Sensor Fusion

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CROPbs “Clever Robots for Crops”
Background

Why do we need multiple sensors?
Background
Applications

• Mapping for mobile robots

• Target detection

• Localization (GPS+INS)
Aims

Acquisition, processing, and combination of information generated by multiple knowledge sources
Aims

Provide improved information for detection, estimation, and decision-making.

\[1+1 >> 2\]

two heads are better than one
Agenda

• Interaction modes
• Representation levels
• Virtual sensors
• Taxonomy
• JDL Model
• Performance measures
• Application examples
• Dirty secrets in sensor fusion
Interaction models

Complementary

Object
Interaction models

Competitive

Object
Interaction models

Cooperative

Object
Representation levels

• Signal level (pixel level)

• Feature level

• Decision level (symbol/object level)
Signal level representation

Sensor 1

Sensor 2

Sensor N

Fused Signal

Output
Feature level representation

Sensor 1

Sensor 2

Sensor N

Feature extraction

Feature extraction

Feature extraction

Classifier

Output decision
Virtual sensors

Instead of using only real sensors, virtual sensors (i.e. combination of algorithms) can be used as sensors.
Virtual Sensor (VS)
Taxonomy

- Architecture
- Update method
- Dynamic/Static
- Feedback and memory
- Algorithms
- Optimization
Architectures

- Distributed
- Centralized
Update method

- Synchronous

- Asynchronous
Dynamic/Static update

• Static

• Dynamic
Feedback and memory

- **Feedback** – incorporated in the fusion system from the last sensory output.

- **Memory** – each sensor can also store in memory the last action it decided.
Feedback and memory

Sensor fusion system with feedback without memory
Sensor fusion system with feedback and memory
Sensor fusion algorithms
Pixel/Signal level algorithms

• Kalman Filtering

• Estimation methods
Feature level SF algorithms

- Neural networks
- Pattern recognition
- Fuzzy logic
- Decision trees
Decision level SF algorithms

• Bayesian inference

• Dempster–Shafer

• Weighted decision methods

• Minimax
<table>
<thead>
<tr>
<th>Optimization criterion</th>
<th>Description</th>
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<tbody>
<tr>
<td>Least squares</td>
<td>Minimize the sum of residuals</td>
</tr>
<tr>
<td>Weighted least squares</td>
<td>Minimize the sum of the weighted squares of the residuals</td>
</tr>
<tr>
<td>Mean square error</td>
<td>Minimize the accepted value of the squared error</td>
</tr>
<tr>
<td>Bayesian weighted least squares</td>
<td>Minimize the sum of the weighted squares of the residuals constrained by a-priori knowledge of the value</td>
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<td>Maximum likelihood estimate</td>
<td>Maximize the multivariate probability distribution function</td>
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JDL Model

Sensor network and corresponding environment/data sources

Pre-processing of source data

Object refinement LEVEL 1

Situation refinement LEVEL 2

Threat refinement LEVEL 3

Refinement of the process LEVEL 4

DBMS

Support database

Fusion database

Human Computer Interface (AI component can be easily added here for more autonomy and decision making)

(Handbook of Multisensor Data Fusion: Theory and Practice 2009)
Many things happen concurrently

Collection Assets (Intelligence)
- SENORS
  - ELINT
  - ESM
  - RADAR
  - EO
  - IR

COLLATERAL INTELLIGENCE

PRELIMINARY FILTERING
- @ TIME
- @ LOCATION
- @ TYPE
- @ SIGNATURE

COLLECTIONS MANAGEMENT
- @ ASSET AVAILABILITY
- SENSOR TASKING
- TASK PRIORITIZING

LEVEL 1 PROCESSING
- DATA ALIGNMENT
  - SPATIAL
  - TEMPORAL REF.
  - UNIT OF MEAS.

LEVEL 2 PROCESSING
- SITUATION ASSESSMENT
  - ENVIRON.
  - TOTAL PIC.
  - ENEMY OB

LEVEL 3 PROCESSING
- THREAT ASSESSMENT
  - LETHALITY ESTIMATES
  - DANGER EST.
  - INDICATION WARNINGS
  - TARGETING
  - WEAPONERING

DATABASE MANAGEMENT
- MONITOR
- EVALUATE
- ADD
- UPDATE
- RETRIEVAL
- MERGE
- PURGE

SUPPORT DATABASE
- @ ENVIRON.
- @ DOCTRINE
- @ TECHNICAL

MAN–MACHINE INTERFACE
- # TEXT
- # GRAPHICS

EVALUATION
- $ PERFORMANCE MEASUREMENT
- $ MAINTENANCE

(Handbook of Multisensor Data Fusion: Theory and Practice 2009)
Performance measures

- Object detection
- Misclassified objects
- Error in distance of classified objects
- Rate of detections
- False positive detections
- ...
GPS, INS (Inertial Navigation System) integration – **Signal level**
Both the GPS and INS provide the same data (location). Each sensor has its own characteristics:
GPS – long time stability, large noise; INS – short time stability

The fusion system is: **distributed, asynchronous, dynamic, feedback, no memory.**
This type of GPS, INS fusion is called loose coupled
Autonomous vehicle must drive and detect obstacles.

Each sensor (3 laser scanners and ultrasonic sensor) creates an independent obstacle map. Sensor fusion task is to fuse the various obstacle maps.
Examples 2

The fusion level is at the decision level. The fusion system is: centralized, asynchronous - each sensor can work in different frequency, dynamic – the vehicle moves, memory – the last map remains in the memory, new obstacles are added to it. Each obstacle map can have a different resolution and is updated as soon as sensory information is available.
Example 2 – other alternatives

If the sensors send their raw data, then:

The fusion level is at the **feature level**.

The fusion system is: **centralized, asynchronous** - each sensor can work in different frequency, **dynamic** – the vehicle moves, **memory** – the last map remains in the memory, new obstacles are added to it.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>Can have more precise results</td>
<td>Depended on all sensors</td>
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<tr>
<td>More sophisticated algorithm is needed</td>
<td>Hard to predict behavior In complex environment</td>
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cRops Sensor Fusion
crops sensor fusion

- Decision level
- Centralized
- Asynchronous
- Dynamic
- Feedback
- Adaptive weighted decision methods
cRops sensor fusion

The accuracy of each virtual sensor:

\[ a_i = \sum_{t=1}^{m} (c_i(t) \equiv y(t)) / m \]

* a – accuracy of each virtual sensor
* c – classifier result
* m – number of training data

The final classification result is the weighted sum:

\[ C(j) = \sum_{i=1}^{n} w_i c_i(j) \]

When:

\[ \sum_{k=1}^{n} a_i \]
Weights adapt to changes in sensory performances by changing the accuracy of each sensor depending on feedback:

\[
a_i(t) = \frac{\sum_{j=t-k+1}^{t-1} (c_i(j) \equiv C(j))}{k}
\]
Dirty secrets in sensor fusion
(Handbook of Multisensor Data Fusion: Theory and Practice 2009)

• There is no substitute for a good sensor.
• There is no substitute for good data.
• All sensors have limitations.
• Downstream processing cannot absolve the sins of upstream processing.
• The fused answer may be worse than the best sensor.
• There are no magic algorithms.
• There will never be enough training data.
Thank you!
Questions?

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