Developing Multimodal SLAM Applications Using 3D Simulations

November 13, 2024

Toyota Motor Corporation
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Agenda

1. Our Company

2. Localization technology for new autonomous mobilities

3. Developing localization technology using MATLAB

4. Conclusion

TOYOTA MOTOR CORPORATION

- **Foundation** August 28, 1937
- **Number of Employee** 70,224 employees
  (380,793 employees, Toyota Group)
- **Main business Activities** Automobile production and sales

Personal Own Vehicle

TOYOTA

New Small Mobilities

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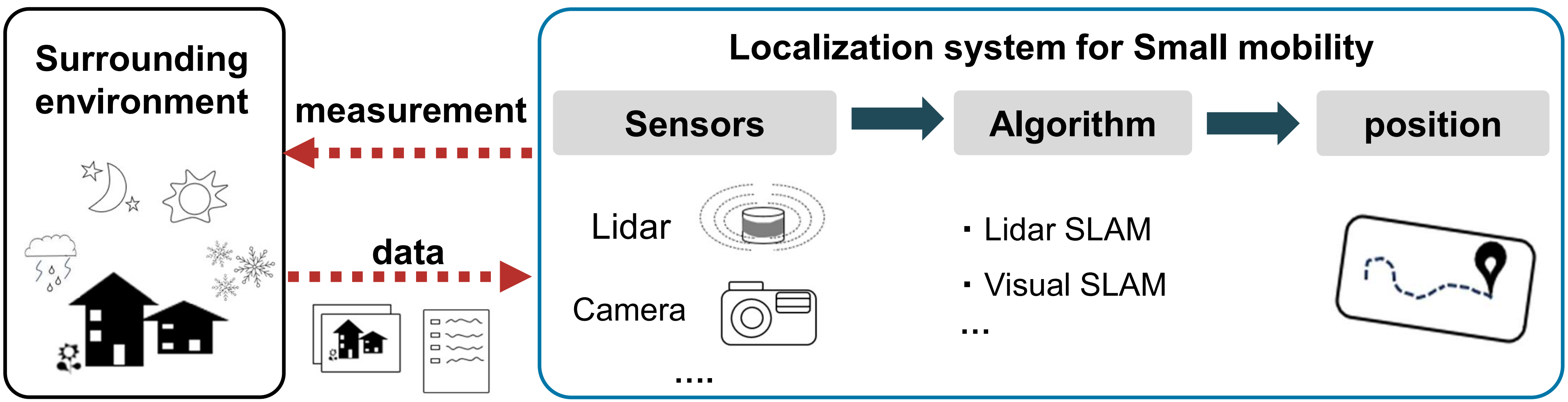
Accurate localization technology is required for the management and autonomous driving of mobilities

Simultaneous Localization and Mapping (SLAM)

Using sensors such as LiDAR and cameras to accurately track the position of mobility systems



The accuracy of SLAM is often influenced by the surrounding environment, <u>necessitating testing under various conditions to ensure system robustness.</u>

Using MATLAB to accelerate the development

Development Challenges

Difficulty of carrying out testing under desired and controlled environment

Developing Multimodal SLAM Application using 3D Simulations

Benefits of using MATLAB

✓ Complete all steps of simulation in MATLAB

- Link to Simulation environment and control the simulation execution.
- Set up measurement path and sensors' parameters.
- Process and visualize the measured sensor data and implement SLAM.

✓ Various products for simulation and data analysis

- Simulink, Simulink 3D Animation, RoadRunner
- Automated Driving Toolbox™, Computer Vision Toolbox™, Lidar Toolbox™, Navigation Toolbox™, ROS Toolbox

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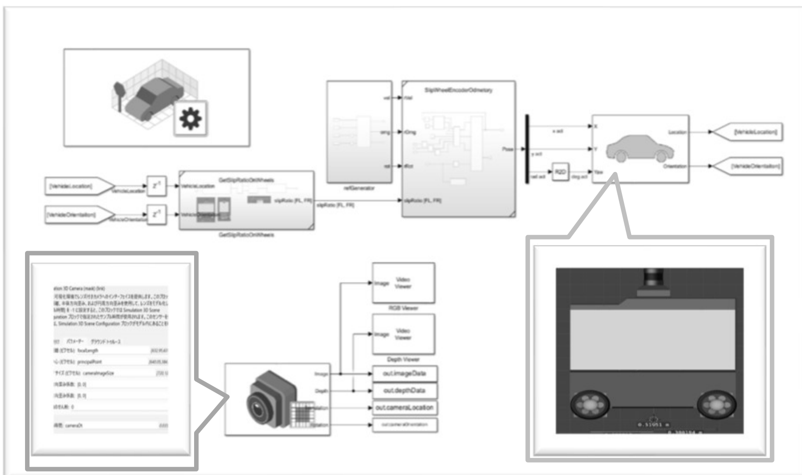
The presentation consists of two parts

Part 1

- 3D Sensor Simulation



Part 2

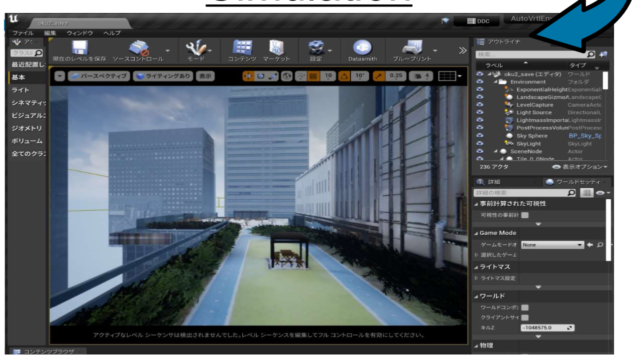
- Sensor Fusion Filter

The process of developing a simulation environment

Step1 Create a 3D environment

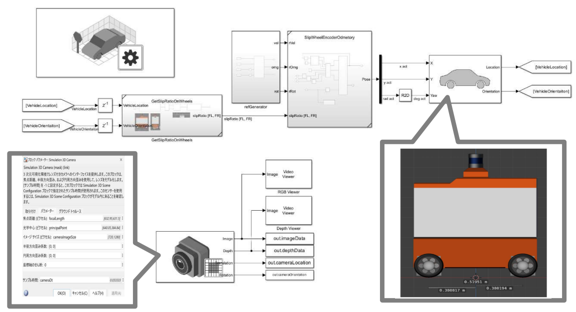
Reality

Simulation

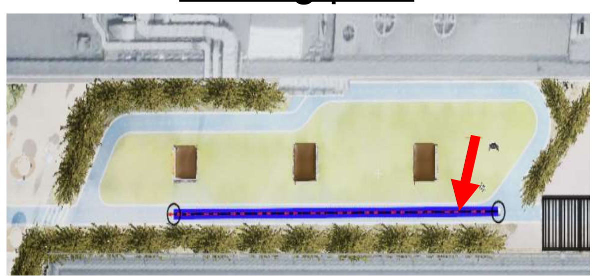


Step2 Set up sensors and path

Simulink model



Setting path

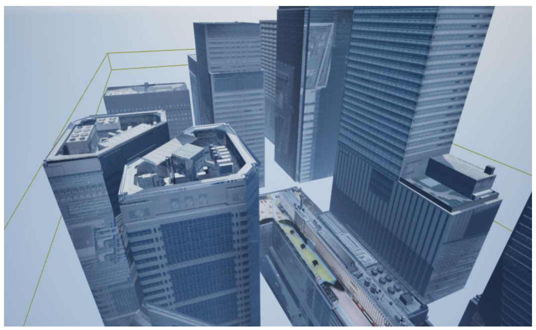


Simulation execution

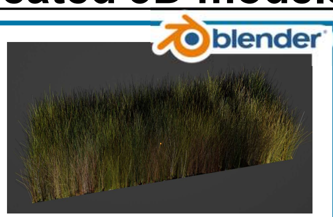
Detailed 3D models and pictures were used to make the simulation more realistic

■ Base：Source model

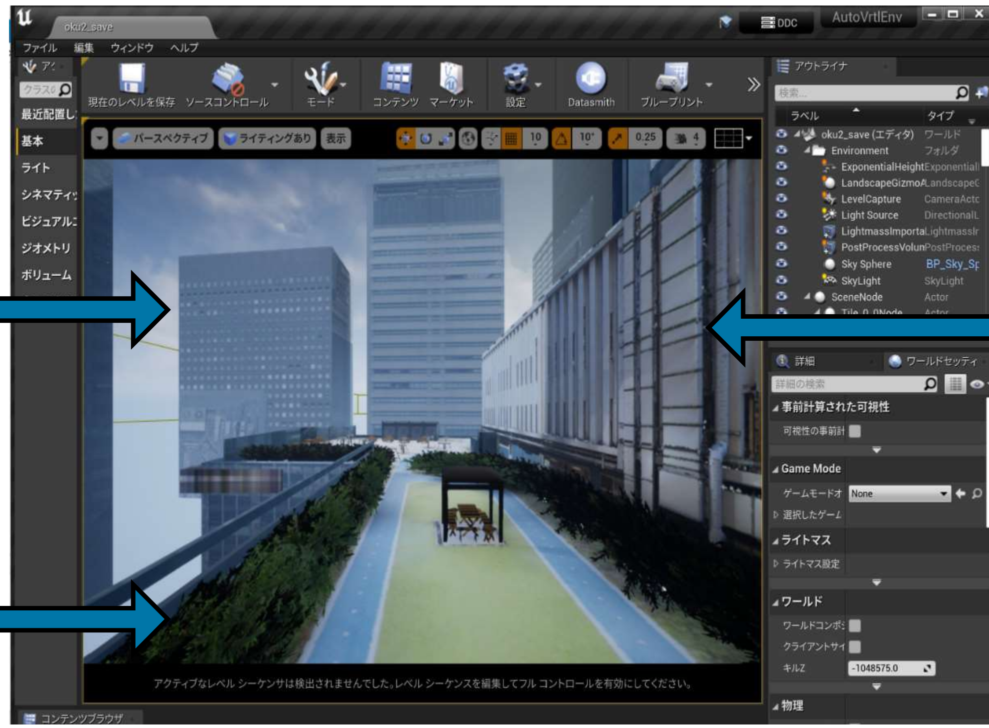
Source: Ministry of Land, Infrastructure, Transport and Tourism of Japan (https://milt.go.jp/plateau/)



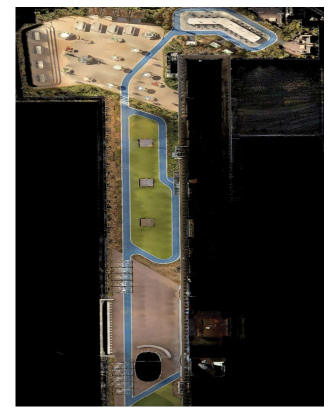
■ Details: Created 3D models



3D environment for Simulation



■Texture: Picture

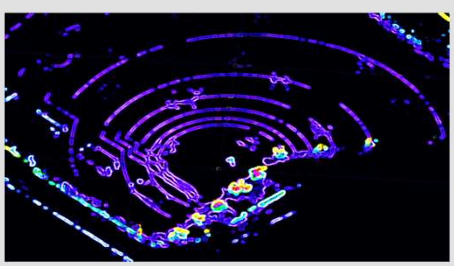


Simulation sensor blocks of Simulink provide interfaces to sensors in the simulation environment

3D Lidar

・Determining distance to objects by sending out a laser and measuring the time it takes to objects.

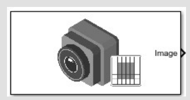
・Lidar model

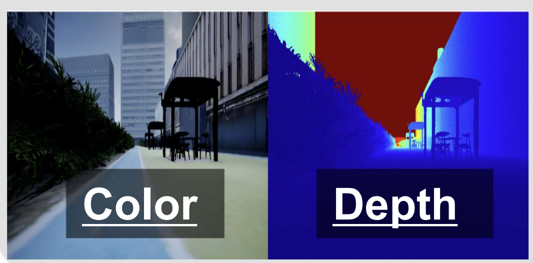


Camera (RGB-D)

・Capturing both color images and depth images of objects using stereo vision technology.

・Camera model

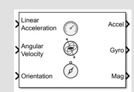


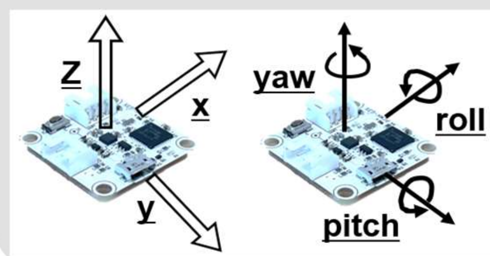


IMU

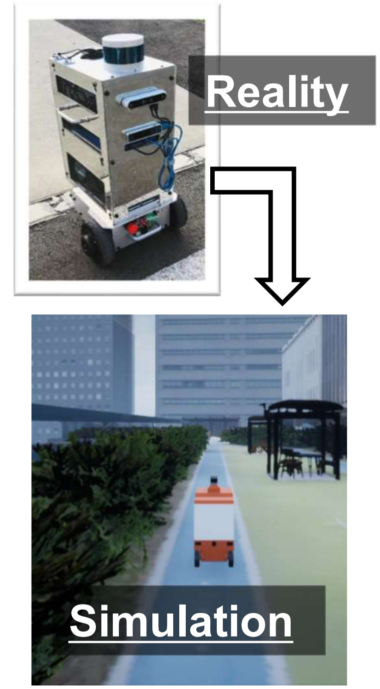
・Providing position, rotation, and orientation by measuring acceleration and angular rate.

・IMU model





Deploy to Mobility



Data obtained from various 3D Lidar models for SLAM yield results similar to those from a real Lidar

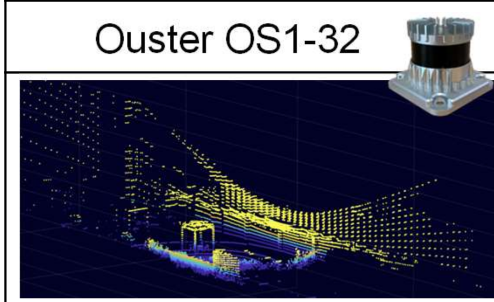
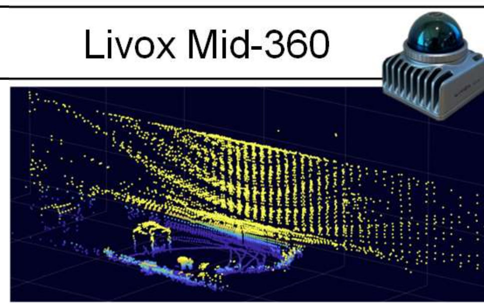
3D Lidar Localization using NDT SLAM

NDT Map
created by point cloud Map

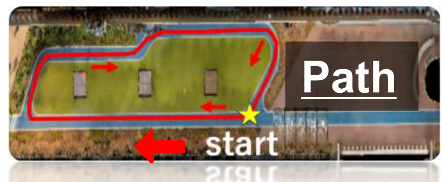
Point Cloud
obtained by 3D Lidar

→ **Localization**

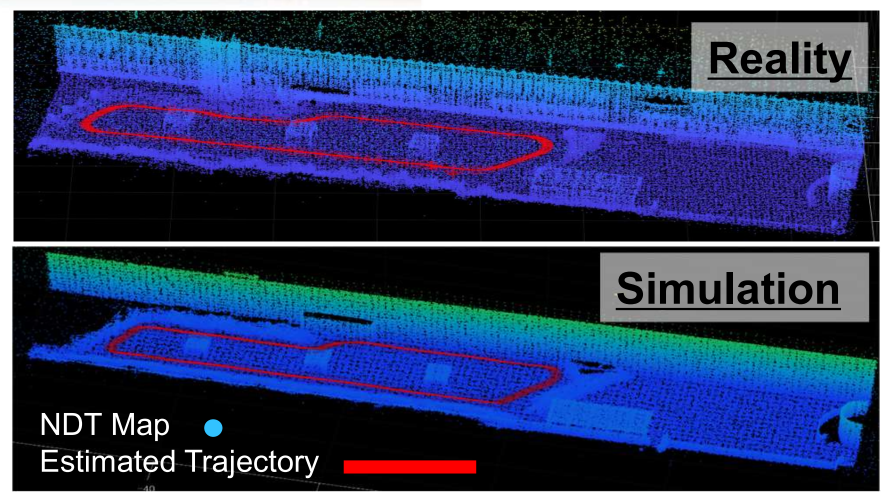
Different scan pattern's 3D Lidar can be simulated

Ouster OS1-32	Livox Mid-360
	

Result of Localization (Livox Mid-360)



Consistent with the results obtained in reality, simulations in analogous environments also achieved successful localization.



Data obtained from the RGB-D model for SLAM yield results similar to those from a real RGB-D

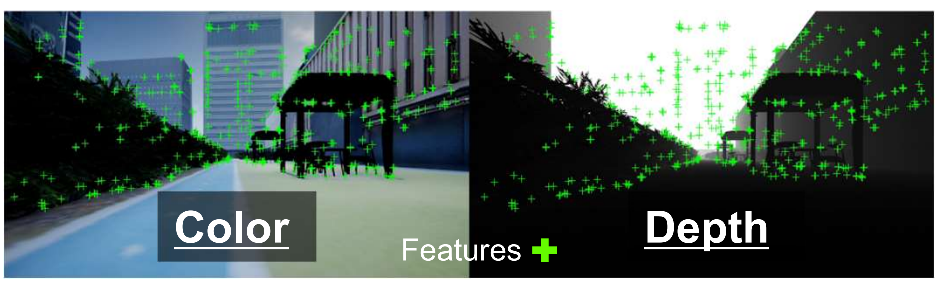
RGB-D Camera Localization using ORB SLAM

Features
extracted by color images

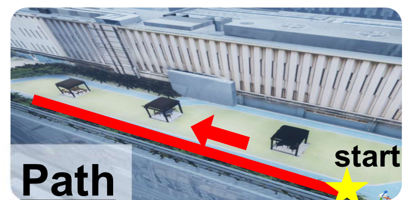
3D world position
extracted by depth images

→ **Localization**

Extracting features from camera model images



Result of Localization (Intel RealSense Camera D455)



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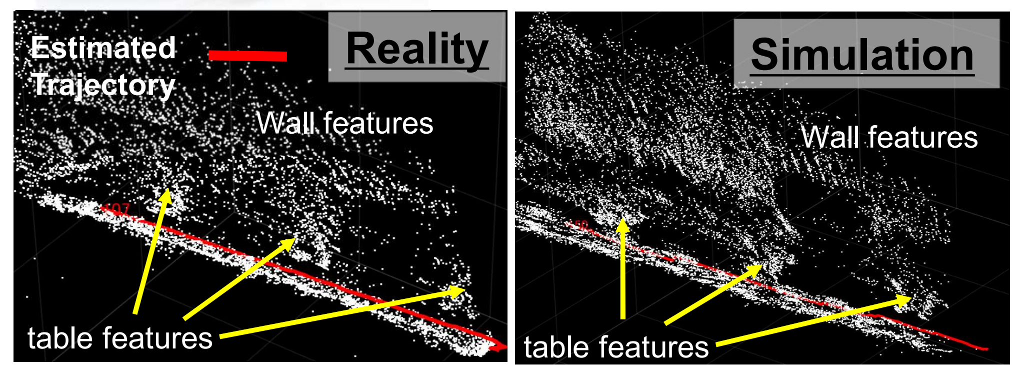


Data obtained from the IMU model for Localization can yield results similar to those from a real IMU

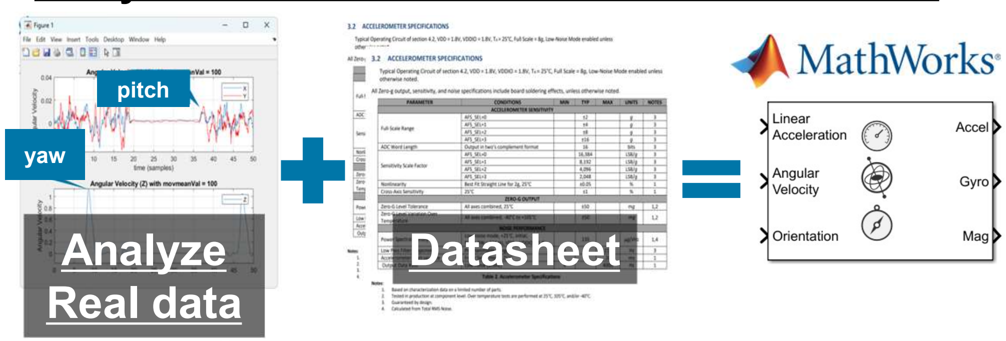
IMU Localization

Linear Acceleration
obtained by Accelerometer

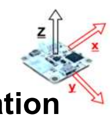
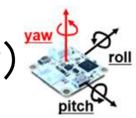
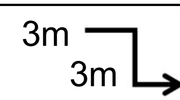
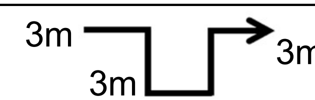
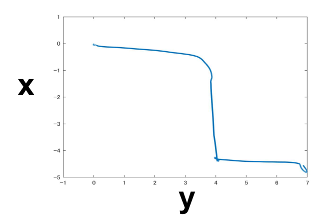
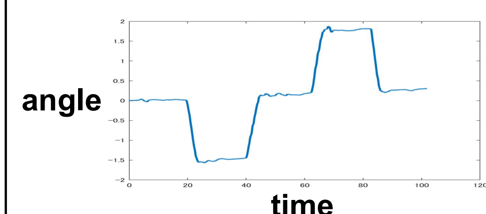
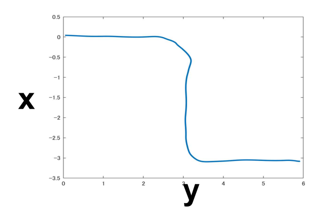
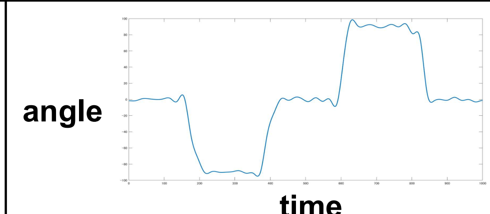
Angular Velocity
obtained by Gyroscope

→ **Localization**

Analyze real data and datasheet to simulate IMU



Result of Localization

	Position(x,y) from **Linear Acceleration** 	**Orientation(yaw)** from **Angular Velocity** 
Path		
Reality		
Simulation		

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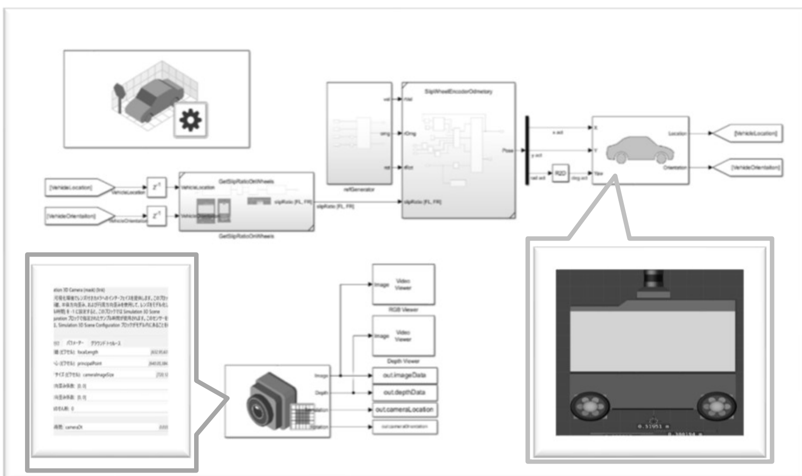
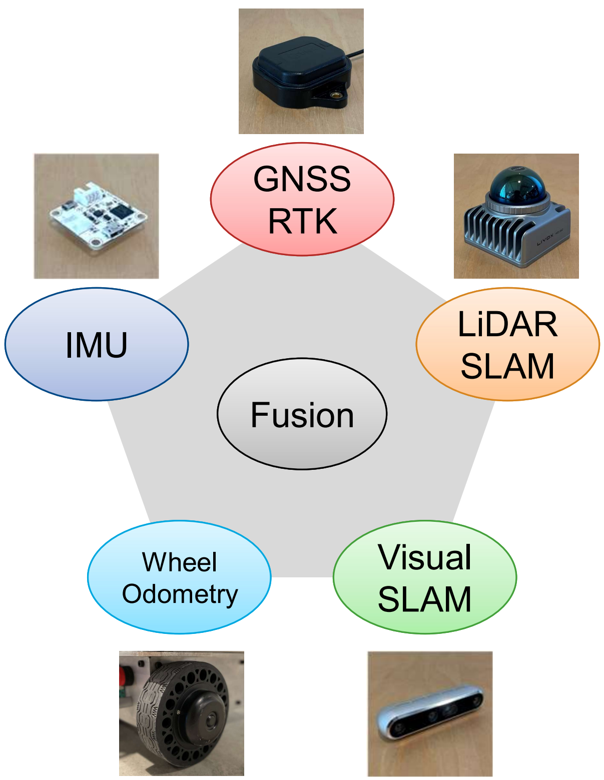
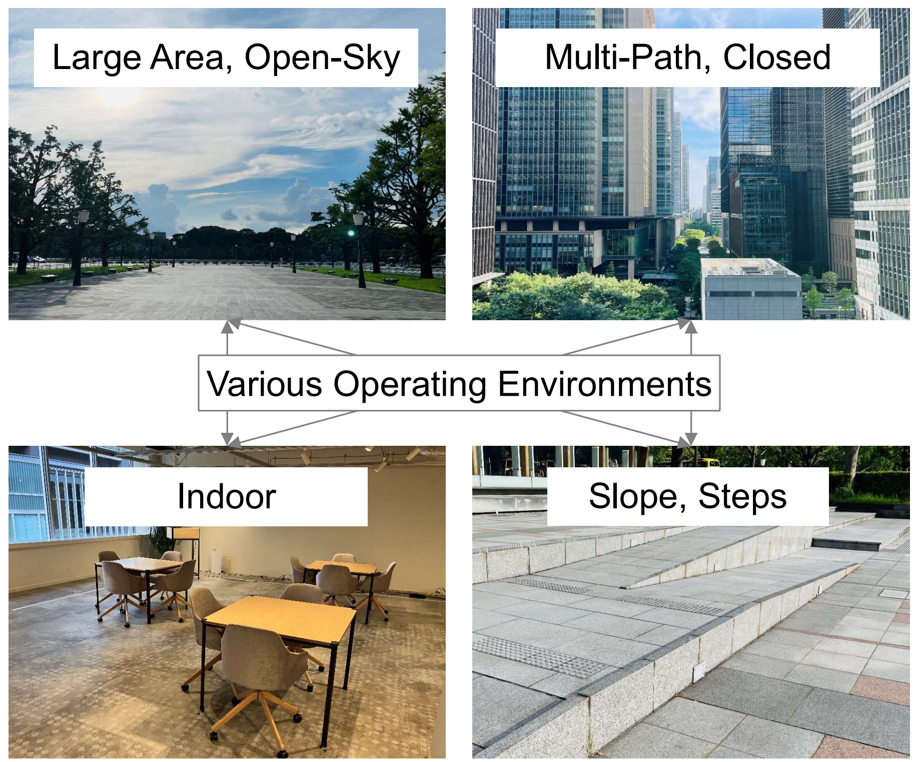


Part 2

- Sensor Fusion Filter

Stable localization in various environments requires selection and fusion of necessary technologies





MATLAB's rich functions enable efficient filter design and deployment.

Study of an outdoor localization system using GPS and SLAM, fused by MATLAB's Kalman filter function

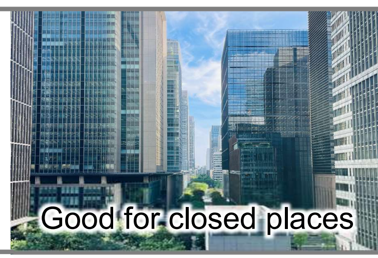
Sensor input with noise and nonlinear error

GPS（RTK）

cm-level-accuracy GPS by using correction data from base stations

SLAM（LiDAR）

Localization by scanning surrounding objects by laser beam



Wheel Odometry

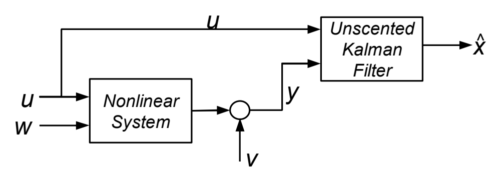
Localization by accumulating information from wheel encoders

State estimation

Unscented Kalman Filter

State estimation algorithm suitable for nonlinear systems such as sudden jump or drop of GPS(RTK) measurement

MathWorks

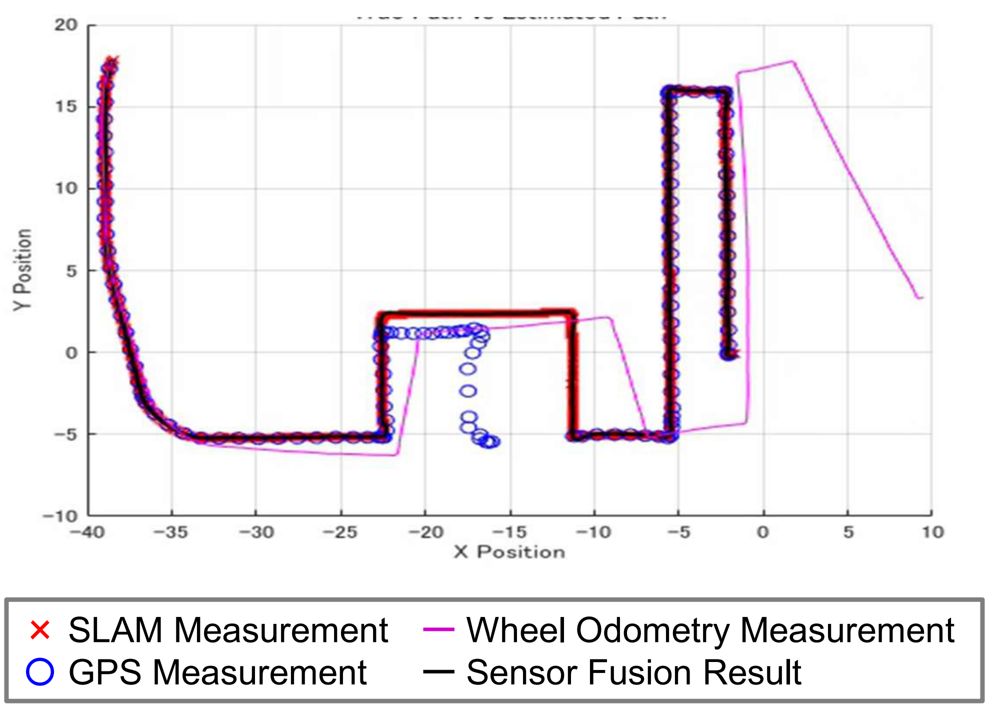


x: state estimation
u: sensor input
w: process noise
v: measurement noise
y: sensor output

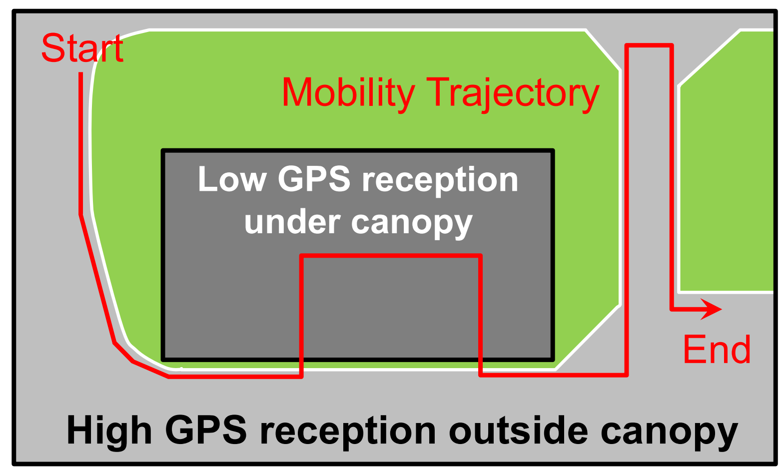
Fused Localization Result

Sensor fusion of SLAM and GPS with low reception has shown stable estimation throughout mobility trajectory

Sensor Fusion Result



Filter reduced GPS dependency by judging its reliability based on reception status and covariance.



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Conclusion

Part1: 3D Sensor Simulation

- Developing small mobility localization systems requires testing under various conditions for robustness.
- Simulation is explored to speed up development, showing that simulated sensor data can be similar to real sensor data.

Part2: Sensor Fusion Filter

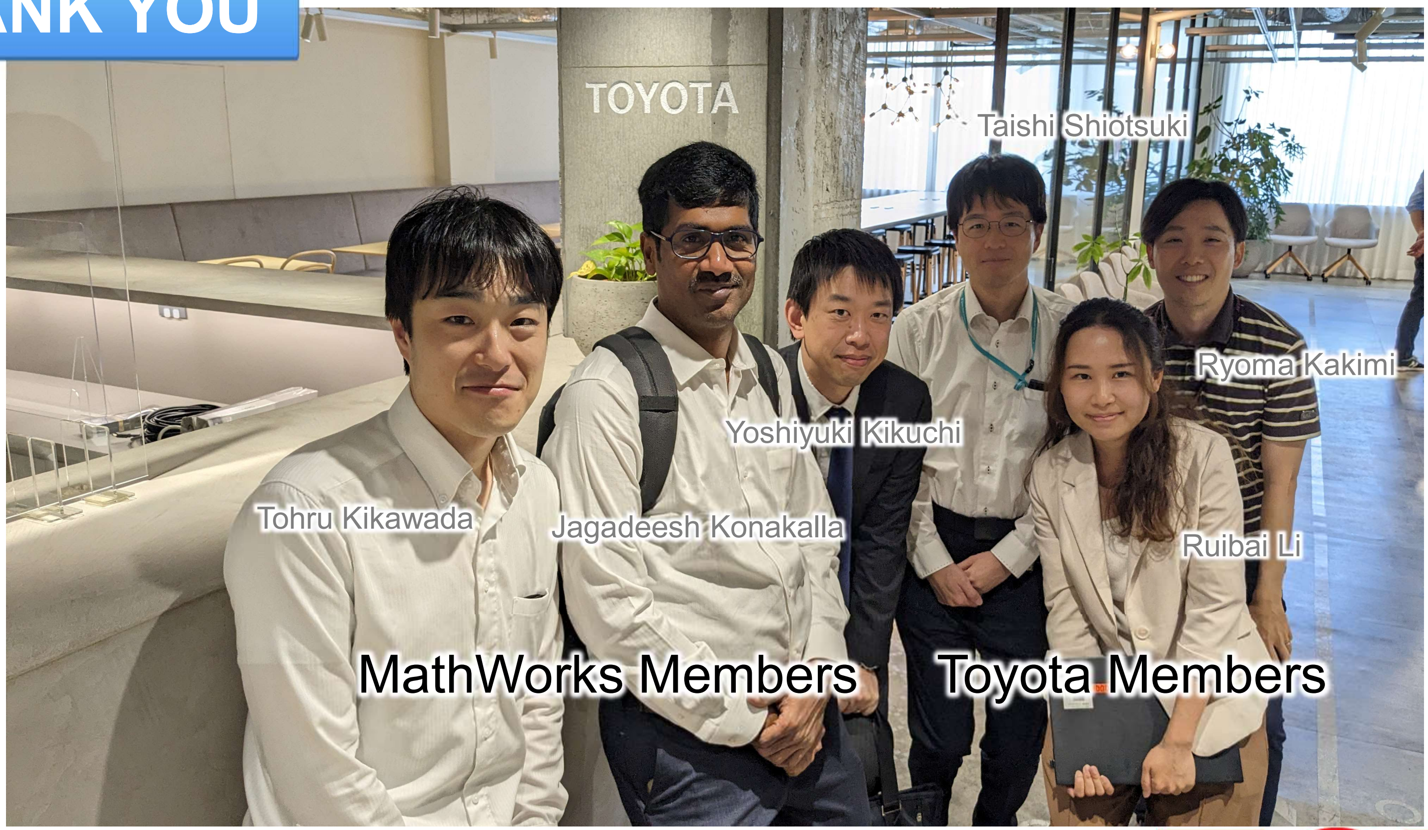
- Stable localization needs multiple sensor fusion, and MATLAB helps design these filters efficiently.
- The unscented Kalman filter effectively stabilized localization by fusing LiDAR & RTK-GNSS in a semi-outdoor scenario with low satellite reception.

Future Goals

・Create a unified development pipeline of simulation and filter design in MATLAB.

・Efficiently explore various combinations of sensors and parameters to determine a robust localization system configuration.

THANK YOU



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