Standoff Detection and Tracking of Vehicles Using a Compact Magnetic Sensor

Mines, Demolition & Non-Lethal Conference and Exhibition

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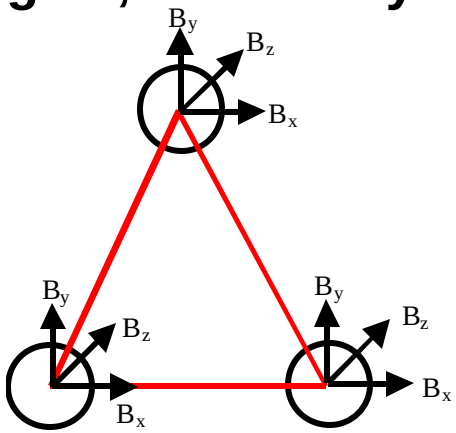
Towards a compact sensor

- **Magnetic Gradiometry at QM**
  - SQUID based gradiometer
  - Non-cryogenic sensor based gradiometers
- **Fluxgate Gradiometers**
  - Background
  - QM's development of fluxgate gradiometers
- **Magnetoresistive (MR) Sensor Gradiometers**
  - Cost, size considerations
  - Sensitivity issues
  - Compact gradiometer
- **Summary and Conclusion**

Magnetic Tensor Gradiometry

- Measurement of spatial differences or gradients of magnetic field
- Suppression of response to magnetic interference and motion noise
- Vector measurements of complete gradient tensor enable locating and characterizing targets, not merely detecting them

$$G = \begin{pmatrix} G_{xx} & G_{xy} & G_{xz} \\ G_{yx} & G_{yy} & G_{yz} \\ G_{zx} & G_{zy} & G_{zz} \end{pmatrix}$$



- Target characterization afforded by measuring target's magnetic moment
- Scalar magnitude of gradient tensor gives <u>unambiguous measure of proximity</u>

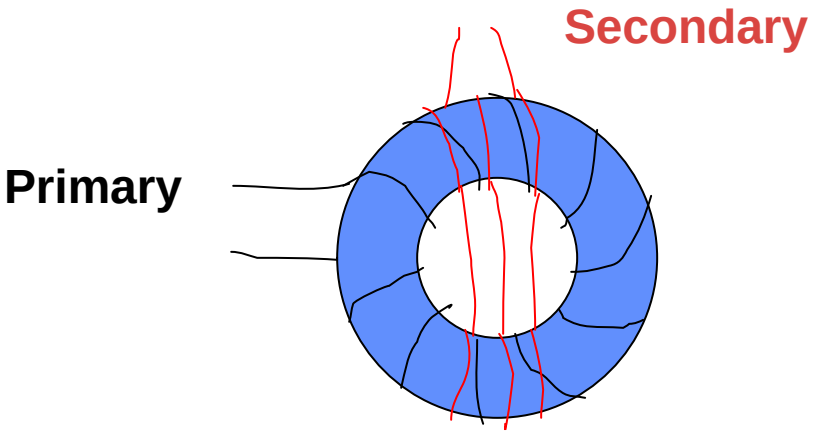
Superconducting Gradiometer

- **Based on Superconducting Quantum Interference Device (SQUID)**
  - **Most sensitive magnetic field sensor**
  - **Operates at cryogenic temperatures – liquid helium temperatures for maximum intrinsic sensitivity**
- **Superconducting Gradiometer Magnetometer System (SGMS)**
  - **Built by QM and IBM for the Navy**
  - **Most sensitive gradiometer in motion**
- **Non-cryogenic (Room Temperature) Gradiometers**
  - **Lower cost, ease of use**
  - **Sensitivity limits are usually not the sensor's**

Room Temperature Gradiometer

- **Based on non-cryogenic magnetic sensors**
  - **Fluxgate sensors**
  - **Magnetoresistive (MR) sensors**
- **Adequate for most applications**
  - **Sensitivity limits are usually defined by the environment**
  - **Pointless to use an expensive, sensitive sensor**
  - **Room temperature systems are easier to use and adapt to various applications**
- **Applications**
  - **Vehicle tracking, buried mines/UXO**
  - **Underwater anomalies**
  - **Commercial applications**

Fluxgate Sensors

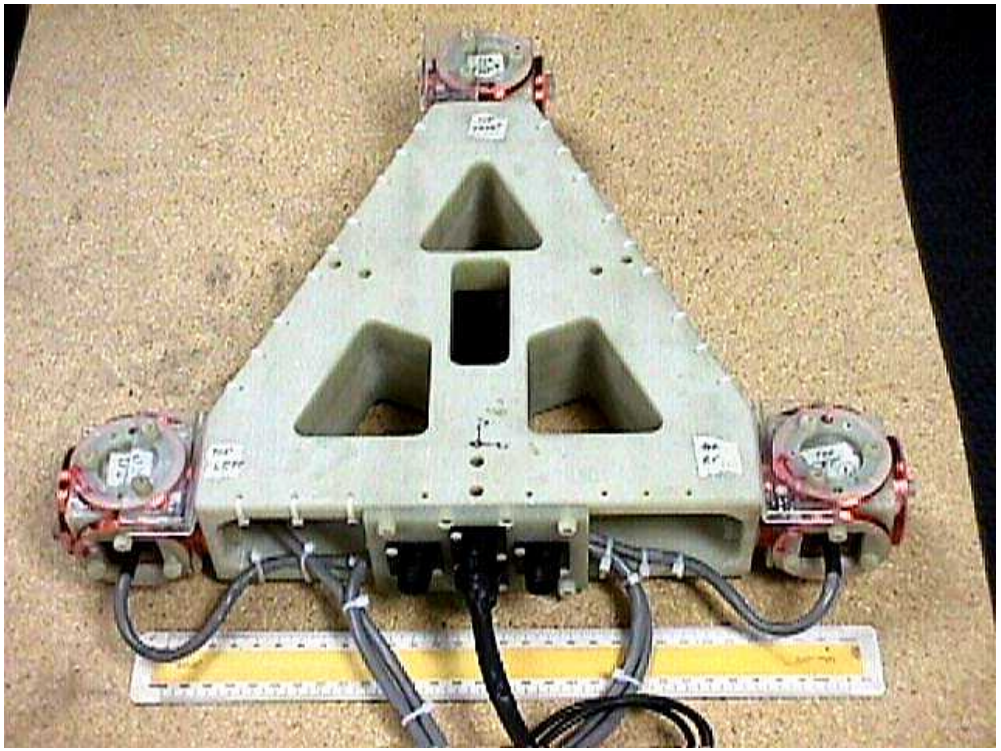


- **Primary coil drives core to saturation or near saturation with ac field.**
- **Signal picked up on the secondary coil is modulated by the external field and the changing permeability of the core.**
- **Secondary signal is at harmonics of the fundamental frequency (usually the second harmonic is detected).**
- **Sensitivities of 1pT/Hz$^{1/2}$ at 10 Hz.**
- **DC detection, but usually small ac bandwidth (of the order of 100 Hz).**

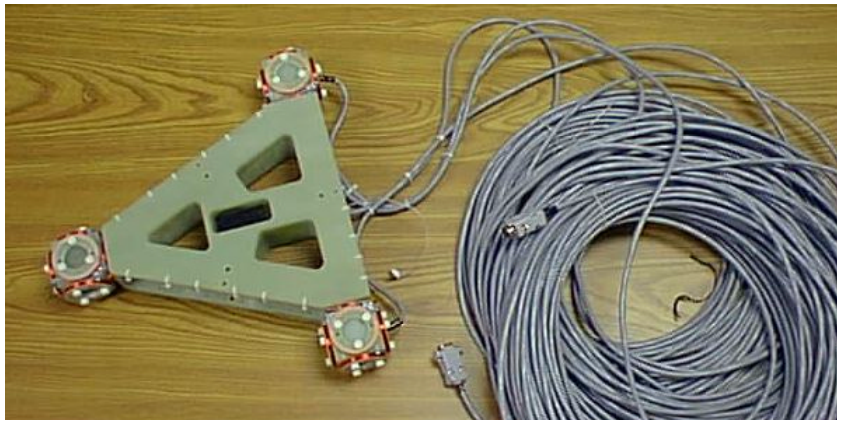
QM Fluxgate Gradiometer

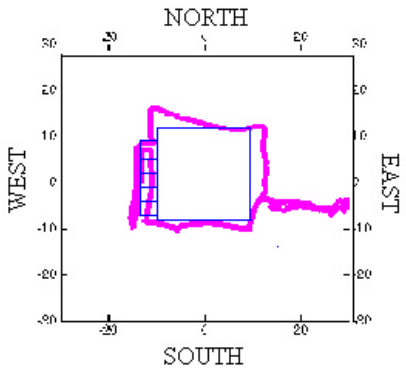
- **Three three-axis *primary* fluxgate sensors**
  - **Sufficient to measure all five independent components of magnetic gradient.**
- **One three-axis *reference* fluxgate sensor**
  - **Allows cancellation of ambient field at primary sensors.**
  - **Mitigates dynamic range requirements for primary sensors.**
  - **Based on the “Three Sensor Gradiometer” arrangement first invented at IBM.**
- **Customer**
  - **Unit built for the Navy: Coastal Systems Station, Panama City, FL. “Real Time Tensor Gradiometer”, RTG.**

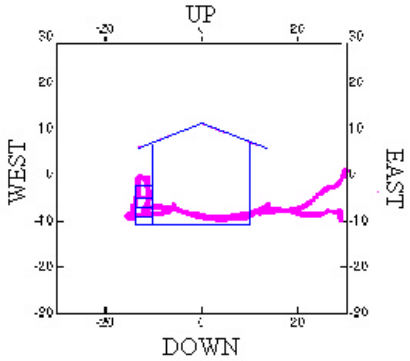
Real-time Tensor Gradiometer (RTG)



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







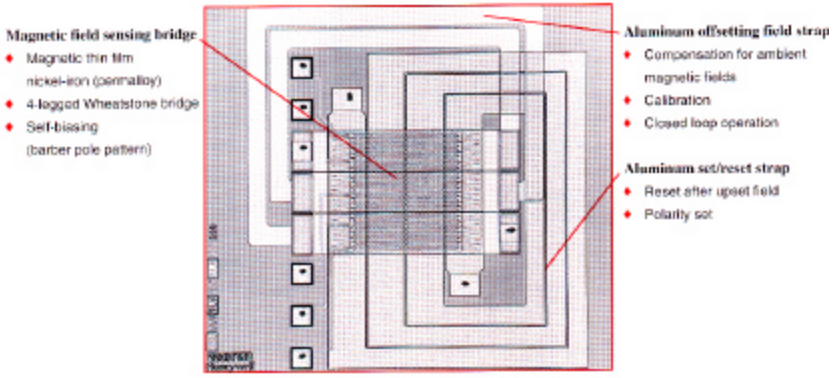
- Gradiometry suppresses motion noise
- Gradient tensor magnitude is scalar quantity that enables unambiguous anomaly detection
- Tensor components enable three-dimensional, real-time target tracking capability and evaluation of magnetic moment
- Demonstration uses Navy Frahm-Wynn algorithm
- Passive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

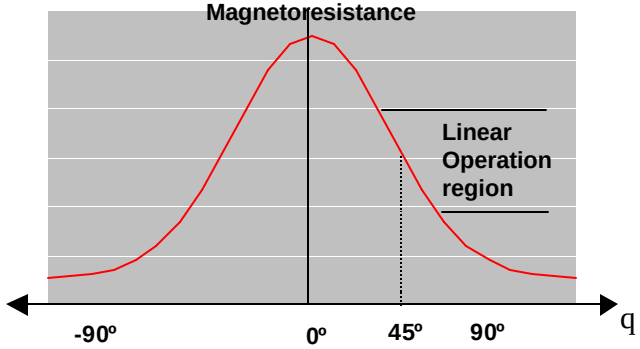
Magnetoresistive (MR) Sensors

- Based on anisotropic magnetoresistance
- Resistance depends on the external magnetic field
- Low cost
- Small size (less than 1 cm^2)
- Broad detection bandwidth; DC to megahertz
- Honeywell MR Sensors run with QM designed electronics produces sensitivity of 50 $pT/Hz^{1/2}$ at 1 Hz.

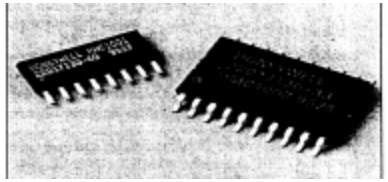
Honeywell MR Sensor

- Two on-chip coils can be driven to couple field onto sensor bridge

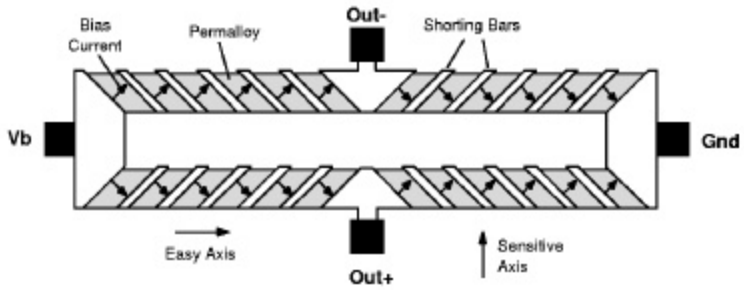




- Film resistance variation depends on angle between vector magnetization and direction of measuring current flowing through it



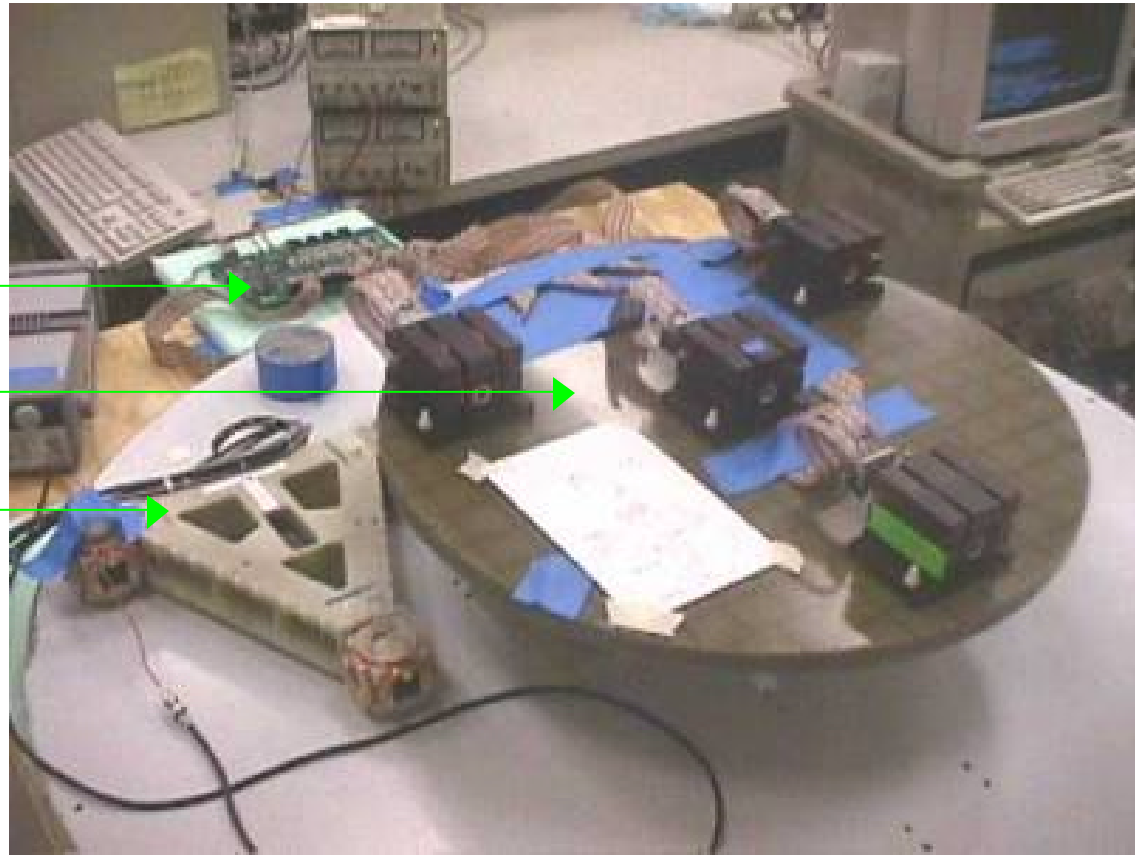
- 1- and 2-axis Honeywell MR chips



- MR Bridge made up of four permalloy parallel strips
- Barber pole biasing by laying conductive conductive shorting bars at 45º across film's width

First-Generation MR Tensor Gradiometer

- Laboratory lash-up using commercially available MR sensors (Honeywell) and special QM electronics
- Full gradient tensor measurement, plus ambient field vector

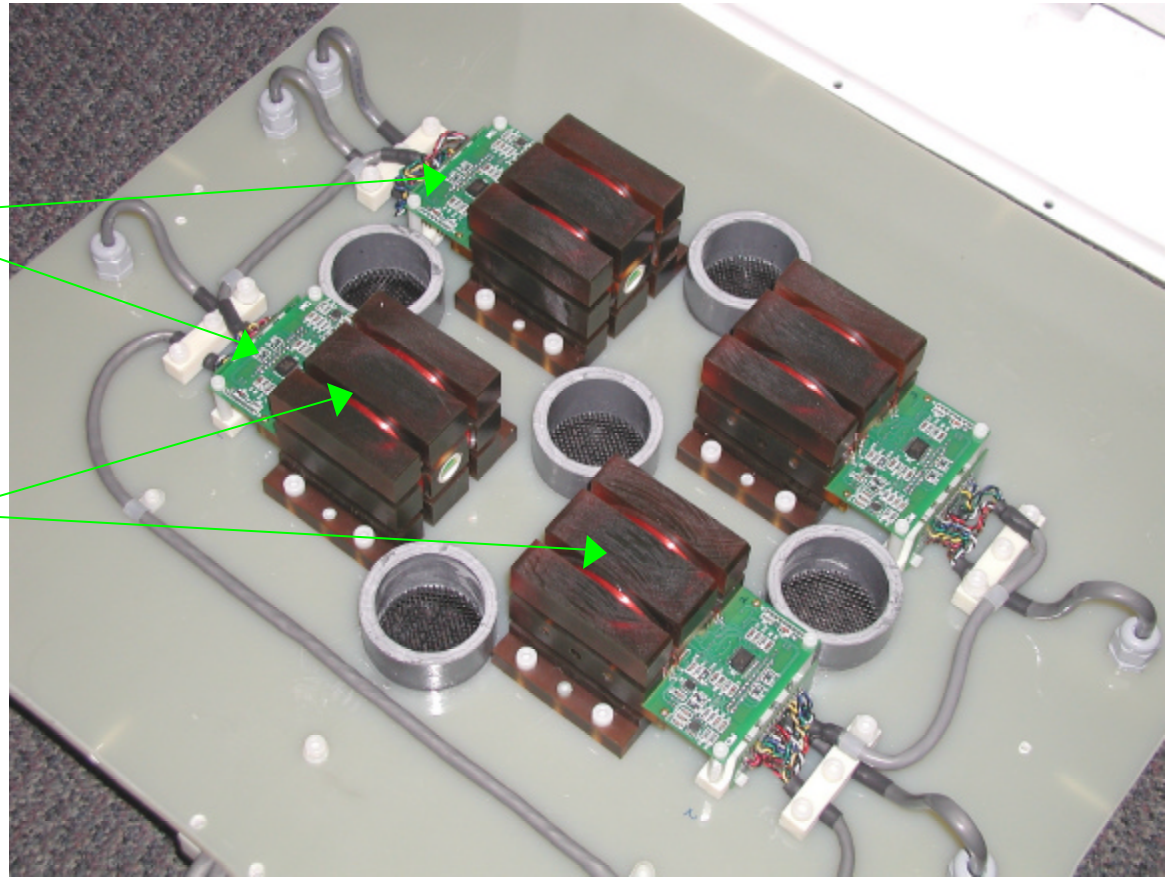


Second-Generation Gradiometer

- Same sensors and electronics as first generation
- Layout redone to put sensors on NGSM-compliant baseline
- Repackaged to render field-worthy

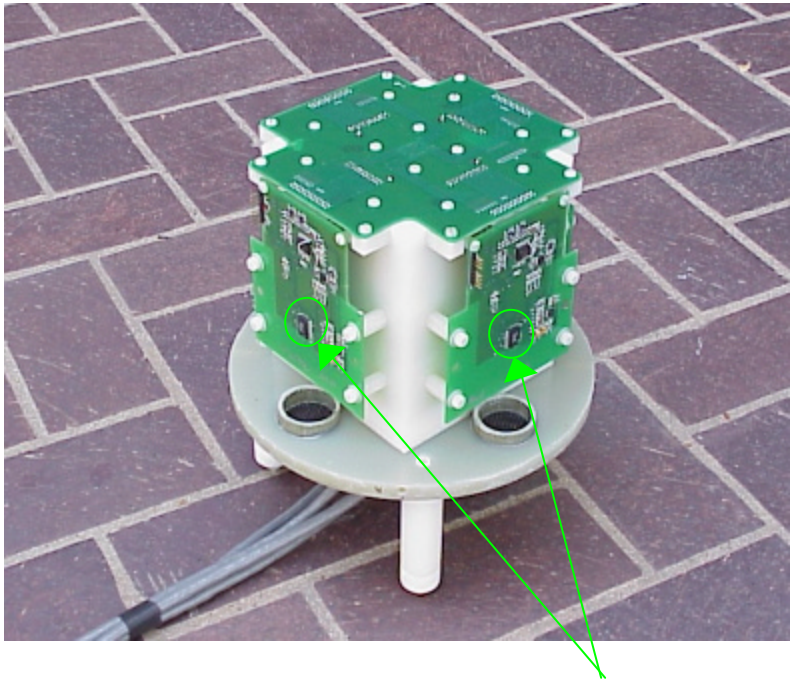
Each board houses 3 MR magnetometer axes

Each board resides inside a “flux cube” that cancels ambient field uniformly



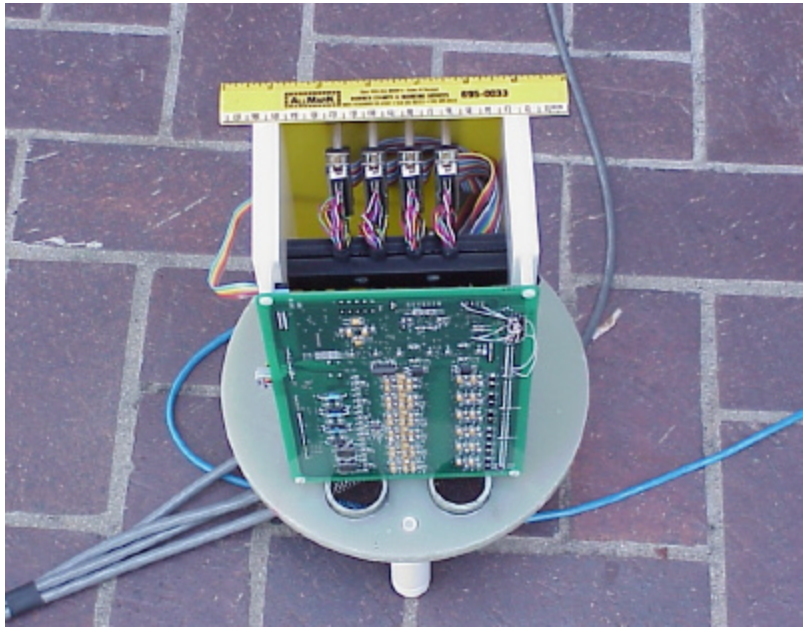
Third-Generation Gradiometer

- Uses new, developmental MR sensors with on-chip feedback
- Reduced cross-axis nonlinearity renders flux cubes unnecessary
- Sensor baseline 14.5 cm; unit fits inside 20 cm container



Sensor head with MR magnetometers

Electronics board was not redesigned in this iteration



Third-Generation Gradiometer

- Sensor and electronics in identical containers
- Powered by battery pack with >8-hour operating capacity
- Data sent via RS-485 cable to laptop computer (not shown)

Applications of QM MR Tensor Gradiometer

- Vehicle detection and tracking – Army
- Detection of underground structures – DTRA
- Detection of unexploded ordnance (UXO) – Army
- Concealed weapons detection and tracking – NIJ

Conclusions

- Compact magnetic tensor gradiometers based on MR sensors can be used for vehicle tracking.
- Such gradiometers can be used for numerous applications including vehicle tracking, detection of buried UXO and mines, detection of underground structures, and concealed weapons detection and tracking.
- With appropriate water-proofing, the gradiometers can be used for underwater applications.
- Future improvements may include the use of lower power sensors (such as SDT sensors).
- Number of commercial applications are also possible.