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Upgrading Metal Detection to Metallic Target Characterization in Humanitarian Demining

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Outline

- Background and motivation
- Metallic target characterisation (MTC) concept
  - State-of-the-art
  - Induced dipole model
- Experimental research
- Towards potential deployment in the field
- Conclusions

Background and motivation

- Conventional metal detectors (MDs) → prime tools for close-in detection in humanitarian demining (HD)
- Recent developments of MD technology focus on:
  - Increasing sensitivity (i.e. probability of detection)
  - Enhancing performance over non-cooperative soils
  - Improving other technical features (device autonomy, etc.)
- The problem:
  - Inability to discriminate between mine and metallic clutter results in extremely high false alarm rates (FAR)
- The challenge:
  - Reduction of FAR by upgrading metal detection to **metallic target characterisation** using advanced electromagnetic induction (EMI) methods ?

Metallic target characterisation (MTC) concept

- MTC implies getting information on target's:
  - Average size
  - Shape (principal axes aspect ratio)
  - Spatial orientation
  - Relative position in 3D
  - Material properties (electrical conductivity / magnetic permeability).
- Extracted information could provide a reliable basis for target classification and identification
- Implementation - decision support system for detection, confirmation and excavation phase
- MTC using a single (EMI) sensing modality only, as opposed to existing multi-sensor approaches

State-of-the-art in MTC

- Methods relying on analytical EMI-based models are field-proven in security, geophysical surveys and non-destructive testing (NDT) applications.
- Models featuring magnetic dipole approximation:
  - Induced dipole model (suitable for “small” targets)
  - Models featuring discrete number of spatially distributed magnetic dipoles (“large” targets, UXOs..)
- Computationally efficient parameter estimation, capable of operating in real-time
- Still no commercial devices for HD applications!

Induced dipole model

- Model parameters:
  - Magnetic polarizability tensor (MPT)
  - Target position

$$\vec{m}_{\text{target}} = \overleftrightarrow{M}\vec{H}_{\text{prim}}(\vec{r}_{\text{TX}} - \vec{r}_{\text{target}})$$

Magnetic moment of the target, **M** is MPT (symmetric 3x3 matrix)

$$\vec{H}_{\text{sec}}(\vec{r}, \vec{r}_{\text{TX}}, \vec{r}_{\text{RX}}) = \frac{1}{4\pi|\vec{r}|^3}\left(\frac{3\vec{r}(\vec{r}\cdot\vec{m}_{\text{target}})}{|\vec{r}|^2} - \vec{m}_{\text{target}}\right)$$

Magnetic field of a target at the receiver location

$$\vec{u}_{\text{RX}} = f_{\text{FWD}}(\overleftrightarrow{M}, \vec{r})$$

Forward function

- Forward function:
  - Linear with respect to MPT
  - Non-linear with respect to target position

Estimating target geometry /material type

- Model parameters (***M,r***) obtained through nonlinear optimization algorithm based on the least-squares criterion,

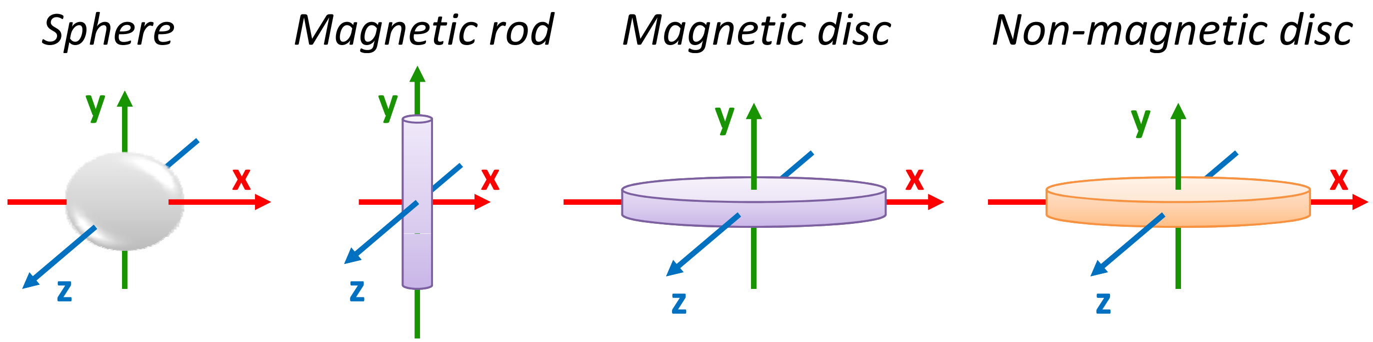
$$\arg\min\left(\left\| \vec{u}_{\mathrm{meas}} - f_{\mathrm{FWD}}\left(\overleftrightarrow{M}, \vec{r}\right) \right\|^2 \right)$$

- Extracting target information from MPT:

$$\overleftrightarrow{M} = \overleftrightarrow{R}^T(\theta,\phi)\overleftrightarrow{\beta}(\omega)\overleftrightarrow{R}(\theta,\phi) \qquad \overleftrightarrow{\beta} = \begin{bmatrix} \beta_x(\omega) & 0 & 0 \\ 0 & \beta_y(\omega) & 0 \\ 0 & 0 & \beta_z(\omega) \end{bmatrix}$$

- Target orientation – from rotation matrix ***R***
- Target shape and material properties – from frequency dependent eigenvalues of ***M***

Extracting target information from MPT

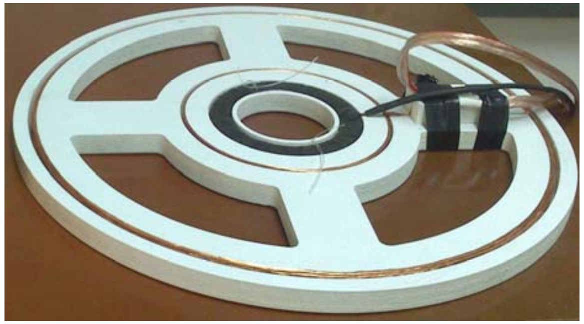


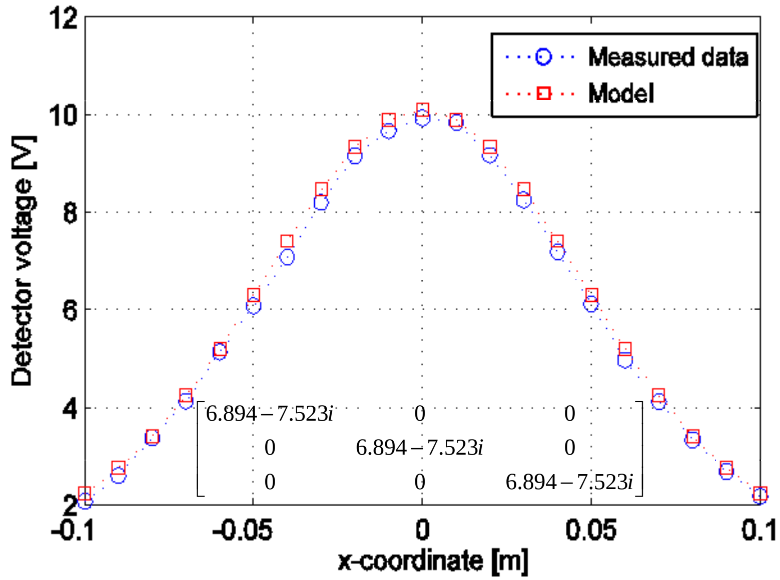
$$\begin{bmatrix} \beta & 0 & 0 \\ 0 & \beta & 0 \\ 0 & 0 & \beta \end{bmatrix} \quad \begin{bmatrix} 0 & 0 & 0 \\ 0 & \beta & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad \begin{bmatrix} \beta & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \beta \end{bmatrix} \quad \begin{bmatrix} 0 & 0 & 0 \\ 0 & \beta & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

Basic principles of metallic target characterisation via magnetic polarizability tensor

Experimental research (AIG, UniZG-FER)

- Development of a next-generation EMI detector for landmine detection in humanitarian demining
- Experiments on laboratory samples of test targets (ITOPs, CWA-14747).
- Inversion procedures for the estimation of target position and MPT optimized with respect to execution speed and low SNR.





Towards deployment in the field

- Tracking the relative position and spatial orientation of the detector's sensing head during scanning motion
  - Handheld device – tracking system with sub-centimetre accuracy and high update rate needed
  - Robotic application – defined by manipulator kinematics
- Preferred mode of operation
  - Handheld device – two-step procedure (standard MD + MTC mode)
  - Robotic application - depends on objectives and requirements of a particular robotic mission

Conclusions

- In order to overcome the well-known limitations of existing metal detector technology in terms of FAR, a new mine detection concept relying on model-based metallic target characterisation (MTC) is proposed.
- MTC concept already verified in other applications (such as security and UXO detection)
- The concept could lead to a new enabling technology for developing next-generation metal detection devices – either in the form of manual mine detectors or for integration with robotic systems.

Incoming events

Deadlines:
24 October 2014

Link:
http://sensorapps.org/sites/default/files/uploads/sas-2015_cfp_v5.pdf

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