Unmanned Aircraft System for Flight Inspection

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ABSTRACT

In recent years, small unmanned or uncrewed aircraft systems (UAS) have been developed into valuable instruments for various applications. These for instance include remote sensing, agriculture, logistics, infrastructure inspection, or emergency relief and disaster management. It has been established in various publications, that small, uncrewed aircraft systems can constitute an effective tool to support conventional crewed flight and ground inspection operations. For this, UAS can be used to measure and evaluate radio signals from radio navigation aids or to inspect runway lighting and PAPI installations with optical sensors.

The institution represented by the author has started developing an unmanned aircraft system to support flight inspection tasks. In order to allow for a versatile application of the UAS in flight inspection, the payload can be flexibly modified according to the signal under inspection. Typical payloads consist of receivers and antennas for the measurement of ILS localizer and glide slope signals, or cameras for the inspection and calibration of visual landing aids.

This paper presents considerations and scenarios for the application of small, uncrewed aircraft systems in flight and ground inspection tasks. A small, uncrewed flight inspection aircraft system for calibrating signals of ILS installations is introduced and its demonstration flight results are presented and discussed.

INTRODUCTION

Uncrewed aircraft have developed from highly specialized, military tools to consumer products, which are widely available commercially. In addition, the number of civil applications for small, uncrewed aircraft has significantly increased over the last years. These range from aerial photography [1], meteorological measurements [2] to applications in civil protection [3] and water safety [4]. Thus, this paper is going to investigate the application of a sample uncrewed aircraft in flight inspection (FI).

Before getting into detail with the topic of unmanned or uncrewed aircraft, a common nomenclature should be defined. Uncrewed aircraft (UA) or uncrewed aerial vehicles (UAV) are most of the time connected to a ground station via a data link for command and control (C2) functions. In case this control of the UA is done by a remote-pilot, who can interact with the aircraft at any time, ICAO uses the term remotely-piloted aircraft (RPA). Thus, RPA are considered a subset of UA. Both, the aircraft and the ground segment including the C2 data link, are described as an uncrewed aircraft system (UAS) or remotely-piloted aircraft system (RPAS) [5]. An overview on the different subsets of uncrewed aircraft is provided in [6]. The terms uncrewed aircraft and unmanned aircraft have the identical meaning for this paper.

APPLICABILITY OF UAS IN NAVAID INSPECTION

Navigation aids (NAVAID) for aviation require a regular inspection and calibration. This is achieved in various ways. ICAO's Doc 8071 [7] recommends ground and flight inspection for the check of NAVAIDs in regular intervals. For both tasks, small, uncrewed aircraft can be a useful and convenient tool for complementing other measurement sources.

During ground inspection, a drone is able to reach measurement locations, which are not accessible by a road vehicle or a measurement mast on a trailer. In this way, periodic checks of radio NAVAIDs like ILS or VOR, or of optical infrastructure like PAPIs or runway lighting can be performed conveniently from the ground while being enabled to reproducibly reach measurement points not accessible otherwise.

For flight inspection tasks, it is clear, that a small, uncrewed aircraft system cannot replace a conventional, crewed flight inspection aircraft. A small multi-copter drone would not be able to achieve the flight times, distances and velocities of a conventional flight inspection aircraft like a Beechcraft King Air. Instead, a small NAVAID inspection drone can support conventional flight inspection in different ways.

The main reason for using small drones as a tool in flight inspection is the reduction of expensive crewed flight time. The easiest way to achieve this is to do a drone-based pre-calibration of NAVAIDs before conducting the crewed flight inspection. Ideally, the crewed flight inspection would not have to repeat flight procedures due to adjustments at the NAVAIDs, since these have already happened during the pre-calibration. This pre-calibration is possible for both periodic and commissioning flight inspections.

Furthermore, the reduction of crewed flight time can be extended by using drone measurements in order to increase the time span between periodic conventional flight inspections. For this, the correlation between the drone and crewed aircraft measurements should be proven, similar to ground and flight inspection, see section 1.15 and 1.18 of [7]. First results on this correlation between uncrewed and crewed flight inspection are available in [8].

A couple of features can support the correlation between drone and crewed flight inspection results. Especially using identical software libraries for crewed and uncrewed flight inspection are beneficial:

1. Same facility database used by drone and flight inspection aircraft
2. Identical flight profile definition
3. Same flight inspection algorithms
4. Common, compatible data recording
5. Comparison of drone and crewed measurements in the same flight inspection software

The exact repeatability of drone measurements can be achieved by the automatic flight of pre-defined flight inspection procedures and by the use of a high accuracy position reference like real-time kinematics (RTK) or precise point positioning (PPP).

CHALLENGES OF DRONE FLIGHT INSPECTION: PROPELLER MODULATION

Especially the measurement of radio NAVAIDs from multi-copters with numerous electric motors and propellers close to the receiver antenna can lead to several challenges. As an example, this paper shows the influence of the propeller modulation on the measurement of a localizer signal.

Any propeller made of conductive materials like carbon fiber induces an unwanted modulation on the received signal. The coupling between the transmitter signal from the ground and the airborne receiving antenna is not constant due to attenuation or reflection on the rotating propeller blade. Any changes in the receiver signal strength result in additional amplitude modulation (AM). Unfortunately, the normal ILS modulation is also AM and cannot be separated from the additional noise.

In order to evaluate the severity of the influence of the propeller modulation on a localizer signal, a test was conducted using different types of propellers – the carbon fiber propeller of the original equipment manufacturer (OEM) and a set of propellers made from a non-conductive material. The localizer reference signal was provided from a signal generator with a transmitter antenna on the ground, emitting a localizer signal without the 90 Hz and 150 Hz side lobes. The drone was equipped with an appropriate dipole antenna. This antenna was connected via a 20 m long, thin cable to a spectrum analyzer on the ground. This setup allowed for mainly vertical flight maneuvers while measuring the unaltered signal at the drone.

The influence of the propeller modulation from a carbon propeller can be seen in Figure 1. The peak in the middle is the measured localizer signal at 108.1 MHz, as broadcast by the signal generator. Left and right of the main peak, two smaller peaks can be seen at close to ±90 Hz from the main peak. ILS signals mix two modulating signals at 90 Hz and 150 Hz to the carrier frequency. Thus, the propeller modulation matches exactly the 90 Hz ILS signal and highly disturbs the measurement of this signal.

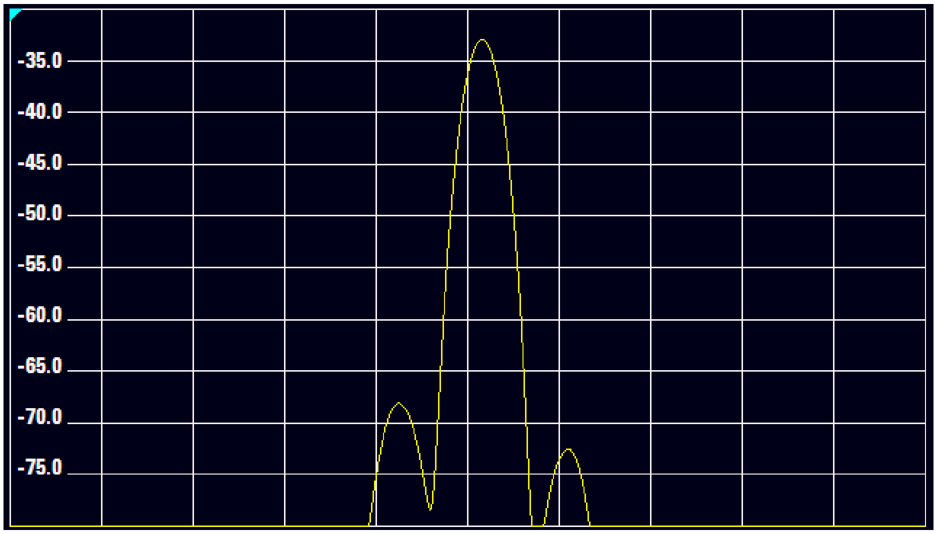

Figure 1: Spectrum of a localizer signal at 108.1 MHz broadcast without side lobes, measured by a drone with carbon propellers showing the influence from propeller modulation (*x*-axis: frequency in kHz with a center frequency of 108.1 MHz and a distance of 100 Hz between vertical lines, *y*-axis: power level in dBm)

The same experimental set-up was used in order to test propellers of a non-conductive material. The result of this measurement can be seen in Figure 2. Comparing this to Figure 1, the lack of peaks next to the main peak at 108.1 MHz is clearly visible. This means, that the influence of the propeller modulation on the localizer measurement has been greatly reduced or removed almost completely by using propellers of a non-conductive material.

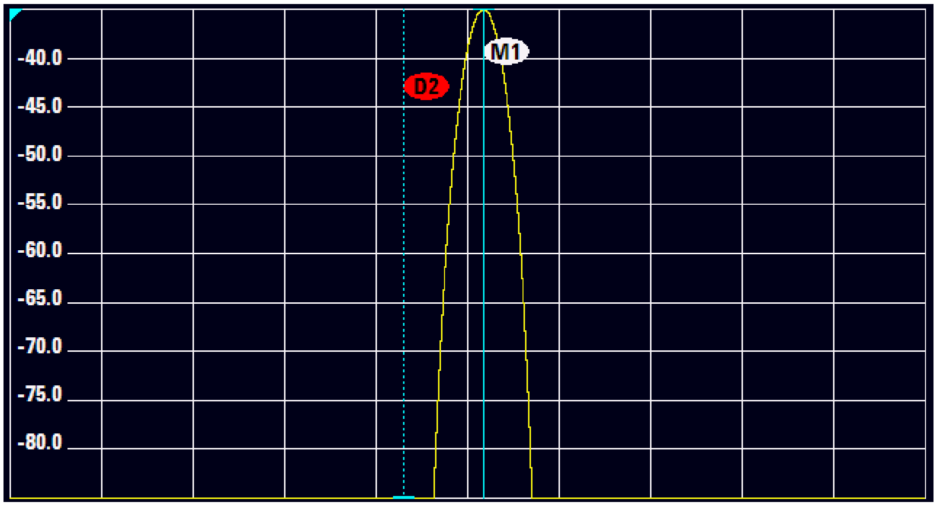

Figure 2: Spectrum of a localizer signal at 108.1 MHz broadcast without side lobes, measured by a drone with propellers of a non-conductive material (*x*-axis: frequency in kHz with a center frequency of 108.1 MHz and a distance of 100 Hz between vertical lines, *y*-axis: power level in dBm)

INSPECTION DRONE SYSTEM OVERVIEW

The preceding paragraphs described the benefits, requirements, and challenges of a drone based flight inspection tool. Based on these, the Aerodata AG has been developing a small, uncrewed aircraft system for flight inspection applications called AeroFIS® Flybot.

The complete AeroFIS® Flybot system consists of a remote control, a FIS operator laptop computer, an RTK ground station, the drone platform itself, and a task-specific FIS payload. This modular payload is composed of two elements:

- The FI Core module provides general functionality for the recording, processing and transmission of flight inspection measurements from the FI Sensor module.
- The FI Sensor modules are easily interchangeable and provide the sensor specific to the measurement task. It can consists of navigation receivers and antennas for radio NAVAIDs or optical sensors for the inspection of VGSI installation or infrastructure.

The general system architecture of a FIS drone with an FI Sensor payload for ILS calibration is shown in Figure 3. Figure 4 shows the AeroFIS® Flybot with ILS payload in flight and the UAS remote control running the AeroFIS® Flybot Remote Control software. The FI payload and FIS operator computer are highly integrated with the professional UAS platform DJI Matrice 300 RTK. DJI as the world's leading manufacturer of consumer UAS offers well-proven and reliable functions as well as software development kits (SDK) for extending the functionality.

The drone's multi-constellation GNSS RTK-aided position, velocity, and attitude solution allows for a high accuracy FIS position reference. The FIS payload can use the drone's telemetry system to communicate with the remote control and the FIS operator laptop. In this way, the AeroFIS® software running on the FIS operator laptop provides the prepared flight procedures and tuning of the receiver to the drone pilot's remote control. The remote control runs the specialized AeroFIS® Flybot Remote Control software for the control and supervision of the inspection and calibration tasks.

The AeroFIS® Flybot software and the AeroFIS® user interface for crewed flight inspection aircraft are identical. In this way, the FIS operator can easily switch between crewed and uncrewed operation while benefiting from the well-established AeroFIS® user interface and flight inspection algorithms on both platforms.

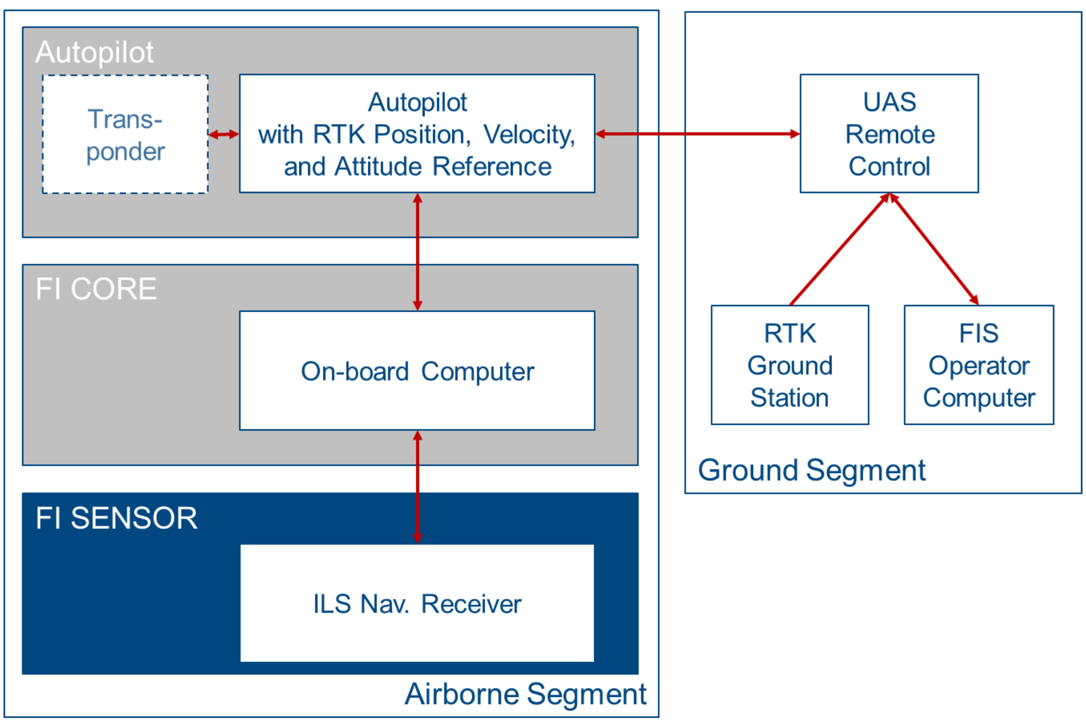

Figure 3: AeroFIS® Flybot system architecture for ILS calibration

Two persons – a remote pilot and a FIS operator – usually operate the AeroFIS® Flybot. Similar to crewed flights, the remote pilot communicates with ATC, and controls and monitors the drone in flight. The FIS operator utilizes the AeroFIS® software of the FIS operator laptop for the set-up of the drone flight profiles and the recording, supervision, and interpretation of the measurements. The flight inspection measurements and parameters are visualized in near real-time at the FIS operator laptop.

The planed flight inspection procedures are directly transmitted into the AeroFIS® Flybot Remote Control software, which runs on the drone pilot's remote control. This software enables the pilot to get information on the planned procedures and their depiction in a map. In addition, the drone's flight controller can automatically follow these procedures precisely. The remote pilot can activate the automatic flight of these procedures by pressing a button, and can conveniently monitor the state of the UAS and the FIS components from the remote control. For this, the AeroFIS® Flybot Remote Control software provides a map showing the drone position and the selected flight procedure, and a first person camera view of the drone.

Figure 4: Left: in-door flight of the AeroFIS® Flybot with ILS flight inspection payload
Right: AeroFIS® Flybot Remote Control software running on the UAS remote control

DRONE FLIGHT INSPECTION EXAMPLE: GLIDE PATH

In order to evaluate the performance of the AeroFIS® Flybot and its measurement payloads, numerous flight tests have been conducted at a drone flying field in the vicinity of Braunschweig, Germany. This paper presents an example from the verification of ILS glide path signals. A Rohde & Schwarz SMBV100 vector signal generator provides the glide path signal to a transmitter antenna. In this way, a well-known reference signal is available for the measurement by the drone system and for the evaluation.

During the verification flights, the AeroFIS® software was used for the flight planning, measurement data recording, and online near real-time FIS data monitoring. An exemplary view of the software interface and the graphical depiction of the live measurements is given in Figure 5. The left side of the figure shows the standard AeroFIS® software interface for prepared procedures, receiver monitoring and drone state supervision utilizing a map view, EHSI, and PFD. The right side of the figure shows the graphics for flight inspection parameters during the flight.

Selected parameters of a drone-based glide path approach can be seen in Figure 6. The approach was flown at an average ground velocity of 3 m/s over a length of 200 m. The graphic shows the measured deviations in µA, the 90 Hz and 150 Hz modulation depths of the GP signal and the measured power level during the approach versus the time in seconds. It can be seen, that the power level increases with time because of the decreasing distance from the drone to the GP transmitter antenna. Furthermore it can be seen, that the 90 Hz and 150 Hz signals have almost no influence from the propeller modulation due to the usage of propellers made of a non-conductive material. Accordingly, also the measured deviations show no influence from the propeller modulation. The measured deviations have an error with a standard deviation of less than 0.2 µA from the signal generator reference.

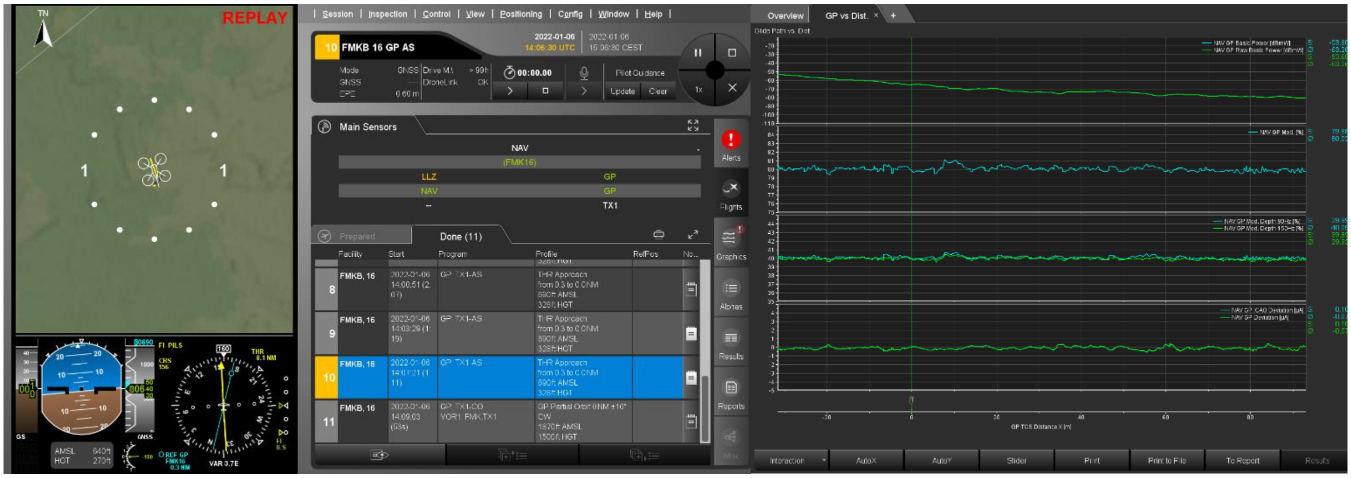

Figure 5: AeroFIS® Flybot software view during a GP short approach measurement flight.

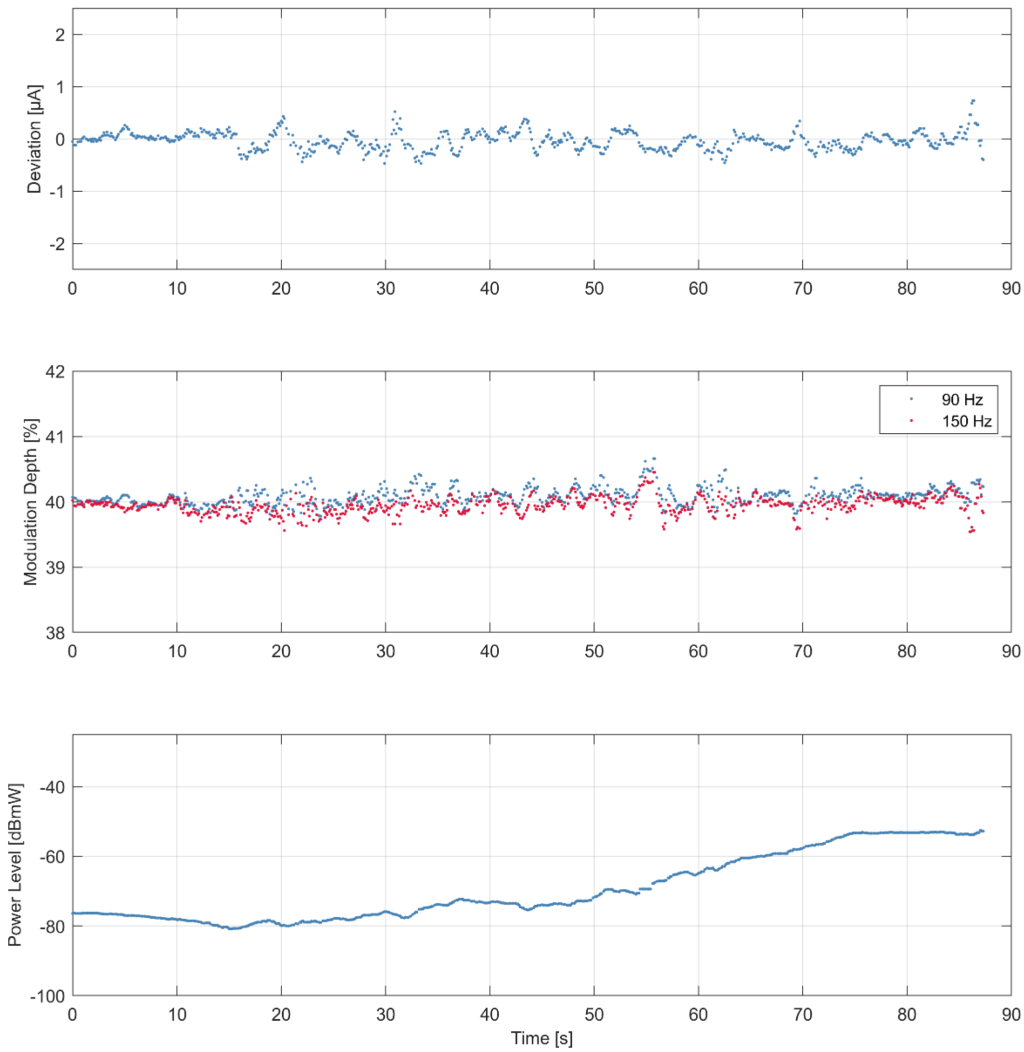

Figure 6: FIS parameters during a 200 m GP approach

CONCLUSIONS

This paper demonstrated that small, uncrewed aircraft systems can be a valuable tool for ground and flight inspection applications. Current technology allows for the integration of accurate navigation receivers and antennas into compact multi-coper drones. By compensating for error sources like the propeller modulation, small, automatic flying drones can become an accurate measurement device. A high communality with crewed flight inspection systems, software, and algorithms guarantees the adequate correlation between crewed and uncrewed flight inspection results.

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REFERENCES

[1] C.-S. Wilkens, T. Krüger, T. Martin, A. Scholtz, P. Vörsmann, M. Reinhold and P. Selsam, "Project ANDROMEDA: Automated Generation of Aerial Photographs with Unmanned Aircraft Systems," *European Journal of Navigation,* vol. 8, pp. 32-38, Nr. 3, 2010.

[2] T. Spieß, J. Bange, M. Buschmann and P. Vörsmann, "First Application of the Meteorological Mini-UAV M²AV," *Meteorol. Z. N. F.,* vol. 16, pp. 159-169, Nr. 2, 2007.

[3] A. Scholtz, C. Kaschwich, A. Krüger, K. Kufieta, P. Schnetter, C.-S. Wilkens, T. Krüger und P. Vörsmann, „Development of a New Multi-Purpose UAS for Scientific Application," in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science, International Conference on Unmanned Aerial Vehicle in Geomatics (UAV-g)*, Zurich, Switzerland, 2011.

[4] C. Niemann, "Wasserrettung aus der Luft," *Drohnenmagzin,* vol. 1, pp. 24-29, Nr. 1, 2016.

[5] ICAO, Cir 328, AN/190, Unmanned Aircraft Systems (UAS), Montréal, Canada: International Civil Aviation Organization, 2011.

[6] ICAO, "Unmanned Aviation Bulletin," 2018. [Online]. Available: https://www.icao.int/safety/UA/Documents/ICAO_UA-Bulletin_2018-01.pdf. [Accessed 23 03 2018].

[7] ICAO, Doc 8071 - Manual on Testing of Radio Navigation Aids, Volume I, Testing of Ground-Based Navigations Systems, 4. ed., Montréal, Canada: International Civil Aviation Organization, 2018.

[8] H. Demule and K. Theissen, "Using UAV Multicopers as an Extension of ILS Ground Measurements: This Innovative Idea has Already Become Reality in Switzerland," in *Proceedings of the 20th International Flight Inspection Symposium (IFIS),* Monterey, CA, USA, 2018.

[9] C.-S. Wilkens, T. Heinke and R. Seide, "Application of Unmanned Aircraft Systems as an Instrument in Flight Inspection," in *Proceedings of the 2018 International Flight Inspection Symposium (IFIS)*, Monterey, CA, USA, 2018.