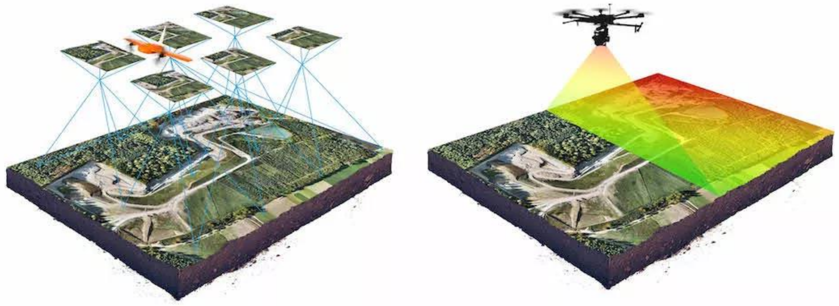
Sensor Fusion Techniques for Accurate Perception of Objects in the Environment

Becky Soltanian
Vice President of R & D
Sanborn

Introduction

- **Definition**
  - Sensor fusion is the process of combining data from multiple sensors to produce information that is more
    - Accurate
    - Reliable
    - Complete



Introduction

- **Importance**
  - Sensor fusion can provide a more comprehensive view of a system or environment
  - Allowing for better:
    - Decision-making
    - Control
    - Automation

Introduction

- **Types of sensors**
  - Passive sensors:
    - Cameras (including thermal camera)
    - GPS
    - IMU
    - HD-map can be considered as a passive sensor
  - Active sensors:
    - LiDAR
    - Radar

Introduction

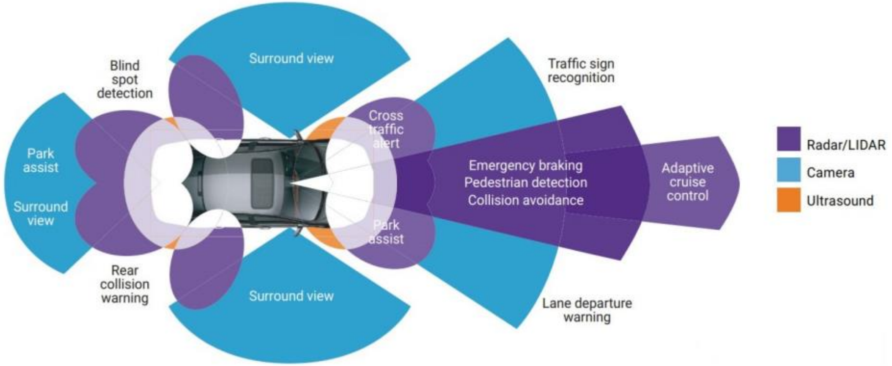
- **Challenges:**
  - Dealing with noise and uncertainties
  - Handling different sensor modalities
  - Synchronizing data from different sensors
  - Selecting appropriate fusion algorithms
- Algorithms can be computationally intensive

Introduction

- **Benefits**
  - Improved accuracy
  - Increased robustness
  - Enhanced situational awareness
  - Reduced cost and complexity

Sensor suite for self driving cars

- To see:
  - 360-degree view
  - Radar and LiDAR
    - Advantages
    - Disadvantages
- To hear:
  - New audio sensors



Sensor fusion

- **The main components include:**
  - Sensors
  - Data acquisition
  - Pre-processing
  - Fusion algorithms
  - Decision-making
  - Control

- **Examples of applications include:**
  - Autonomous vehicles
  - Robotics
  - Surveillance
  - Security
  - Healthcare
  - Industrial automation

Algorithm and approaches

- Bayesian filter
  - Kalman filter (Extended Kalman filter) is a recursive algorithm that estimates the state of a system based on noisy sensor measurements and a mathematical model of the system
  - Particle filter is a Monte Carlo-based algorithm that uses a set of particles to estimate the probability distribution of the system state

Kalman filter

- The key inputs to the Kalman filter for sensor fusion include:
  - State vector
    - Current state
  - System model
  - Sensor data
  - Measurement model
  - Error covariance matrices
- The Kalman filter adjusts the weight given to each input in the fusion process, based on their relative accuracy and reliability. The filter produces a more accurate and reliable estimate of the system state, which can be used for control, navigation, or other applications

Kalman filter : Key strengths and weaknesses

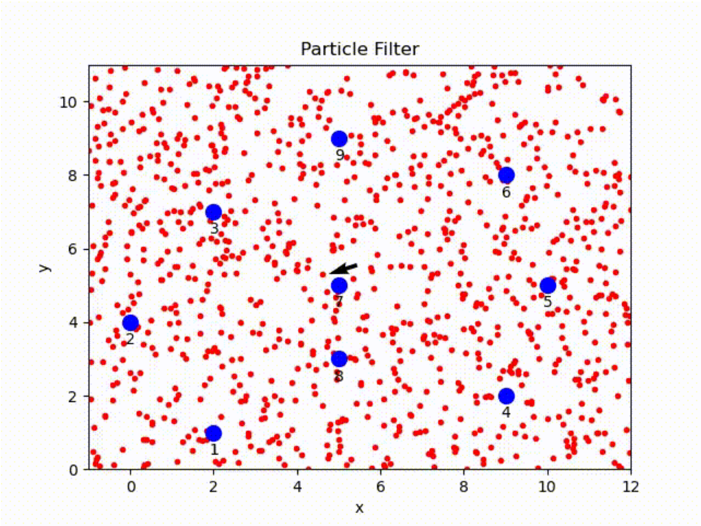
- Strengths:
  - The EKF:
    - Non-linear systems
    - Non-linear measurements
    - Can be used for real-time applications
- Weaknesses:
  - Computationally heavy
  - Linearization of the system dynamics and measurement functions can introduce errors
  - Sensitive to errors
    - Initial state estimate and error covariance matrix
      - Lead to inaccurate estimates of the system state
  - The system noise and measurement noise are assumed Gaussian and independent, and this may not always be the case in practice.
- Note: The extended Kalman filter (EKF) and the Kalman filter are two variants of the same algorithm, with the EKF being an extension of the standard Kalman filter that can handle non-linear systems

Particle filters

- Particle filters:
  - Recursive Bayesian filter
  - Estimate the state of a system
    - Propagating a set of weighted samples or particles through the system
  - Can handle
    - Non-linear
    - Non-Gaussian systems
    - System dynamics or measurement functions
      - Are not well understood or cannot be modeled using a parametric approach
  - Uses the posterior probability distribution of the system state using a set of weighted particles
  - The particles are propagated through the system using a proposal distribution, and the weights are updated based on the likelihood of the measurements

Particle filters

- Techniques can be used to generate proposal distribution:
  - Importance sampling
  - Sequential importance sampling
  - Markov Chain Monte Carlo (MCMC) methods



Particle filter: Key strengths and weaknesses

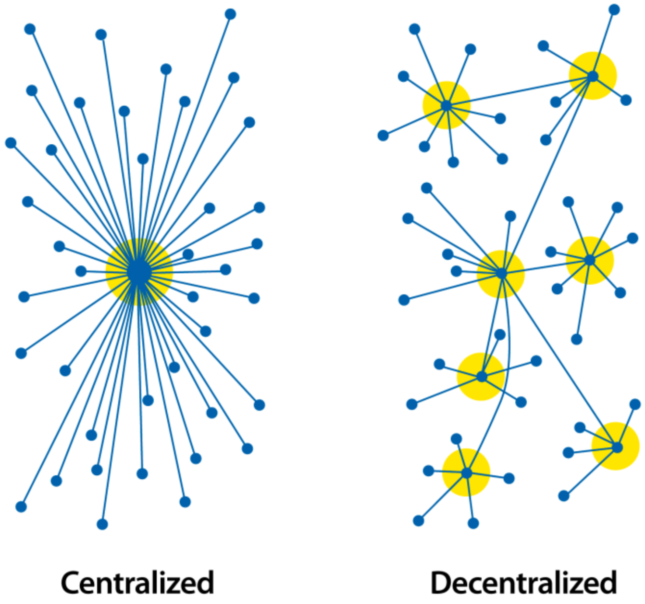
- Key strengths:
  - Particle filters suitable when the system is non-linear, or the noise is not Gaussian
- Weaknesses:
  - The choice of the proposal distribution
    - Critical for the performance of particle filters
  - Computationally heavy
    - Especially for high-dimensional systems
    - When the proposal distribution is complex
    - Solutions:
      - Unscented particle filter
      - Ensemble Kalman filter

Metrics to evaluate fusion approaches

- Accuracy
- Precision
- Robustness
- Computational complexity
- Latency
- Power consumption

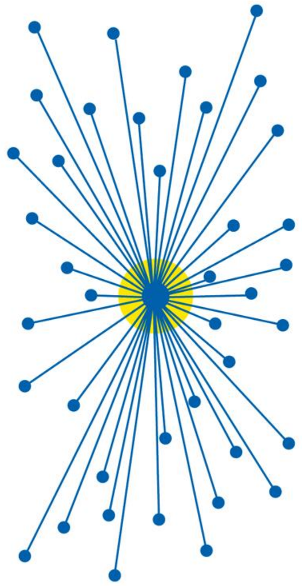
Fusion architecture

- **In centralized,** the clients simply forward all the data to a central location, and some entity at the central location is responsible for correlating and fusing the data
- **In decentralized**, the clients take full responsibility for fusing the data and every sensor or platform can be viewed as an intelligent asset having some degree of autonomy in decision-making
  - More scalable and robust, as it can distribute the processing load across multiple nodes and avoid single points of failure



Centralized fusion use case

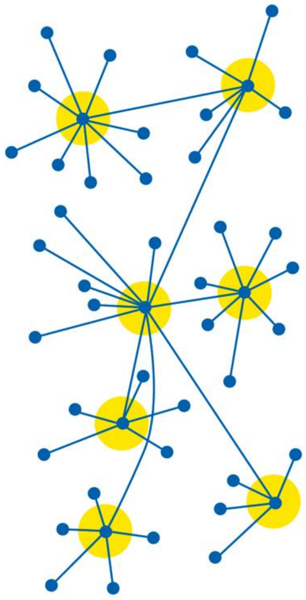
- Centralized sensor fusion may be more appropriate in situations where:
  - There are many sensors involved
    - Can help manage and optimize the flow of data between them
  - The processing requirements are high
    - Can leverage more powerful computing resources to handle the workload
  - There is a need for real-time decision-making
    - Can provide faster processing and response times



Centralized

Decentralized fusion use case

- Decentralized sensor fusion may be more appropriate in situations where:
  - There is a need for greater fault tolerance
    - Can help ensure that the system continues to function even if one or more nodes fail
  - The system needs to be more scalable
    - Can help handle an increasing number of sensors or data sources.
  - The system is deployed in a distributed or remote environment
    - Centralized processing is not practical or feasible.

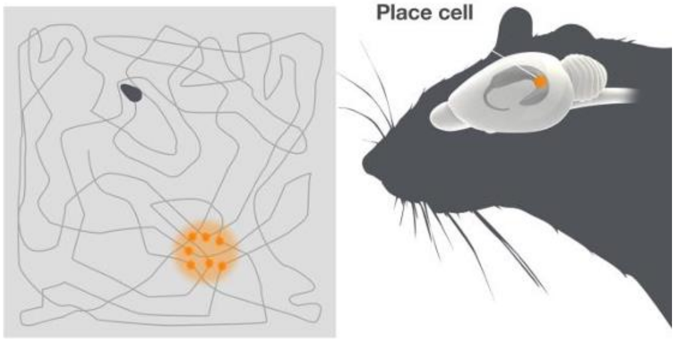


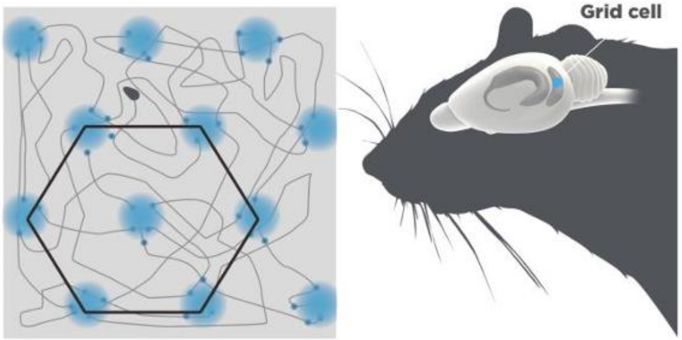
Decentralized

Discovery of place cells and grid cells

- A ***grid cell*** is a type of pyramidal neuron that responds to the location
- To do this, each grid cell creates a cognitive map of space

- Place cells are in the hippocampus
  - Encode spatial information during navigation, by firing selectively when the animal is in a certain part of its environment





- How do humans drive?
- Why do we need HD maps as a passive sensor?

Conclusion

- We talked about:
  - Sensor fusion, its challenges and benefits and types of sensors
  - Algorithms
  - Centralized and decentralized use case
  - HD-map as a passive sensor

Reference

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