자율 이동로봇을 위한 센서퓨전 및 네비게이션 알고리즘 개발
김종현, MathWorks
Smart Autonomous Package Delivery

① Autonomous Driving

② Warehouse Automation

③ Last Mile Delivery
Capabilities of an Autonomous System

Some common Perception tasks

- Design localization algorithms
- Design environment mapping algorithms
- Design SLAM algorithms
- Design fusion and tracking algorithms
- Label sensor data
- Design deep learning networks
- Design radar algorithms
- Design vision algorithms
- Design lidar algorithms
- Generate C/C++ code
Capabilities of an Autonomous System

- Visualize street maps
- Connect to HERE HD Live Map
- Design local and global path planners
- Design vehicle motion behavior planners
- Design trajectory generation algorithms
- Generate C/C++ code
Capabilities of an Autonomous System

Some common Control tasks

- Connect to recorded and live CAN data
- Design reinforcement learning networks
- Model vehicle dynamics
- Automate regression testing
- Prototype on real-time hardware
- Design path tracking controllers
- Design model-predictive controllers
- Generate production C/C++ code
- Generate AUTOSAR code
- Certify for ISO26262
In This Talk, You Will Learn

- Reference workflow for autonomous navigation systems development
- MATLAB and Simulink capabilities to design, simulate, test, deploy algorithms for sensor fusion and navigation algorithms
  - Perception algorithm design
  - Fusion sensor data to maintain situational awareness
  - Mapping and Localization
  - Path planning and path following control
Many Options to Bring Sensor Data to Perception Algorithms

Perception
- Tracking
- Localization
- Mapping

Planning

Control

Scenario Definition and Sensor Simulation
- Ownship Trajectory Generation
- Actors/Platforms
- INS (IMU, GPS) Sensor Simulation
- Lidar, Radar, IR, & Sonar Sensor Simulation

Sensor Data
- rosbag data

Multi-object Trackers

Fusion for orientation and position

Visualization & Metrics

SLAM

Perception
- Tracking
- Localization
- Mapping

Planning

Control

Many Options to Bring Sensor Data to Perception Algorithms
Live Data Can Be Augmented for a More Robust Testbench

- Perception
  - Tracking
  - Localization
  - Mapping

- Planning

- Control

Define scenarios

Simulate sensors
Autonomous Systems Can Track Objects from Lidar Point Clouds

Track Objects Using Lidar: From Point Cloud to Track List

Track surrounding objects during automated lane change
2D radar Can Be Used to Track Position, Size, and Orientation

Perception
- Tracking
- Localization
- Mapping

Planning

Control

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MATLAB EXPO
Fusing Multiple Sensor Modalities Provides a Better Result

- Perception
  - Tracking
  - Localization
  - Mapping

- Planning

- Control

3-D Lidar → 3D cuboid tracks → Tracks
2-D Radar → 2D rectangular tracks → Tracks

Fuse tracks

Point cloud

MATLAB EXPO
Radar and Lidar Fusion Can Increase Tracking Performance

- Perception
  - Tracking
  - Localization
  - Mapping

- Planning

- Control

![Diagram showing radar and lidar fusion](image)

- Ground Truth
- Radar Tracks
- Lidar Tracks
- Fused Tracks
  - Point Cloud
  - Radar Detections
  - Lidar Bounding Box Detections

- Front View (Time Step = 1)
- Lidar
- Radar

- Track Level Fusion
  - Fusion of track by LIDAR
Radar and Lidar Fusion Can Increase Tracking Performance

Perception
• Tracking
• Localization
• Mapping

Planning

Control

- Missed Target Metric
- False Track Metric
- GOSPA Metric
Estimate the Pose Using Monte Carlo Localization

- Perception
  - Tracking
  - Localization
  - Mapping

- Planning

- Control

Motion Model
(Odometry readings)

Sensor Model
(Lidar scan)

Particle Filter

Known Map
What is the World Around Me?

Egocentric occupancy maps

- Support dynamic environment changes
- Synchronization between global and local maps
What is the World Around Me?

3D Occupancy Map

Perception
- Tracking
- Localization
  - Mapping

Planning

Control

3D map for Autonomous Driving

3D map for UAV motion planning
Where Am I in the Unknown Environment?
Simultaneous Localization and Mapping (SLAM)

Build a map of an unknown environment while simultaneously keeping track of robot’s pose.
Simultaneous Localization and Mapping
SLAM Map Builder App (2D only)

App enables more interactive and user-friendly workflow
Simultaneous Localization and Mapping
3D Lidar SLAM

Perception
  • Tracking
    • SLAM
      • Localization
      • Mapping

Planning

Control

Point Cloud Processing
Local Mapping
Loop Closure Detection
Pose Graph Optimization
Map representation

Computer Vision

Navigation
Simultaneous Localization and Mapping
3D Monocular Visual SLAM (ORB-SLAM)

Planning

Control

Perception

- Tracking
  - SLAM
  - Localization
  - Mapping

Figure 1
Figure 2: Point Cloud Viewer

Map points
Estimated trajectory

Stop on Closure
Update Recognition Database
Process next frame

Figure 1
10x

Frames
Map Initialization
Initial Map Points
Tracking
Key Frame
Local Mapping
Updated Map Points
Key Frame
Loop Closure

1 Frame per process

Discard non Key Frame
Plan a path from start to destination

Perception
- Tracking
- Localization
- Mapping

Planning

Control

Global Planning

Local Re-planning

MathWorks

MATLAB EXPO

Initial Route to Package

Initial Location

Goal Location

Forklift Route to Package
Plan a Path from Start to Destination

<table>
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<th>Behavior Planning</th>
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Global Planning

- Path planning algorithms

Behavior Planning

- High-level decision making

Local Re-planning

- Trajectory generation
Urban Driving Needs Planning on Multiple Levels
Global, behavior, and local planners

Generate optimal trajectories for local re-planning and merge back with the global plan

Perception
- Tracking
- Localization
- Mapping

Planning

Control
Simulate shortest path to change lanes on a highway

Simulate trajectory generation and the lane change maneuver
Mission planning for UAV leads to last mile delivery

Perception
• Tracking
• Localization
• Mapping

Planning

Control

Flight controller running in external mode on the Raspberry Pi

Waypoint Following
Orbit
Launch

Simulink

Setup

Control Inertial Model
Ground Station Commands
Click to Return To Base
Click to Index Host Equipment
Base Wait: 4,000

Video Speed: 4x
Choose a path planner based on your application

Sampling-based planners such as RRT*

Use path metrics to compare different paths

Perception
  • Tracking
  • Localization
  • Mapping

Planning

Control

**MATLAB EXPO**
Computes angular velocity from this desired curvature

Compute Control Commands for Ground Vehicles

Compute linear and angular velocity commands for a mobile robot

Perception
- Tracking
- Localization
- Mapping

Planning

Control
Send Control Commands to the Vehicle to Follow the Planned Path

Calculate the steering angle and vehicle velocity to track the trajectories

Perception
- Tracking
- Localization
- Mapping

Planning

Control
Control Lane Change Maneuver for Highway Driving

Longitudinal and Lateral Controllers to adjust the acceleration and steering

- Perception
  - Tracking
  - Localization
  - Mapping

- Planning

- Control
Simulate High-Fidelity UAV Model with Waypoint Following

Simulate GPS and IMU sensor models

Waypoint following controller

Approximate High-Fidelity Model with Low-Fidelity Model
Test Sensor Fusion and Navigation Algorithms by Deploying Them to Hardware

Perception

Planning

Control

C/C++ Code

HDL Code

GPU Code

ROS Node (roscpp code)

ROS

Processors

FPGAs

GPUs
Full Model Based Design Workflow for Autonomous Systems

**Verification & Validation**

**Connect / Deploy**

**Autonomous Algorithms**

- Sensor Fusion and Tracking Toolbox
- Computer Vision Toolbox
- Image Acquisition Toolbox
- Perceive
- Plan & Decide
- Robotics System Toolbox
- Automated Driving Toolbox
- Control
- Stateflow
- Reinforcement Learning Toolbox
- Model Predictive Control Toolbox

**Platform**

MATLAB
Simulink
There Are Many Resources to Get Started with

**Product pages**

- Sensor Fusion and Tracking Toolbox
- Automated Driving Toolbox

**Tech Talks in Youtube**

- https://www.youtube.com/channel/UC6Zjgg_0PQBm96aHeiXrjXQ

**White papers**

**Demos**

In This Talk, We Learnt About..

- Localization
- Mapping
- Tracking
- Perception
- Planning
  - Global/Mission Planning
  - Local Re-planning
  - Path Following / Tracking
  - Control
Thank You !!