findmine
findmine GmbH – Explosives search with the help of UAVs.

FindMine GPSAR

Ground Penetrating Synthetic Aperture Radar
Model Version LR01

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1. INTRODUCTION

The FindMine ground penetrating synthetic aperture radar system (FM-GPSAR) is a UAV-based radar sensor system for the detection of mines or other explosive remnants of war from a safe flight altitude of several meters.

The purpose of the FM-GPSAR is to detect hazardous objects which are hidden in dense vegetation or buried in the ground.

The system supports demining teams, demining machines and robotized demining by air-based sensor data wherever optical sensors cannot help.

It is developed for civil and humanitarian use. Possible applications can be found in technical and non-technical survey clearance support and quality supervision.

The system was designed by the FindMine GmbH based on research results from various Universities. The initial research on which the system is based was conducted between 2015 and 2022. The Urs Endress Foundation financed the initial research and continues to support the operations of the FindMine GmbH.

2. STATE OF THE SYSTEM

The present version, LR01, of the GPSAR system described in this document is a unique new product at technology readiness level TRL7 - TRL8 (ISO 16290 technology readiness level scale). In 2026 a small number of systems are made available for selected pilot customers who are open to innovation.

3. SYSTEM OVERVIEW

The FindMine GPSAR-System consists of the GPSAR UAV, a base-station and router unit (BSR), a field processing unit (FPU) and the operation processing and evaluation software (EPOS). An overview of the system is visualized in Figure 1.

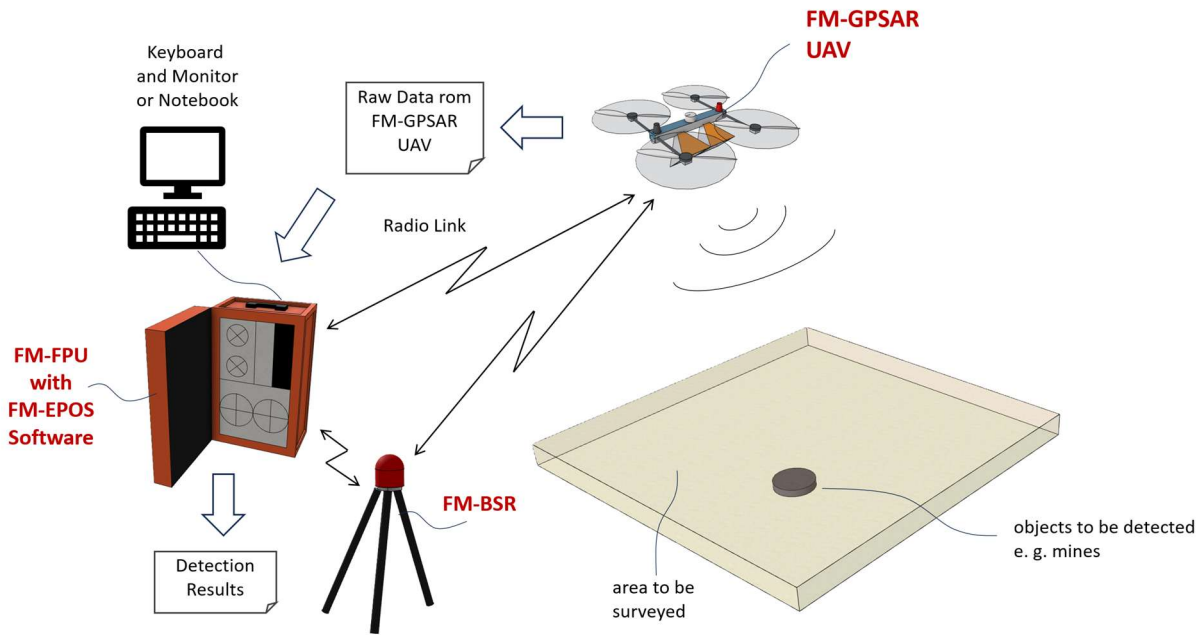

Figure 1: Simplified visualization of the FindMine GPSAR system

A flight plan for the area to be surveyed is generated from aerial images or map data by the operation software in the FPU. On this basis an automated measurement flight is performed by the GPSAR UAV over the area to be surveyed. For the measurement flight the GPSAR UAV, the FPU and the BSR cooperate and communicate via the EPOS software. During the measurement flight the radar sensor of the GPSAR UAV records many localized and time-stamped radar scans from the area to be surveyed. After landing the recorded data is transferred from the GPSAR UAV to the FPU and processed and evaluated by the EPOS software. By a special ground penetrating SAR-processing in the EPOS software, processing and evaluation of a scanned area can usually be done faster than the scanning by the GPSAR UAV. So, during processing of the last flight in the FPU, the following flight can be performed by the GPSAR UAV. The software provides a graphical user interface for all functionalities and extensive mapping features to display the survey results. The results can be exported to third party mapping solutions for CSV and GEO-Tiff interfaces.

4. SYSTEM DATA

The system operation parameters can be set over a wide range and may vary depending on the survey task. In the following table, typical system data are given from good practice obtained from many evaluation tests performed since 2023.

Parameter	Typical Value	Comment
Flight altitude over ground	4m – 10m	
Synthetic aperture operation	Side-Looking	Typical 45° declination angle
Measurement flight duration	15min	FM-GPSAR UAV with radar sensor and one battery set.
Maximum windspeed	5m/s	For undisturbed operation. 10m/s maximum rating.
Typical operation speed	1m/s - 3m/s	
Maximum transfer flight speed	5m/s	
Typical measurement flight coverage	2000m²/h	
Processing time per 1h measurement flight	1h	
Area resolution	<10cm	
Depth resolution	<5cm	Dependent soil properties and moisture.
Maximum depth	20cm – 50cm	Dependent on objects, moisture and soil properties.
Radio link bands	2.4GHz	Commercially available modems are used.

5. RADAR SENSOR

Typical operation parameters of the radar sensor of the GPSAR system are in the following table. They can be adjusted in wide ranges for adapting the system to soil conditions, vegetation and terrain. The necessary frequency range for penetrating vegetation and soil typically covers many allocated frequency bands. Though the radiation is very low and directs downward, the system operation requires special permission by local authorities.

Parameter	Typical Value	Comment
Radar Type	FMCW	
Maximum frequency range	0.4GHz -4GHz	
Measurement rate	100Hz	
Ramp duration	1ms	
Channels	2 transmit (TX) and 2 receive (RX)	2 RX-channels working in parallel.
Polarimetric measurements	yes	VV, HH, VH and HV
Transmit power (EIRP)	<20dBm	
Localization type	RTK GNSS	
Localization accuracy	+/- 1cm	differential, with the fixed base-station as reference
Declination angle	nominal 45°	adjustable and programmable from 15° to 90° via a servo elevation drive

6. UAV

The FM-GPSAR UAV is basically a flying radar sensor. The combination of the sensor with the UAV provides an optimum of flight duration and cost. The device is designed to be easy to repair, and the components were selected with an eye toward worldwide availability and usability in developing countries.

Parameter	Value	Comment
Size: length, width and height w/o rotors	78cm / 100cm / 66cm	rotors foldable for transport, plus 55cm in width and length with unfolded rotors
Gross weight	9.5kg	with maximum capacity battery
Batteries: number/voltage/capacity	2 / 22.5V / 15Ah	maximum capacity set: 2x 333Wh
Optical camera	no	
Altimeter	radar and lidar	
Collision avoidance	no	
Geofence	yes	maximum radius from base-station and programmable
RTK-controlled automated flights	yes	
Manual operation via remote control	yes	
Anti spoofing/jamming	no	except some SW emergency procedures

7. FIELD PROCESSING UNIT

The Field Processing Unit (FM-FPU) is a ruggedized PC-system which allows users to run the entire FindMine software EPOS for operating, processing and evaluating the GPSAR system. The FM-EPOS software runs in a local wireless network on site with or without external internet access.
The EPOS software on the FPU can be operated by the user either by

a) directly connecting monitor, keyboard and pointing device to the FPU,
b) operating the FPU from a notebook in the wireless network on site,
c) operating it from a remote computer if external internet access is available.

Option c) is recommended only for processing and evaluation and not for doing search flights with the GPSAR UAV on the field. On the other hand, it is a very good solution for remote support, training and trouble shooting.

8. BASE-STATION AND ROUTER

During the measurement flight the Find Mine base-station and router (FM-BSR) provides the GPSAR UAV GPS correction data based on its known and fixed position and routes data transfer between the FM-FPU and the FM-GPSAR UAV. Data transmissions are done with standard modems and WIFI modules. A local wireless network is set up during system initialization. The base-station and router is mounted on a special tripod at about 2m height over ground. The tripod is included as an accessory with the items being delivered by FindMine.

9. FINDMINE OPERATION PROCESSING AND EVALUATION SOFTWARE

All software for using the FindMine GPSAR system is integrated into a single software package named EPOS. A summarizing insight on the EPOS SW is given in the following three sections broken down by operation, processing and evaluation.

9.1. Operation

The operation parts of the EPOS software provide all necessary functions for planning and performing GPSAR measurement flights. In the following table the main functionalities are summarized.

Function	Description
Mission planning	Interactive input procedure for all necessary data for a flight mission. Setting up the trajectory for covering an area to be observed.
Configuration and initialization	Initialization and configuration of the system: FMCW-radar, radio-links, base station and router, UAV, reference position of the area to be surveyed.
Automated flight	Performing and supervising the planned measurement flight.
Automated radar measurement	Performing the radar scans during the measurement flight and storing localized and time-stamped results.
Localization	Deriving accurate position and orientation coordinates from RTKGNSS sensors for localizing the radar scans.
Data assembly for evaluation	Providing data packs of the radar measurements together with all necessary meta-data.

9.2. Processing

In a GPSAR system the measurement results of each voxel in an area to be observed are calculated from all radar measurements which have illuminated the voxel in the search flight. The search-flights are done in a way that very many radar scans from different perspectives contribute and each radar-scan needs to be accurately localized. The calculations for this fundamental processing step are very intensive and require special algorithms for doing them in reasonable time and with moderate computing hardware. The diagram in Figure 2 roughly explains the complete processing and evaluation chain of the FindMine EPOS software. The area to be surveyed is automatically separated into illuminated sub-areas to be evaluated. The FM-KS Method is the basis of the processing and integrates the phase corrected energies from all radar scans for each location in the area to be surveyed. By assuming soil properties and combining data from different observation looks (directions or perspectives), depth resolution is obtained.
The result is a 3D matrix of complex values representing radar reflection intensity for every voxel in the volume of the surveyed area (Reflection intensity matrix in Figure 2). Each layer of the matrix can be understood as a horizontal cross-section of one depth of the observed soil-area. The air-to-soil boundary surface is one layer of the matrix. Horizontal voxel resolution is typically 5cm, vertical resolution 1cm.

9.3. Evaluation

In the following evaluation steps, the reflection intensity matrix is searched for clusters of high intensity values which are likely to be caused by man-made objects. The search uses 2D- or 3D-correlation and CFAR techniques. Computational effort for the evaluation is much lower than for processing. This allows executing multiple evaluations of one intensity matrix. Evaluation is usually adapted to the given scenery i.e. expected objects, depth and vegetation. The results of the evaluation are detection images or target lists from an auto detector. Detection images are color coded piles of detected pixels in a predefined depth range. They can be overlaid on ortho-photos to correlate detections with visible objects or ground marks. Target lists are geo-referenced lists of automatically detected anomalies. Both intensity and probability-based detectors are implemented. Finally, the user can mark points of interest and export the georeferenced results for documentation and mapping.

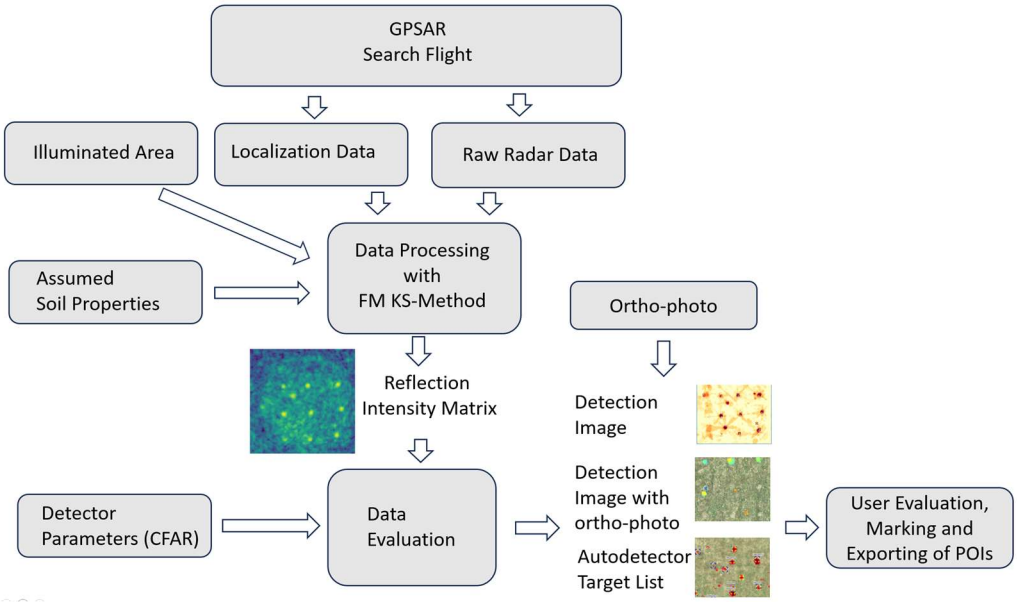

Figure 2: Simplified schema of the GPSAR processing and evaluation.

10. PICTURES OF THE SYSTEM

In the following picture (Figure 4) the main hardware building blocks of the present system are shown.

Figure 3 shows some screenshots of the FM-EPOS Software.
Accessories such as batteries, charger, monitor, keyboard or spare parts are not visualized.
Two people can operate the FM-GPSAR-System and all hardware can be transported in one medium-size car.

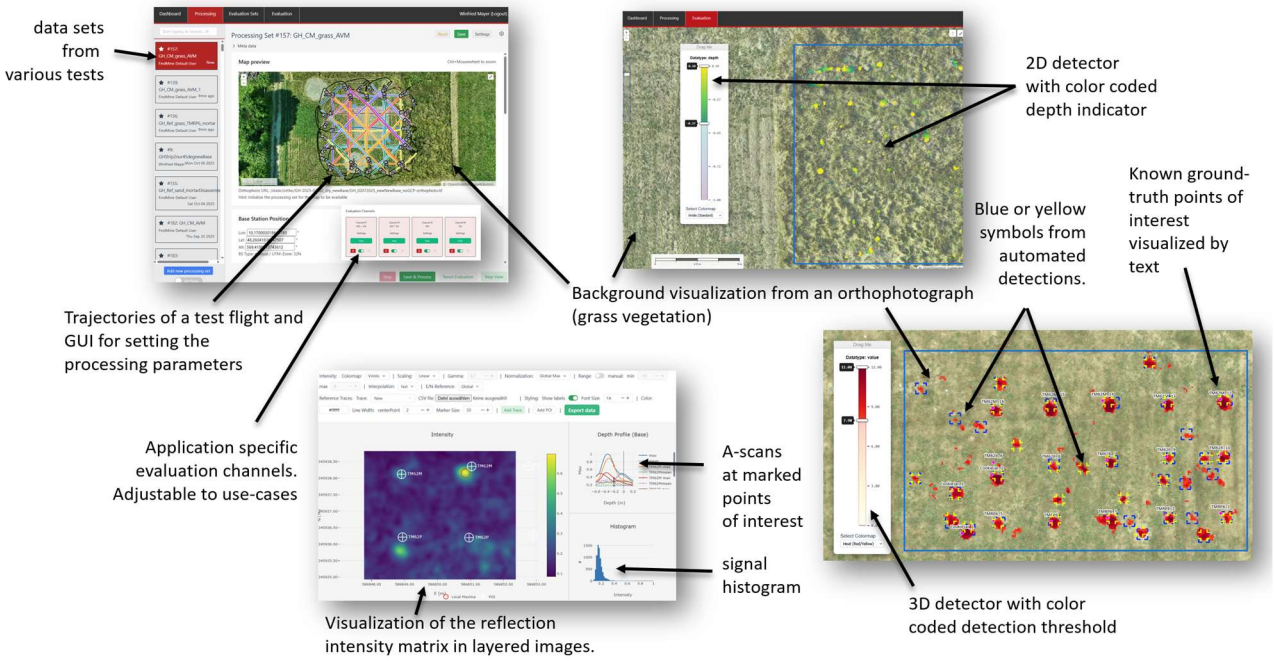

Figure 3 Screenshots of the FM-EPOS software indicating some of its features.

Figure 4 Hardware components of the FM-GPSAR system. The ground station is just a commercial notebook and not shown.