision-making. Comparable to AMAN and DMAN support systems, research is developing surface management systems (SMAN) that calculate optimised “4-dimensional” taxiway routes to and from the runway. These calculations are presented to the controllers as recommendations for advisories to guide aircrafts [5].

6. UAS-AIRPORT APPLICATIONS

In this paper, we discuss three different possible UAV applications: The inspection of the runway, a new means for bird control, and the use of a UAV as a mean to guide aircrafts timely based on efficient surface management concepts. Finally, a concept is presented for a system capable of performing these three tasks.

6.1. Runway Inspection

This section describes aspects of the possibility of using a LIDAR or camera system for the inspection of a runway. Estimations are based on the technical data of a commercially available LIDAR system. A tentative estimation will show the theoretical feasibility, but also the operational problems still to be addressed. Alternatively, the possible use of an electro-optical system for this task is discussed.

The ICAO describes basic guidelines (Standards and Recommended Practices – SARPS) for airport maintenance, where special attention is given to the integrity and preventive maintenance of paved moving areas and to the serviceability of indicating lights [25].

The methods to undertake runway maintenance are to be developed by the countries and not described by the ICAO. However, they summarise the parameters to be taken into account:

- “avoiding and eliminating any loose objects/debris that might cause damage to aircraft”
- “a surface friction characteristic at or above the minimum friction level specified by the State”

An Airport Services Manual [26] describes the necessary action in more detail. Runway inspections (for foreign objects) should be carried out at least four times per day. Measurement of runway friction should not only be done under dry conditions, but also for “slippery” and ice-conditions. The reason for these inspections to be carried out on a regular basis is the expectation that the runway surface will deteriorate over time and consequently change its characteristics.

While the process of visual inspection needs to be done several times daily, the measurement of runway friction is usually carried out more seldom in dry conditions and only at higher frequencies during adverse weather conditions. Current state of the art does not provide practical solutions for measuring surface friction from UAVs. Whereas the detection of debris by UAS is a task within reach of current technology. Given that a runway is a flat surface, two methods for inspection seem feasible:

- Optical inspection with a camera system
- Surface probing with range-finding sensors

The electronic evaluation of sensor data is currently researched with great efforts by the automotive industry to improve driver assistance or enable self-driving cars. Usually, the focus lies on detection of humans and large objects impairing the intended path. Optical inspection of a runway surface focuses on detection of smaller objects like screws or dead animals. It might be carried out by comparison of saved reference data (pictures of the runway) with newly acquired images. This process requires UAVs to be equipped with:

- Systems for exact positioning of the vehicle to produce images identical to a reference image
- A camera system with sufficient resolution (the resolution requirement depends on the distance above ground of the vehicle and the size of the object to be identified)
- For low-light conditions, sufficient lighting power to illuminate the area to be pictured or

- Cameras with extreme low light sensitivity
- Data transmission means capable of sending large data of high-resolution images to a ground station, since it is impractical to store processing equipment in the vehicle.

6.1.1. Inspection via LIDAR Technology

LIDAR technology appears to have the most feasible characteristics for runway inspection. The idea is to steer UAVs along the runway at a constant height and detect sudden changes in measured distance to the ground. Given that equipment with sufficient accuracy exists, the vehicle can produce a topography map of the inspected strip of pavement. This map would then be compared to a reference topography map of the runway. While ground-based vehicles may give a better reference distance to compare the sensor data to, typical runway widths of up to 60 m would require LIDAR optics with large detection angles if they were operated close to the ground. Optics for small and commercially available LIDAR systems need to be tilted fast enough in concurrence with the vehicle's speed to produce the required resolution.

The practicability of a LIDAR system is assessed based on a calculation and specifications from the commercially available system "LIDAR lite V2" (40 m range, 500 readings per second, accuracy of around 2.5 cm). To scan a runway of 4000 m length and a width of 60 m with the given accuracy of the system of 2.5 cm by 2.5 cm in 5 minutes:

Scan area:

$$A = 4{,}000m * 60m = 240{,}000m^2$$

Number of measurements (individually scanned surface grid areas):

$$N_{measure} = \frac{1{,}600\,readings}{m^2} * 240{,}000m^2 = 384{,}000{,}000\,readings$$

Necessary reading rate to complete a runway scan in 5 minutes:

$$R_{reading} = \frac{384{,}000.000\,readings}{300\,s} = 1{,}280{,}000 \frac{readings}{s}$$

Necessary amount of scanning units to fulfil this task:

$$N_{units} = \frac{1{,}280.000 \frac{readings}{s}}{500 \frac{readings}{s}} = \mathbf{2,560}\ [\boldsymbol{UAV\ with\ LIDAR\ equipment}]$$

While it may be possible to carry out this task in theory, the necessary amount of units may be impractical under present constraints. Even with 16 systems being installed in parallel on one UAV, which might be within the payload capabilities, there would still be a swarm of 160 vehicles needed for one scan.

6.1.2. Inspection via Optical Systems

With the availability of high-resolution electro-optical systems, this may pose an alternative to the LIDAR approach. Given a data-link with sufficient bandwidth, the sensor information may not even be evaluated on-board. Within the limited area of an airport, the possibility of establishing the required data-link is within reach. A theoretical comparison of an electro-optical system to the LIDAR concept is examined here, based on several assumptions:

- availability of a sufficient data-link
- optical and sensor resolution of 5 by 5 pixels of a grid section of 2.5 by 2.5 cm (this accuracy is based on test techniques from machine learning, where the discretization of hand-written letters into 20 by 20 pixel boxes is used for training of image-processing systems [27]; the desired function of the UAS subsystem is to only recognize differences in runway surface composition to a reference image).

The runway size of 4000 m length and a width of 60 m is now being scanned with a resolution of 0.5 cm per grid segment:

$$N_{pixels} = \frac{1{,}600\,readings}{m^2} * 240{,}000m^2 * \frac{25\,pixels}{reading} = 9.6 * 10^9 pixels$$

The transmission rate of the proposed system is:

$$R_{pixels} = 1{,}920 * 1{,}080\,pixels * \frac{30}{s} = 0.62208 * 10^8 \left[\frac{pixels}{s}\right]$$

This results in a scanning time of:

$$T_{scan,photo} = \frac{9.6 * 10^9 pixels}{0.62208 * 10^8 \frac{pixels}{s}} \approx \mathbf{154\ s}$$

Reflect upon this result, some challenges remain to be addressed: The proposed commercial transmission system's datasheet does not provide information about compression used on the video stream. Current implementations of IEEE 802.11 (Wireless Lan) provide theoretical capabilities (over short distances of around 50 m) for this bandwidth employing complex multi-antenna layouts, but more common two-antenna-layouts provide roughly half of that bandwidth. The possibility of the evaluation of greyscale pictures should be evaluated further since the amount of data could be reduced by roughly two thirds. The 4G-LTE standard also provides a theoretical bandwidth of 37 MB per second, but for distances up to several kilometres. Only next-generation (5G) cellular standards available around the year 2020 may provide sufficient bandwidth for compressed stream of full colour images. While video compression standards may reduce the required data rate by a factor of 10 to 100 with little deterioration in visible video quality, the decompressed stream may not be clear enough for automated evaluation against reference images. This is mainly due to the fact, that video compression does not only compress individual frames but rather depends on storing changes within a series of frames.

Another factor to be considered besides data transmission is a technique to align the captured images to the correct positions within the reference image of the runway. Travelling speeds of 50 – 100 km/h of the vehicle and a high probability of encountering wake vortices and other forms of turbulences during inspection flights over the runway will influence the planned trajectory. A two-stepped approach to solving this problem is proposed: First, a set of dedicated markings would be applied to the borders of the runway and is captured along with the rest of the runway. These markers should be more readily machine-readable and provide a simple solution to align individual frames to the correct position and with the correct size within the reference image of the runway. The process of combining several separate pictures into one is called image stitching. A complete, stitched picture of the runway would be available for comparison to a reference picture.

6.1.3. Multi Vehicle Inspection

The considered approaches to automated runway inspection may be carried out more effectively if multiple vehicles are performing the inspection process simultaneously. Based on the assumption that precise positioning is available, the process of combining scanning information from several vehicles is comparable to the fusion of data from a single vehicle. The deployment of more than one UAV for an inspection process may result in several benefits:

- If the scope lies in reducing the time required for one inspection, the top speed of the vehicle or the sample rate of the equipment is no longer a limiting factor. The runway would be split into segments with several units placed along the runway to enter them as soon as an aircraft leaves it.
- A setup of multiple vehicles capturing images of the runway from various angles may provide a three-dimensional representation of the runway using photogrammetry techniques.

6.1.4. Conclusion on Runway Inspection

Comparing both the LIDAR and electro-optical method the former falls short in terms of the sampling rate of a single unit. Thus, a required large set of sampling units could make this method unfeasible. Furthermore, due to the nature of the measurement, only three-dimensional objects larger than the given accuracy of the system will be detected. If a benefit of the system compared to traditional methods in terms of time-savings is desired, an even higher sample rate or more complex system than available today is necessary.

The electro-optical system is more realistic in terms of sampling rate for the given accuracy. Available data transmission standards are capable of sending the captured data with compression to a ground station. The ground station and a transmission of data are considered essential for fast evaluation of the data. The necessary data-link may become available with the introduction of 5G cellular standards.

6.2. Bird Control on Airports with UAV

The presence of birds on an airport pose a serious threat to aircrafts engines and thus to their safe operations. In the years from 1990 to 2008, 90.000 bird strike events regarding commercial operations were reported in the USA [29] or roughly every 2.000 flights. In some areas, numbers of birds are rising due to environmental protection and other factors [30]. Furthermore, the statistics show that most of the collisions happen below 3000 ft. This indicates the importance of clearing the terminal manoeuvring area (TMA) and especially the airport itself from the hazardous presence of birds. In the last decades, substantial research was carried out to find solutions for the bird strike problem [4]. Existing traditional methods are reviewed in this chapter against a possible way of utilizing an UAS for a more efficient execution of the task.

6.2.1. Bird Control on Airports

In general, researches show that there may be no single solution to solve the birdstrike threat. The rates of success of different approaches differ greatly and depend on species, season, and location among other factors. Even contradictory results were seen applying similar methods to different species under different circumstances. The methods are divided into three (partly overlapping) categories of methods:

- Habitation modification: Making areas on or near the airport less attractive for birds. Natural and human-made conditions like abundant presence of food or fresh water are pointed out. Counter measures include the setup of zones around airports where agriculture or commercial fishing is prohibited. Within the airport limits, long grass management makes the fields less attractive for resting and breeding of some bird species, and certain chemicals are applied to the ground that do not harm the birds but make them feel uncomfortable.
- Resource protection: Active methods are described to repel birds from the airport.
- Population management: This includes short-term methods like capturing or killing individual birds that pose immediate threats and long-term techniques with the target of reducing a local population of a specific species.

Habitation modification consists of long-term strategies to reduce bird population on an airport. The necessary steps may include changes of the landscape or other heavy architectural changes. Population management could be performed by similar devices to the ones used in agriculture. In this case, they would not apply fertilizer to the ground but rather poison. Ethical concerns prevent the further discussion of this method.

The active protection of the area using repellent techniques remains a possible UAS application. Most of the methods pointed out here are not reviewed as useful against birds when used regularly. The described methods include:

- Propane cannon: Produces a very loud explosion that scares the birds away. However, the devices are too big and heavy for installation on a UAV.
- Pyrotechnical devices: Scare cartridges, flares, and shell crackers are described as having the desired effect as long as they are not used routinely. These devices come in different shapes and ranges. Usually they are fired from a device roughly the size of a small firearm. Size and weight allows to be mounted on a quadcopter.
- Smoke, light, and laser devices: Studied repellent methods, but without clear success rates. They would be small enough for on-board mounting.
- Noise and bioacoustics: Generally, loud noise seemingly does not have a lasting effect on birds. However, playing recorded distress calls near the birds has shown success in scaring them away. Birds get used to the method or are even drawn to it out of curiosity when it is used to regularly.

An active repellent method that has shown effect was the deployment of model aircraft near targeted birds [4]. The most important factor for success was neither the shape nor colour or noise of the model, but rather a convincingly realistic imitation of a style of flying of a predator (of the targeted bird). Some complex and agile manoeuvres are described as difficult to execute. State-of-the-art path planning and flight control software can execute these manoeuvres automatically, even in strong winds or turbulences.

The idea of a bird control method including the use of UAV is partly elaborated in [28]. The concept does not solely rely on harassing the birds to land anywhere but the airport; instead, a designated area is chosen that acts as a target zone where birds are no longer a threat to the aircraft operations. The UAV's function is to urge the birds to fly to this chosen spot. The information available on this project suggests that a swarm of birds is completely circled by UAVs flying so close together that the animals will most likely not try to pass between the vehicles.

An application that may be linked to bird control in the future is the detection of animals [31]. A multicopter equipped with an infrared camera scans agricultural areas for young fawn before harvesting takes place. The fawn, which have not yet developed reflexes to escape dangerous situations, can be identified due to their body temperature contrasting to the colder soil. However, the airport environment calls for significant modification before it could be applied to automated detection of birds.

Methods like the described use of pyrotechnics or scare cartridges appear to be the most practical solution for bird eviction by multirotors. A single vehicle or a very small fleet are sufficient to carry some devices that are effective against flocks.

6.2.2. Bird Control Process from an ATC perspective

The bird control UAS is a conceptual approach to enhance current bird control methods. Due to the complex nature of this field, the designed system should be capable of coping with all possible threat scenarios. Traditionally, bird control staff has to drive to sites of bird activity and perform the adequate measures manually. With an UAS system installed, several base and recharging stations will be distributed on the airport and aerial vehicles will be placed there as well. Provided there is a certain amount of "spare" vehicles in the fleet that are not executing other tasks, the nearest one to the problematic site can be chosen for bird eviction. Until automatic technology for the detection of wildlife is available, this task may remain a manual one that has to be performed by the staff.

If the detected species is susceptible to mimicking of a bird of prey, the vehicle should perform its task without any payload. As indicated by studies in [4], a fast and agile vehicle will give best results in this situation. Typically, smaller birds are prone to this method. Bigger birds of prey will require additional methods to scare them away. In the past, pyrotechnical cartridges have shown success. A payload should be provided to be attached automatically at a base or recharging station.

For reasons of safety, security, and operational ease, the positions and tasks of all UAVs should be communicated to an A-SMGCS. It is strongly recommended to include routines in the system that makes use of this information to separate the UAVs from taxiing aircraft. Through this separation and a defined lighting pattern emitted by the on board lighting system it will be avoided that crews confuse these UAVs with the ones performing guidance tasks.

6.3. UAV as Surface Guidance Device

Controller assistance tools like SMAN model the airport environment and apply algorithms to recommend solutions for optimised sequencing and routing of the ground traffic. The inputs to these calculations may be derived from strategic planning information from stakeholders involved. On a tactical timeframe, actual position data like ADS-B or surface movement radar will be incorporated for adjustments to planned trajectories. Conversely, stakeholders need to receive information about the results of optimisation tools.

For the tactical execution phase, this chapter presents an aerial vehicle to communicate adjustments in the taxi phase to the flight crew. One challenge for pilots is the little feedback about his exact aircraft's speed, as current aircraft's cockpit instrumentation does not provide for accurate low speed measurements. Yet this may prove critical for successful implementation of accurately-to-the-second 4d-surface management systems: A more accurate speed-reading would allow a higher utilisation of given taxiway systems while maintaining separation and safety levels.

6.4. Ground Operation through UAV-Guidance

The surface guidance UAV is a concept to accompany future surface management systems. Its aim is to provide a method for the realisation of ground trajectories calculated by a surface management system. A mobile vehicle will work as an external display unit to relay movement information to the pilot. Neither any modification to the aircraft nor to the lighting infrastructure of the airport is necessary, which makes the UAV-based solution favourable in terms of investment.

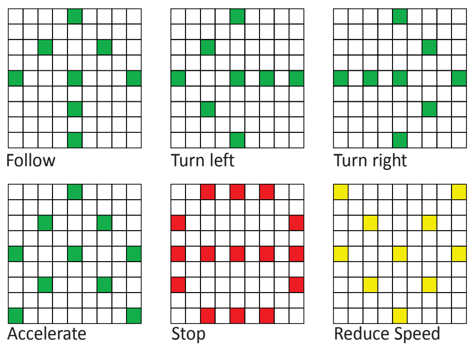

Fig. 2 Set of guidance signals for UAV.

To enable an airport to implement time-based ground trajectories, a display carried by an aerial vehicle have to relay information about direction and speed to the pilot. Only a limited amount of symbols will be displayed to the crew to keep advisories simple and clear (Fig. 2). The display unit is designed as a lightweight structure supporting an array of 25 multicolour LEDs. Its size is to be determined so that a 5-by-5 matrix of lights can easily carried by the UAV and can be distinguished from the flight deck (Fig. 3 and Fig. 4). A distance between the aircraft and the UAV needs to be established so that the aircraft is not endangered be the UAV's proximity.

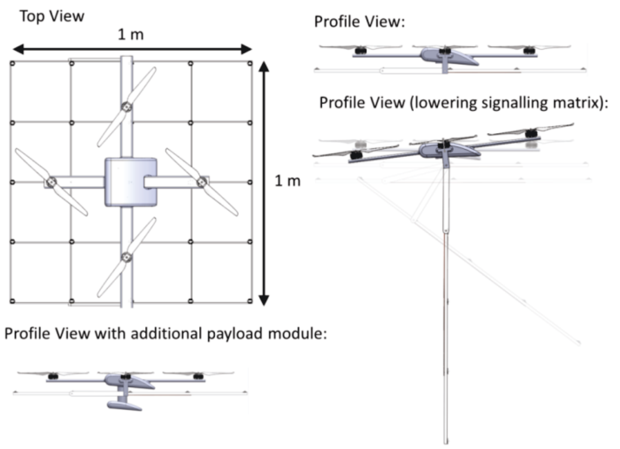

Fig. 3 Example for a quadrotor configuration of a guidance UAV.

The layout of the signalling matrix should be a topic of further investigation. The light emitted from a single LED may be visible well from a distance of several meters. However, the combination of several LEDs positioned sparsely on a large hollow support structure should be reviewed under the constraints of the airport environment. Other lights visible behind the signalling matrix may interfere with the recognisability of the signalling matrix. A non-transparent background behind the LEDs or a denser configuration of LEDs may solve this problem, but the susceptibility to wind and the weight of the structure will rise accordingly.

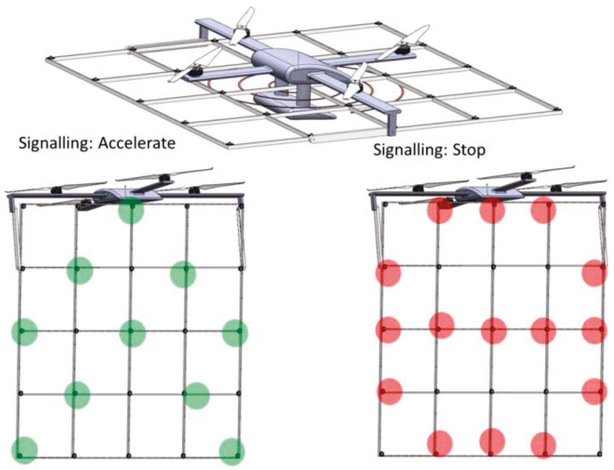

Fig. 4 UAV with inductive charging coil and additional payload attached.

During the guidance mission, the UAV will fly at a fixed position in front of the aircrafts nose tip at the height of the cockpit window. For normal taxi operations, airports define safety regions behind taxiing aircrafts that must not be entered or passed. The length depends on the size (and thrust) of the taxiing aircraft and may extend up to 200 m behind heavy aircrafts. For UAV operations, an additional space should be defined. Based on available positioning accuracy of augmented GNSS systems, an additional distance of 5 m should provide sufficient protection. Additional safety margins between the guidance UAV and the aircraft as well as between the UAV and any preceding aircraft are advised (Fig. 5).

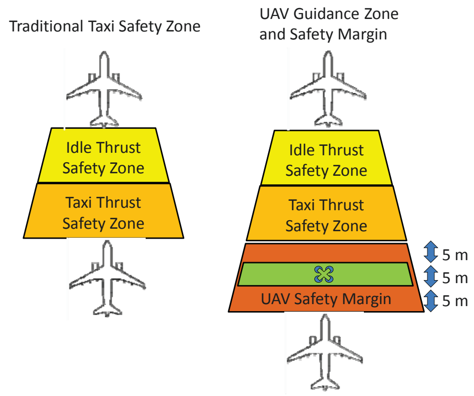

Fig. 5 Additional safety zones for UAV guidance.

While A-SMGCS provides airports and ATC with information about aircrafts with relatively high accuracy, exact positioning of the UAV in front of the aircraft is advised to be augmented by further means like LIDAR. Accurate positioning that is kept during the guidance phase is essential; this way, ATC can handle an aircraft and the guidance vehicle as one unit.

The guidance phase is defined for outgoing aircrafts from the end of the pushback phase to the beginning of the runway or in case there are several aircraft waiting to depart, as reaching the end of the queue on a taxiway with no further intersection. For arriving aircrafts, the guidance phase starts when the aircraft leaves the runway and ends when it arrives at park position. For incoming aircraft, the difficulty lies in matching the speed of the aircraft rolling off the runway. Due to an uncertainty regarding the runway exit chosen by the pilot, vehicles with signalling equipment need to be positioned at every possible runway exit. A detection of the chosen exit needs to be evaluated at an A-SMGCS level.

Allocation of UAVs to aircraft is performed by a central computer that refines routing information provided by a surface management system. The information from an SMAN has to be extended by a trajectory that positions the UAV and the aircraft together at a rendezvous point. For departing aircraft, this may involve meeting near busy passenger terminals where other vehicles and aircraft are moving. Thus, knowledge of the position of other traffic on the apron is important in order to avoid collisions.

A factor of high importance for this concept is the endurance of the batteries used by the UAVs. For some taxi routes on larger airports, current rechargeable battery technology does not provide for UAV flights as lengthy as the corresponding route. In addition, adverse weather conditions like strong winds may diminish flight times of the aerial vehicles. Delays in the planned sequence of taxiing may be a third factor that prolongs the guiding mission beyond the capabilities of one vehicle. In this case, and until battery technology has evolved, a mid-flight switch of the guiding UAV has to be incorporated into the mission profile. This should be done in a fashion that does not interfere with other procedures that ATC and the pilot follows. When a battery of a guiding UAV falls short, another vehicle should approach a position close to the guiding one, but slightly in front of the original one (when looking from the cockpit's direction). Highly accurate positioning equipment (with accuracy in the centimetre range) is advised to be installed on the UAV for reasonable operation. A synchronized shutdown of the first guidance vehicle's signalling lights with an immediate activation of the replacing UAV's lights is executed, with an immediate evacuation of the first vehicle to clear the pilot's view to the new guide.

7. CONCLUSIONS

Summarizing, the possibilities to deploy UAVs on airports for guidance and maintenance support are multifarious. For the use of runway inspection, bird control, and taxiing guidance support, commercially available multirotor vehicle should be powerful and matured enough today. However, additional needed sensors like lightweight and fast LIDAR and swivel-mounted lightning systems have to be developed or specially customized. For bird control, the additional application of UAVs in connection with traditional methods promises more long-term success to increase the flight safety in the vicinity of airports. Especially to take the full advantages of UAV guidance support possibilities, a sophisticated Surface Management System with ASMGC-S linkage should be installed at the airport.

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