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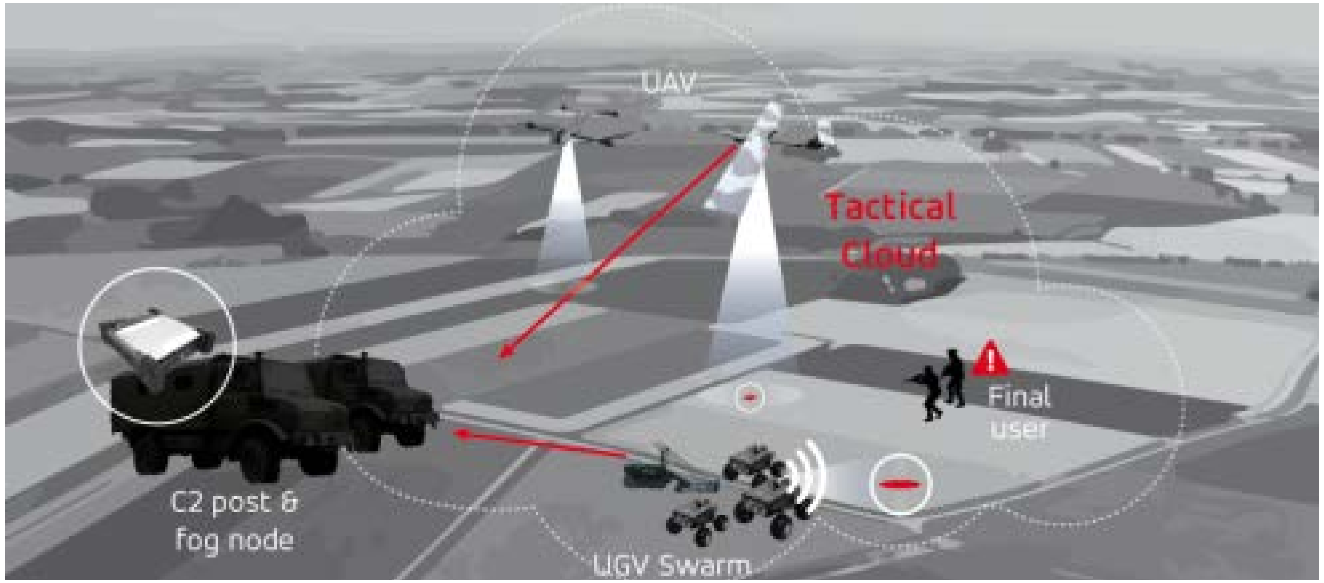
Model-Based GPR Landmine Detection Using Full-Wave Inversion

M. Freixo Gonçalves

Co-Authors: P. Bielski, S. Lambot, É. le Flécher, G. De Cubber

This project has received funding from European Defence Fund under call 2022 EDF-2022-LS-RA CHALLENGE-DIGIT-HTDP

CONVOY



Multi-robot, multi-sensor mine detection system

UGV swarm
Autonomous ground robots for area scanning

Multi-sensor
GPR, EMI, THz, IR-Laser, Solid-State LiDAR, cameras

Tactical Cloud
Shared situational awareness

C2
Real-time alerts to operators

This talk : Model-based GPR landmine detection using Full-Wave Inversion — first field results from DOVO

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European Commission

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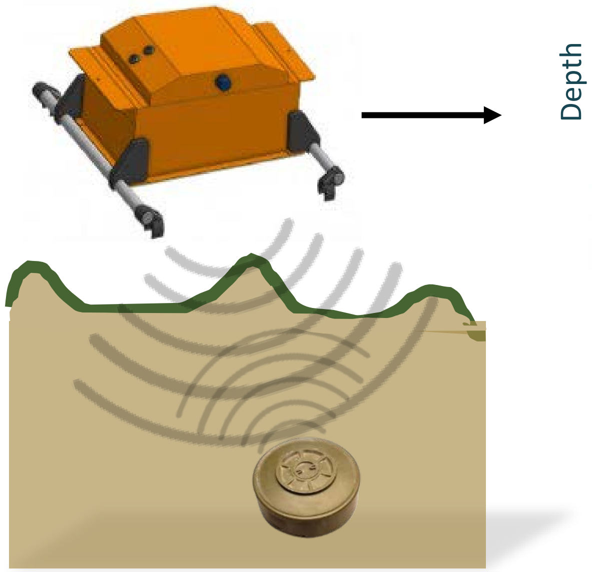
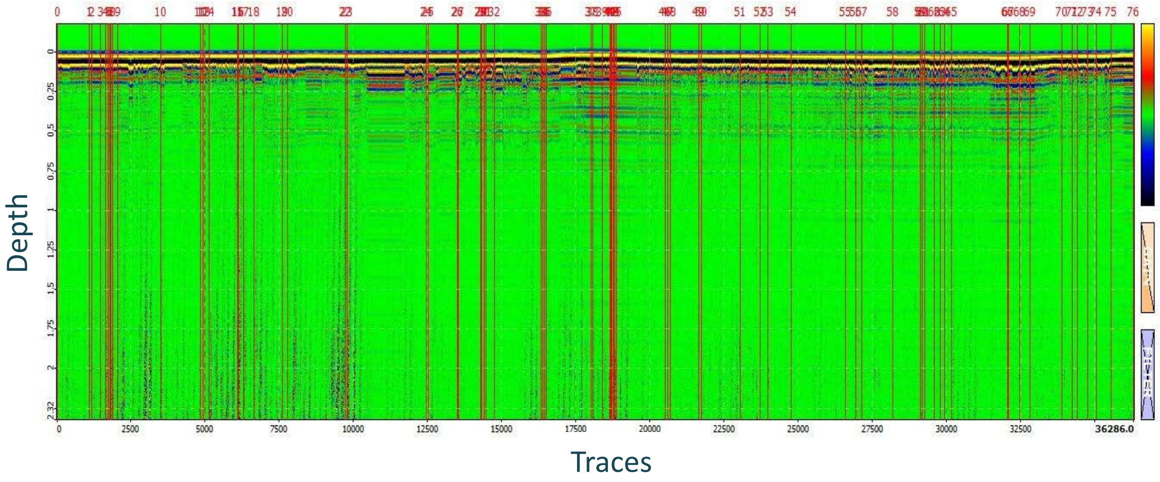
Temporal Ground Penetrating Radar (GPR)

Zond-Aero 500, RadarSystems



Radargram (B-scans)



Difficult to develop ATR

Automatic Target Recognition (ATR) requires extensive signal processing

Relies on hyperbola detection

Clutter from soil moisture complicates detection

Prone to false alarms

Inhomogeneous soil produces similar B-scan signatures

Stepped-Frequency Continuous-Wave (SFCW) - GPR

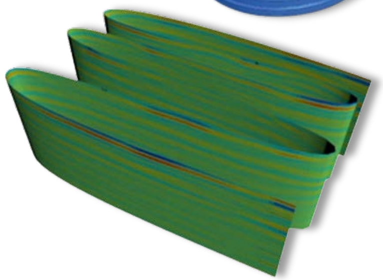
Model-based approach using Green's function EM formulation

ALIS® handheld GPR
Sato (Tohoku University)

800 MHz – 2.6 GHz
Step-Frequency Continuous-Wave radar

Dual sensor (EMI + GPR)
SAR processing for 3D mine imaging

Field-proven system
54 units deployed to Ukraine, Cambodia, Colombia



gprSense®
Lambot (UCLouvain)

800 MHz -6.0 GHz
Same waveform: SFCW

Model-based approach
Green's function EM formulation of the radar equation

Geolocalised data
EMLID M2 GNSS/RTK receiver

Web-based User Interface
Live data visualisation

Robot integration
TCP/IP communication and ROS2 driver

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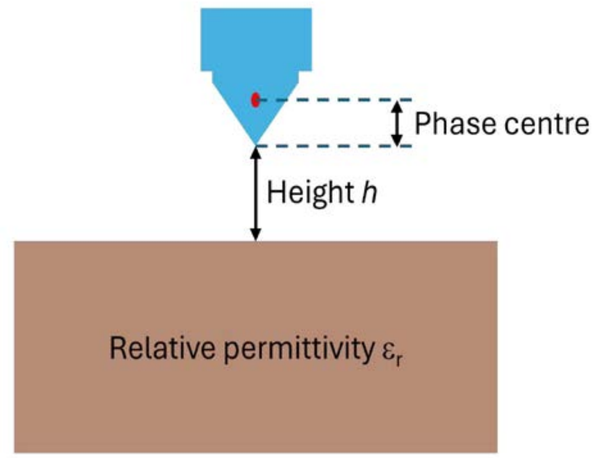
Image from Motoyuki Sato , Tohoku University, Emerging Trends in Radar: Ground Penetrating Radar for Landmine Detection, DOI. No. 10.1109/MAES.2025.3540830

gprSense® × Full-Wave Inversion

Model-based approach to subsurface characterisation



Half-space assumption

Model assumes one uniform soil layer.

Bare soil

Model fits → ϕ low & stable

Buried object

Model fails → ϕ spike + ε_r shift

Measured signal

$S_{11}(f)$ at each frequency step

$G_{xx}(f)_{\,measured}$

EM forward model

Homogeneous half-space for (ε_r, h)

$G_{xx}(f, \varepsilon_r, h)_{modelled}$

Objective function

$$\phi = \| G_{meas} - G_{model} \|^2$$

minimise over (ε_r, h)

ϕ — Model error

Detection feature

ε_r — Soil permittivity

Material classification

h — Sensor height

Antenna-to-ground distance quality control

Real-time output at each position — no B-scan preprocessing required

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Field Tests at DOVO

Belgian demining center — June 2025

Test conditions

- Outdoor environment
- Multiple targets buried at 5–15 cm depth
- Robot teleoperation, back-and-forth passes
- Two orthogonal scan directions per target
- Ground truth via manual keypress triggers

Robotnik Summit-XL + gprSense® during data collection at DOVO

Goal: can ϕ and ε_r alone serve as simple ATR features?

ROBOTICS & AUTONOMOUS SYSTEMS

RMA Royal Military Academy

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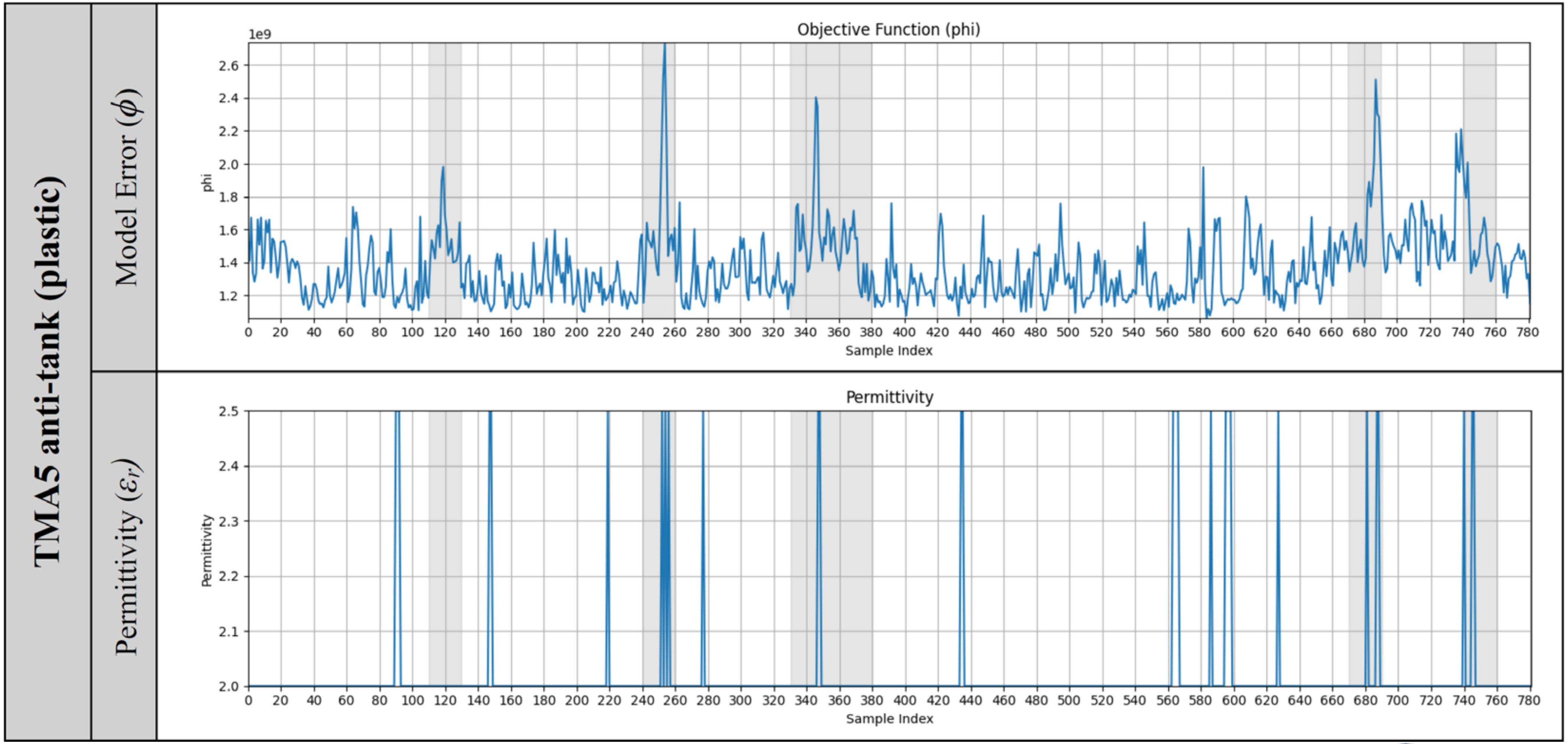
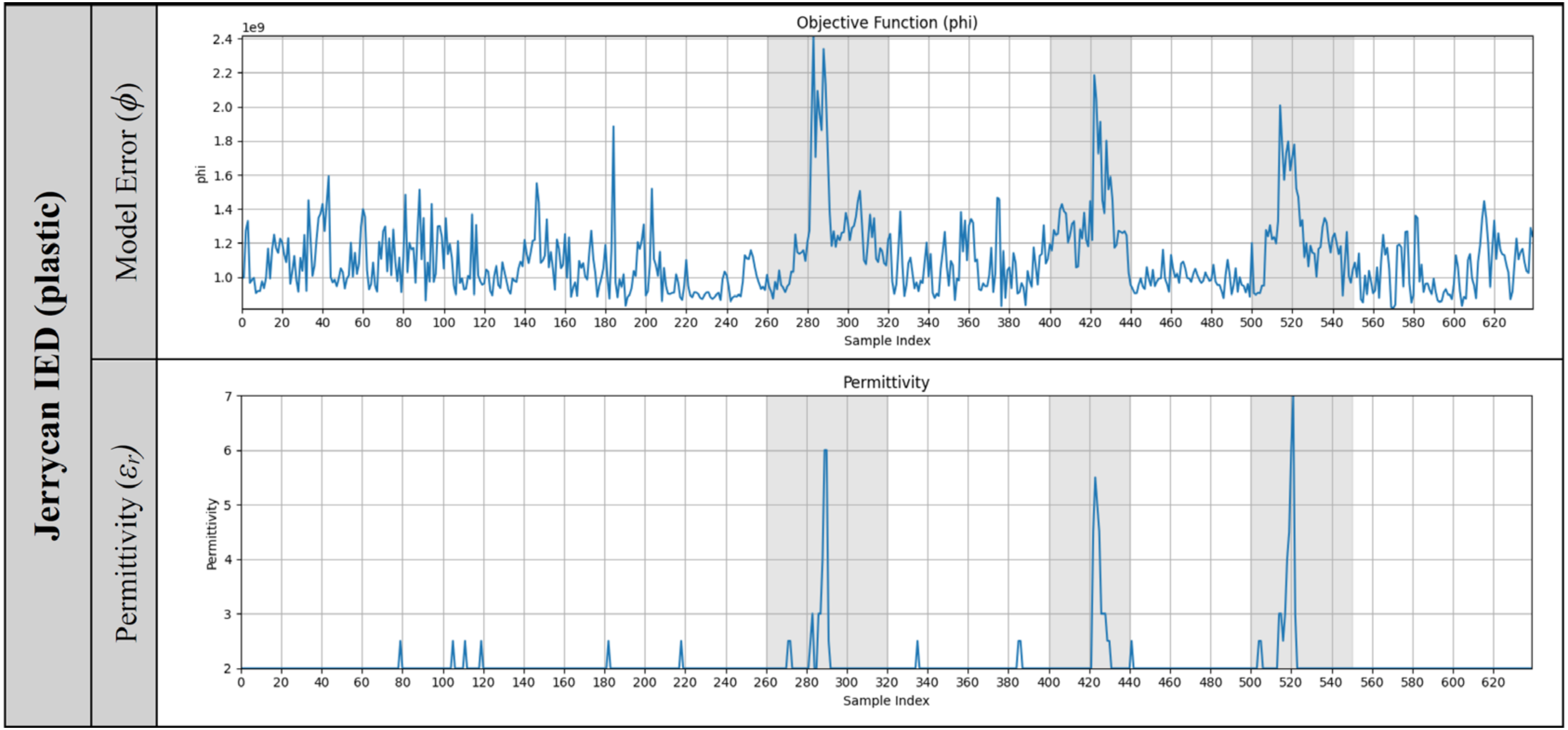
Target used

TMA5 Plastic AT mine	Jerrycan 10L Plastic IED simulant	105 mm Shell Metal IED
Buried 	Buried 	Buried 
Excavated 	Excavated 	Excavated 

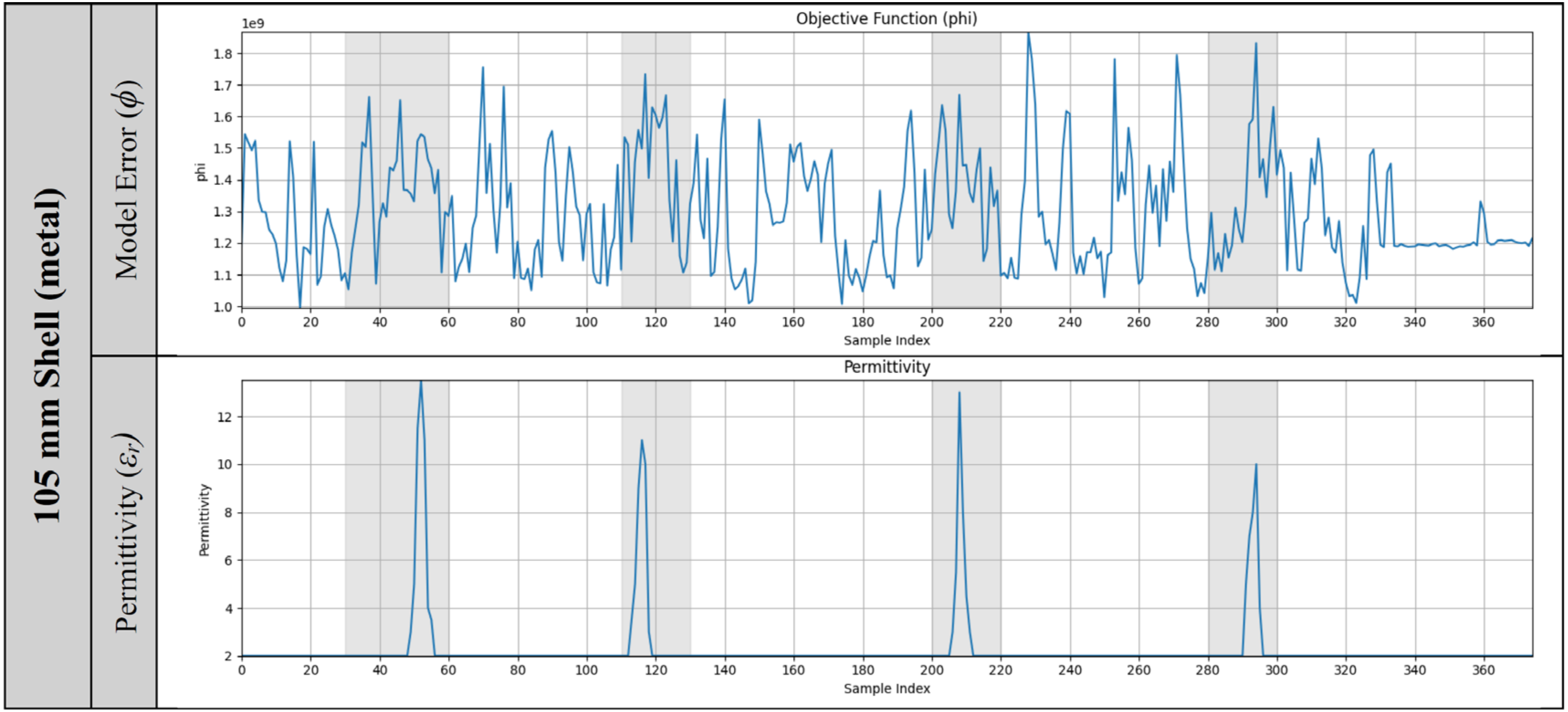
TMA5 – Plastic AT mine



Jerrycan 10 L – Plastic IED



105mm shell – Metal IED



Conclusions

TMA5 Anti-Tank	ε_r stable	φ ↑ (clear spikes)
Plastic Jerrycan 10 L	$\varepsilon_r \approx 6\text{-}7$	φ ↑ (clear spikes)
105 mm Metal Shell	$\varepsilon_r \approx 10\text{–}13$	φ stable

Key Takeaway

The gprSense® SFCW-FWI outputs (φ, ε_r) provide physically meaningful ATR features directly usable for detection and preliminary material classification — no B-scan preprocessing or hyperbola detection required.

Discussion & Next Steps

3D Subsurface Imaging

SAR (migration) processing of SFCW data

SFCW is ideal for SAR: discrete measurements at each frequency step enable coherent synthesis

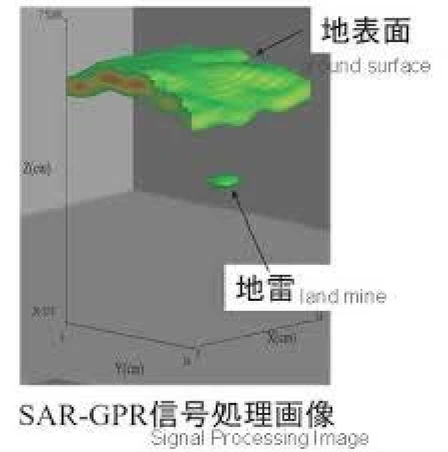


Image from ALIS https://alisys.co.jp/en/alis-tech-en/

2D Scanning Gantry

Rigid mechanical support on robot
Enables repeatable 2D raster scans for SAR input

Eliminates vibration artefacts from current plexiglass crane arm