FindMine

UAV im humanitären Einsatz

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Contents

Introduction – who we are

Mr. Urs Endress founded in 2015 the

Urs Endress Foundation

www.ue-stiftung.org

- Swiss, non-for-profit foundation
- Seat: Arlesheim near Basel, Switzerland
- Board: guided by Urs Endress and accompanied by seasoned professionals with experiences in hightech sensor R&D and production, company management, international sales experiences, and access to humanitarian organizations
- Topic: Humanitarian demining

Motivation – some facts

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- **8605** victims – injured or killed people – in 2016
  (GICHD – Geneva Centre for Humanitarian Demining – gichd.org)

→ 8760 h/y → ~1 person/hour is hit by a mine 24/7

- Victims: 80% civilians, 16% female, 84% male, 42% kids (2016)
- Victims life-long need medical support and suffer from pains
- Today, an estimated 150.000.000 mines exist
- As mines count: *anti-personnel mines* (APM) and *anti-vehicle mines* (AVM)
- Other explosives are e.g. bombs or grenades. They count as UXO (unexploded ordnance) and are ERW (explosive remnants of war)
- APM are intended to injure, but often kill. AVM are intended to kill.
- In > 60 countries one finds APM and AVM

Motivation – some facts

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- Worldwide approx. 2.000 km² are contaminated with APM & AVM

- 2 demining modes:

→ Humanitarian demining:

each 1 cm² to be inspected and cleared mine found !
"clearing":

dig it out carefully

blow-up in controlled manner

extremely time consuming

→ Military demining:

only a restricted area, e.g. a corridor, gets cleared !
"clearing": remove it quickly, mostly by blow-up on site

Motivation – some facts

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- 2016 clearing rate for APM was 172 km² (GICHD)
- 2017 clearing rate for APM was 134 km² (GICHD)
  → decreasing clearing rate due to entities like Islamic State or Boko Haram
- Mines remain active for many decades.
- Mines prevent use of agricultural areas.
- Mines prevent kids to go to school.
- Mines prevent refugees to return back home.
- Mines prevent re-establishment of infrastructure.
- Mines prevent many other but required issues.

→ urgent: contribute in accelerating humanitarian demining

Goal – what we want to achieve

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Reduce the number of injured and killed people due to mines.

Increase speed for humanitarian deminers to reach their goals.

Goal – how we want to achieve it

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Do not touch contaminated

surface, but locate mines!

Solution – how we achieve it

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→ Apply unmanned airborne vehicles (UAV) as flying platforms for mine detecting sensors and georeference identified mine instances

Solution – the basic idea

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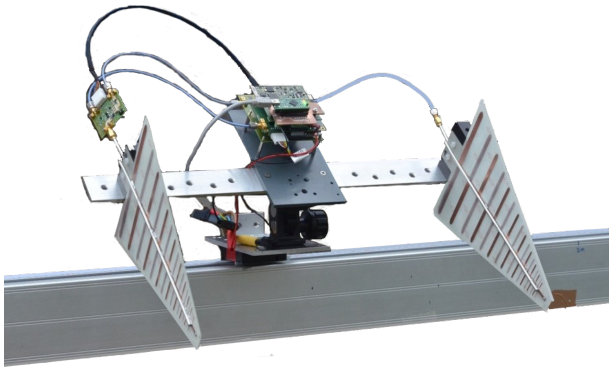
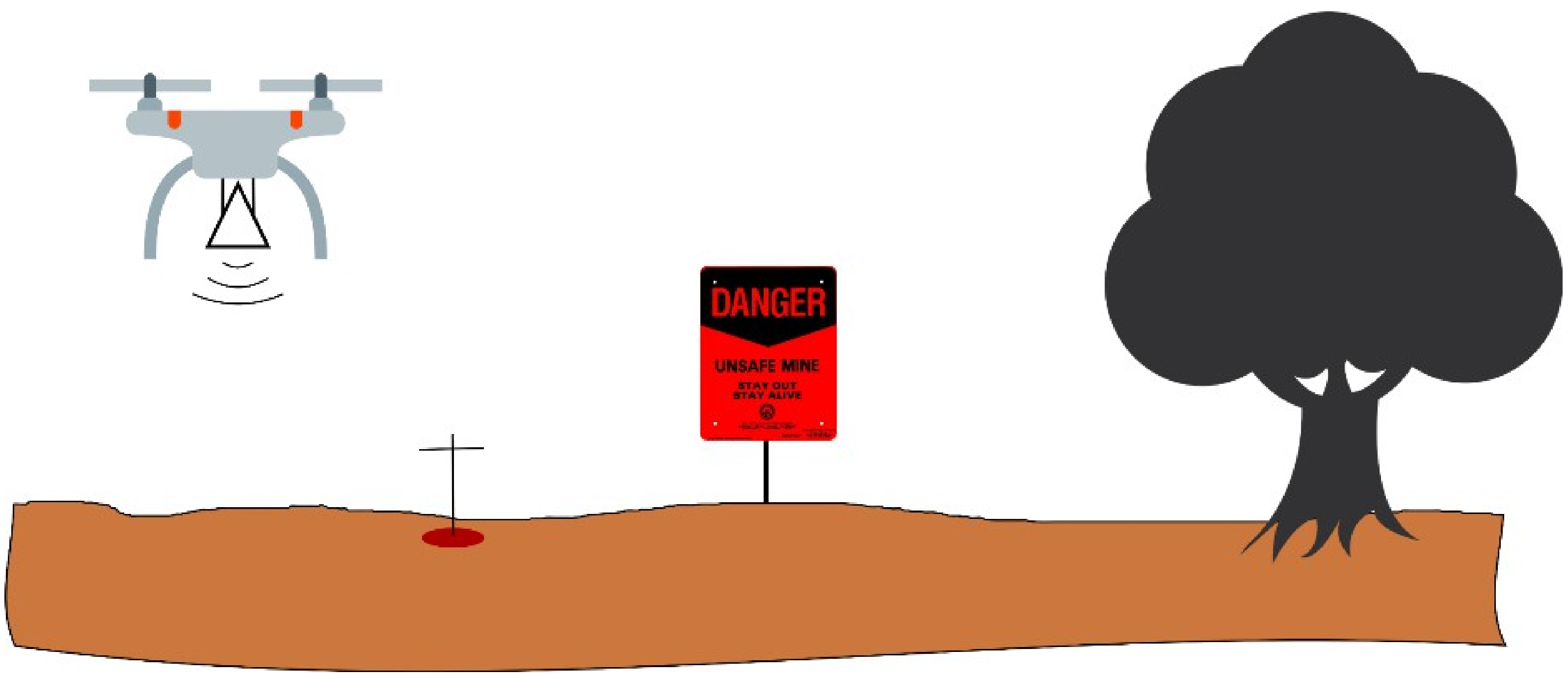
Unmanned **A**irborne **V**ehicle (UAV), autonomously flying, small dimensions, easy handling

+

Ground **P**enetrating **S**ynthetic **A**perture **R**adar (GPSAR) with low energy and light weight ...



Solution – the basic idea



… GPSAR as primary sensor for mine localization mounted on an autonomously flying UAV

Solution – how it looks like

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→ FindMine-System – the GPSAR-UAV

FindMine – the project frame

- FindMine is a R&D-project of the Urs Endress Foundation
- Goal: localize APM and AVM without touching the ground in day&night operation.
- How? → apply UAV technology equipped with appropriate sensors
- Which sensor/s?

→ apply ground penetrating radar FindMine1
→ apply complementary sensor technologies FindMine2

- Scientific R&D-team works on radar and UAV issues

Radar
- Institute of Microwaves, University of Ulm, Germany
- Laboratory of MicroElectronics and MicroSystem Technology, University of Applied Sciences, Ulm, Germany

UAV
- Autonomous Systems Lab, ETH Zürich, Switzerland

FindMine – the situation

- APM typically buried 0 cm to 10 cm deep; explosion on pressure > 20kg
- AVM typically buried 10 cm to 20 cm deep; explosion on pressure > 120kg

→ find objects buried as deep as 20 cm

→ objects have metal or plastic bodies

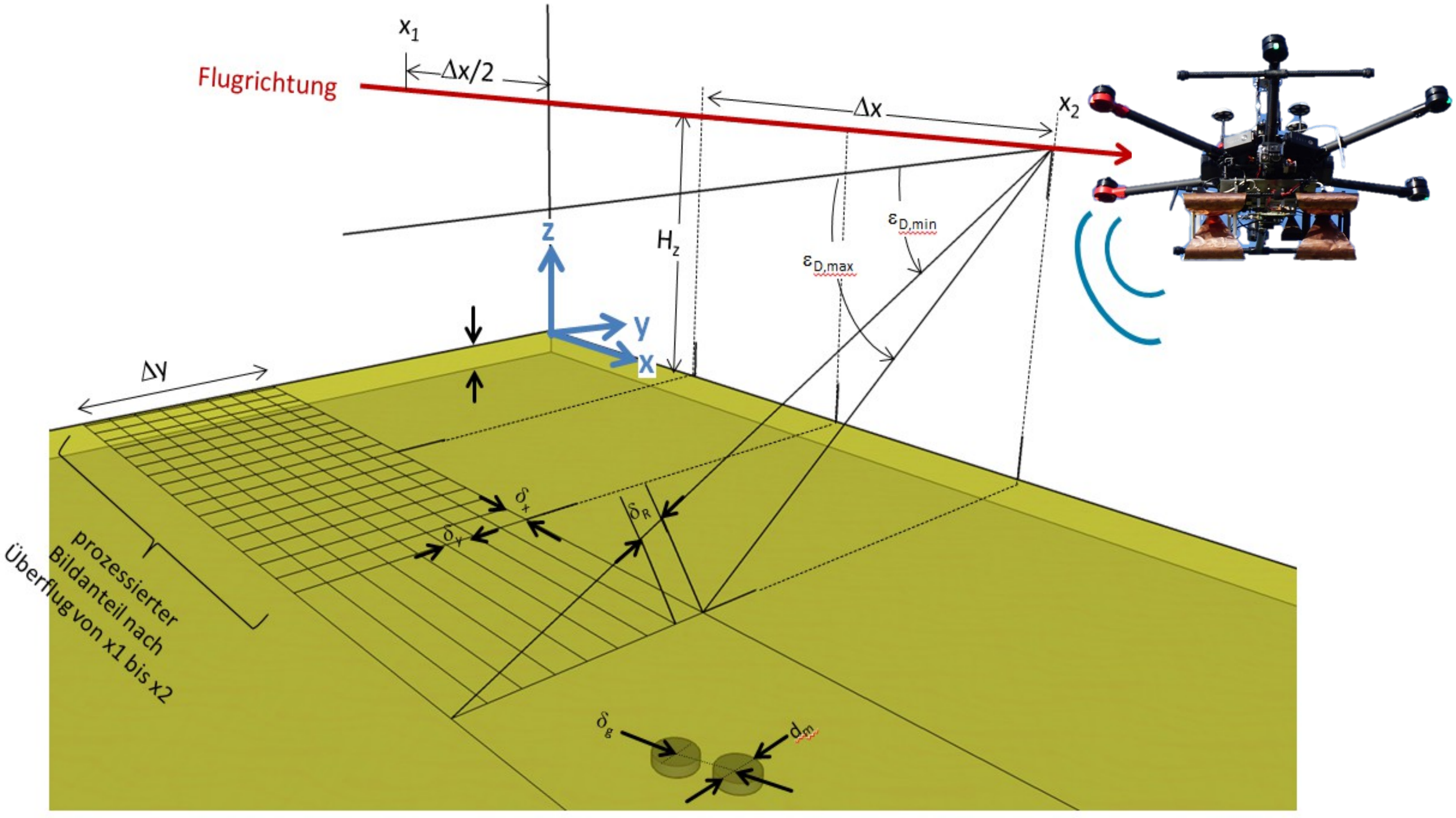
→ tripwires or pressure plates used as initiator, partly

→ when laid by military, then systematically placed
  → pattern recognition supports detection

- Hundreds of different types of mines
- Many sensor technologies were investigated by FindMine, e.g. hyperspectral imaging, thermal imaging, gas sniffing (similar to: dogs, bees, rats), metal detection, ground penetrating radar, others

FindMine – flight situation

requirement for SAR: relative 3D-position x,y,z ≤ ±2cm along min. 5m flight path

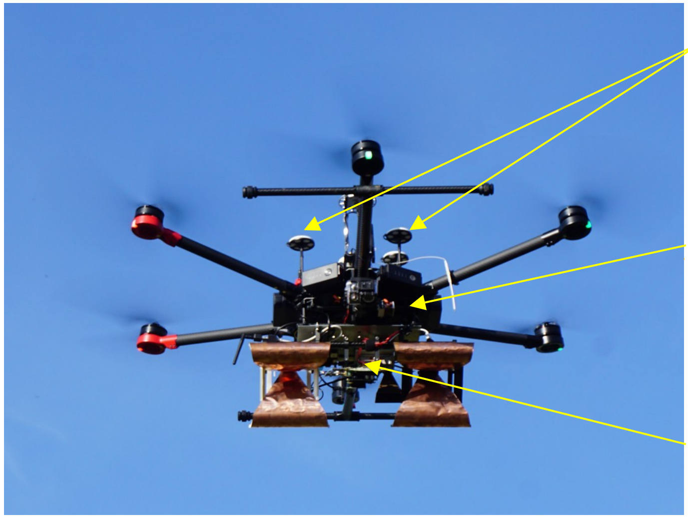


Goal: Obtain ≤ ±2cm accuracy from on-board sensors

FindMine – the measurement system

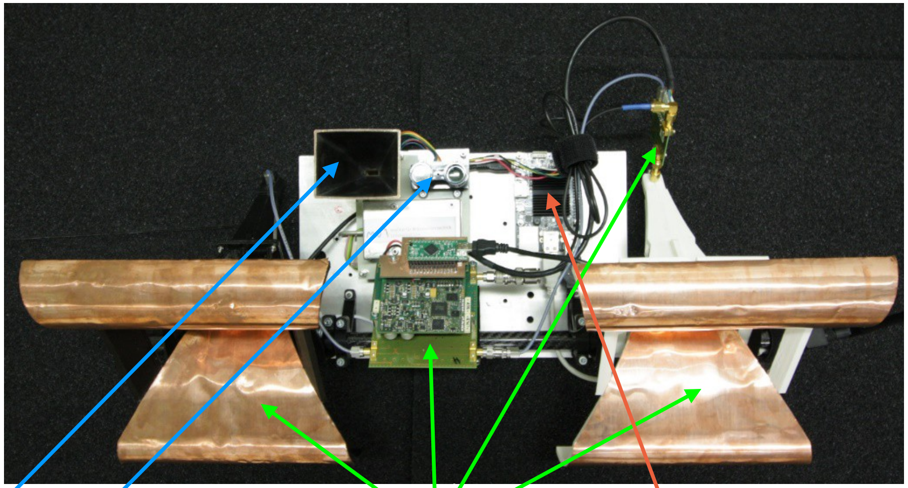
UAV: DJI Matrice 600 Pro

- Copter: 9.2 kg
- Max. payload: 6 kg
- MTOW: 15.2 kg
- Kalman filter (GNSS/IMU)
- Flight time with payload of 2.5 kg: ~20 min



Sensor Module

- 0.5 – 4.5 GHz FMCW GPSAR
- Lidar / Radar Altimeter
- RTK GNSS (several ones)
- Data Logger (Odroid)
- Weight: ~2.5 kg



FindMine – 1st sensor: GPSAR

ground penetrating synthetic aperture radar (GPSAR)

- 0.5 GHz to 4.5 GHz
- Special emit and receive electronics and special antennas
- Polarimetric measurements
- Sensor payload: 2.5 kg
- Radar signal processing
- Requires between 2 m to 4 m flying height AGL
- High demands on UAV flight control
- UAV platform is at time DJI Matrice 600 Pro
- 3D-flight path to be known within ±2 cm relative accuracy

→ high precision RTK + other sensors → enabling autonomous operation

- Ongoing R&D-project since 2016, system now in test

- Important: Radar works on / in dry soil – not in water

FindMine – positioning task

Positioning task: deliver ≤ ±2cm accuracy, SAR-requirement

3D-positioning asks for 3 unknowns X,Y,Z 3 Degrees of Freedom (3DoF)

Challenge: kinematic problem due to moving UAV

3 options identified solving the positioning task:

→ External approach

→ Internal, or "on-board", approach

→ Tag Based Radio Localization – reviewed but discarded

FindMine – positioning task

Actually, we've a 6+1 DoF task:

X, Y, Z, roll, pitch, heading, dTsync

3 angular values, attitude, get measured with Inertial Measurement Unit (IMU) firmly connected to UAV/SAR

3 coordinates get determined, externally or internally, but:

Accuracy of measurements is the key.

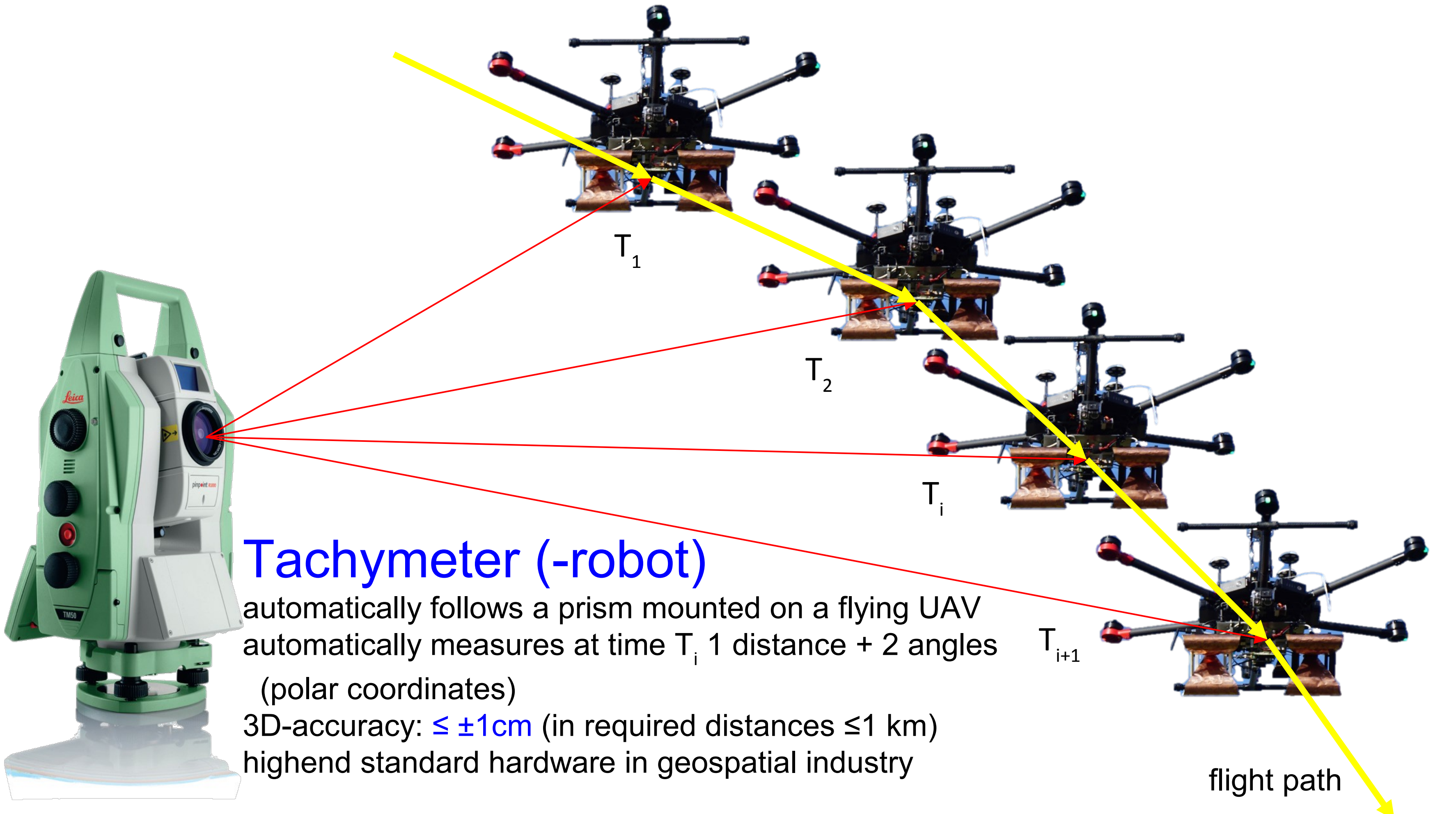
Data fusion (= post-processing) of position data and IMU-data is required to solve for 6 DoF

6 DoF must be complemented with SAR-recordings and calibrated phase-centers of SAR antennas

→ synchronize position data with SAR & IMU: **dTsync**

FindMine – external positioning

External approach works and resolves 3DoF task



Tachymeter (-robot)

automatically follows a prism mounted on a flying UAV
automatically measures at time T_i 1 distance + 2 angles
(polar coordinates)
3D-accuracy: ≤ ±1cm (in required distances ≤1 km)
highend standard hardware in geospatial industry

FindMine – external positioning

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External = tachymeter approach – properties:

Mandatorily requires line of sight (LoS)

Highly accurate, up to 2000 m some devices even more

Some tachymeters can search and find "a lost prism"

Some tachymeters can be fed on-line with coordinates where to look to / where to search for the prism

Delivers 3 coordinates X,Y,Z + T_{tachy} (i.e. resolves 3DoF) only!

No georeference; this requires additional hardware.

Robot-Tachymeter: 30 K€ and more (pricing for commercial use)

Open: synchronization with sensors on platform, e.g. SAR, IMU

→ remaining unknown: **Tsync**

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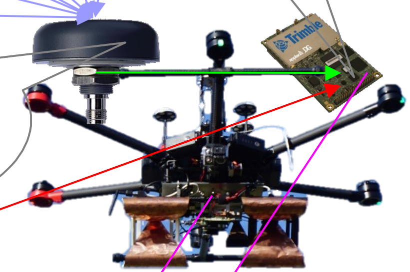
FindMine – on-board positioning

2 GNSS[1] antennas are required

1 stationary GNSS antenna = Base

1 moving GNSS antenna = Rover



Base-Antenna and Base Station GNSS

stationary
determines its 3D position over time highly accurate
3D-accuracy of Base: ≤ ±1cm
sends correction data to RTK-board
highend standard hardware in geospatial industry

[1] GNSS = Global Navigation Satellite System

FindMine – on-board positioning

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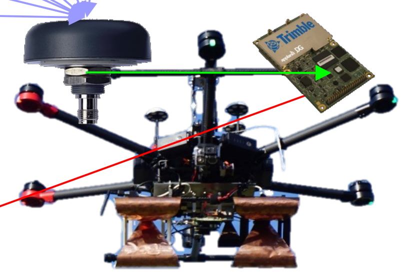
On-board = RTK approach – properties:

No line of sight (LoS) required

→ UAV can operate behind obstacles

Very accurate, up to several thousand meters between Base and Rover

RTK and IMU on 1 board → sync of RTK+IMU is given



Post-processing required; software part of RTK-approach

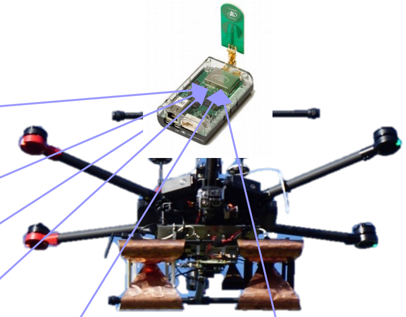
Post-processing delivers 6 DoF values: X,Y,Z,roll,pitch,heading

Delivers georeference of flight mission area, too.

→ ±2cm accuracy planimetry, Z ±2cm via altimeter

→ a priori system calibration for unknown dTsync !

FindMine – tag based positioning



4+ tag based radios (Radar) stationary,
anywhere on ground

1 tag based radio on-board UAV

Today,

accurate indoors only, distances ≤ 200 m, realistically ± 4-5 cm

→ discarded for FindMine

Post-Processing

$T_{i\ [100\ Hz]}$:
X,Y,Z,roll,pitch,heading

FindMine – the remote sensing approach

1. Aerial mapping, all georeferenced
    1. Digital Surface Model (DSM) generation for 3D-mission planning at 3 m above ground level (AGL)
    2. Orthomosaic generation for visualization purposes and updating national and GICHD geospatial data bases
2. GPSAR flight mission planning using DSM
3. GPSAR – remote sensing
    1. Collect GPSAR data
    2. Determine 3D flight path (reconstruct or on-line)
4. GPSAR signal processing
5. Repeat steps 2 to 4 with other sensor/s
6. Result: target localization and visualization on top of orthomosaic
    1. Upload of result into GICHD-database
    2. Hand over result hand to demining staff for mine action

FindMine – test site DLR Oberpfaffenhofen

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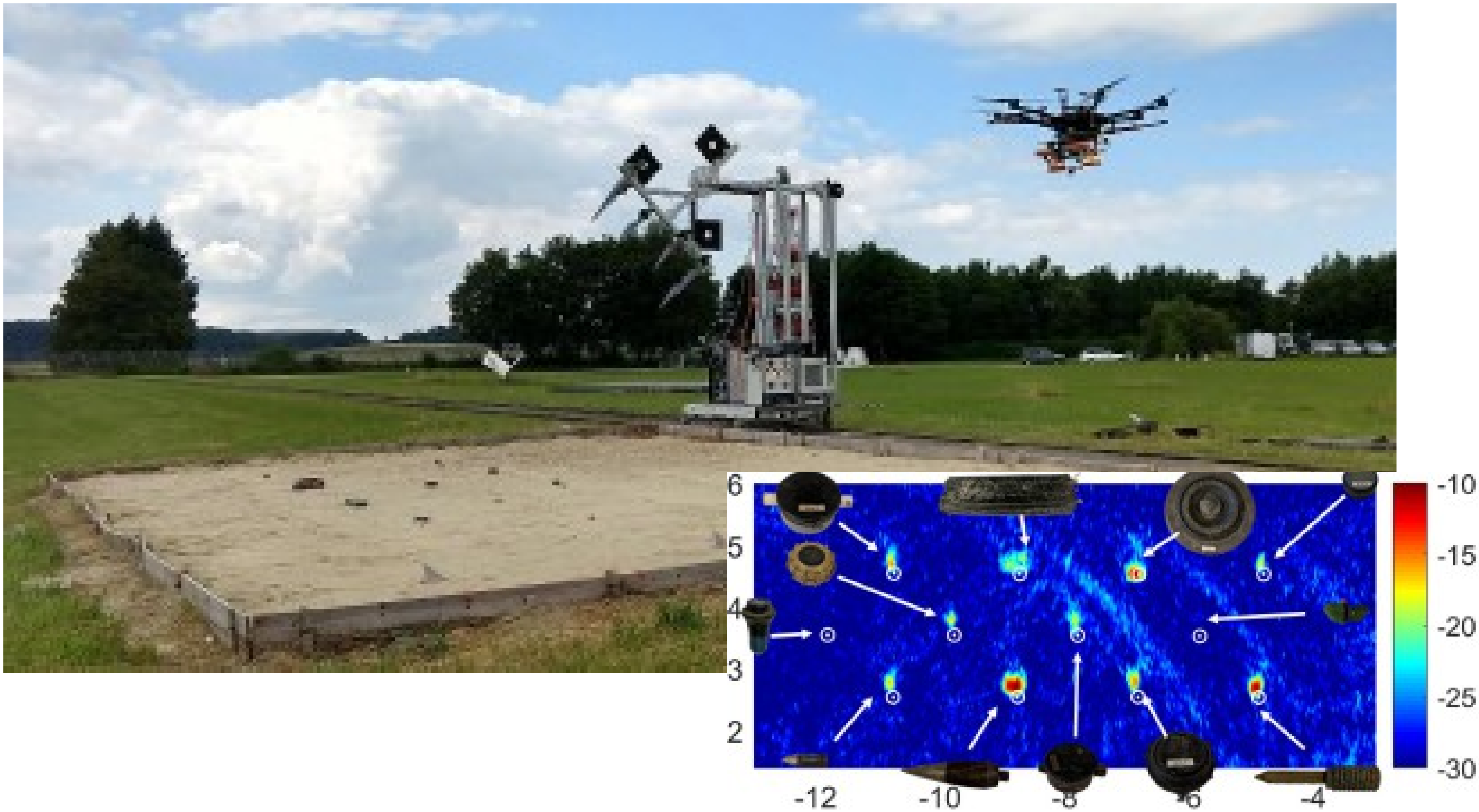
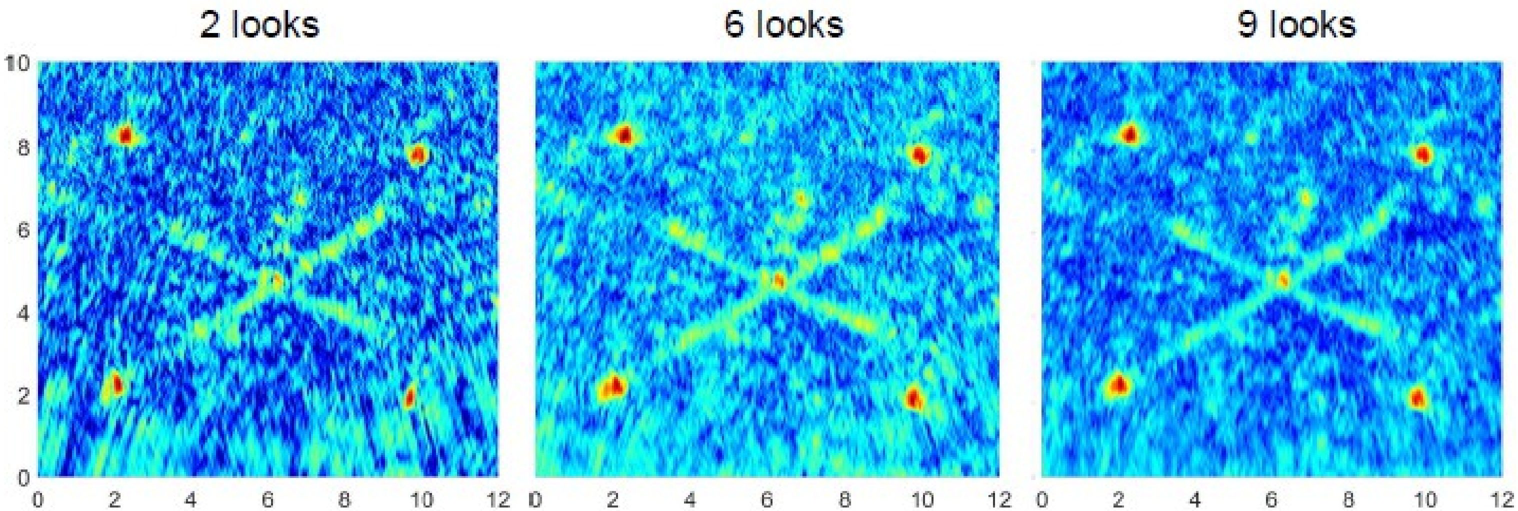
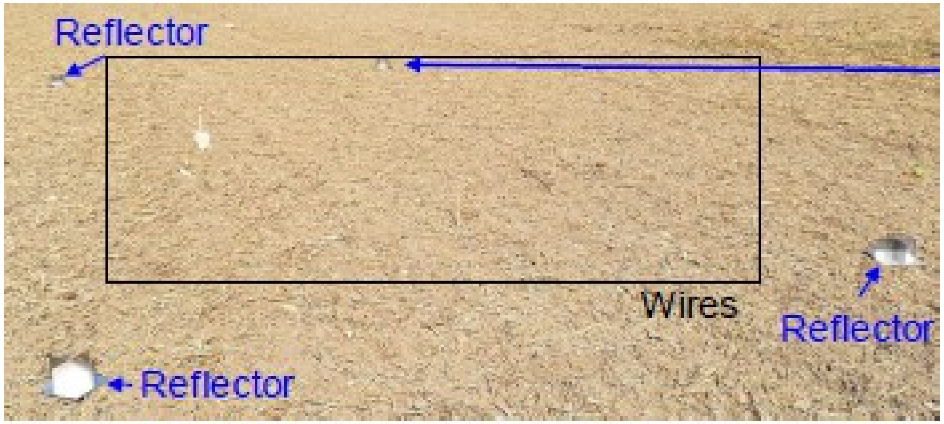


FindMine – we see tripwires



4 corner reflectors
4 tripwires
1 dummy target in the middle



Corn field with tripwires – but where?

FindMine – 2nd sensor: metal detection

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Existing metal detectors:

- Very reliable – works in water, too
- Made for hand-operation by deminer
- Typical coverage 0.5 m² before advance is possible
- Real time procedure (required due to measurement mimic)
- Requires operation < 5 cm proximity to ground, max. 20 cm MD to object
- Hand-operation and proximity to object cause enormous time efforts in mine search
- Due to measurement mimic since approx. 25 years no major techno-logical advancements appeared

FindMine – 2^{nd} sensor: metal detection

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New metal detection technology is required

1. New MD-tech made for operation by UAV → 24/7
2. Double / triple distance MD to object: 40 cm to 60 cm
3. Cover large areas, e.g. > 1000 m² in one fly over
   → collect soil properties → deep learning
4. 2-stage measurement procedure:
   1^{st} collect data
   2^{nd} analyze data → detection & localization

→ new MD => FindMine2

FindMine – where we are heading to

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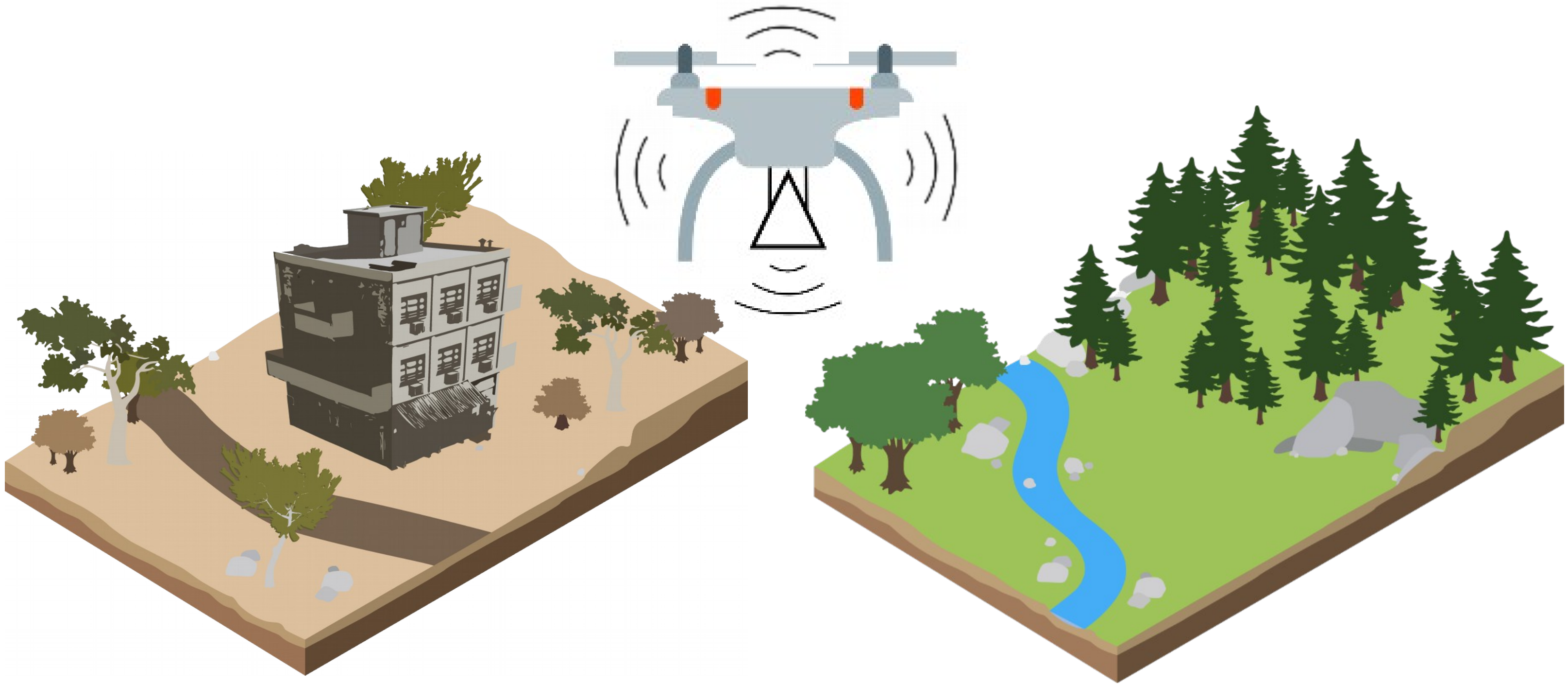

building FindMine3 forest / jungle

Flying in/to suspected buildings and dense forests / jungles

Thank you for your attention!

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