Humanitarian Demining - UAV-BASED DETECTION OF LAND MINES

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Key words: UAV / UAS, flight planning, DTM, SAR / GPR, mine action / demining, technical & non technical survey

SUMMARY

The humanitarian clearance of land mines is still a huge challenge:

- According to UN requirements at least 99.6% of all mines must be cleared up to a depth of 13 cm,
- There are different types and sizes of mines (metal, minimum metal, non-metal)
- Mines were placed in different environments (city, jungle, desert) regularly or irregularly and can be redistributed by erosion and surface movements.

In 2015 a feasibility study [Gottwald et al, 2015] proved the possibilities of a UAV-based mine detection system for the automatic detection and localization of landmines. Since early 2016, in a cooperation of three Swiss and German Universities, a UAV-based system for mine detection has been in development. This system will be used in the process of land release (a very important part of mine action). The system consists simply of a 5kg payload drone, a low-cost RTK-GNSS system, cameras for a photogrammetric production of a DTM, microwave sensors for mine detection and an anti-collision system. One of the key problems is the required high position- and orientation-accuracy of the drone to operate the microwave mine detection sensors (SAR / GPR) properly. The whole system will be designed for easy use by minimally trained operators.

This paper focuses on the current state of the project and on future perspectives and challenges. This project is supported by the Geneva International Centre for Humanitarian Demining (GIHCD) and is financed by the Swiss 'Foundation Urs Endress', Arlesheim/Switzerland.

Zusammenfassung

Die humanitäre Räumung von Landminen stellt auch heute noch vor eine grosse Herausforderung dar:

- Nach UN-Anforderungen müssen mindestens 99,6% aller Minen bis zu einer Tiefe von 13 cm gefunden und beseitigt sein,
- Es gibt verschiedene Typen und Grössen von Minen (Metall, Mindestmetall, Nichtmetall)
- Minen wurden in verschiedensten Umgebungen (Ortschaften, Dschungel, Wüste) platziert und können durch Erosion und Oberflächenbewegungen verschoben werden.

Eine Machbarkeitsstudie [Gottwald et al., 2015] zeigte die Möglichkeiten eines UAV-basierten Minen-Detektions-Systems zur automatischen Erkennung und Lokalisierung von

Landminen auf. Seit Anfang 2016 wird in Kooperation von drei Schweizer und Deutschen Hochschulen ein UAV-basiertes System zur Detektion von Landminen entwickelt. Dieses System soll zunächst im Prozess des ‚Landrelease' (ein sehr wichtiger Teil der ‚Mine Action') eingesetzt werden. Das System besteht im Wesentlichen aus einer Drohne mit ca. 5 kg Nutzlast, einem lowcost RTK-GNSS-System, Kameras für die photogrammetrische Herstellung eines DTM, Mikrowellensensoren zur Minenerkennung und einem Antikollisionssystem. Eines der Hauptprobleme ist die geforderte hohe Positions- und Orientierungsgenauigkeit der Drohne, um die Mikrowellensensoren (SAR / GPR) richtig betreiben zu können. Das gesamte System wird für eine einfache Bedienung durch minimal geschultes Bedienpersonal ausgelegt.

Dieser Artikel fokussiert sich auf den aktuellen Projektstand und auf Perspektiven und Herausforderungen. Unterstützt wird dieses Projekt vom Geneva International Centre for Humanitarian Demining (GIHCD) in Genf. Die Finanzierung erfolgt über die Stiftung Urs Endress, Arlesheim / Schweiz.

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1. INTRODUCTION

1.1 General introduction and motivation

Every day approximately 10 people around the world lose their lives or their limbs to a landmine or through explosive remnants of war (ERW). This means that about 4,000 people are hurt or killed worldwide every year. Approximately 60 countries around the world are contaminated by landmines and / or ERWs. Landmines / ERW prevent the productive use of the land (eg agriculture). They generate a lasting sense of insecurity long after the end of war conflicts, delay peace processes and hinder the development of the affected countries for many years.

Nobody knows exactly how many mines have been laid in the ground worldwide (in the literature one finds estimates of 60 to 100 million). The actual number is less important than its impact: a few mines or the mere suspicion of their presence can make a piece of land unusable. An important feature of the antipersonnel-mines is that they are designed to maim rather than kill a human. In the meantime, antipersonnel mines are also being used against the civilian population to terrorize communities, to prevent access to agricultural land and to restrict freedom of movement.

The average cost of locating and clearing landmines is US$ 2.25 (US$ 0.6 - 8.75) / m^2 [http://www.mineactionreview.org]. Further to this, the average area searched to find one mine is approximately 2500 m^2 (i.e. US $ 5625 per mine found and cleared.).

At the end of 2014, the idea of using UAV/UAS with an appropriate mine detecting sensor system was discussed at the FHNW. A study project was initiated (financed by the FHNW Foundation http://www.stiftungfhnw.ch) to check the feasibility of these ideas. The study project was finalized in July 2015 and the results summarized in an internal study report (Gottwald et.al 2015). Following this study, it was decided to set up an R&D project (see 2.2) with the aim to develop an operational system by the end of 2018.

1.2 Mine action standards

According to the current Mine Action Standards [UNMAS, 2016], the mine search and removal process has three stages:
3.159. land release (2013) - in the context of mine action, the term describes the process of applying all reasonable efforts to identify, define, and remove mines or the suspicion of mines / ERW through
- Non-technical survey (NTS),
- Technical survey (TS)

- and / or clearance.

NTS is defined in [IMAS 04.10, 2014] as " the collection and analysis of data, without the use of technical interventions, about the presence, type, distribution and surrounding environment of mine/ERW contamination, …" Examples for NTS are mapped minefields from known battlefields (direct combat areas, strategic bridges and roads, …), reports from residents, or accidents. TS is defined in [IMAS 04.10, 2014] as " the collection and analysis of data, using appropriate technical interventions, about the presence, type, distribution and surrounding environment of mine/ERW contamination, …" . Examples of TS are the classical deminers with needles or metal detectors for finding the mines or protected demining machines with a rolling chain in front to deploy the mines.
The process starts with NTS. For example, there may exist mine maps of an area or visible mines seen by residents. The area is to declare the suspected area, which could be very large (e.g. 3 km x 1 km). The next step is to localize the contaminated areas inside the suspected area. For example, demining machines (TS) could do this. The demining machines drive in patterns through the suspected areas and locate specific areas. After reducing the large suspected area into smaller contaminated areas (e.g. 200 x 100 m), human deminers can start to clear the area. After that, the area is released to the residents (land-release).

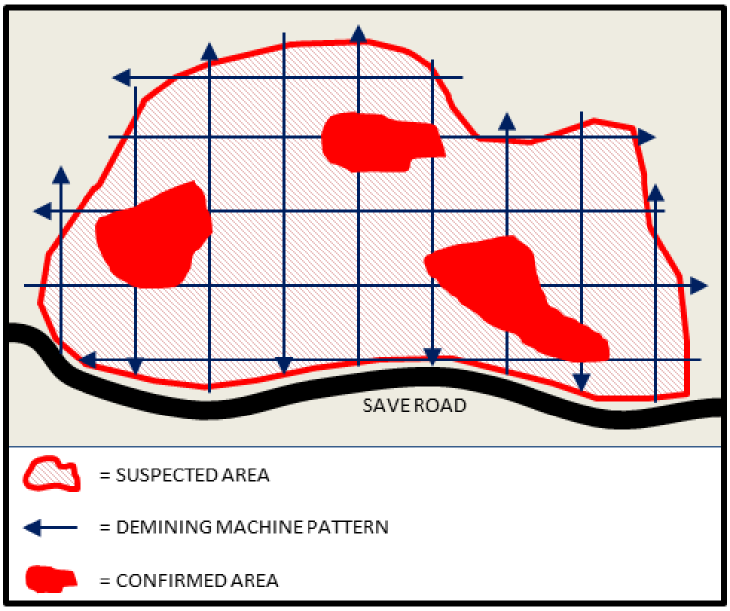

Fig. 1: Overview Mine action standards that shows the different sizes of the areas [N. Docci, 2017]

2. THE FIND-MINE PROJECT

2.1 General Process

The main target of FindMine is to reduce the time-consuming search for confirmed areas (TS). The currently used demining machines, which are expensive to buy and use, can clean an area of about 1000 m^2 per hour. In comparison, a human deminer can clean 35 m^2 per hour [FINDMINE1, 2016]. A UAV/UAS-based system is much cheaper and is able to check about 10'000 - 20'000 m^2 per hour.

Process chain:

- generate an overview of the suspected area including orthophoto-mosaic and surface models (UAS, RGB camera and additional sensors)
- flight planning for the radar flight (challenge - relative position accuracy 2mm, max. flight height over ground 2 m, depression angle for GPR 20-30°)
- Changing sensors on the UAS - GPR-flight (on board data collection)
- Post processing (fusion of GNSS and GPR data), update of the GIS database
- Generation of handprints and/or data exchange to the human deminers and the national demining database (IMSMA GIS).

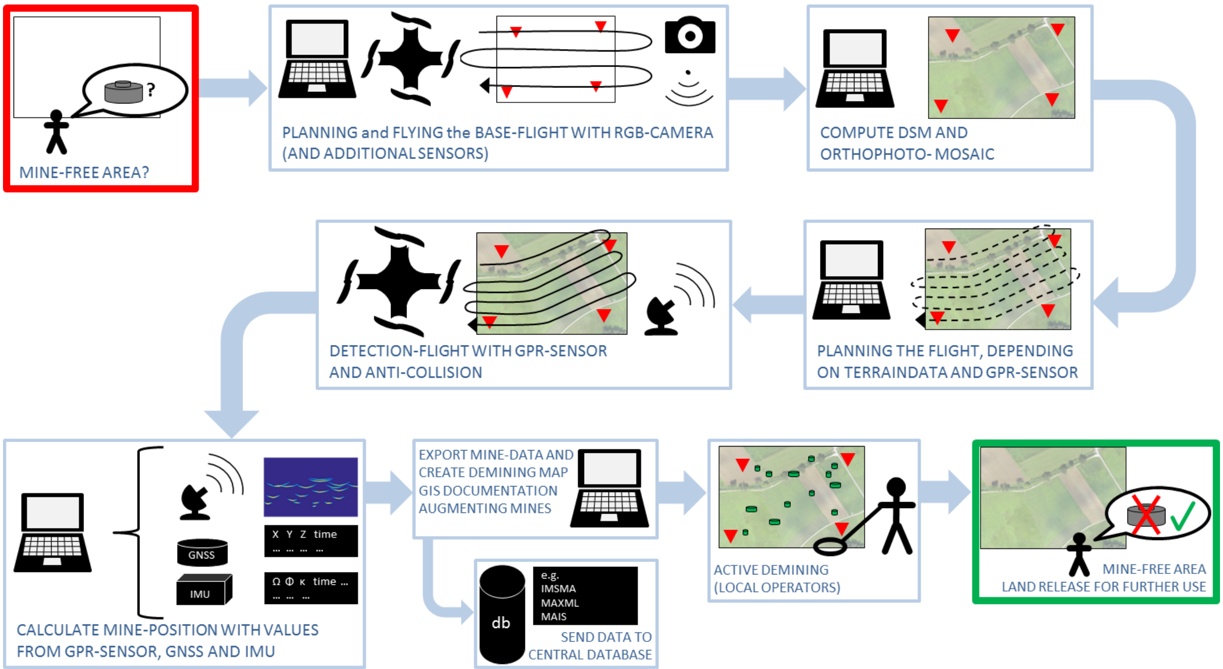

Fig. 2: Process-chain FindMine Project [N. Docci, 2017]

2.2 Project-Team & Partners

Project-Team:

- University of Applied Sciences and Arts Northwestern Switzerland (FHNW) - School of Architecture, Civil Engineering and Geomatics - responsible for the UAS/UAV, GIS/DTM/mapping and documentation
- University of Applied Sciences and Arts Northwestern Switzerland (FHNW) - School of Engineering - responsible for the overall system integration
- University Ulm and the University of Applied Sciences Ulm - responsible for SAR/GPR, antenna, detection technology and radar processing

Partner:

- Technical and operational support by GICHD (Geneva International Centre for Humanitarian Demining) and FSD (Fondation Suisse de Deminage)
- The project is financed by the "Foundation Urs Endress", Arlesheim/Switzerland.

3. BASIC SYSTEM

3.1 UAS / RTK GNSS

Nowadays there are numerous areas of application for a UAS. There are different types of planes, multicopters or helicopters. In the project, a multicopter will provide the aerial platform. A multicopter is able to hold its position steady and has a firm speed range in slower speed conditions. The project uses a combination of commercial and open-source products. The frame is a DJI S1000, an Octocopter with 8 motors, in-built power distribution and with a total load of ~9.5 kg. [DJI] As a flight controller, which controsl the UAS and is able to flying autonomously, we will use a Pixhawk. Pixhawk is an open-hardware project developed at the ETH Zürich [Pixhawk, 2013]. The gimbal, which stabilizes the camera or the radar antennas, is based on an AlexMos controller with an external IMU [Basecamelectronics]. Other hardware needed to fly comes from commercial sources.

Fig. 3: Current setup of UAS [N. Docci, 2017]

To process the data, accurate position must be available in real time with a high frequency. Therefore, an integrated RTK GNSS system provides accurate relative positions. In an RTK system, two or more GNSS receivers communicate with each other. The base station is motionless and mounted on the ground at a known position; the rover is mounted on the mobile system [Drotek, 2016]. The base station sends its position to the rover station, after which the difference between the carrier wave signals is measured and a position is calculated.

Currently we are using a French product, which includes a U-Blox-M8T chip. The on-board mounted Intel Edison processor calculates the solution by using the open-source software RTKLIB [Drotek, 2016]. To use this UAS around the world in places without internet GSM connectivity, the position data from the base station is transmitted via radio.

3.2 Flight Planning / GIS

There are dozens of ground control stations (GCS) / flight planning software programmes on the market. We based this project on the Opensource software *MissionPlanner* [ardupilot.org]. This software provides flight planning, parametrization and a dynamic control supplement from livestream data from the UAS [ardupilot.org]. The implemented flight planning tool will be used to plan the baseflight over the entire suspect area. However, for the radar flight, a special flight planning tool is necessary. We fly close to the surface and the antenna must be guided by the gimbal in relation to terrain surface elevation The implemented code requires the generated DSM as geo-tiff file from the baseflight (figure 3 top right) as input data. The code computes stationary obstacles (e.g. trees, fences), and computes the collision-free position and theoretical radar-antenna angle depending on the slope and flight height. At the end, a waypoint file, containing waypoints and the gimbal angle, in generated automatically from the code. With this file, we can feed the UAS during the radar-flight mission autonomously.

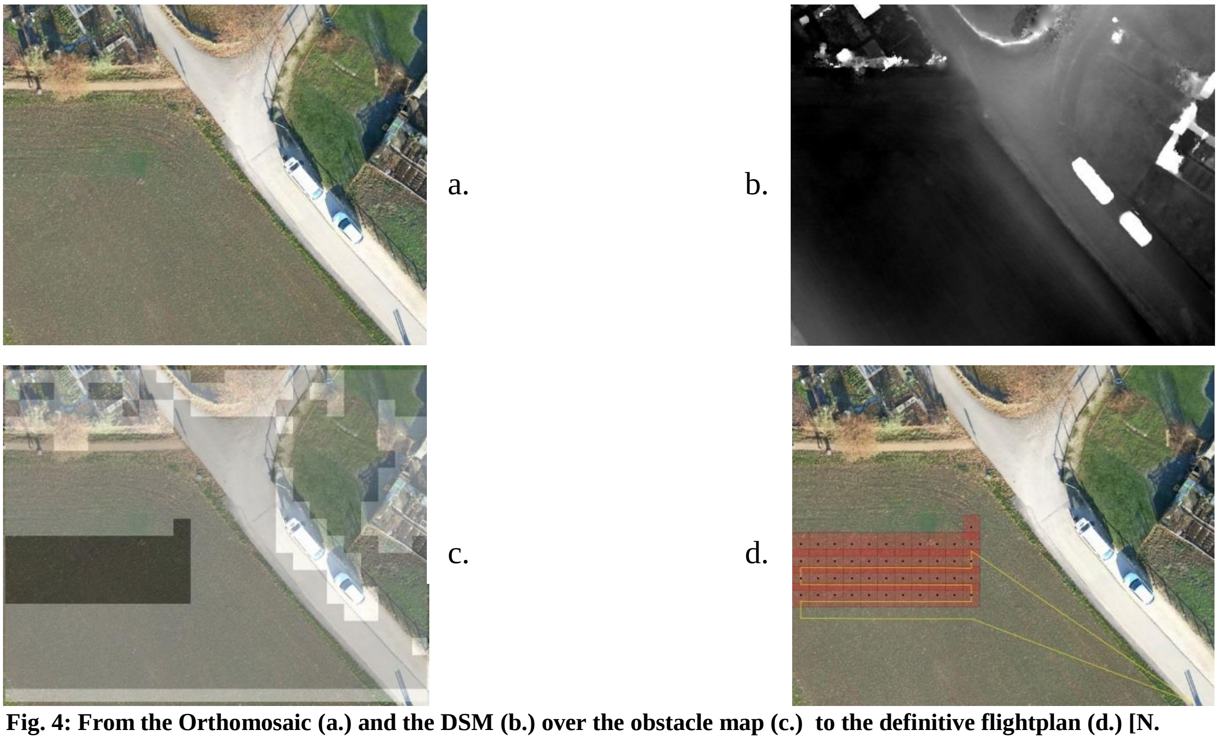

Fig. 4: From the Orthomosaic (a.) and the DSM (b.) over the obstacle map (c.) to the definitive flightplan (d.) [N. Docci, 2017]

The GIS is an important part during the whole process, especially for spreading the collected data. For this project, QuantumGIS (QGIS) is used. QGIS is *"cross-platform free and open-source desktop geographic information system application that provides data viewing, editing and analyses"* [Wikipedia, 2017]. In the first step of the process, QGIS and existing maps are used to determine the shape and size of the suspected area. The outputs from the base flight are the basis for further analysis. After the radar flight is processed, possible mine locations are illustrated. Exporting the data into different datatypes or accessing a national database to share the data is the most common use of the entire demining process.

4. SENSORS

4.1 Synthetic Aperture Ground Penetrating Radar

Ground penetrating radar (GPR) has been used for more than 20 years to detect buried objects [Daniels 2007]. As the detection possibilities of radar are not limited to metal objects, it has become a promising approach for finding modern plastic landmines with minimum metal contents. Presently most GPR sensors for mine detection operate very close to the surface often in combination with metal detectors. There are handheld single antenna versions [Daniels 2006] and vehicular-based array systems [GICHD 2006]. With these systems the safety and efficiency of clearance actions can be supported by the radar principal. But they are not useful for technical surveys of large suspected hazardous areas. For these areas, a combination of the radar principle with an UAV is very promising.

Radar allows for remote detection. Electromagnetic waves, however, penetrate the ground only at low frequencies. In [Frizsche 2001, Fischer 2003], microwave frequencies between 0.5GHz and 5GHz are proposed for the detection of landmines to a maximum depth of 20cm.

For the detection of mines, a minimum ground resolution in the range of the object diameter is necessary. Antenna structures for focusing microwaves from a flying UAV to achieve ground resolution in the range of 0.2m would need apertures of several meters, even if the altitude above ground Hz was less than 5m. Such apertures would greatly extend the payloads and dimensions of UAV platforms.

The synthetic aperture radar (SAR) principle [Mensa 1991] solves this problem by combining the necessary aperture from numerous measurements coherently recorded along a properly defined and typically linear flight path. The arrangement of an SAR system is depicted in Figure 5.

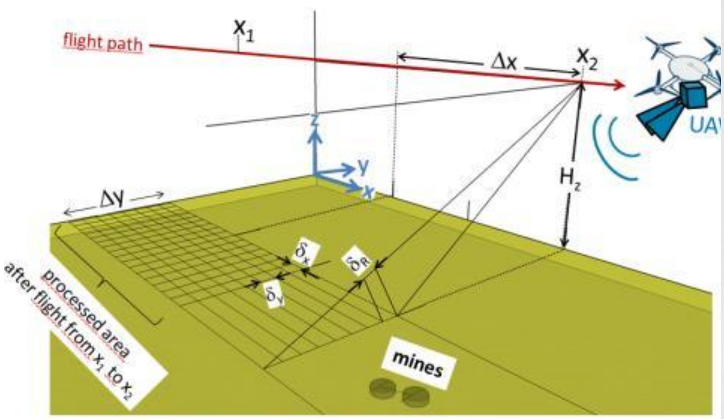

Fig. 5. Basic SAR geometry.

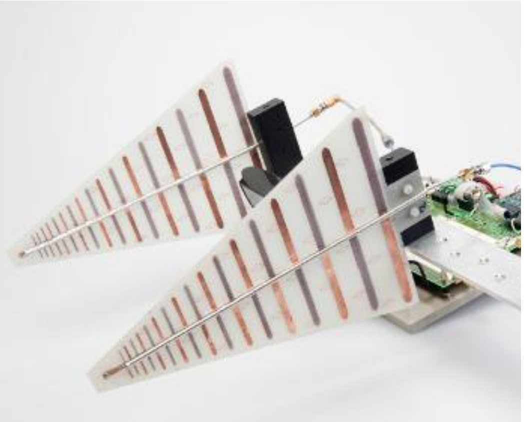

Fig. 6. Radar sensor hardware mounted on a rail system for first tests.

The UAV performs a linear flight path with the radar antenna in a skew direction downwards to the area to be observed. With the skew orientation, the range resolution δ_R of the radar sensor resolves the area in the y-direction. The resolution δ_y depends on the skew angle and the bandwidth of the radar. For technically feasible bandwidths of more than 2GHz cell size, δ_y in the y-direction can be in the range of 0.1m.

The resolution in the x-direction uses the synthetic-aperture principle and is available only after the processing of many radar measurements which have been collected as complex (phase preserving) signals from known positions over the flight path. With the signals collected over a path length Δx, if there was a reflection from an x-position $\Delta x/2$ can be tested. The processing principle inverts the wave-front of a suspected reflection originating from the observed x-position by phase reconstruction with complex calculations. The necessary path length Δx for a required resolutions δ_x depends again on the skew angle and the altitude H_z. For UAVs flying below 5m, altitude Δx is in the range of 3m to 5m.

One challenge of the approach is the precision of the positions of the collected radar measurements along the flight path. Radar measurements are performed along Δx at regular intervals of a few centimeters, and the SAR algorithms will only allow maximum position errors in a range of 1/8 of the wavelength of the radar system. Therefore, for a center frequency of 2,5GHz, the UAV must perform a flight path with deviations of a maximum of 15mm from linearity over lengths of several meters. Known deviations from the flight path, however, can be compensated for by the algorithms if they can be collated with the radar scans.

A second challenge is the uncertainty of the soil's dielectric property. This makes the standard SAR algorithms, which are used for surface scanning, ambiguous for buried objects. The consequence is incorrect y positions of mines below the ground surface. A good solution for this problem is multi-look by systems with several locally displaced antennas [Schreiber 2016]. Unfortunately, a compact UAV cannot carry large antenna arrays. So our approach is to use orthogonal flight paths for resolving the ambiguities of buried objects. This however further increases the requirements for flight path and/or position recording from relative accuracy to absolute accuracy in cm range.

With a radar sensor developed in 2016 (Fig. 6), the system concept was evaluated based on flight paths simulated with a rail system. In the next months, the sensor will be integrated into the UAV.

5. CONCLUDING REMARKS

FindMine is an ambitious research project to significantly improve the performance of the entire mine action process. The project was launched in March 2016. The first results are expected for mid-2017. If it is possible to safely detect landmines using the UAV / GPR combination, the time needed to detect and eliminate landmines should be significantly reduced.

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BIOGRAPHICAL NOTES

Reinhard Gottwald is professor for geodetic metrology and dean of the FHNW Bachelor program in Geomatics Engineering. He received his diploma in geodesy at the University of Bonn, Germany, in 1975 and his 'Vermessungsassessor' in 1978. After 3 years of practical work at a publicly appointed surveyors' office, he returned to university as a research assistant. He received his PhD from the RWTH Aachen University in 1984. After 8 years in industry (project management, R&D management), he was appointed professor at the University of Applied Sciences and Arts Northwestern Switzerland (FHNW). He is a member of the Swiss Geodetic Commission and of several other national and international organizations. He is responsible for the FindMine project coordination

Winfried Mayer is senior expert for radar technology at Endress+Hauser GmbH + Co. KG in Maulburg, Germany. He received a Dipl.-Ing. (BA) degree in communication technology from the Berufsakademie Ravensburg in 1994 and the Dr.-Ing. title from Ulm University in 2008. From 1994 to 2001, he was with EADS Germany Microwave Factory R&D. From 2002 to 2007, he did research on imaging radar sensors and digital beam-forming at the Institute of Microwave Techniques of Ulm University. Since 2007, he has been with Endress+Hauser and responsible for predevelopment and technology in radar. In the FindMine project, he coordinates the radar sensor activities.

Nando Docci is a research assistant with special skills in UAVs. He finished his apprenticeship as a surveyor in 2009. After a year of military service, he decided to do a BSc in Geomatics. He received his degree after part-time studies in 2015. Because of his interest and experience in constructing and flying UAVs, he became part of the FindMine team. He is responsible for the entire UAS and GIS parts of the project.

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