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Technical Report: Non-Invasive Detection of Explosives Using Bespoke Unmanned Aerial Systems

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Where opportunity creates success

INTRODUCTION

- 100 million buried landmines,
- 61 states worldwide impacted,
- 1,000 deminers lost their lives or suffered injuries (1999-2012),
- The precise locations of legacy landmines unknown,
- Discovering and clearing legacy explosives using a force made up of humans or animals
    - extremely risky,
    - labour- and time-intensive.
- More than a century required to remove all buried explosives using conventional methods
- Development of a landmine/UXO/IDE detection system that is quick, safe, and economical is urgent.

INTRODUCTION

- 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.
- Autonomous easy-to-use drones can
  - expedite surveying and
  - provide better access to challenging terrain with hard-to-reach topography and thick vegetation

INTRODUCTION

- In this work, an autonomous robotic drone, MagnoUAS, integrated with a magnetometer developed
  - ✓a bespoke,
  - ✓low-cost,
  - ✓small size
  - ✓lightweight
  - ✓small footprint,
  - ✓easy-to-use
- to detect landmines/IDE/UXO locations
  - ✓rapidly and safely.
  - ✓with extreme height precision and terrain following mode.

Sensor technologies

TABLE I: Properties of Fluxgate sensor — HWT3100-485.

Sr.No.	Features	Properties
1	Output	MF and heading angle
2	MF range	-800uT—+800uT
3	Heading angle range	-180—-+180
4	Sensitivity	13nT/LSB
5	Return rate	can be adjusted between 0.2-100Hz
6	Components	Built-in sensor chips: 2*Sen-XY-f(pn13104) and 1*Sen-Z-f(pn13101) geomagnetic module; 1*Mag12C(pn13156) control chip
7	Resolution	16 bits for each axis
8	Voltage	5V—36V
9	Current	<10mA
10	Volume	83mm*25mm*25mm
11	Data interface	485 serial port (the specific level depends on the selection, the baud rate
12	Casing	Waterproof and vibration-resistance aluminium casing

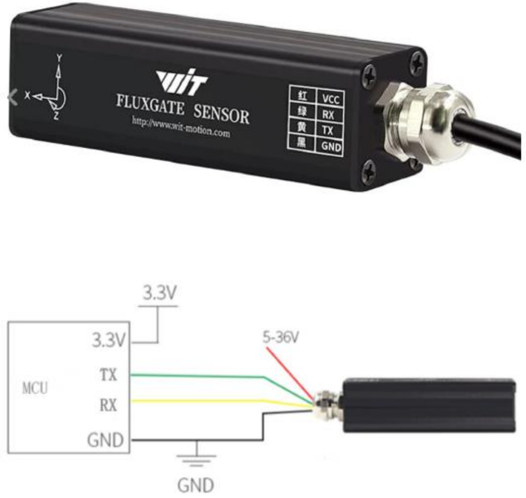

Fig. 1: Fluxgate sensor with three-axis MF output. Model: HWT3100-485.

Integration of MagnoUAS With Sensors

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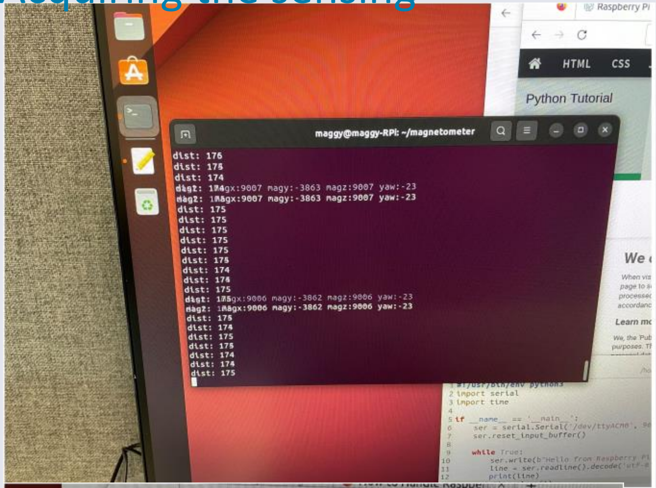
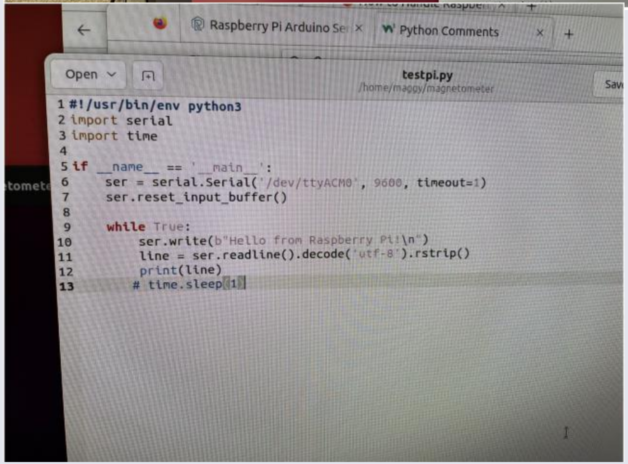
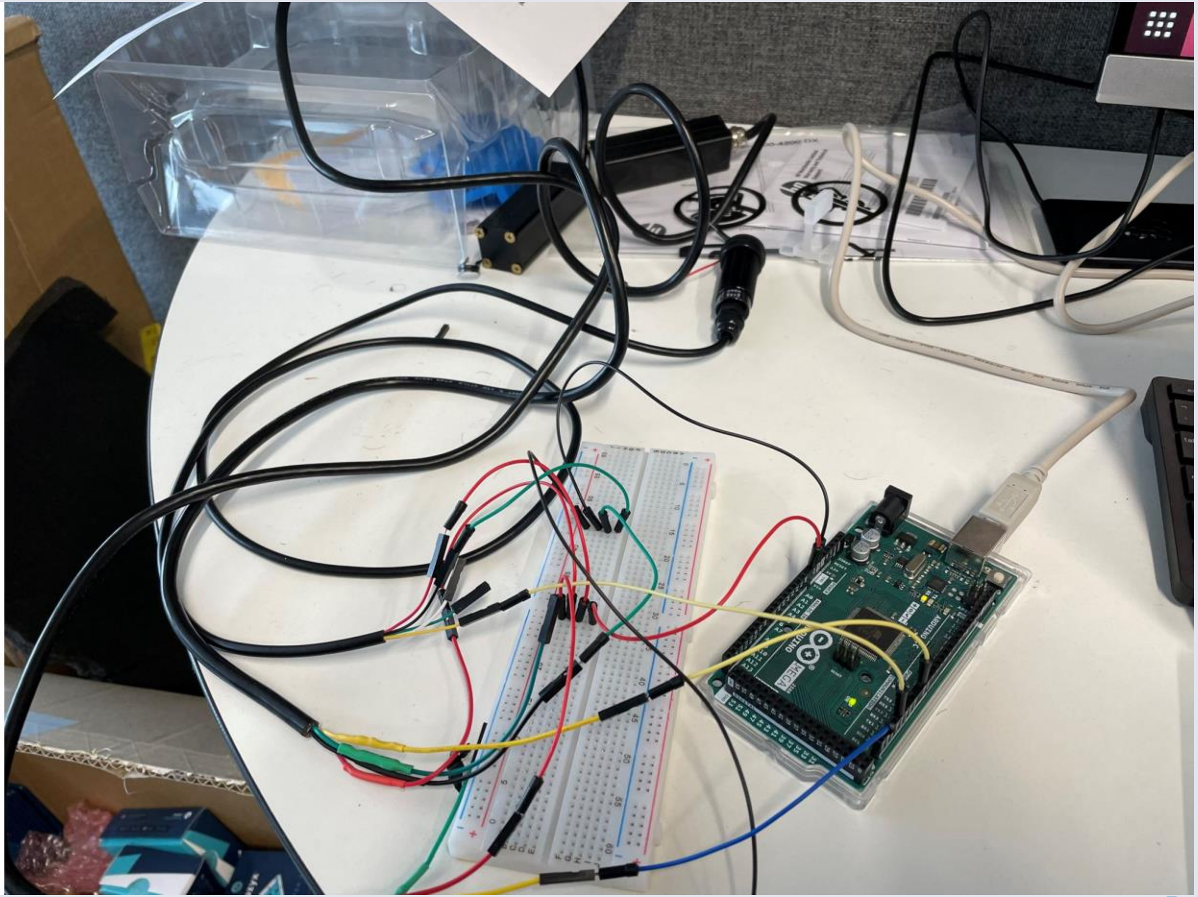
Acquiring the sensing





Programming of sensing using Python



Integration of sensors with onboard Arduino

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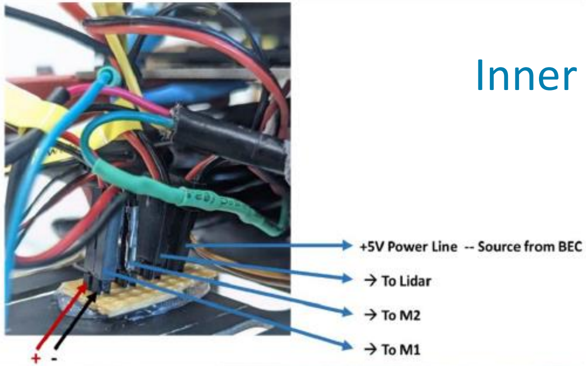
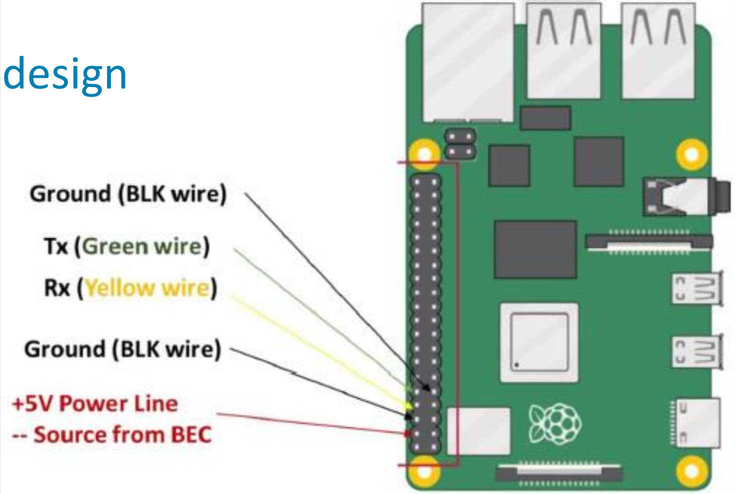
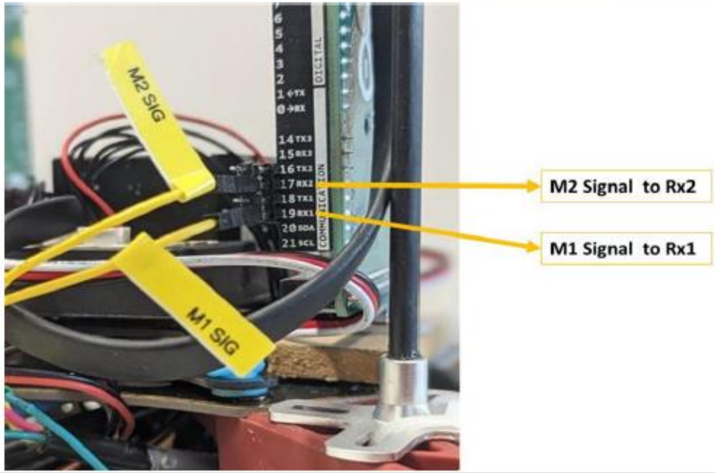
Inner component design







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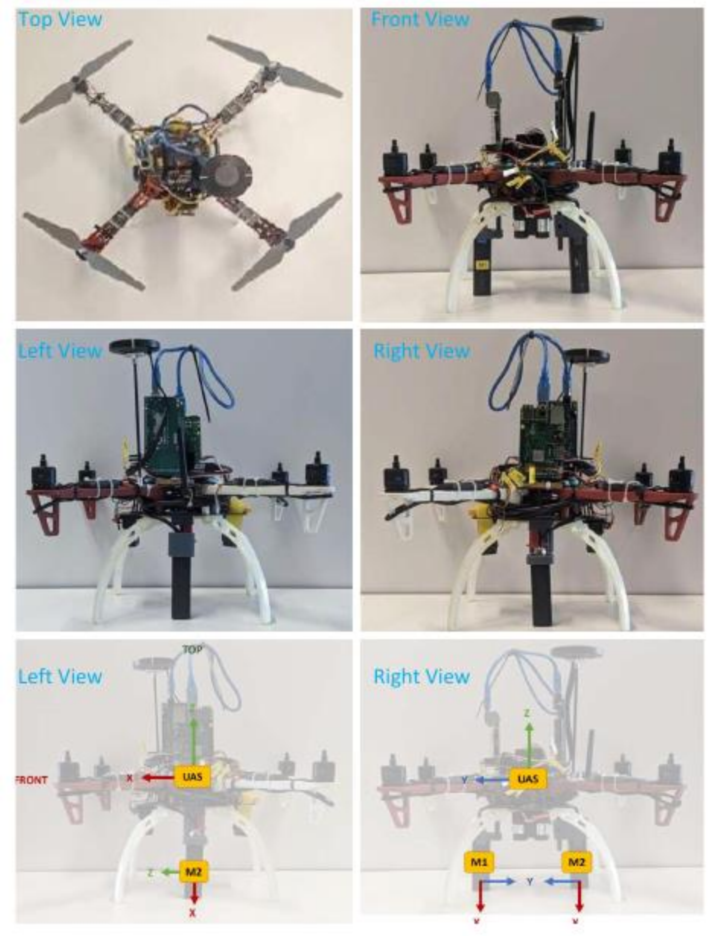
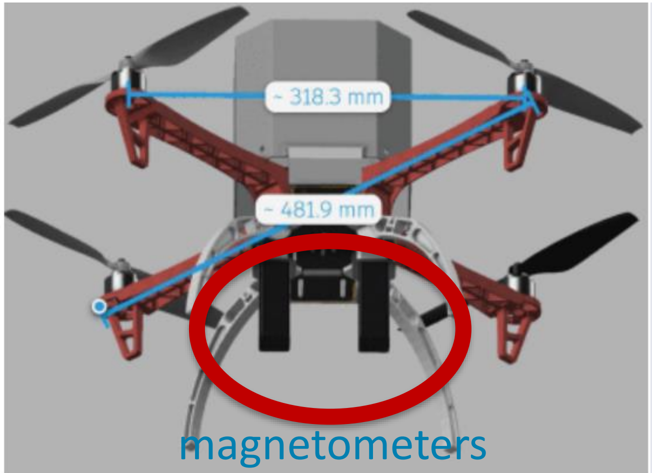


Fig. 2: Outer design of MagnoUAS.

Features of the drone

Component	Features
UAS/aircraft model name	DJI F-450
UAS battery packs	Tattu 4S 1800mah
UAS battery chargers	Overlander Charger
Transmitters model name	Futaba T8J
Transmitters battery packs	NiMH 4.8V
Transmitters battery chargers	Futaba Battery Charger
Ground station control model name	HP 15inch Laptop / Android Tablet + chargers
SiK telemetry	HolyBro ground side unit
Data communication	Netgear + charger
Data transfer	USB flash Drive, Arduino – Pi Cable
Propeller set	9X4.5
Software	QgroundControl, Wit-motion software



Features of integrated MagnoUAS

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Particular features of the integrated MagnoUAS considering operational objectives.

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.

Development of the Application

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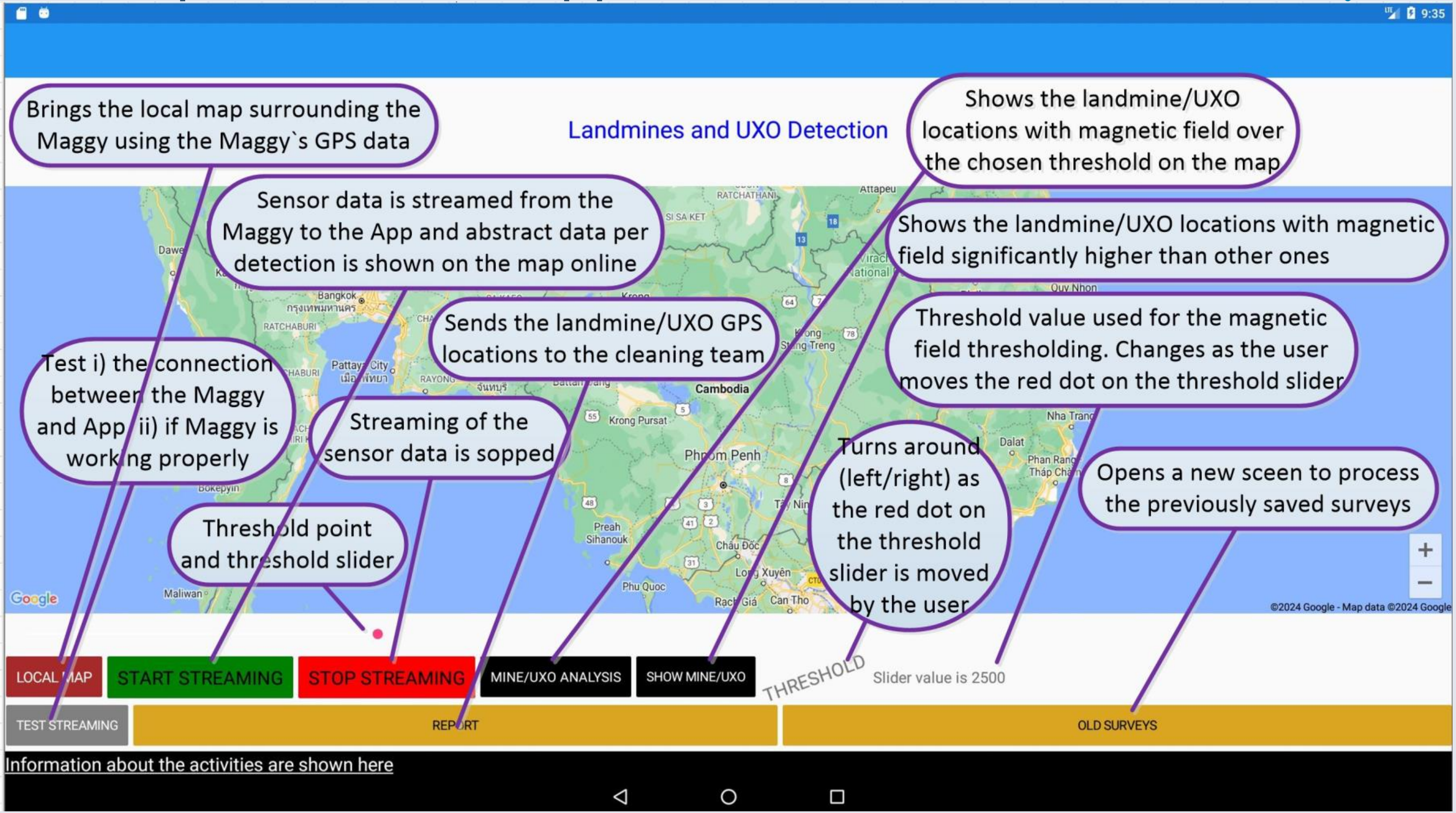

Lab tests with MagnoUAS

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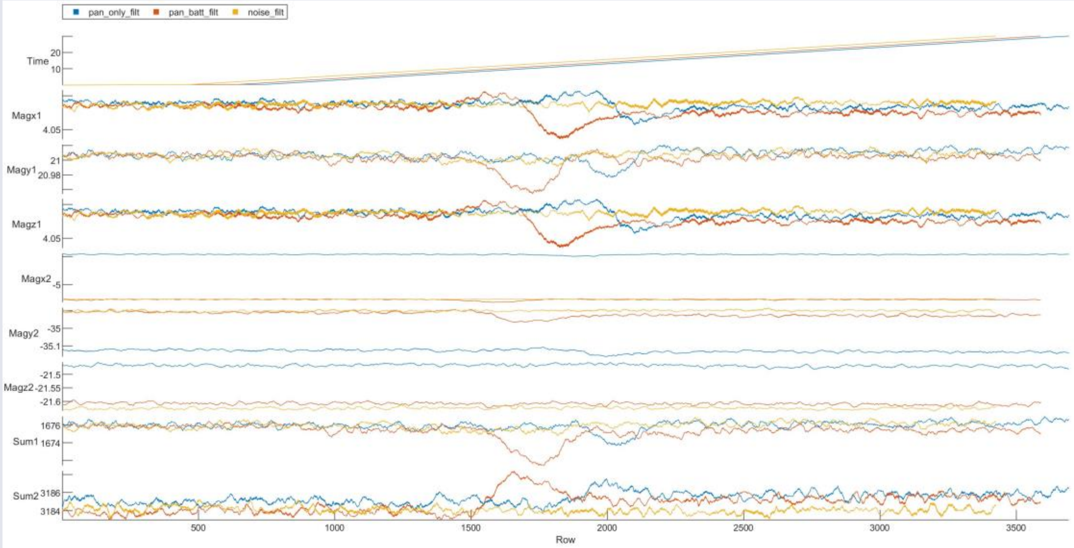


$$\begin{aligned} MF(uT) &= (Maggy_{rawdata} * Sensitivity)/1000; \\ & where\ Sensitivity = 13nT/LSB; \\ & -800uT < Maggy_{rawdata} < +800uT; \\ & 1000\ converts\ nT\ unit\ to\ uT\ (micro - Tesla); \end{aligned} \tag{1}$$

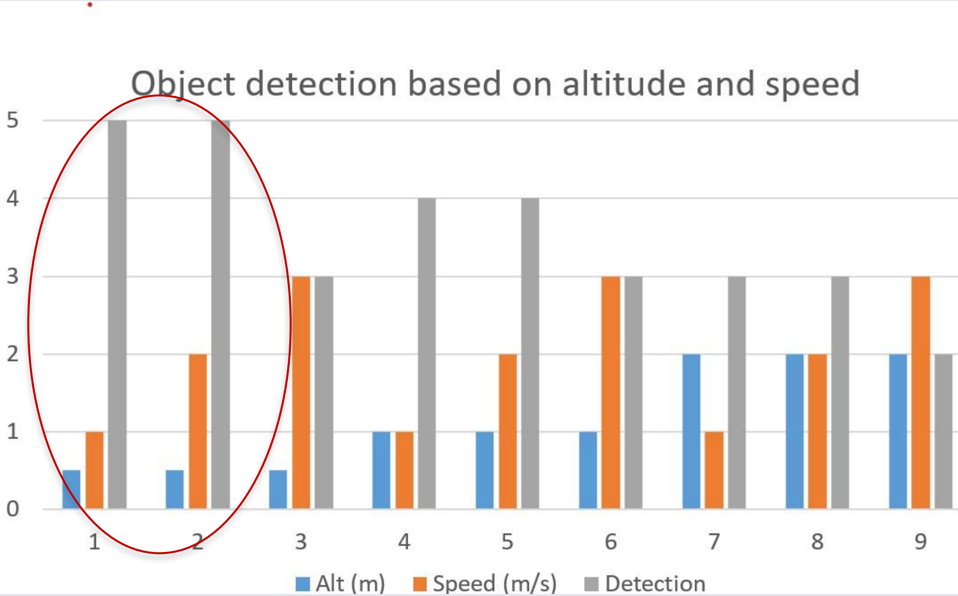
$$\begin{aligned} MF_{XYZ} &= sqrt(MF_X^2 + MF_Y^2 + MF_Z^2); \\ & where\ MF\ is\ the\ magnetic\ field\ with\ respect\ to\ axis. \end{aligned} \tag{2}$$

$$\begin{aligned} Maggy_{heading}(degrees) &= atan2(mag_y, mag_x) * (180/pi); \\ & where\ mag_x\ and\ mag_y\ are\ the\ magnetic\ field\ strength \\ & values\ in\ the\ x\ and\ y\ axes\ respectively; \\ & 180/pi\ converts\ radians\ to\ degrees; \end{aligned} \tag{3}$$

X, Y and Z component directions of the magnetometers are processed as formulated in Eqs. 1, 2, 3

Lab tests with MagnoUAS

			Metalic part	Very High	Very Low	Low	High	Very High
			Depth (m)	0.25	0.25	0.1	0.25	0.5
#	Alt (m)	Speed (m/s)	Detection					
1	0.5	1	5	✓	✓	✓	✓	✓
2	0.5	2	5	✓	✓	✓	✓	✓
3	0.5	3	3	✓	–	–	✓	✓
4	1	1	4	✓	–	✓	✓	✓
5	1	2	4	✓	–	✓	✓	✓
6	1	3	3	✓	–	–	✓	✓
7	2	1	3	✓	–	✓	✓	–
8	2	2	3	✓	–	✓	✓	–
9	2	3	2	✓	–	–	✓	–



MagnoUAS operates with high detection accuracy at low altitudes and speeds (i.e., 0.5 m, 1 m/s).

Field tests with MagnoUAS at UCLAN Landmine Field

Fig. 4: Autonomous use of MagnoUAS in the UCLan landmine field. All data points.

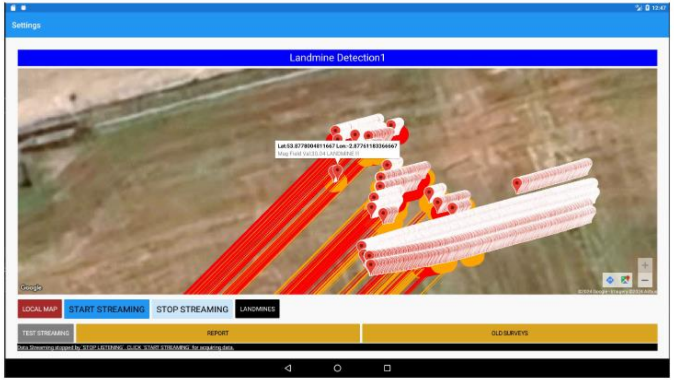


Fig. 5: Landmine locations, until the current scanned point in the route, shown by user during data streaming while MagnoUAS is still in operation.

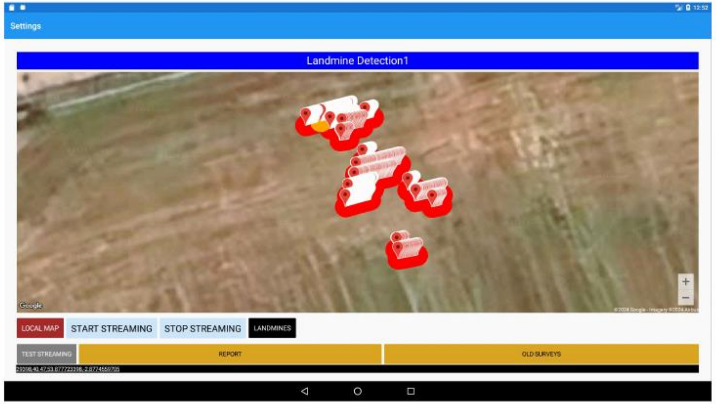


Fig. 6: All landmine locations, with "very high" MF (red), shown by the user.

Fig. 7: Landmine locations, with "very high" (red) and "high" (orange) MF, shown by the user.

Real field tests at the Latvia Field

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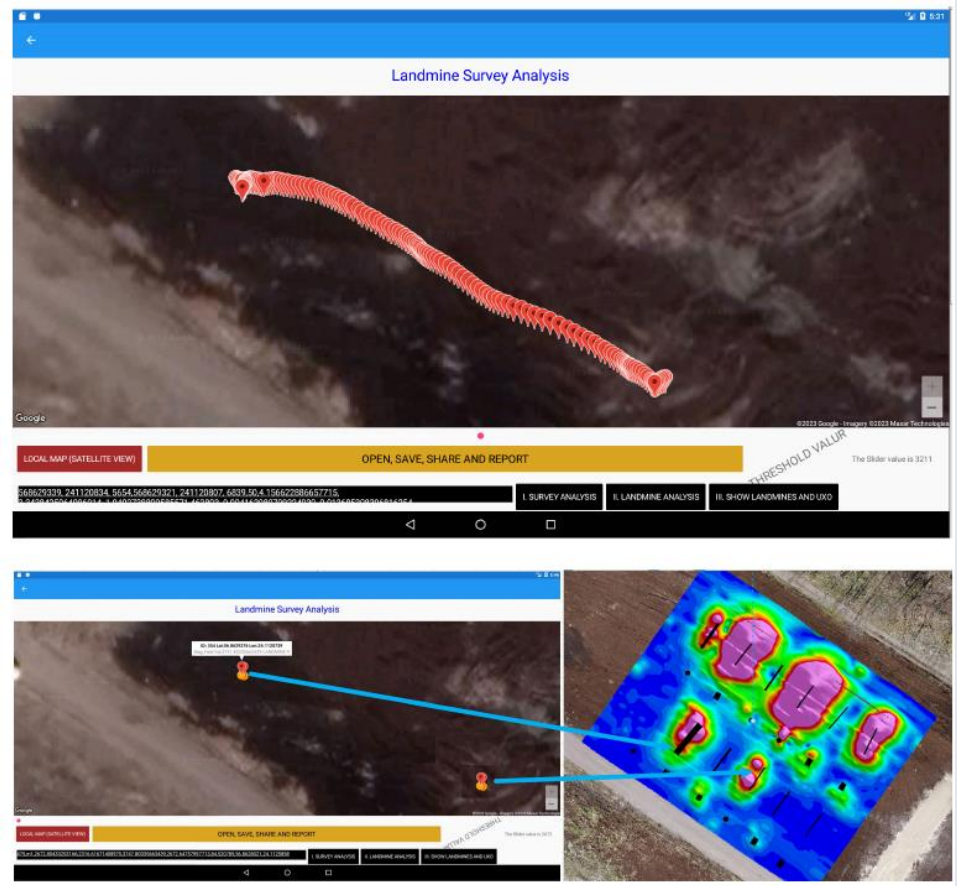

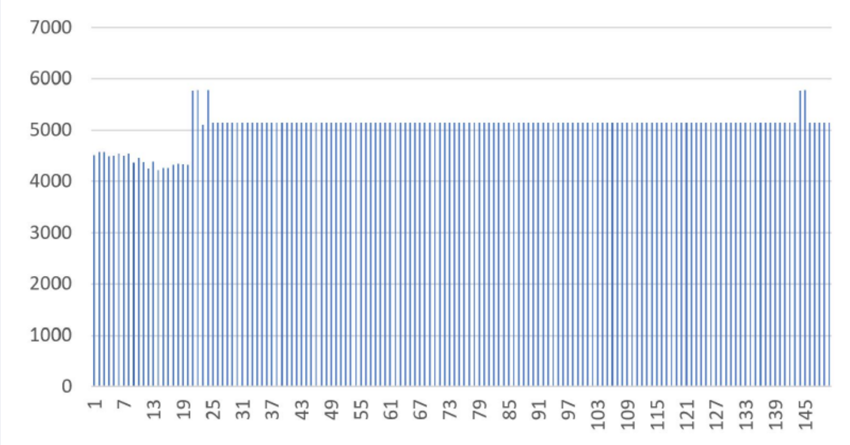

Fig. 8: Latvia field test -III-. Top: all data points; middle: high MF; bottom: MF graph for all data points in the route depicted at the top.

DISCUSSION AND LIMITATIONS Evaluation of MagnoUAS

#	CRITERIA	✓/-	NOTES
1	Detection of all explosive types	-	only explosive objects with ferrous metals can be detected by Maggy.
2	Determination of the type and composition of metallic objects	-	only MF location of metallic objects can be detected.
3	Small and light weight	✓	Fig. 19, payload < 1 kg.
4	Manoeuvrable	✓	rotary, vertical take-off and landing.
5	Terrain following mode	✓	Maggy uses a radar altimeter.
6	Autonomous/automated mode	✓	Maggy uses UgCS system – drone flight planning software.
7	Low energy consumption	✓	Fig. 19, payload < 1 kg, most of the processing and computing is performed by the tablet application.
8	Good flight time, long battery life	-	Maggy can fly 4.5 minutes per battery
9	Robust	✓	Maggy was designed to perform robustly (Figs. 11, 12, 13, 14). The GPS component will be replaced with a robust one.
10	Accurate/reliable	✓	Maggy is tested in the benchmark test fields with the benchmark outputs.
11	Air-to-ground data streaming	✓	Maggy provides near real-time scanned streaming data to the user while in operation.
12	Real-time data processing	✓	Maggy provides real-time scanned streaming data to the user, which is displayed on a small tablet/smartphone device.
13	Easy to use/off the shelf	✓	Maggy is a compact tool.
14	User friendly	✓	30 minutes of training is sufficient to use Maggy effectively.
15	Resource friendly	✓	not resource-hungry processing. Ability to run ordinary computing device.
16	Ability to analyse old surveys	✓	AI-based tablet/smartphone application provides users with multiple decision-making abilities.
17	Classification and clustering abilities	✓	AI-based tablet/smartphone application provides users with multiple decision-making abilities.
18	Ability to fly under 1 meter	✓	to increase the efficacy of sensors.
19	Small footprint	✓	Fig. 19, payload < 1 kg.
20	Accessible, low-cost, affordability	✓	Maggy is low-cost compared to commercially available magnetometer systems.

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, the so-called MagnoUAS, is a small, lightweight drone that can be rapidly deployed by a demining team to scan a large area for any magnetic anomalies caused by the presence of metal in landmine/UXO/IDE.
- The risk to human operators can be reduced significantly with MagnoUAS.
- This research provides the related research community and industry with fundamental design and implementation parameters (e.g. flight speed, flight altitude) in building and using magnetometer-integrated UAS.

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