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TECHNICAL REPORT:
Automated Airborne Ordnance Detection Via Data Fusion of Ground Penetrating Radar and Magnetometers

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Where opportunity creates success

INTRODUCTION: Global landmine crisis

- 100 million buried landmines,
- For every mine removed, 10 more are laid,
- 61 states worldwide impacted,
- The precise locations of legacy landmines unknown,
- Each year, approximately 26,000 people exposed to the explosions,
- With children accounting for 80% of the victims,
- Hinder recovery by affecting agriculture and infrastructure economic development.

INTRODUCTION: Limitations of Conventional Methods

- Manual detection is slow, costly ($300–$1,000 per mine) and risky.
- One person dies for every 5,000 mines removed
- 1,000 deminers lost their lives or suffered injuries (1999-2012),
- Biological and chemical methods are inefficient,
- High false alarm rates with metal detectors,
- Land-based vehicles (wheeled, legged, and dragged robots) face a number of challenges,
  - ➢including accurate navigation over rough terrain
  - ➢it takes a while to scan larger terrain with those slow, heavy vehicles.
- More than 1,100 years required to remove all buried explosives

INTRODUCTION: Objective: Use UAVs, AI, and sensor fusion

- Landmines made from a variety of materials,
  - ➢including wood, glass, metal, and plastic, and they vary in size
- To improve accuracy, multiple sensors with different capabilities, allowing for
  - ➢data fusion and
  - ➢more informed decision-making.
- Development of a landmine/UXO/IDE detection system that is quick, safe, and economical is urgent.
- Autonomous, easy-to-use drones instilled with AI and the fusion of sensors can
  - ➢expedite surveying and
  - ➢provide better access to challenging terrain with hard-to-reach topography and thick vegetation.

INTRODUCTION: Fusion of magnetometers and GPR

- In this work, an autonomous robotic drone developed, integrated with
  - ✓ magnetometers and GPR
  - ✓ AI-powered fusion algorithms
- to detect landmines/IDE/UXO locations
  - ✓rapidly and safely.
  - ✓large coverage,
  - ✓cost-effective,
  - ✓with extreme height precision and terrain following mode.

Sensor technologies: Magnetometers and GPR integrated UAS.

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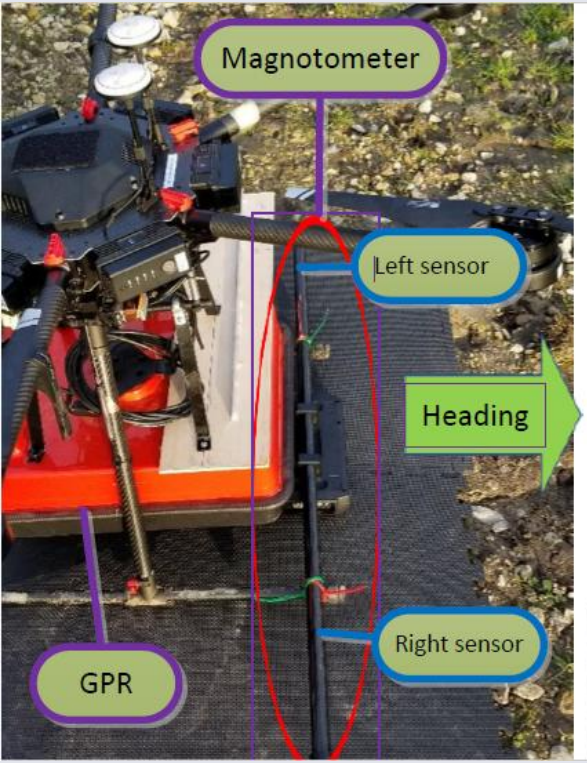
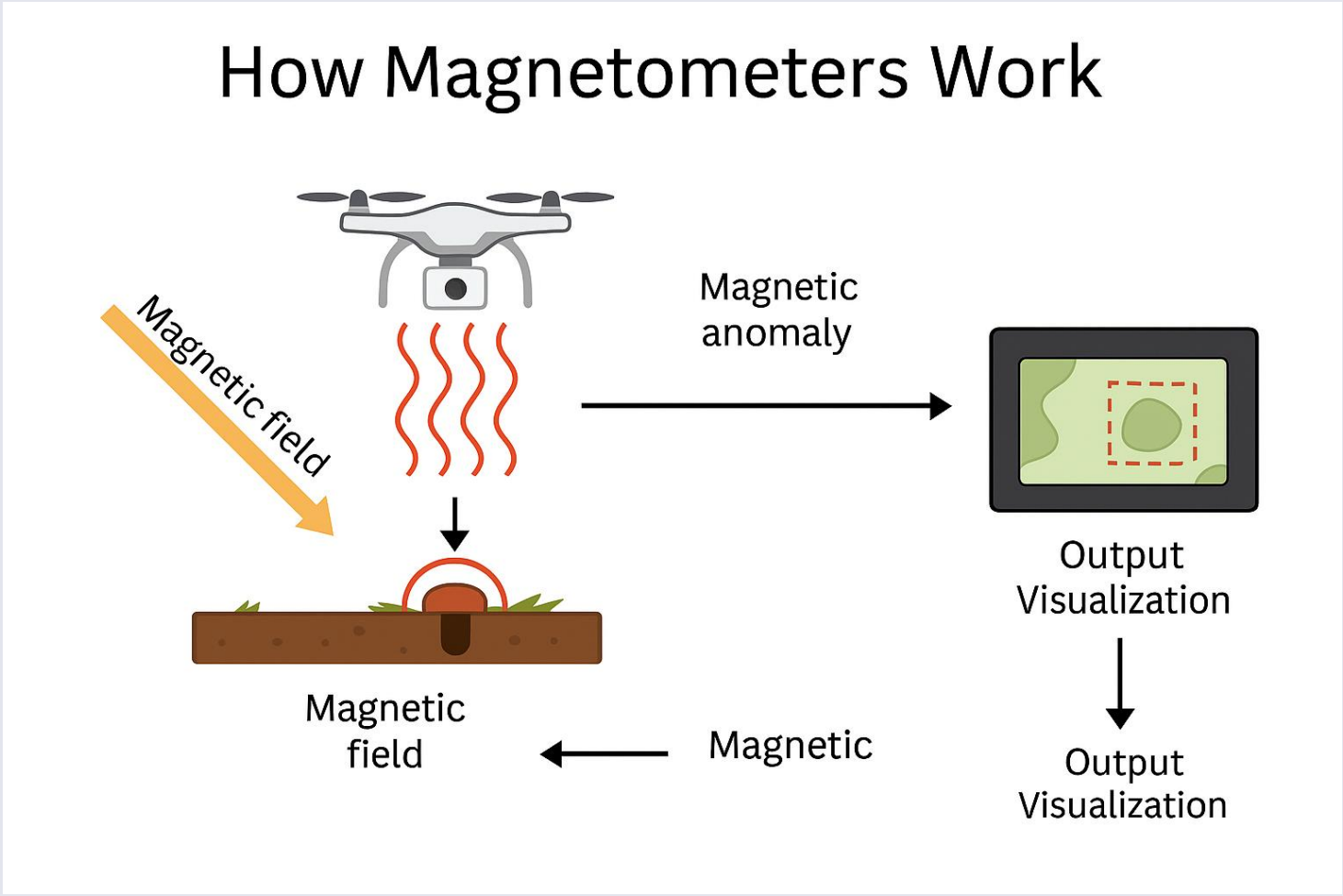
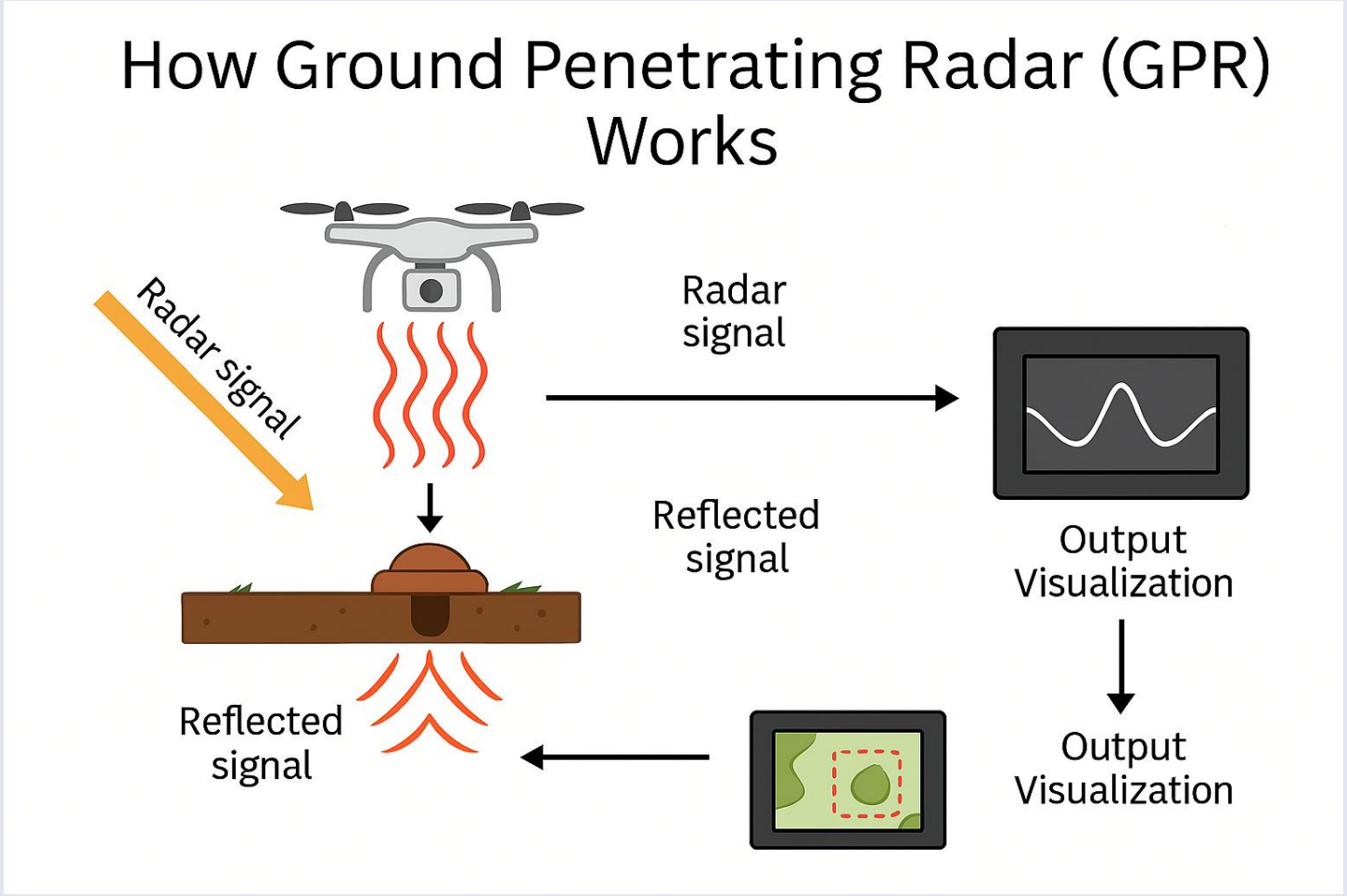


LMIoTUAV: Dedicated data acquisition systems collect sensor data, enabling real-time transmission to a ground station via Wi-Fi, Bluetooth, or telemetry links for instantaneous processing

Sensor technologies: Functionality of Magnetometers



Sensor technologies: Functionality of GPR



Features of Magnetometers

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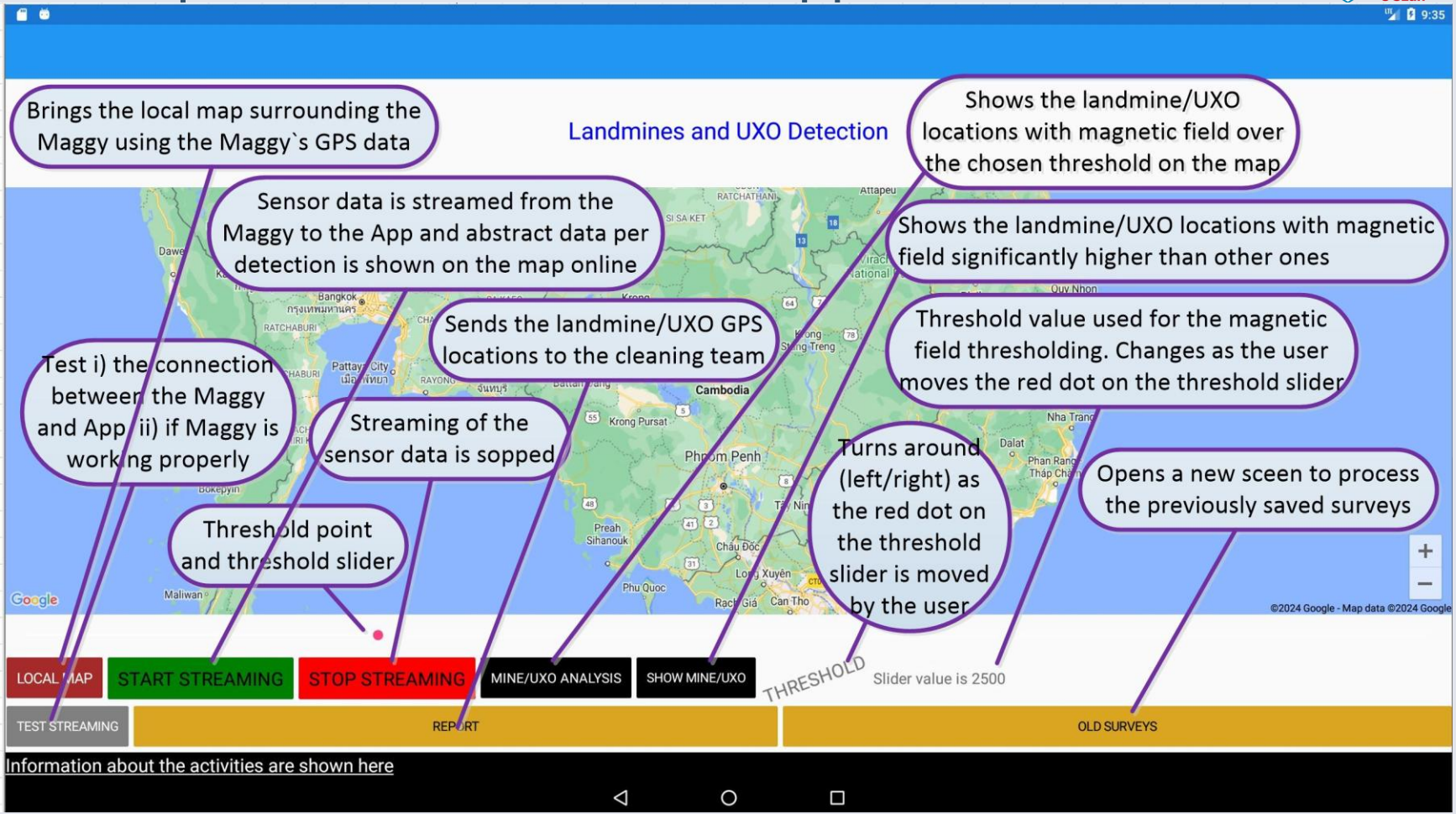
Element	Feature	Description
Magnetometer.	FGM3D/75 Fluxgate	Two FGM3D/75 Fluxgate
Operational weight	880 gr	The operational weight when mounted to the UAV is 880g including the battery.
Power supply	1V, 1,950 mAh Li-Ion	Re-chargeable battery.
Connection 1	Bluetooth	Bluetooth module is implemented into the MagDrone device.
Connection 2	Fischer connector	The Fischer connector can be used as a telemetry port.
GPS receiver 1	Internal GNSS	The GNSS receiver contains a support battery for memorising the Almanach and the configuration. The Fischer connector is used as a telemetry port becomes the GPS input.
GPS receiver 2	External GPS	The Fischer connector can be used as the GPS input while the telemetry port is Bluetooth.
Sampling	200Hz.	All three axles of every sensor are sampled at 200Hz.
Data logger	SD card	The capacity of the SD card is 2GB . This capacity is enough for about 24 hours of uninterrupted recording.
Software	MagDrone Data Tool	The MagDrone device provides a telemetry port that allows for live data output and reception of start and stop commands.
Data	Binary raw data	Moving directions, tracks and overlapping. The data can be converted into a readable format using the MagDrone Data Tool
Offset correction	Temperature offset data	Offset correction data such as temperature offset data are stored. These data are applied to the data measured by the magnetometers.

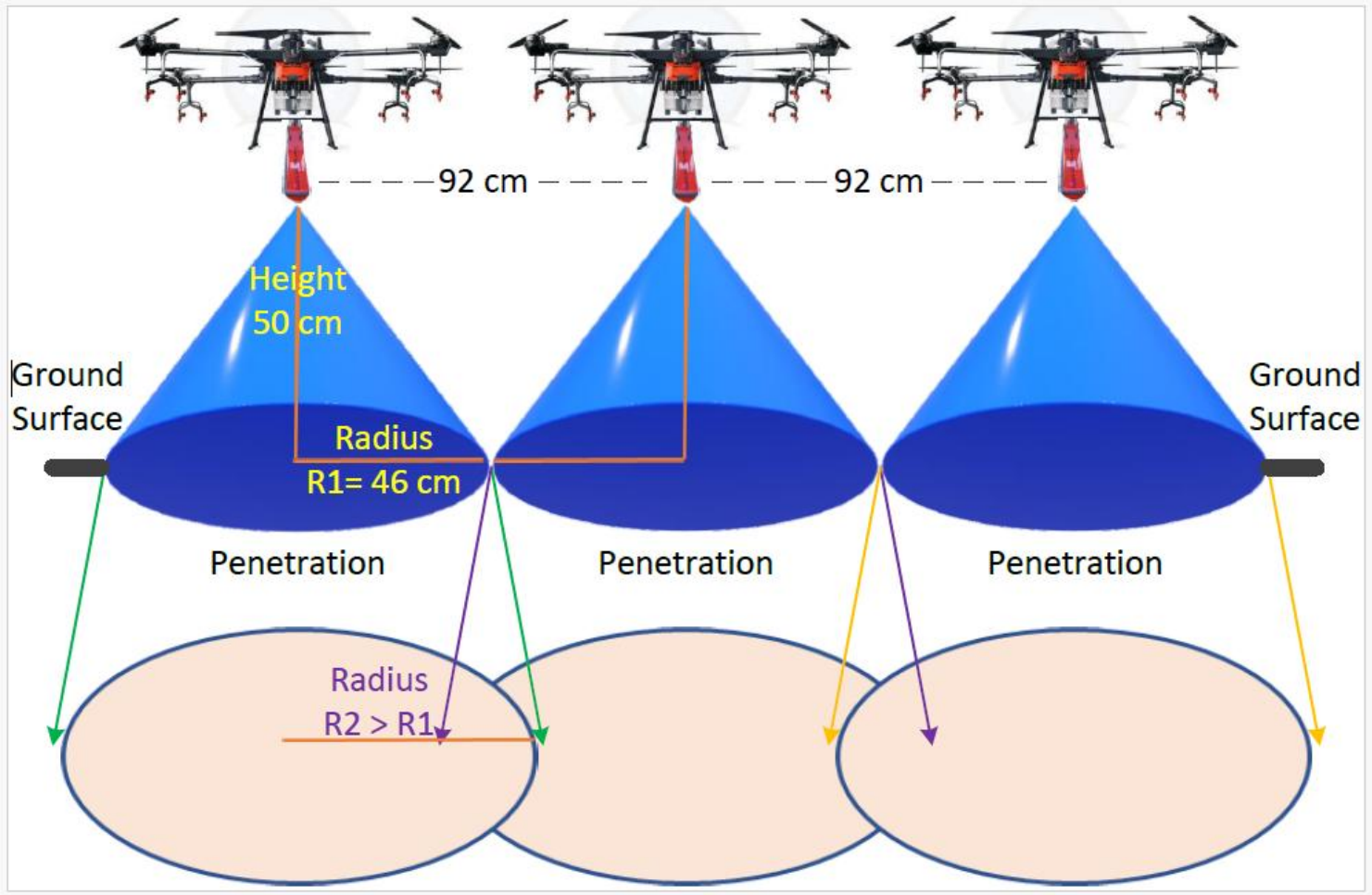
Features of GPR

- 4-channel Cobra Quattro GPR
- Bandwidths ranging from 10 to 4000 MHz
- Triple frequency antennas with 200, 400 and 800 MHz centre frequencies
- 200 MHz operates from 100 to 300 MHz,
- 400 MHz from 200 to 600,
- 800 MHz from 400 to 1200,
- Measured at -10 dB levels.
- display both shallow and deep targets simultaneously
  - ➢using an integrated 2-channel GPR that allows both shallow and deep surveys

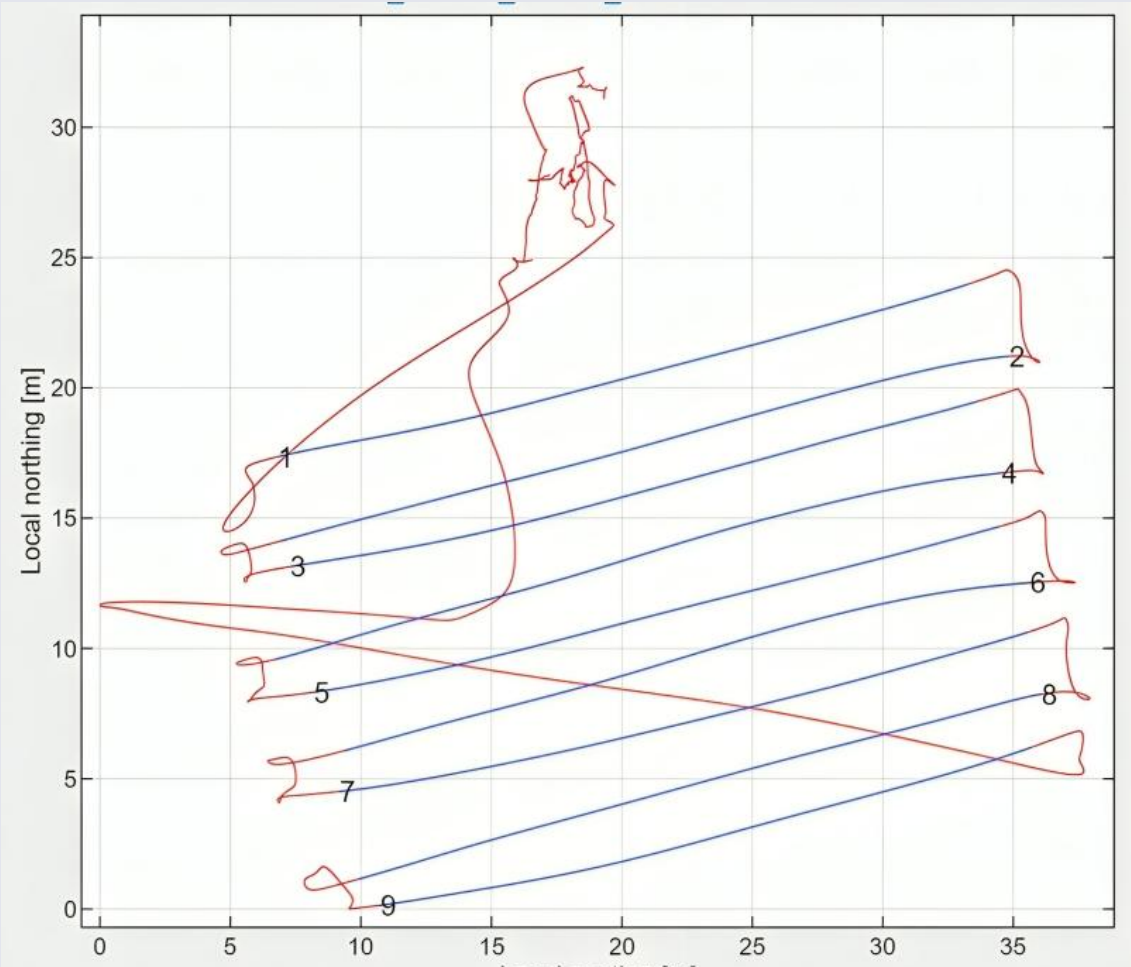
Development of the AI-based Application



Design of the flight path for data acquisition



Autonomous mission monitoring



Magnotometer and GPR in mission

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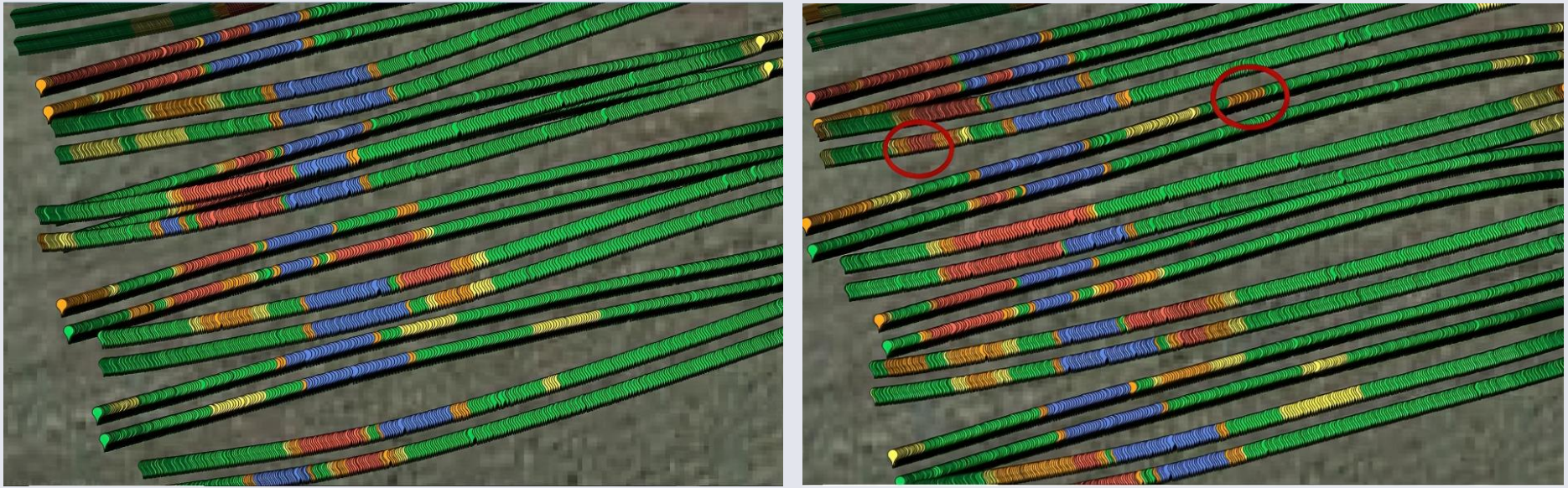

Fig. 7: All magnetometer data points highlighted with 7 categorised colours which indicate the level of MFs. Two exact parallel lines (the data points acquired from two magnetometer at a time (Fig. 1), 18 lines in total) demonstrate one flight line direction within the autonomous route with 9 lines (Fig. 6). Left: Only the magnetometer is active; right: both magnetometer and GPR are active at the same time acquiring data with no interference between them.

Magnotometer and GPR in mission

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Fig. 8: Extremely high MF points. Left: Only the magnetometer is active; right: both magnetometer and GPR are active.

RESULTS

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- The performance of the individual sensing modalities was evaluated through field tests conducted in Latvia, Croatia, and Cambodia.
- The complete integrated system tested in a landmine field in the UK.
- Results from these outdoor trials confirm the effectiveness of the proposed fusion techniques in detecting
  - ✓ legacy landmines,
  - ✓ Unexploded Ordnance (UXO) and
  - ✓ Improvised Explosive Devices (IEDs) with high accuracy.

CONCLUSIONS

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- This study mainly aims to help in making new fully automated landmine/UXO/IDE detection systems in a time-and-cost-efficient manner.
- The methods created in this study address the drawbacks of ground-based operations, such as high operator risk and inefficiency, and provide a quicker, safer, and more economical substitute for conventional landmine/UXO/IDE detection techniques.
- The developed platform in this work can be rapidly deployed by a demining team to scan a large area.
- The risk to human operators can be reduced significantly.
- This research provides the related research community and industry with fundamental design and implementation parameters (e.g. flight speed, flight altitude) in building magnetometers and GPR-integrated UAS.

BENEFITS AND IMPACT

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- It is highly imperative to detect all the explosives in one survey to speed up the demining operations safely.
- This report highlights the importance of fusing data from various sensor modalities to overcome the limitations of individual sensors in detecting explosive devices.
- Sensor data fusion significantly reduced the number of false alarms.
- Results from outdoor trials confirm the effectiveness of the proposed techniques and approaches in detecting ordnance with high accuracy.
- The developed UAS reduces danger, increases reliability, and significantly improves safety for humanitarian teams.

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