Inspection Technologies for a Better World

Target Vehicle Selection Using Heading, Speed and Magnetic Signature

Mines, Demolition & Non-Lethal Conference and Exhibition

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A.R. Perry, P.V. Czipott, Y. Dalichaouch, S. Kumar, and H. Trammell

Quantum Magnetics, Inc.

Presentation Outline

- **Brief Corporate Background**
  - Historical sketch
  - Core technologies
- **Magnetic Gradiometry**
  - What and why
  - How much information do you need?
  - Quantum Magnetics' work in gradiometry
- **Magnetic Tracking**
  - Magnetic Tracking Demonstration
  - Results on other programs
  - Vehicle Tracking
- **Summary and Conclusion**

Corporate Background

- **Founded in 1987 and started operations in 1988 as R&D subsidiary of Quantum Design (QD)**
  - **World's leading developer and manufacturer of laboratory instrumentation using superconducting (SQUID) magnetic sensors**
- **Major responsibilities: Government contract R&D and QD product development**
- **Major technology areas:**
  - **Magnetic sensing (primarily SQUIDs)**
  - **Low-Field Magnetic Resonance (MR)**

Corporate Background

- **Early 90's: began developments in Quadrupole Resonance (QR)**
- **1994: became independent company to pursue airport security market with QR explosives detection technology**
- **1997: became independently operated subsidiary of InVision Technologies in a pooling of assets**
- **R&D and product sales to date total >$50M**

Selected Technology Awards

- **R&D 100 Award, 1992:** High-Resolution Scanning Magnetometer
- **R&D 100 Award, 1995:** QR Explosives Detector (QED)
- **Aviation Week & Space Technology Award, Most Innovative Product, 1997:** QScan-500 checked baggage scanner
- **SBIR Technology of the Year Award, Sensors, 1998:** QR strain gauge
- **SBIR Technology of the Year Award, Grand Prize, 1999:** QR landmine detection

Customer Base

- **DOD**
  - **<u>Navy</u>: ONR, NSWC (Dahlgren Division, Coastal Systems Station), NRaD/SPAWAR, NAVAIR (NAWC Patuxent River, NAWDC China Lake), USMARCORSYSCOM**
  - **<u>Army</u>: ARO, ARL, CECOM/NVL**
  - **<u>Air Force</u>: AFOSR, WPAFB, AFGL (Hanscom AFB)**
  - **DARPA, OSD, BMDO, DTRA**
- **Other Government Agencies**
  - **DOE**
  - **Dept of Transportation: FAA**
  - **Dept of Justice: NIJ**
  - **Treasury Dept: Customs Service**
  - **White House: ONDCP**
  - **Dept of Health and Human Services: NIH**
- **Private Sector**
  - **IBM Federal Systems, Lockheed-Martin Federal Systems, Alliant Techsystems, Lockheed-Martin Missiles & Space, …**

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Areas of Expertise

- **Magnetic Detection and Localization Systems**
  - Real-time vehicle tracking/targeting
  - Naval/Land mines and Unexploded Ordnance (UXO)
  - Underground facilities and pipelines
  - Concealed weapons
  - Applications in medicine and nondestructive evaluation (NDE)
- **Low-Cost Magnetic Resonance Systems**
  - Detection of liquid explosives, concealed non-metallic weapons, and contraband
  - Process control and NDE
- **Quadrupole Resonance Systems**
  - Explosives and drug detection
    - In luggage
    - On people
    - In landmines
    - QR not suitable for detection of metal-clad UXO

Magnetic Detection and Tracking

- **Detecting and locating an unknown object requires solving for 6 unknowns:**

  position *r* = (r_x, r_y, r_z) and moment *M* = (m_x, m_y, m_z)

- **A single magnetometer produces at most 3 data points, insufficient to solve the problem**

- **At first glance, measuring the gradient tensor components g_{ij} = ¶B_i/¶x_j gives nine data points**

  However, Ñ·*B* = 0 and Ñ´*B* = 0 mean that only five are independent

- **Gradients alone can give bearing to a target and the orientation of its moment, but conflate range and moment magnitude**

  Gradients alone also yield four possible bearings: 3 “ghosts” and the true solution

Unambiguous Magnetic Tracking

- **Eliminating range-moment ambiguity and ghosts:**
  - **Use a *moving* gradiometer**
    - **Measurements at two points separated by a known vector**
    - **Suffices to locate *stationary* targets unambiguously**
  - **Use a *stationary* gradiometer *and* magnetometer**
    - **Yields eight data points**
    - **Suffices to resolve range-moment ambiguity and eliminate ghosts**
    - **Enables real-time tracking of *moving* targets**
- **The second approach meets the criteria of the Army program: scatterable munitions that track military vehicles and target them at the CPA**

Signal Processing Approaches

- **Classical approach: inversion of gradient equations to solve for *r* and *M***
  - **Frahm-Wynn Algorithm and its offspring**
  - **Deterministic approach**
  - **Equations are nonlinear; results can be highly sensitive to noise in data**
- **Statistical approach: finding best correlation to possible signal**
  - **Matched-filter algorithms**
  - **Based on matching observed signal to space of solutions to the forward problem**
  - **Linear statistical analysis**
  - **More robust against noise in data**

Matched-Filter Processing

- **Solve for bearing first**
  - Define pixels on a unit sphere around observation point
    - Number of pixels, corresponding to angular resolution, is user-selectable
  - Unit dipole at each pixel is decomposed into 3 components
    - Radial, azimuthal, meridional
  - Forward solution is computed (just once) and stored
  - Measured gradients are compared to forward solutions
  - Pixels yielding highest correlation to observed gradients are the most likely target bearings
- **Resolve ghosts and range next**
  - Ghosts eliminated by comparing forward-solution field orientations to observed field orientation
  - Range and moment determined by ratio of gradient and field magnitudes

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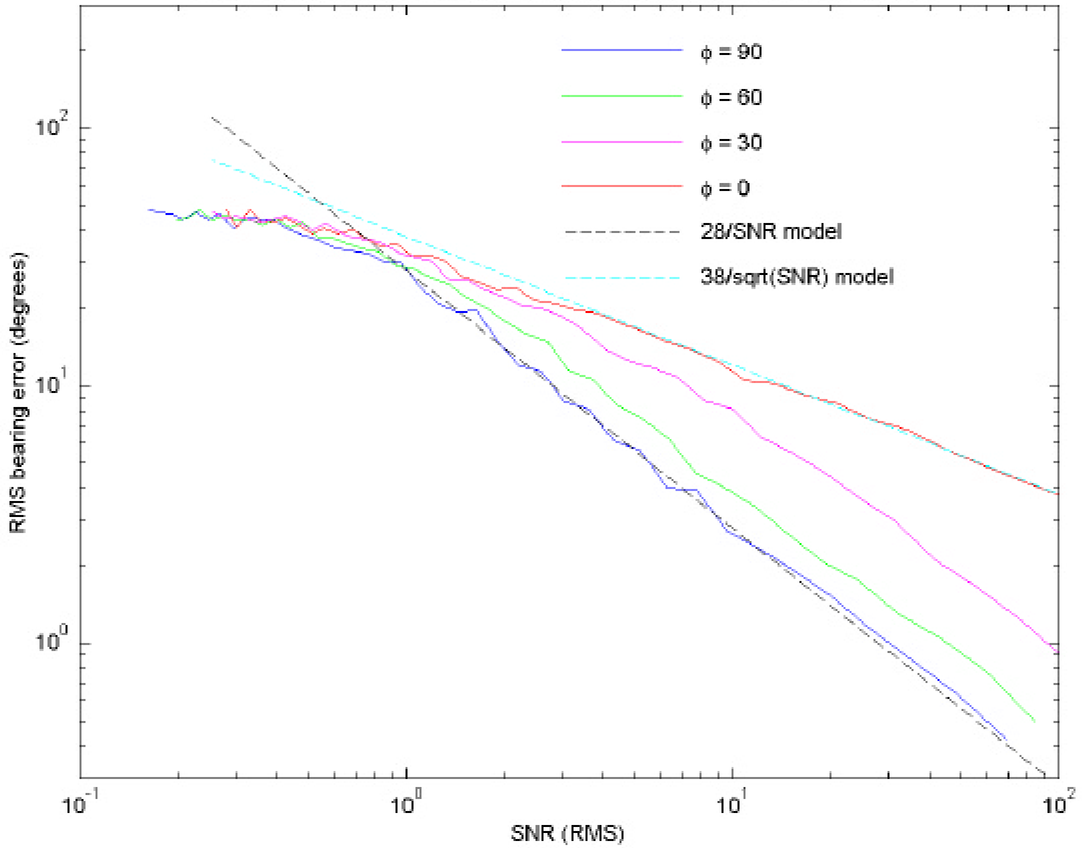
Errors and Noise

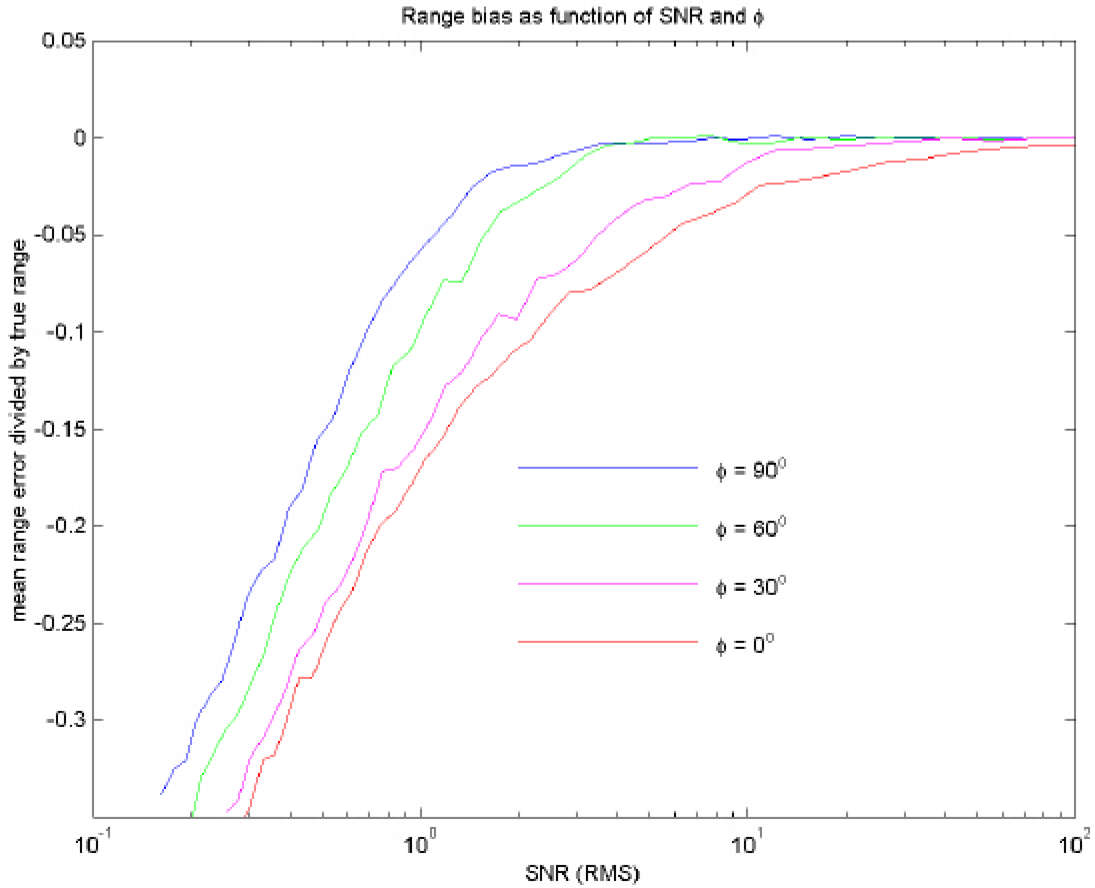
- **Bearing error vs SNR depends on the angle, F, between the bearing vector and the moment vector**

Bearing error as a function of angle ϕ between moment and bearing vectors

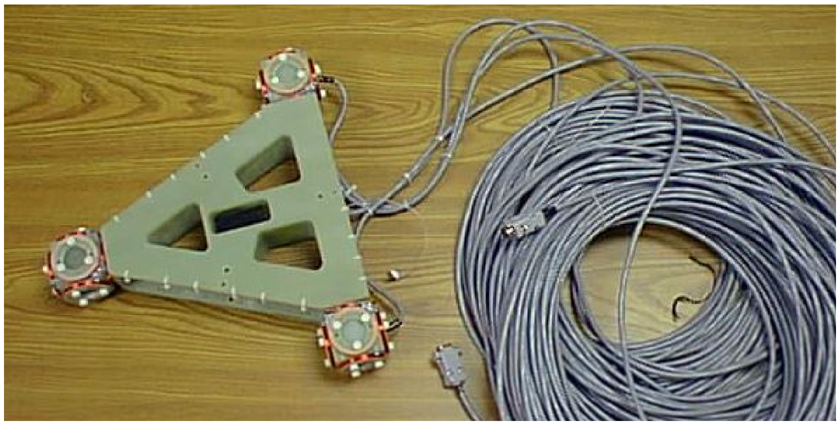


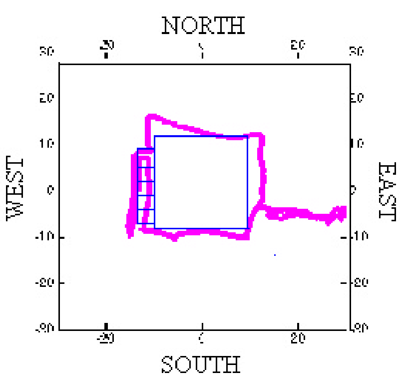
Errors and Noise

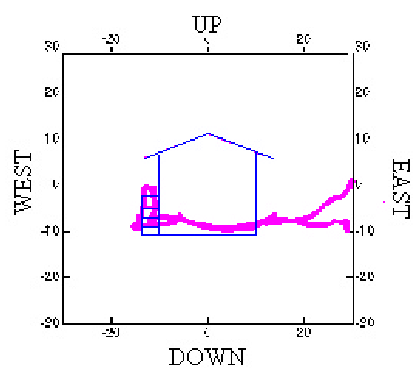
- **Range is systematically underestimated as SNR decreases**



Target Detection and Tracking with the Real-time Tensor Gradiometer (RTG)



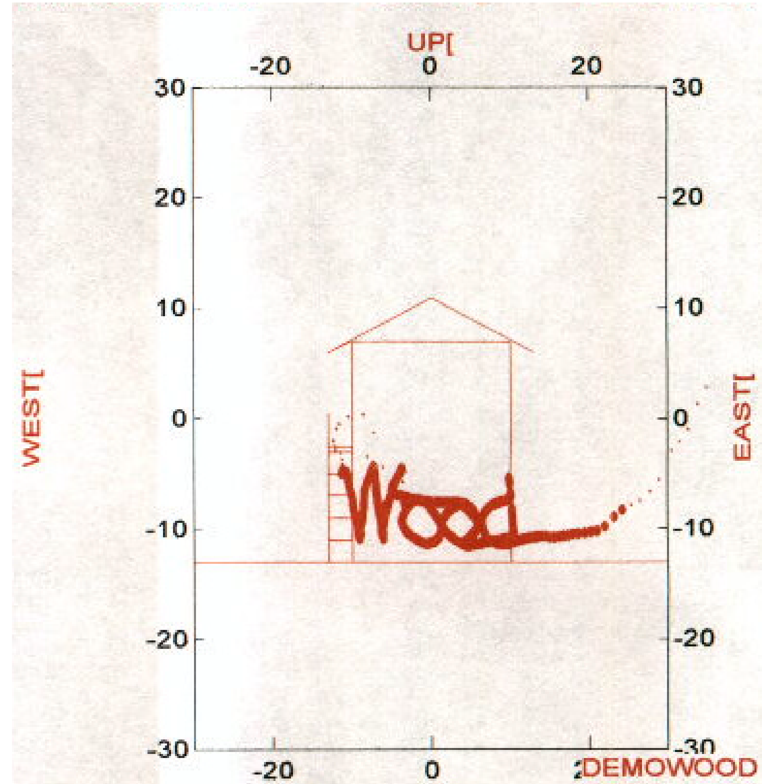




- **Gradiometry suppresses motion noise**
- **Gradient tensor magnitude is scalar quantity that enables unambiguous anomaly detection**
- **Tensor components enable three-dimensional, real-time target tracking capability and evaluation of magnetic moment**
- **Demonstration uses Navy Frahm-Wynn algorithm**
- **Passive and man-portable**

RTG Demo at CSS Non-Magnetic Facility

Bar magnet used in demo; RTG operated on second floor of non-magnetic building



Demo of RTG tracking ability (in honor of program manager Jody Wood)

Naval Sea Systems Command NSWC Naval Surface Warfare Center Dahlgren Division Panama City Dahlgren

RTG Weapon Tracking in a Cluttered Environment: QM Lobby

- **Sensor, hidden under plant in kiosk, tracks a handgun**

Frames from a surveillance video:

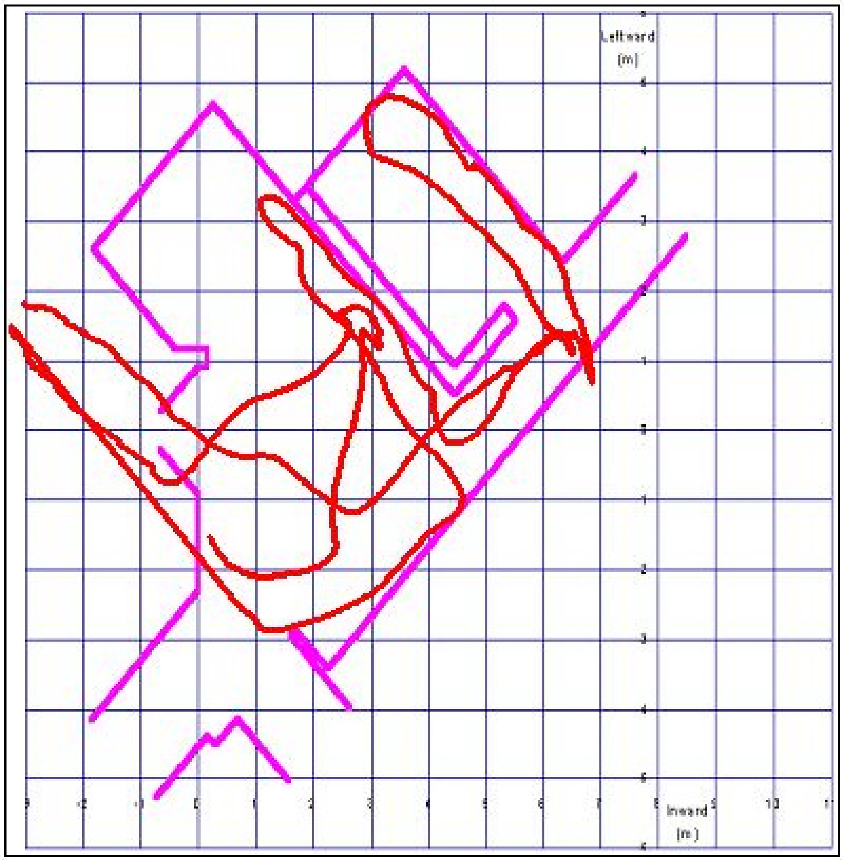
Left: entering lobby with gun (H&K USP .40 S/W plastic pistol) in waistband under coat.

Right: revealing the weapon.

System displays red icon in real time on video; location is accurate despite steel in walls and floor.

Similar background mitigation may be applicable in magnetic geological environments.

RTG Weapon Tracking in a Cluttered Environment: QM Lobby



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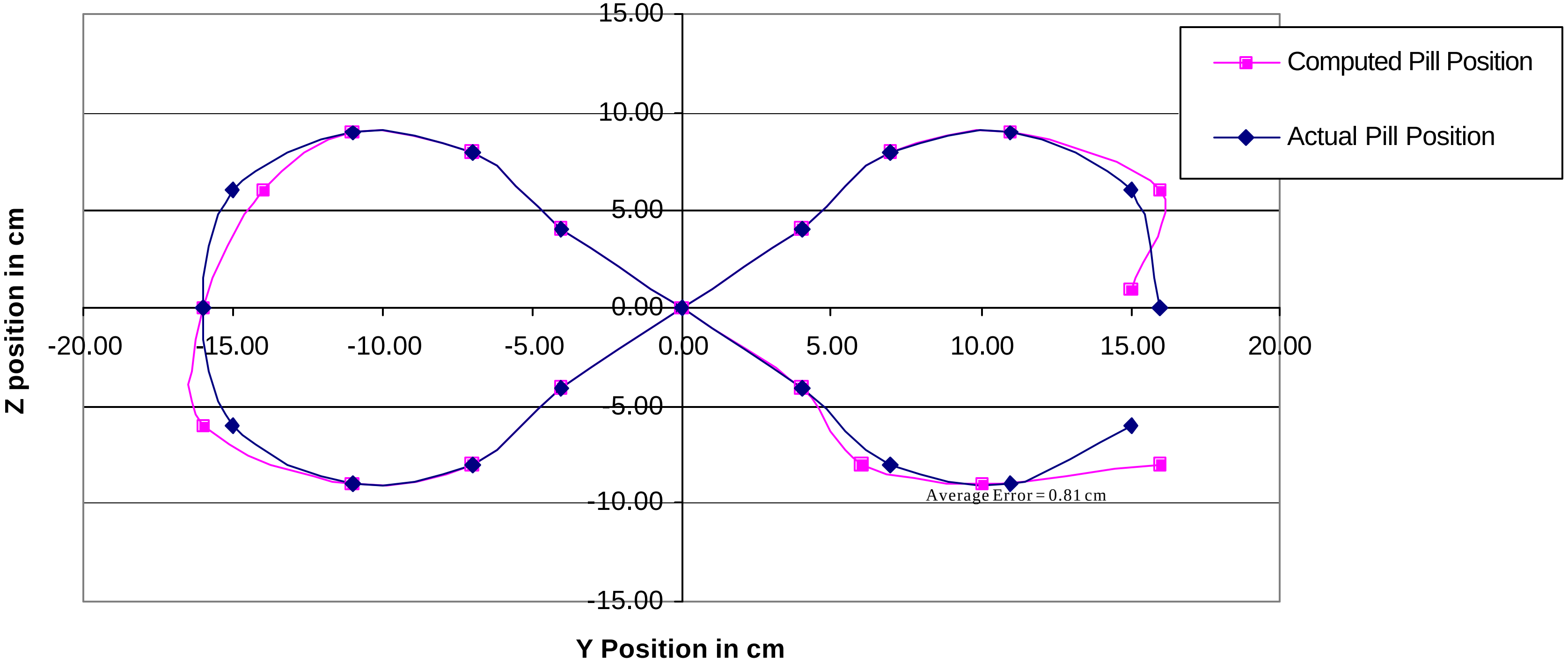
Track of target at a distance of 15-20 cm from nearest sensors. Average Error is 1 cm.



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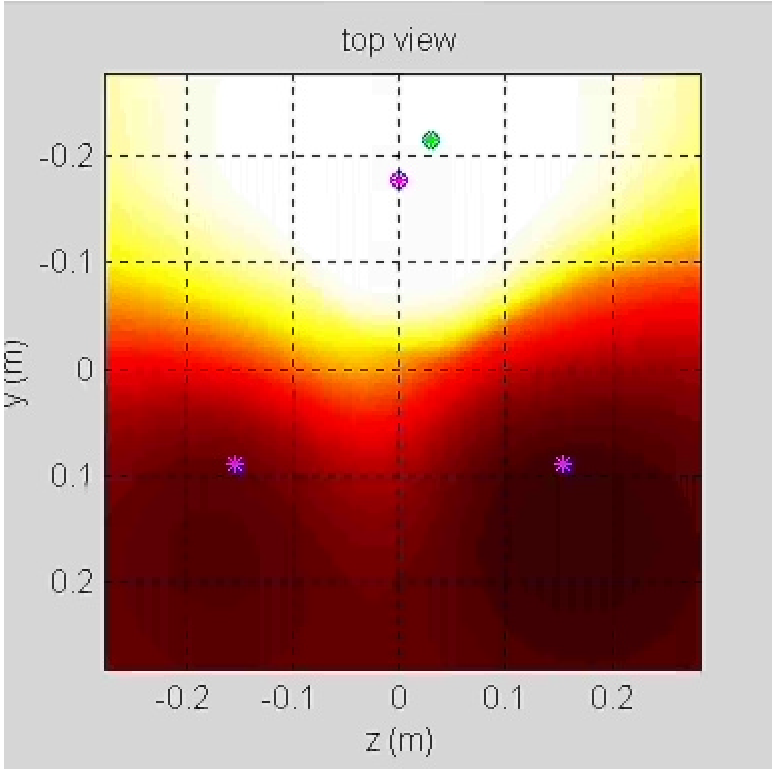
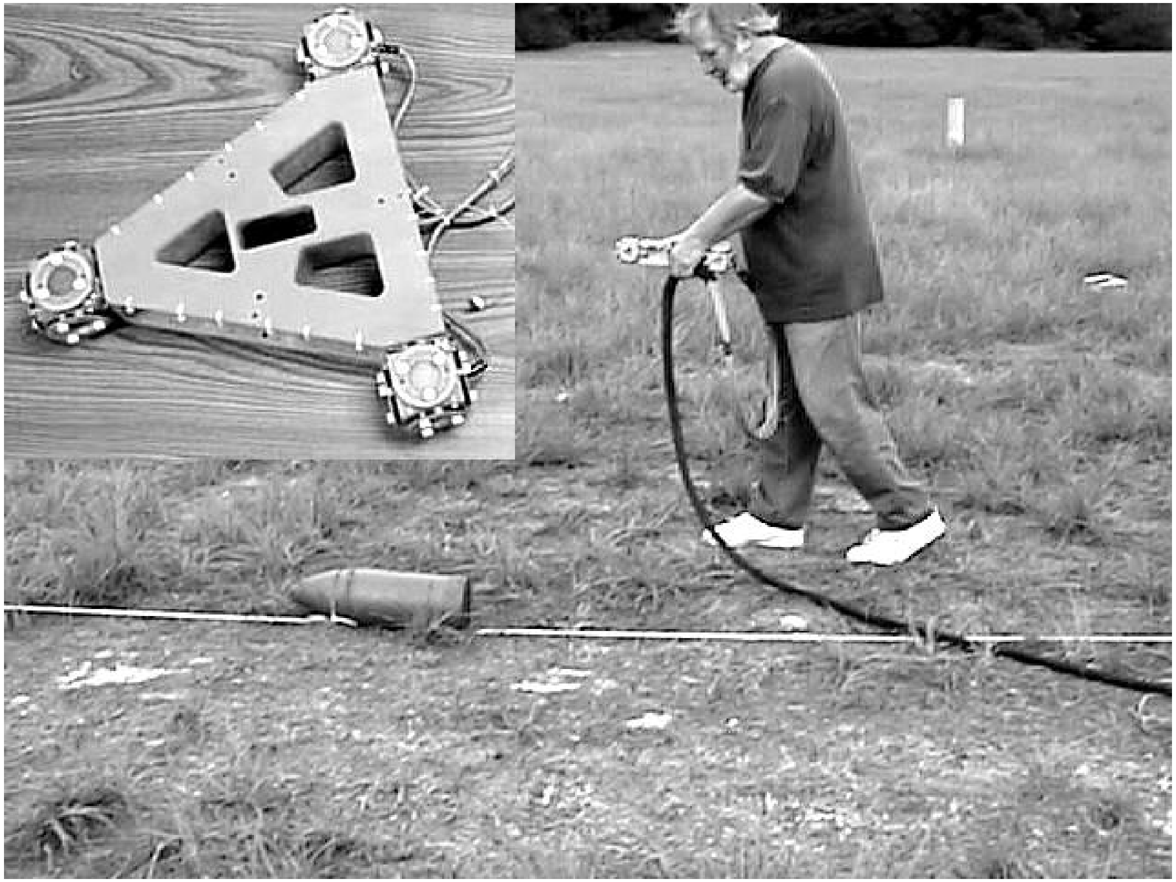
Reconstruction of Pill Track



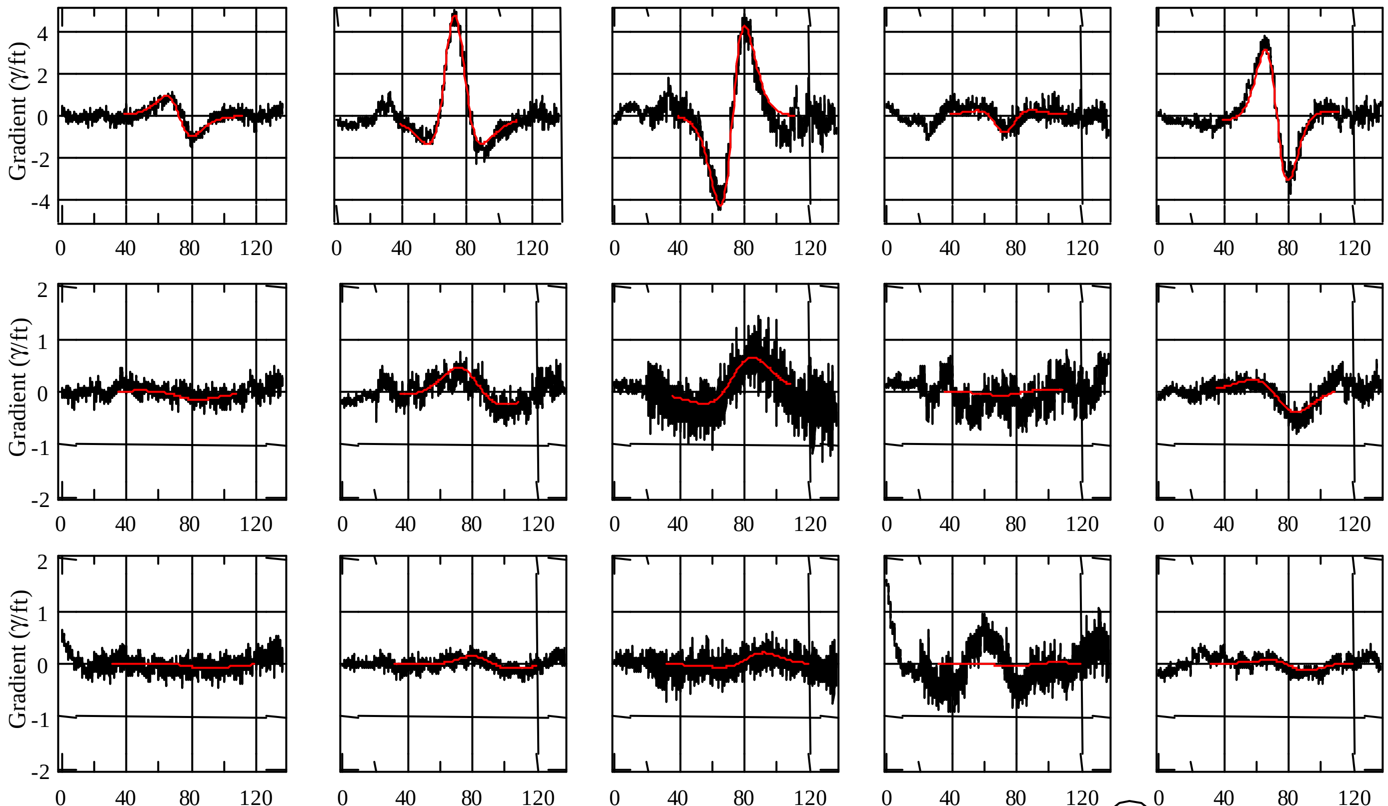
Naval Sea Systems Command
NSWC
Naval Surface Warfare Center
DAHLGREN DIVISION
Panama City Dahlgren

Moving-Sensor Data



Moving-Sensor Data

- 150 mm shell beside track
- Five gradient signals as MTG walked past target
- Fusion of five channels yields target detection in low-SNR conditions



Closest Point of Approach:

6.1 m

10.7 m

13.7 m

Low Cost Sensors for RTG

- **Magnetoresistive (MR) Sensors – QM has built gradiometer with 6” baseline between sensors**
- **Since RTG will be environmentally noise limited, less sensitive MR sensor will be better adapted to noise environment, not wasting sensitivity**
- **QM is also working with the Army Research Lab (ARL) to test newly developed spin dependent tunneling (SDT) sensors for applications in magnetic microsensors in battlefield applications**

Conclusions

- **Magnetic gradiometry has tracked vehicles in real time and targeted them successfully**
- **Known problems with current sensor system can be eliminated (noise spikes) or mitigated (imbalance) to improve tracking range substantially**
- **Further algorithm developments may enable track extraction at lower SNRs**
- **Magnetic methods remain a short-range tracking solution**
- **Long-range solutions require line of sight to target and good weather conditions**
- **Magnetic methods are impervious to weather and require no line of sight**