Research Notes 1
Grace Gillam

Areas of Interest for Next Week's Research

- Joint directors of laboratories fusion model implementation
- Research the data return of relevant sensors, fusion models already existing for these data types
- Thin plate splines technique for spatial alignment
- Gradient boosting decision trees and logistic regression
- Fourier-based features for EMI data
- Histogram of Oriented Gradients (HOG) features for GPR data

Sensor Fusion for Buried Explosive Threat Detection for Handheld Data

The researchers specifically focus on combining data from Ground Penetrating Radar (GPR) and Electromagnetic Induction (EMI) sensors. They explain that these sensors have complementary strengths: *EMI is effective at detecting small metal mines, while GPR excels at detecting large plastic mines.* The article describes a system that uses these two sensors in a handheld configuration and applies both linear and non-linear fusion algorithms to combine their data, ultimately improving detection performance.

Sensors and data types:

Electromagnetic Induction Sensors

These induce electric currents in underground metal objects and then measure the magnetic field produced. Inexpensive!!

Ground Penetrating Radar

These sensors emit electromagnetic pulses into the ground. When these pulses encounter a dielectric discontinuity, such as a buried threat, they are reflected back to the sensor. GPR data can reveal the presence of both metallic and non-metallic threats.

GPS Location

Fusion Models/Methods Mentioned:

Logistic Regression: Linear model that predicts the probability of a target being present based on the combined EMI/GPR scores

Gradient Boosting Decision Trees: Non-linear model that iteratively adds trees to a model with each tree attempting to correct errors in previous trees

Thin Plate Splines: Technique to interpolate the EMI and GPR scores onto a common grid to ensure that both sensors; data is considered for the same locations, since there can be spatial misalignment of the EMI and GPR measurements

Key Takeaways:

EMI and GPR are probably the two most important sensor types for this project.

Spatial alignment of the sensors is crucial and could pose an issue.

Offset with thin plate splines

GPR data must be preprocessed and things like ground alignment, depth normalization, and median filtering are important for improving signal-to-noise ratio and enhancing feature extraction

Feature extraction may concern the use of Fourier-based features for EMI data and Histogram of Oriented Gradients (HOG) features for GPR data

Mean shift to identify clusters of high fusion scores and declare alarms. This approach helps to reduce the number of false alarms and provide a more focused indication of potential threat locations

A Review of Sensor Data Fusion for Explosives and Weapons Detection

Sensors Mentioned:

- x-ray CT
- x-ray diffraction
- metal detectors
- millimeter-wave imagers
- nuclear quadrupole resonance
- trace detection
- thermal neutron activation
- laser induced breakdown spectroscopy
- Raman spectroscopy
- IR spectroscopy
- MEMS sensors

Fusion Models Discussed:

- Joint Directors of Laboratories model9
    - 5-leveled model that can be used in large and complex fusion applications (article mentions battlefield scene analysis) to track and analyze many objects at once. Explosive detection is mainly concerned with level 1 of the model.
    - Level 1 fusion can combine the data in the following ways:
    - *Data level/Pixel or image level:* forms a meaningful object representation
        - Image fusion, a subset of data-level fusion, focuses on merging images from different wavelengths or modalities to improve operator interpretation
    - *Feature level:* Identifies features, such as edges
    - *Decision level:* Detection decisions fused to form a joint decision
        - Common techniques include AND/OR logic (used in aviation security), voting strategies (like majority voting and sensor dominance), and probabilistic methods (such as Bayesian fusion and Dempster-Shafer theory)

Receiver operating characteristic curves describe the trade-off between detection rate and false alarm rate as sensitivity is altered. This is how we will evaluate the performance of detection systems. Also discusses sensor orthogonality.

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Key Takeaways:

- Performance prediction is important! We can sue ROC curves for this.
- Sensor orthogonality degree establishment is critical in ensuring we have a good sensor combination and that our fusion algorithm is effective and efficient. We can focus on defining and establishing the correlation between sensors in relation to specific landmine types, operational environments, and concealment methods.
- Operator-interpreted data that may not have numerical output is difficult, but crucial. This includes sensor data from sensors like GPR. We may need to devise a way to convert this data into quantitative measurements.

Multi-sensor Fusion Applied to the Detection of PB-IEDs

Sensors Mentioned:

- Millimeter-wave imaging
- Radar technology
- THz technology
- Infrared sensors
- Explosive trace detection systems

Fusion Models/Methods Discussed:

- Confirmation of a threat (AND): Threat confirmed if ALL sensors detect it
- Complementary systems (OR): Threat confirmed if ANY sensor detects it
- Cascade: Sensors divided into subsets for which fusion is applied within each, and then applied again to the subset outputs. Can have combined confirmation or combined complementary implementation.
- Majority: Threat confirmed if > half the sensors detect it