Information Fusion for Wireless Sensor Networks: Methods, Models, and Classifications

Presentation By: Michael Scherer

Paper By: EDUARDO F. NAKAMURA, ANTONIO A. F. LOUREIRO, ALEJANDRO C. FRERY
Outline

• Definitions
• Basic Concepts
• Inference Methods
• Estimation Methods
• Feature Maps
• Example Applications of Sensor Fusion
What is Information Fusion?

• “the theory, techniques and tools created and applied to exploit the synergy in the information acquired from multiple sources (sensor, databases, information gathered by humans, etc.) in such a way that the resulting decision or action is in some sense better (qualitatively or quantitatively, in terms of accuracy, robustness, etc.) than would be possible if any of these sources were used individually without such synergy exploitation”

Dasarathy 2001
Multisensor Integration?

• “is the synergistic use of information provided by multiple sensory devices to assist in the accomplishment of a task by a system; and multisensor fusion deals with the combination of different sources of sensory information into one representational format during any stage in the integration process.”

  Luo
  2002
How do all these work together?

[1] Nakamura, Loureiro, Frery
What is a WSN

- WSN stands for Wireless Sensor Network
  - Graph of sensor nodes which work cooperatively to give feedback on an environment
Important Factors

• Complementary:
  ▫ Two different sources are combined to give information about a broader environment

[1] Nakamura, Loureiro, Frery
Important Factors

- Redundancy:
  - Two sources providing the same information are fused to give confidence to readings

[1] Nakamura, Loureiro, Frery
Important Factors

- Cooperative:
  - Two sources are fused to form new, more complicated information based off the readings

[1] Nakamura, Loureiro, Frery
Inference Methods

- Used to fuse decisions
  - **Bayesian Inference**
  - **Dempster-Shafer Inference**
  - **Fuzzy Logic**
  - **Neural Networks**
  - **Abductive Reasoning**
  - **Semantic Information Fusion**
Inference Methods

Bayesian Inference

• Based on Bay’s Rule of probability:

\[ P(Y \mid X) = \frac{P(X \mid Y) \times P(Y)}{P(X)} \]

• Probability of Y given X = Probability of X given Y times Probability of Y divided by the Probability of X

• Works well, however constants for the probabilities must be guessed
  ▫ Sometimes solved by using a neural network
Estimation Methods

- “Clean up” sensed values
  - Maximum Likelihood (ML)
  - Maximum A Posteriori (MAP)
  - Least Squares
  - Moving Average Filter
  - Kalman Filter
  - Particle Filter
Estimation Methods
Moving Average Filter

• Given input signal $z$ with size $M$, we estimate $x$ by the following:

$$
\hat{x}(k) = \frac{1}{M} \sum_{i=0}^{M-1} z(k - i)
$$

• In the practical discrete case, $z$ would be a circular array that is filled at every sample time
Estimation Methods

Kalman Filter

- Unfortunately, too complicated to cover in 5 minutes
- Essentially, we have some sensor data, and a linear model of what the sensor should output ideally
  - Noise is modeled by Gaussian Noise
- We can tune coefficients of the sensors and the model based on which we “trust” more
- Extensively used, if interested also look up the “Extended Kalman Filter,” which works for nonlinear systems
Practical Implementation Notes

• In general, these filters should ideally be run in continuous time
• In practice, these are not
• An individual sensor node can transmit its information at speeds which are orders of magnitude slower than it is able to sample information, therefore some filters should be done on the sensor itself
Feature Maps

- Extract “features” of the environment to use for the application
  - Occupancy Grid
  - Network Scans
Applications, Examples

• Environmental Sensing
  ▫ seismography, climate, etc.

• Internal Security
  ▫ Security systems, cameras, motion sensors

• Surveillance
  ▫ UAV’s, ground reconnaissance

• Robotics
  ▫ Strapdown kinematics, object detection, collision avoidance
Example: Strapdown Kinematics

• Strapdown means that all sensors are “strapped down” to the unit, gaining no external input
• Kinematics means that we are trying to get feedback on the motion that a unit is undergoing
  ▫ Position, Velocity, Acceleration, Orientation, Rotational Velocity, etc.
Example: Strapdown Kinematics

What sensors will we use?

- **Accelerometers**
- **Gyroscopes**
- **Magnetometers?**
  - Relies on Earth’s magnetic field, however can be easily disrupted when near ferrous materials
- **GPS?**
  - Relies on satellites, this information is not usable inside of a building and underwater
Example: Strapdown Kinematics

Strengths & Weaknesses

- **Accelerometers**
  - **Strengths:**
    - Good at getting low-frequency changes
  - **Weaknesses:**
    - Poor at getting high-frequency changes
    - Can only resolve 2 dimensions

- **Gyroscopes**
  - **Strengths:**
    - Good at getting high-frequency changes
  - **Weaknesses:**
    - Poor at getting low-frequency changes
    - Integration errors result in a DC drift
Example: Strapdown Kinematics

Fusing the sensors

- On the Accelerometer, apply a low-pass filter
- On the Gyroscope, apply a high-pass filter
- Add them!

$$\text{high \_ pass}\left(\int_{t_0}^{t_1} \omega_g \, dt\right) + \text{low \_ pass}\left(\begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix}\right)$$
Example: Strapdown Kinematics

Example Platform

Robotics Club at UCF
http://robotics.ucf.edu
Example: Object Detection

What sensors will we use?

- **Cameras**
  - Good at getting a view of different kinds of objects
  - Often have a hard time differentiating objects, and getting a sense of depth

- **LIDAR (Light Detection And Ranging)**
  - Good at identifying object distance
  - Most only reveal a single plane
Example: Object Detection

Example Platform
Camera

Robotics Club at UCF
http://robotics.ucf.edu
References


Other Useful Resources