Autonomous Navigation using Model Based Design

MATLAB EXPO, San Jose
November 6, 2018

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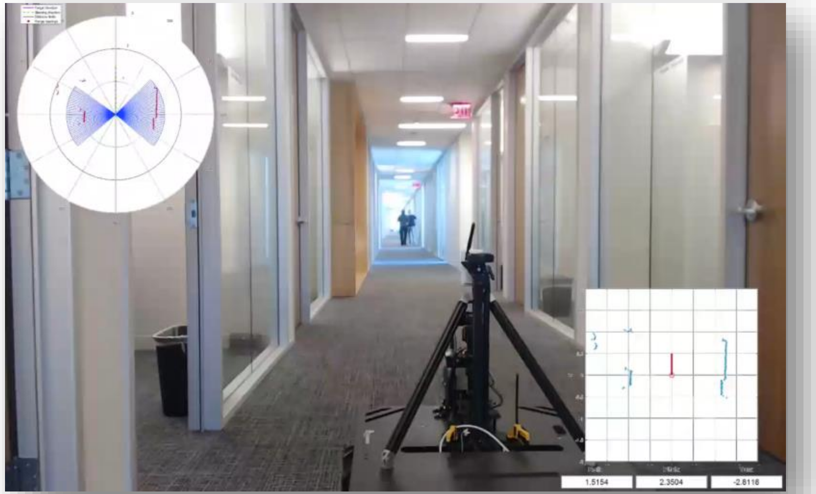
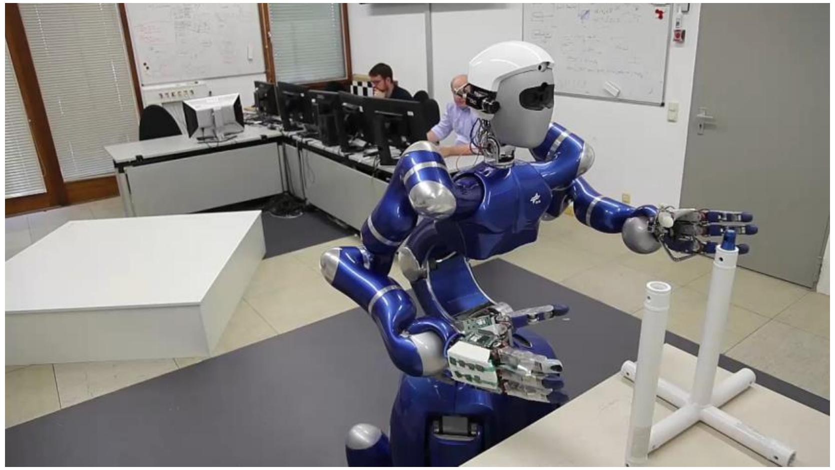
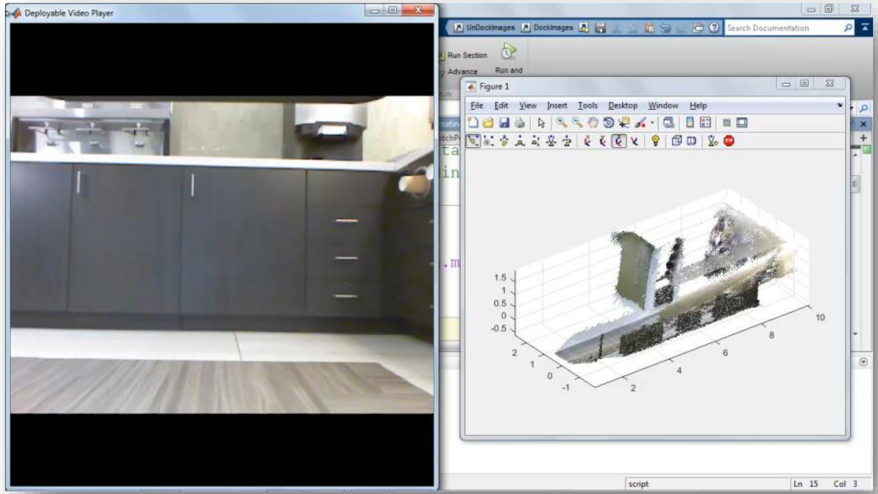
Autonomous Systems Development using MATLAB and Simulink



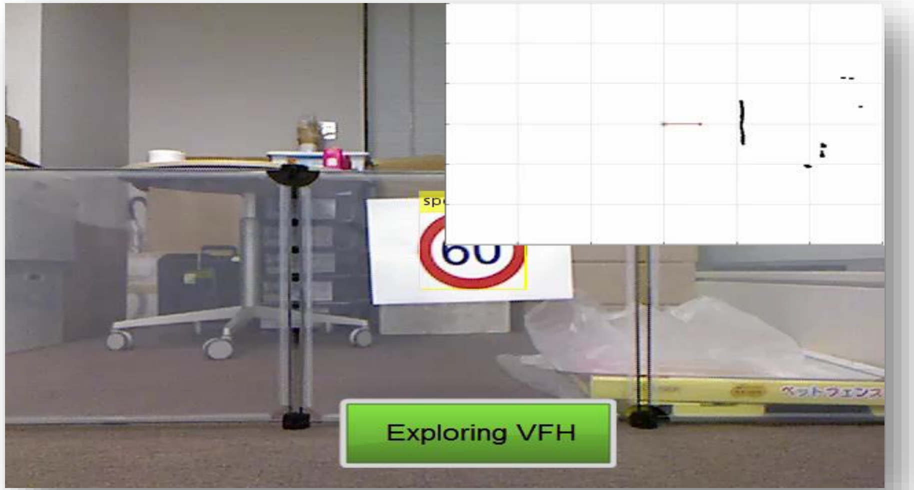
Autonomous Ground Robots



Manipulator Arms/Humanoids

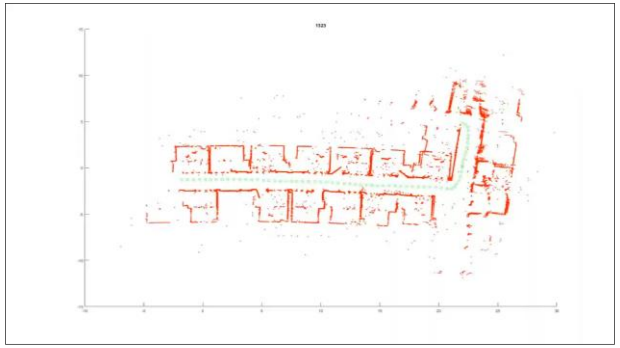


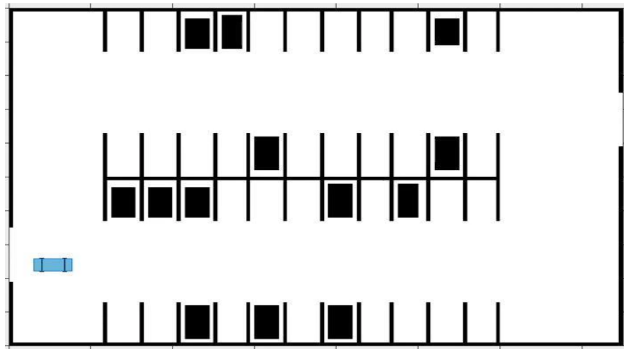
Mapping the Environment



Machine Learning and Controls

Components of Autonomous Systems





Localization → **Planning**

Planning ↓ **Control**

Control → (autonomous systems) → **Perception**

Perception ↑ **Localization**

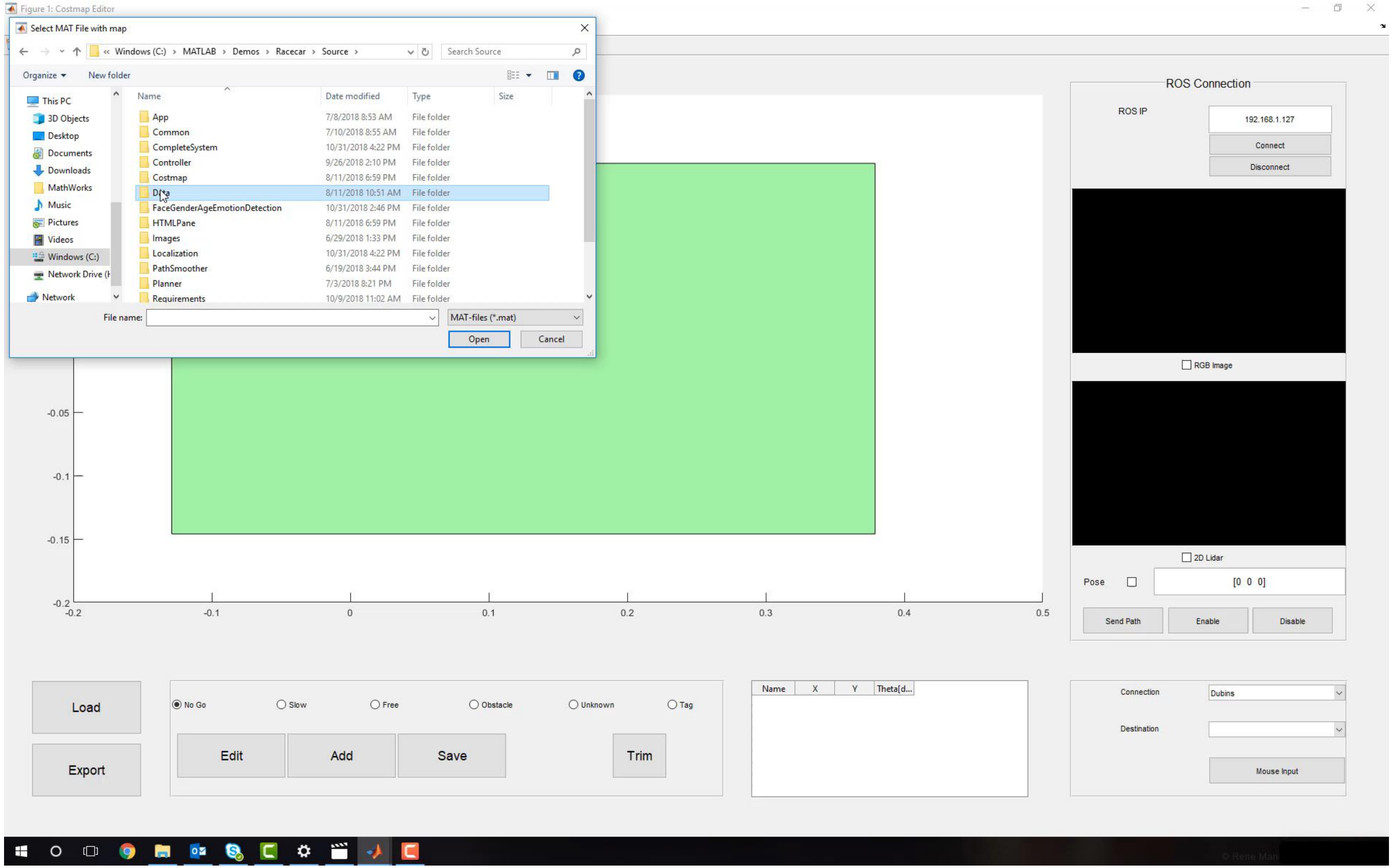
Key Takeaway of this Talk

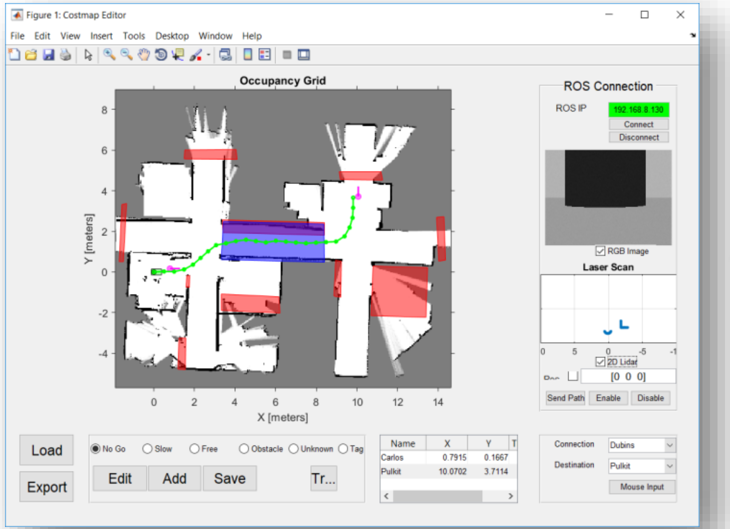
Success in developing an autonomous robotics system requires:

1. Multi-domain simulation with newer technologies
2. Trusted tools which make complex workflows easy and integrate with other tools
3. Model-based design provides the flexibility for changing development needs

Task: Autonomous Delivery Robot

Autonomous Delivery Workflow





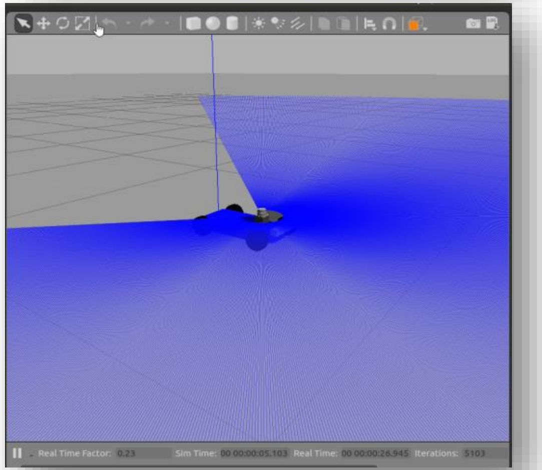
Mapping and Planning

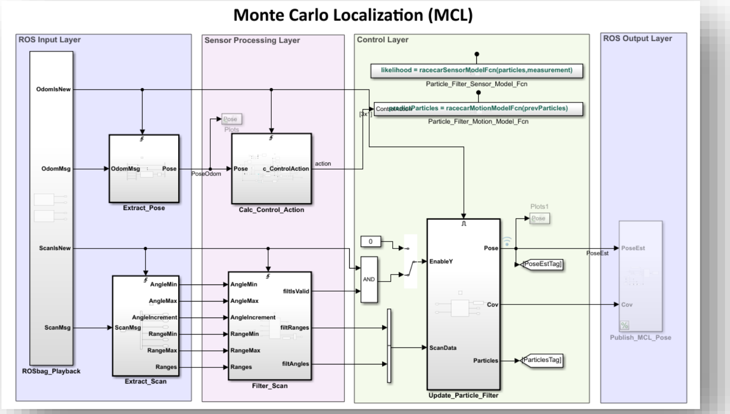
Data Import and Playback

ROS

Networking

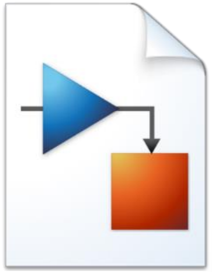
C++ Code

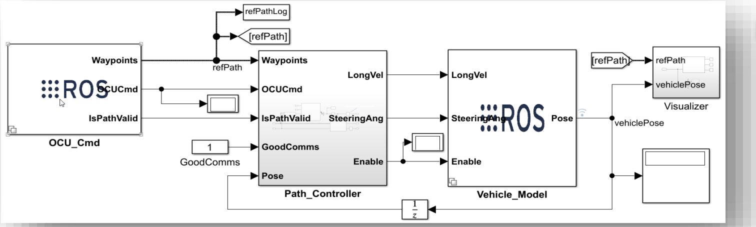




Localization

Code Generation





Code Generation

Path Following

Navigation Stack – Key Components

Sensing & Perception

Mapping

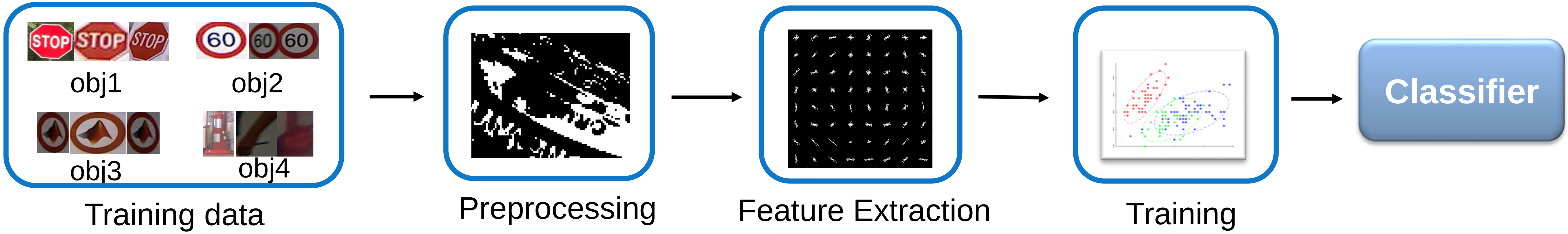
Planning & Decision making

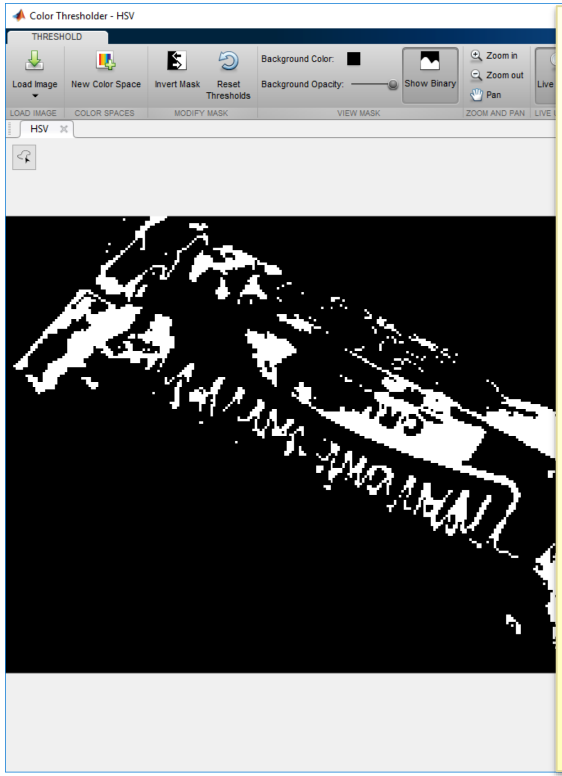
Localization & Control

Physical System + Environment

Key Components for Enabling Full Autonomy

Complex workflows made easy with MATLAB





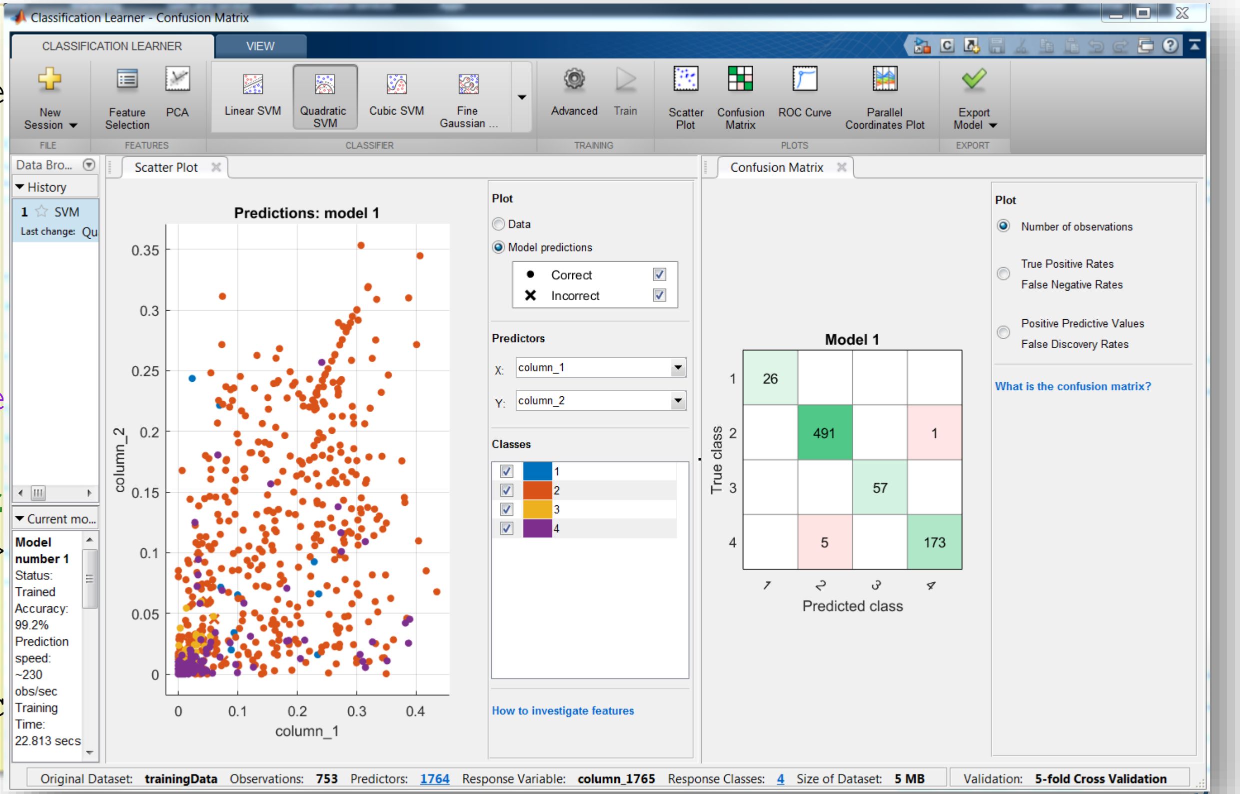

```
% Detect regions
BW = createMask(videoFrame

% Fill image regions
BW = imfill(BW,'holes');

% Get bounding boxes
stats = regionprops('table

% Filter based on area siz
targetIndex = stats.Area >

% Get bounding boxes from
testFeatures(k,:) = extrac
```



Deep Learning with MATLAB

“How do I *label* my data?”	“How do I *access* the latest models?”	“How do I make training and prediction *faster*?”	“How do I *deploy* my new model?”
New App for Ground Truth Labeling Label pixels and regions for semantic segmentation	Caffe model importer LSTM (time series, text) DAG Networks Library of pretrained models	Multi-GPUs in parallel Optimized GPU code Training plots	**NEW PRODUCT:** **GPU Coder- Convert to NVIDIA CUDA code**
Data	**Models**	**Train / Predict**	**Deploy / Share**

R2017b

Navigation Stack – Key Components

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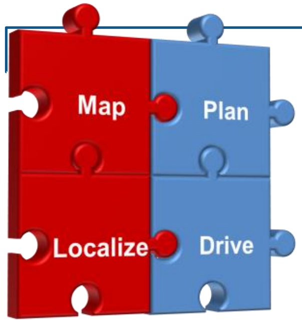
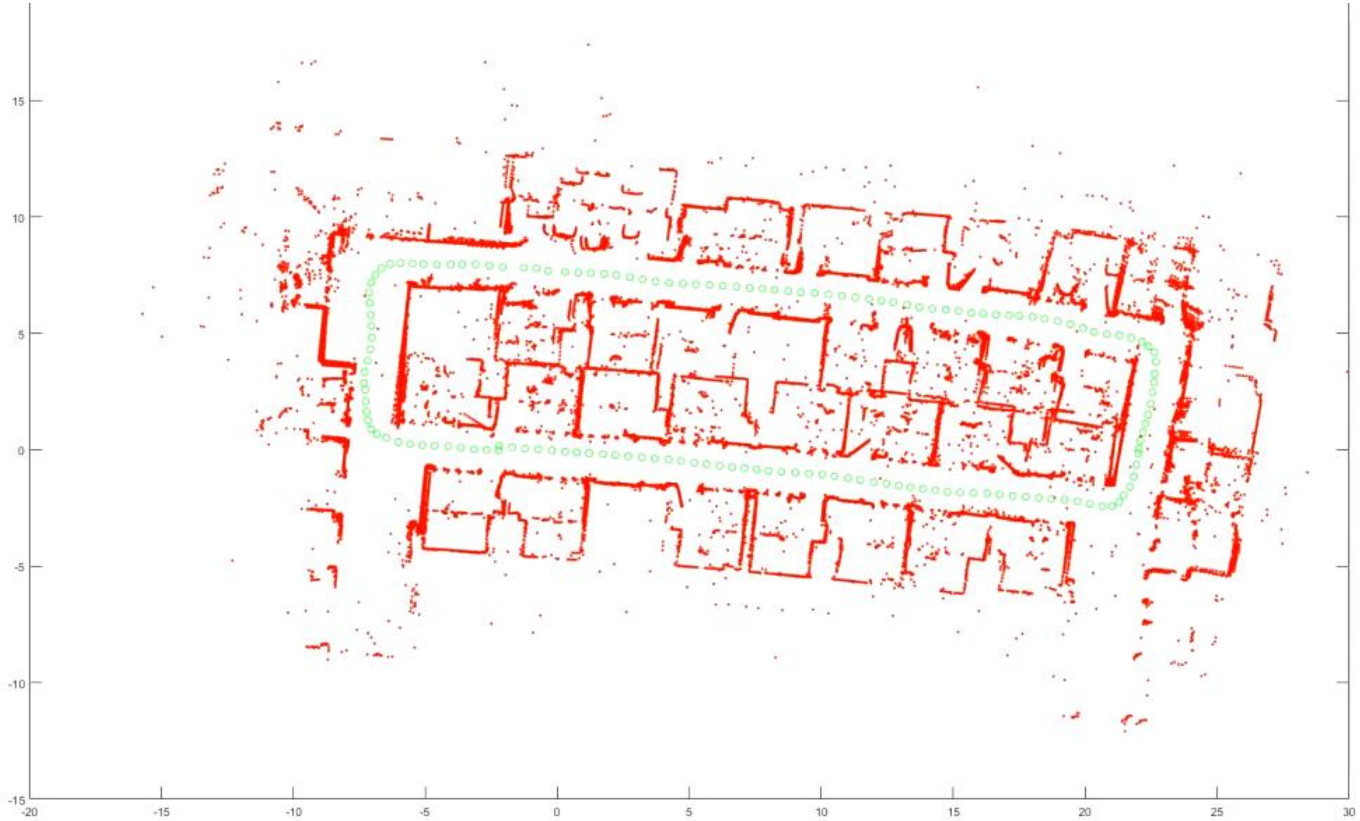
Key Components for Enabling Full Autonomy



Simultaneous Localization and Mapping (SLAM)



Robotics System Toolbox™

R2018a

Lidar SLAM Components

Sensor Data

Drifts over time

"Loop closure detection"

Sensor **Specific**

Front-End

Estimate robot motion locally

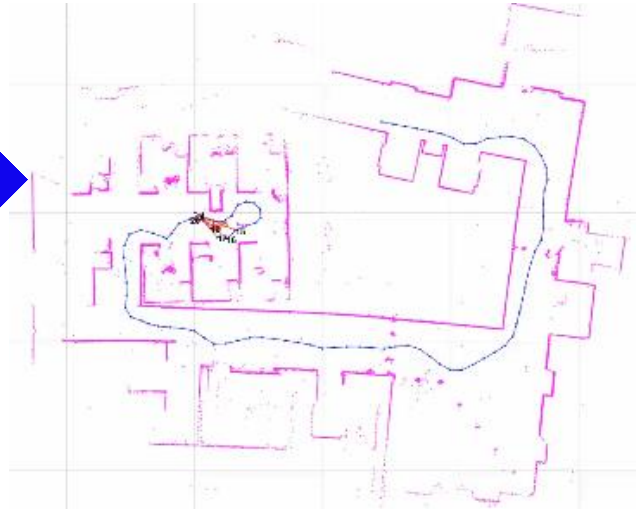
Recognize previously visited places

Sensor **Agnostic**

Back-End

Globally re-align all scans

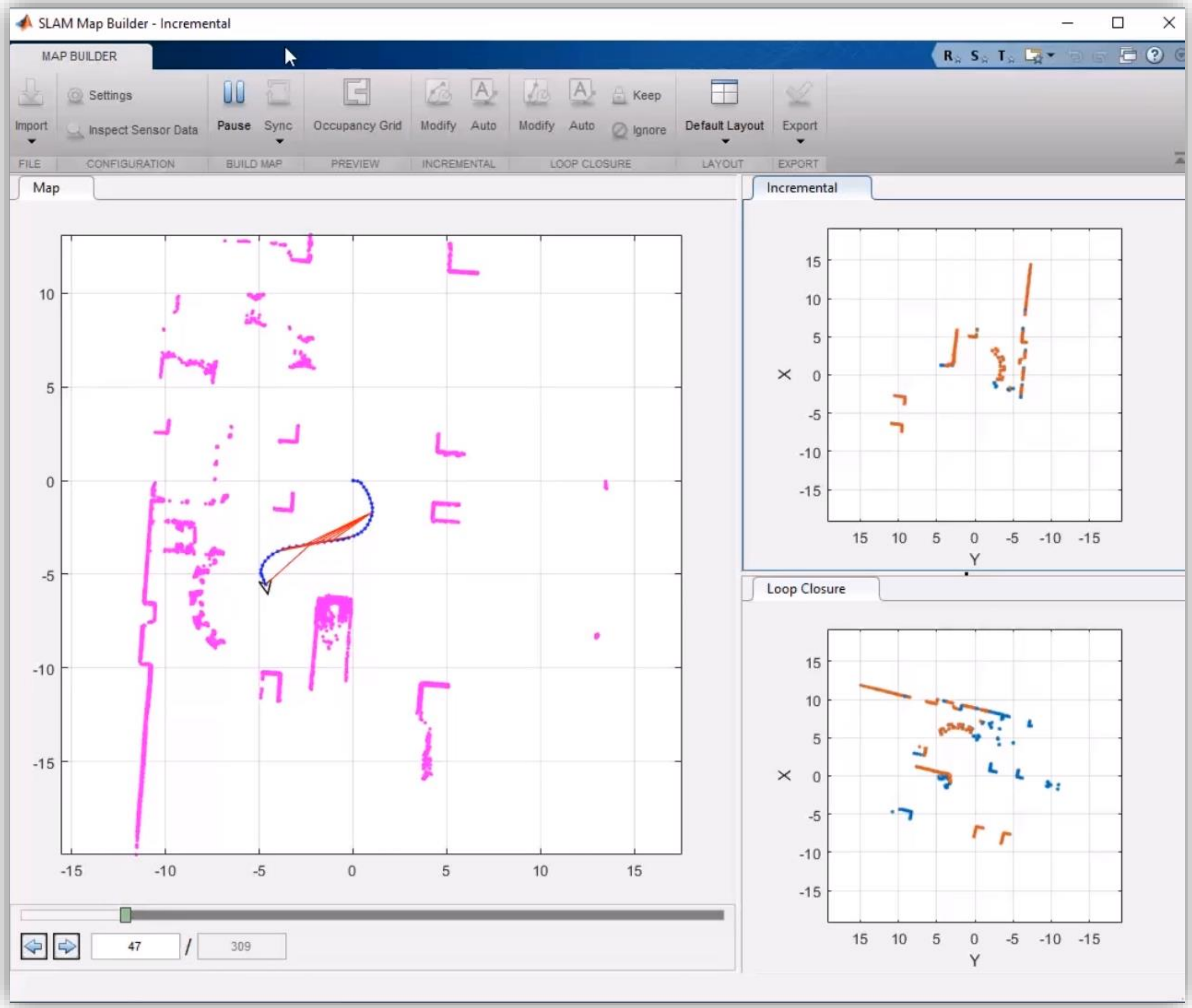
SLAM Estimate



SLAM Map Builder App

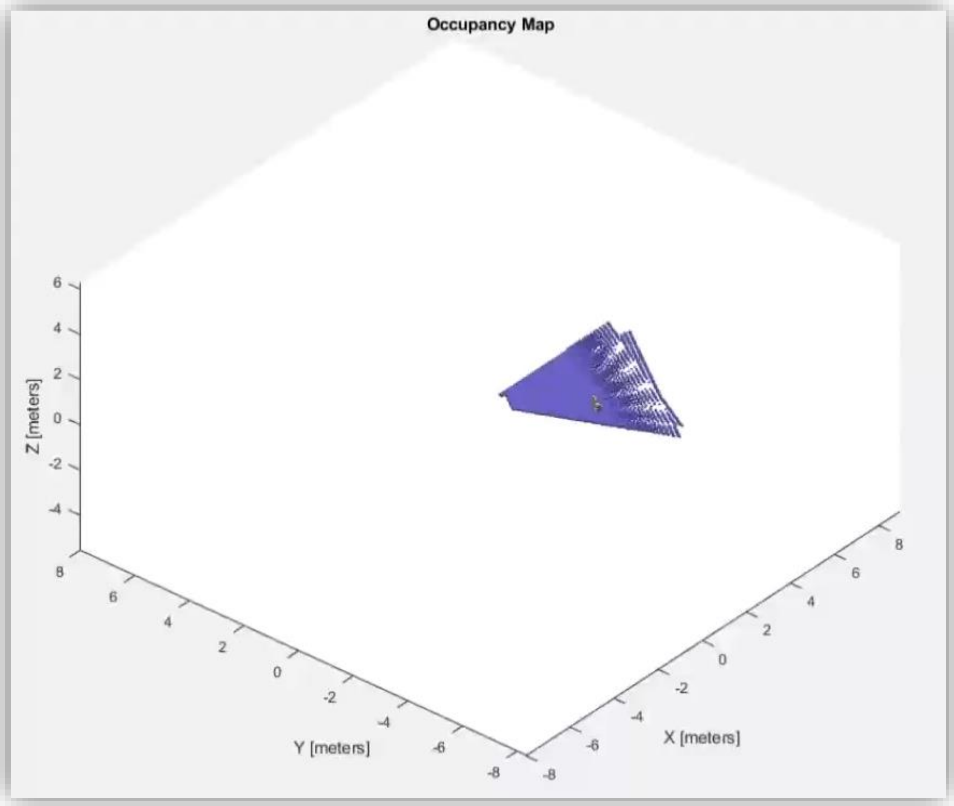
R2018b

- **Build 2D map of environment** based on Lidar and odometry data
- Modify loop closures and incremental scan matches to improve map quality
- Export the resulting occupancy grid and **use for path planning**



Integrate your Own Sensors for Custom SLAM Implementation

- Use your own **custom sensor processing**
- **Re-use infrastructure** for building and optimizing maps



Navigation Stack – Key Components

Sensing & Perception

Mapping

Planning & Decision making

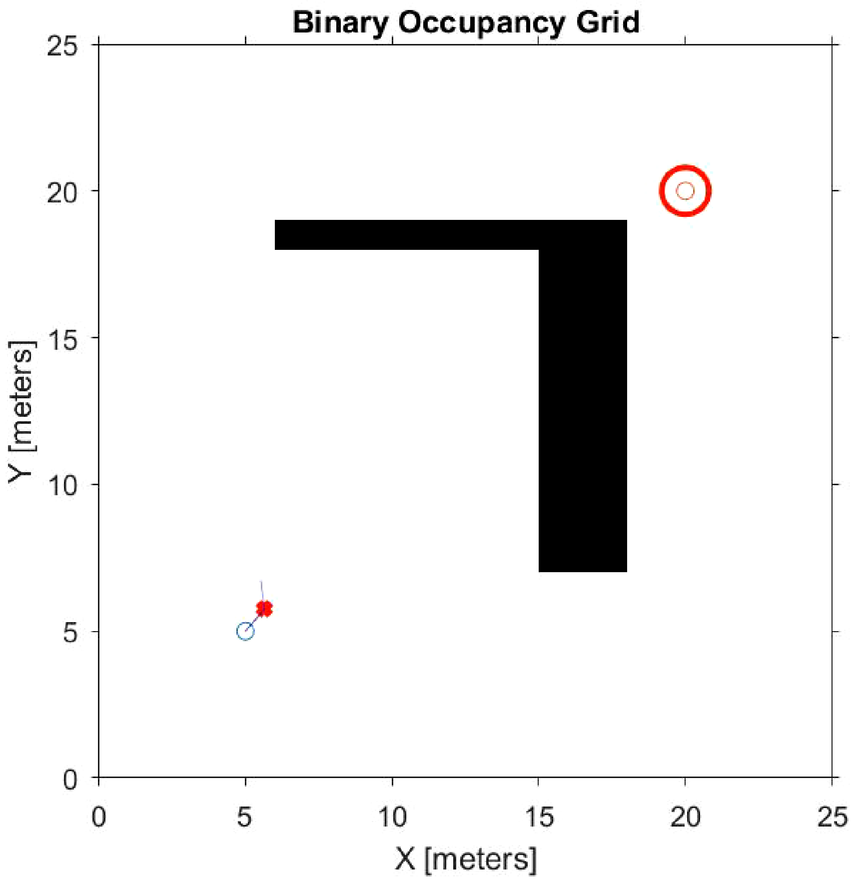
Localization & Control

Physical System + Environment

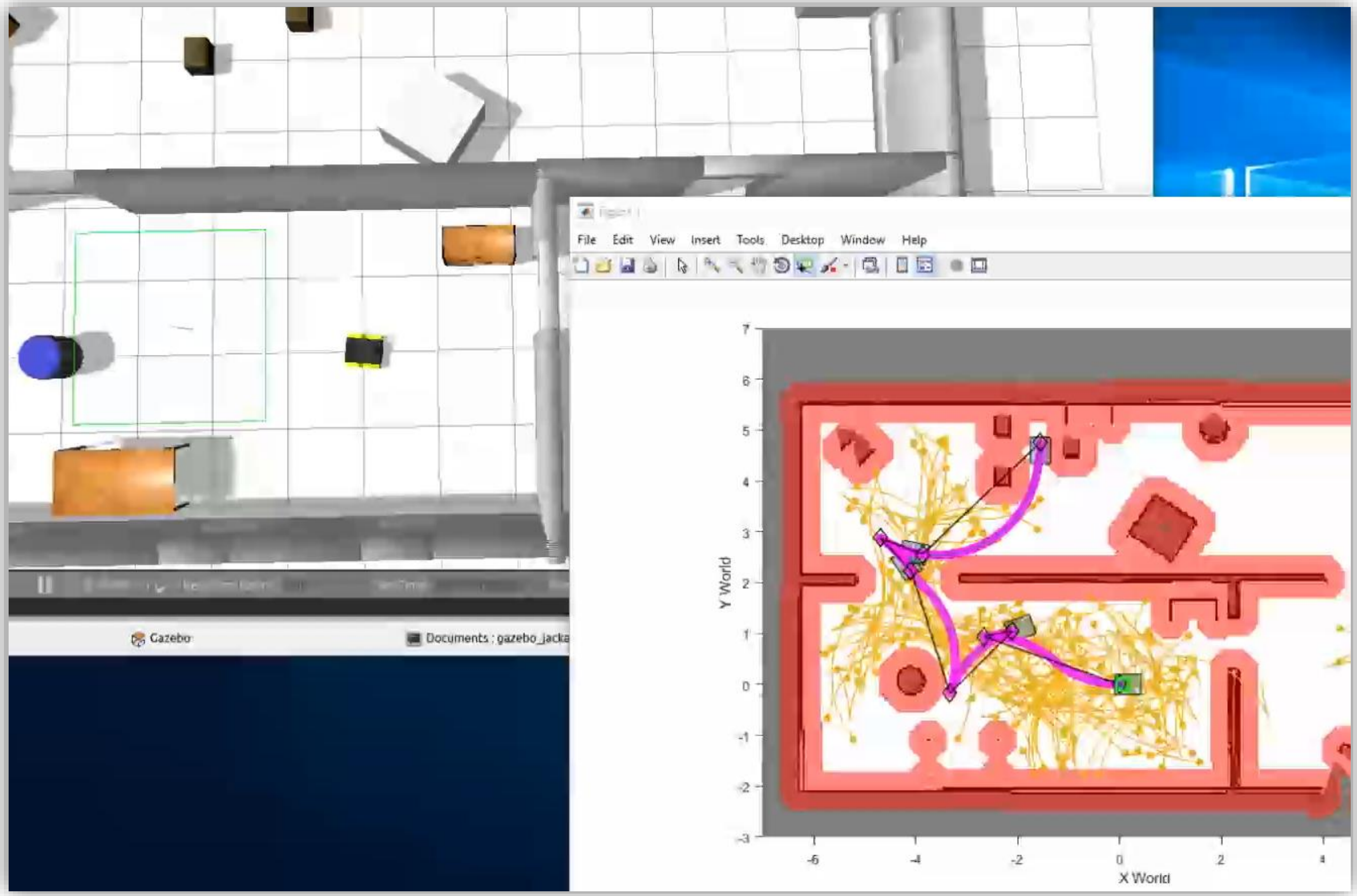
Key Components for Enabling Full Autonomy

Path Planning

- Optimization or search problem
- Map representation is needed
- Data structures like graphs, heaps, and queues
- Post-processing is sometimes required: smoothing



Plan Paths for Nonholonomic Vehicles using RRT*



Navigation Stack – Key Components

Sensing & Perception

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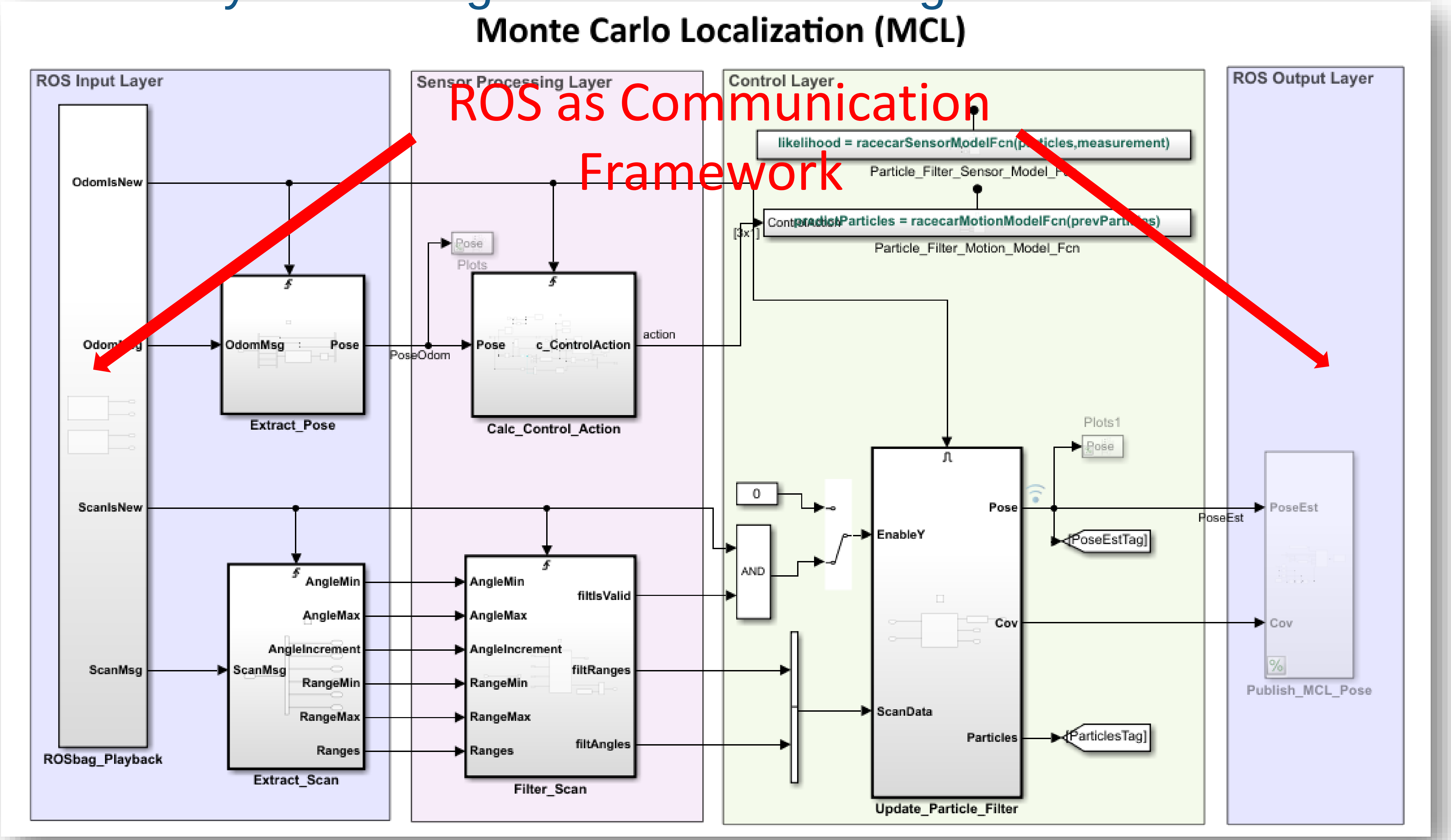
Localization & Control

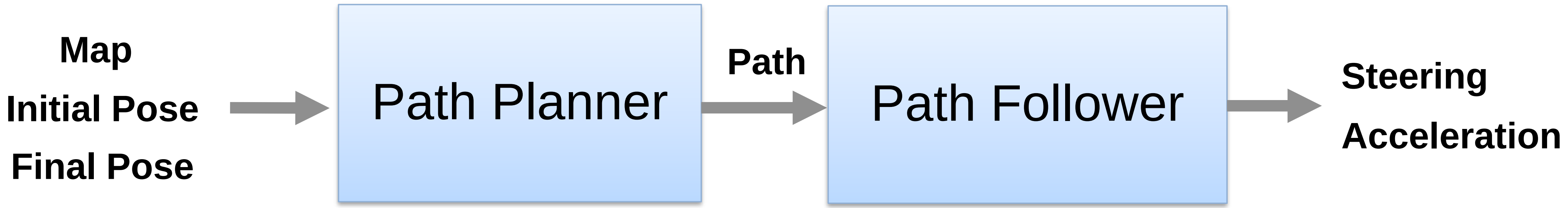
Physical System + Environment

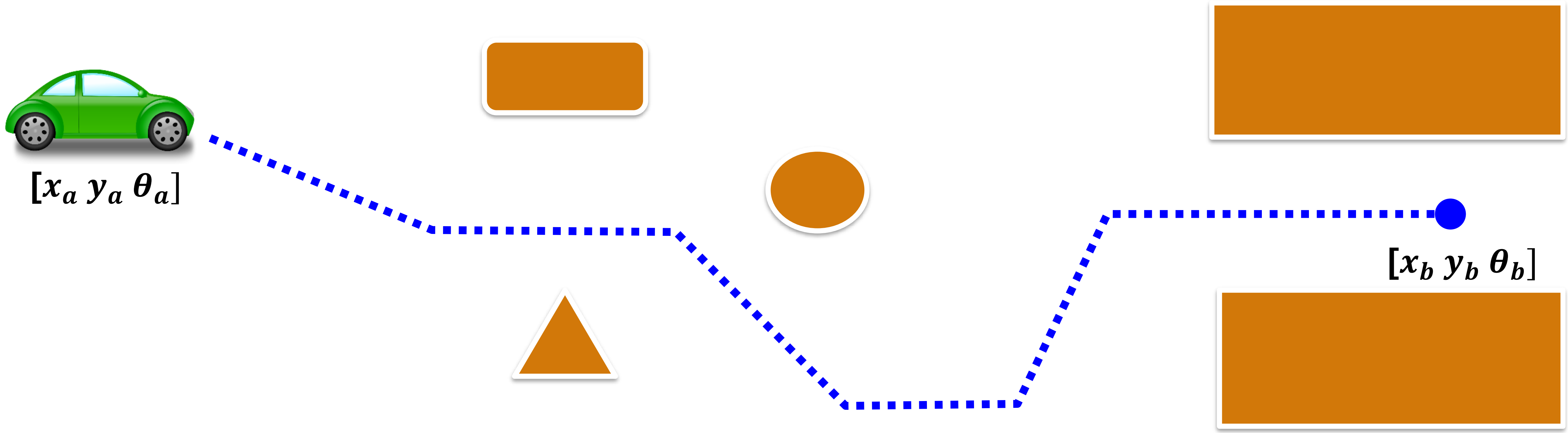
Key Components for Enabling Full Autonomy

Localization System using Model Based Design



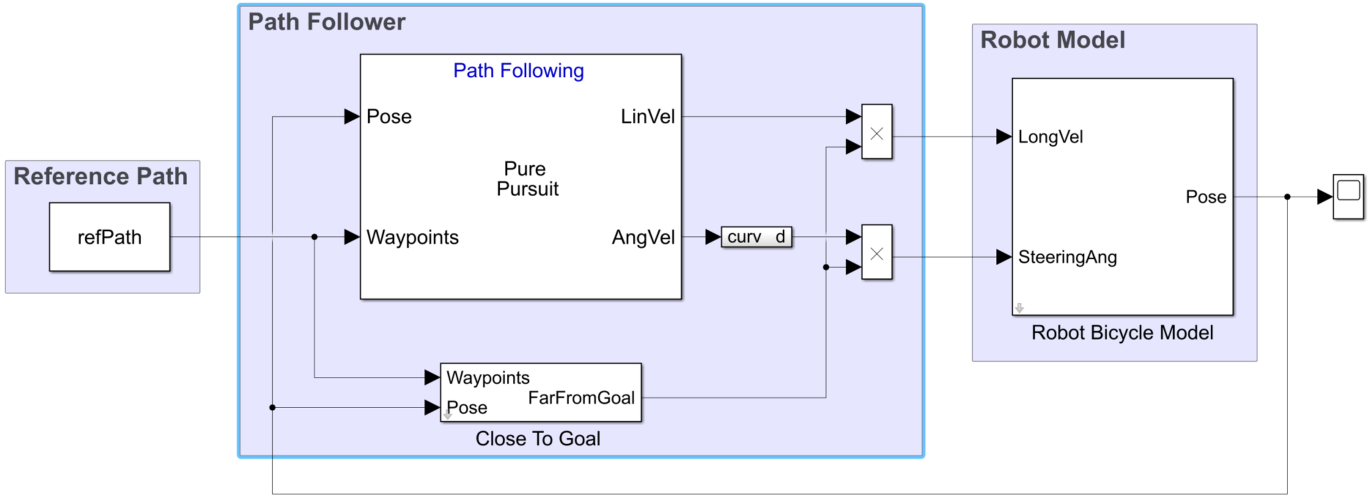
Control - Path Following

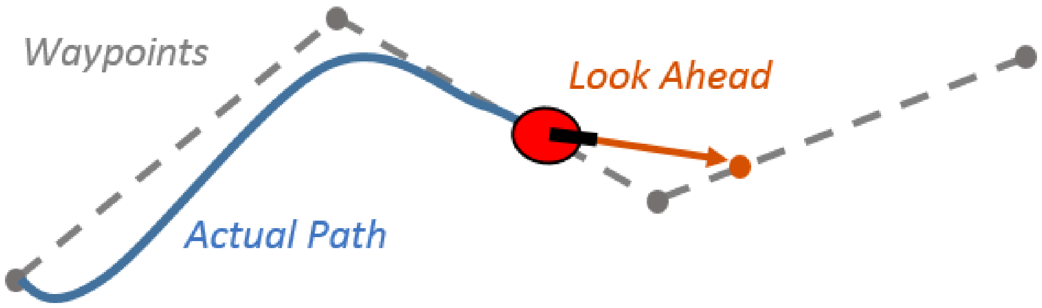




Controls: Path Following

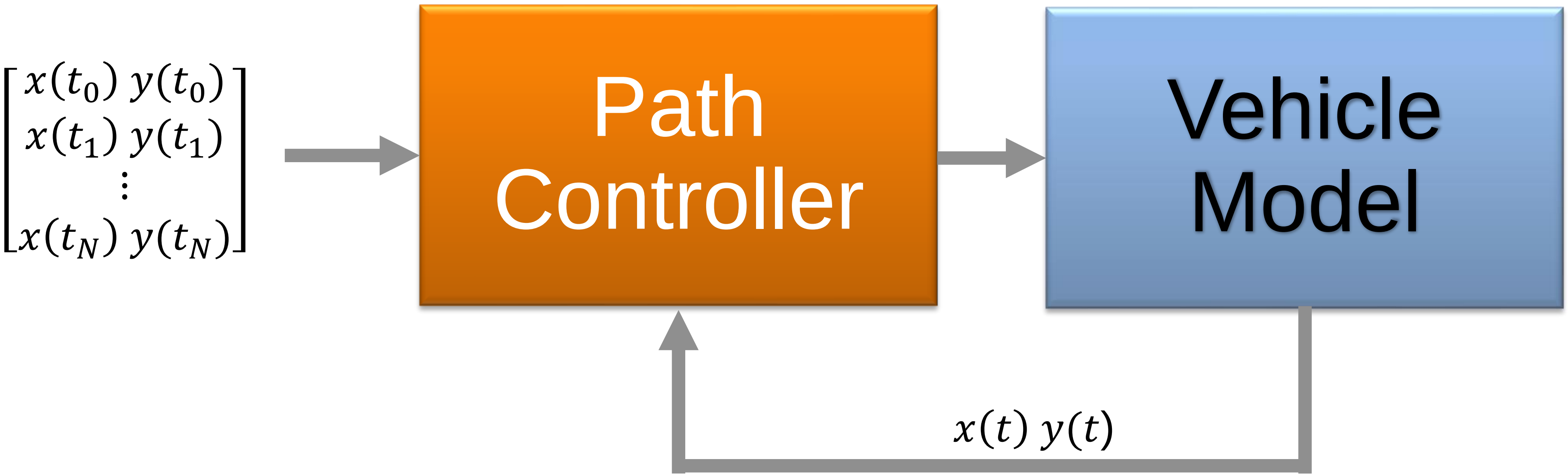
- Control Problem (feedback)
- Map representation (most of the time)
- Suited for graphical programming
- State machine for Supervisory logic





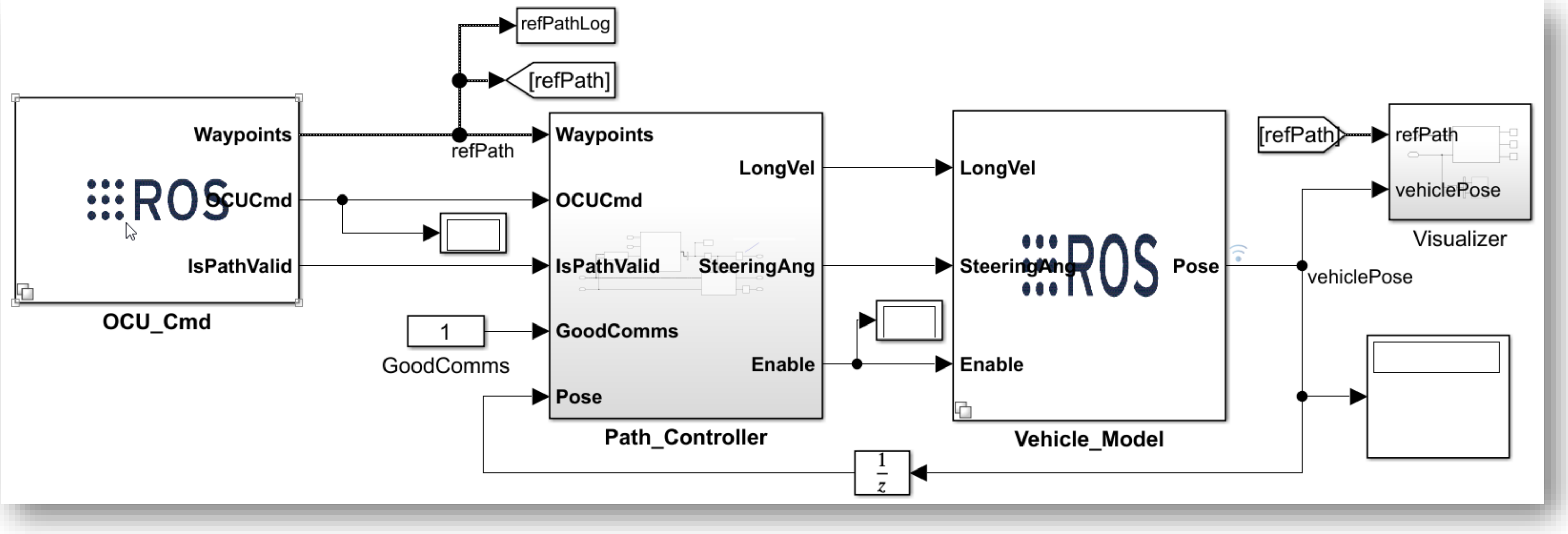
Angular velocity to go from current position to the lookahead

Path Controller



We need a vehicle model to design and test our algorithm

Pure Pursuit in Action



Complete System

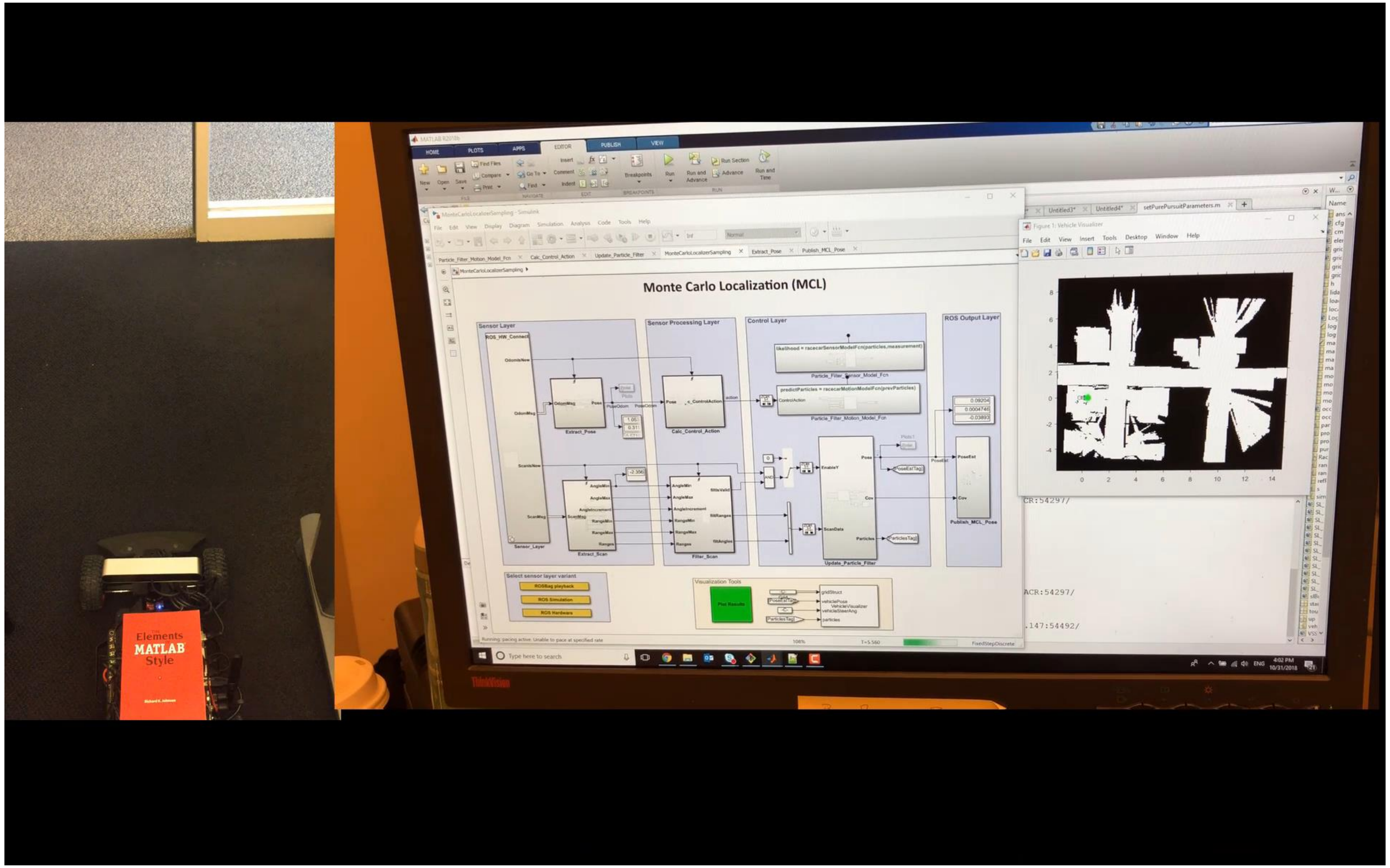


Table of Features for Autonomous Navigation

Algorithm	Application Area	MATLAB Implementation

SLAM	Ground Robots, ADAS, UAVs	`robotics.LidarSLAM`
		`robotics.PoseGraph`
		`robotics.PoseGraph3D`

Localization	All Autonomous Systems	`robotics.MonteCarloLocalization`
Scan Matching	ADAS, Ground Robots	`matchScans` `matchScansGrid`

Point Cloud Registration	ADAS, Computer Vision	`pcregrigid`
		`pcregistericp`
		`pcregisterndt`

Estimation Filters	All Autonomous Systems	`trackingKF,trackingEKF,trackingUKF` `robotics.ParticleFilter`
Path Planning	All Autonomous Systems	`robotics.PRM` `pathPlannerRRT(parkMap)`

Third-Party Simulator Integration

- Use co-simulation with **third-party simulators** for rich sensor and environment simulation

Gazebo

Unreal

Clearpath Robotics Accelerates Algorithm Development for Industrial Robots

Challenge

Shorten development times for laser-based perception, computer vision, fleet management, and control algorithms used in industrial robots

Solution

Use MATLAB to analyze and visualize ROS data, prototype algorithms, and apply the latest advances in robotics research

Results

- Data analysis time cut by up to 50%
- Customer communication improved
- Cutting-edge SDV algorithms quickly incorporated

An OTTO self-driving vehicle from Clearpath Robotics.

“ROS is good for robotics research and development, but not for data analysis. MATLAB, on the other hand, is not only a data analysis tool, it’s a data visualization and hardware interface tool as well, so it’s an excellent complement to ROS in many ways.”
- Ilia Baranov, Clearpath Robotics

Link to user story

Voyage develops longitudinal controls for self-driving taxis

Challenge

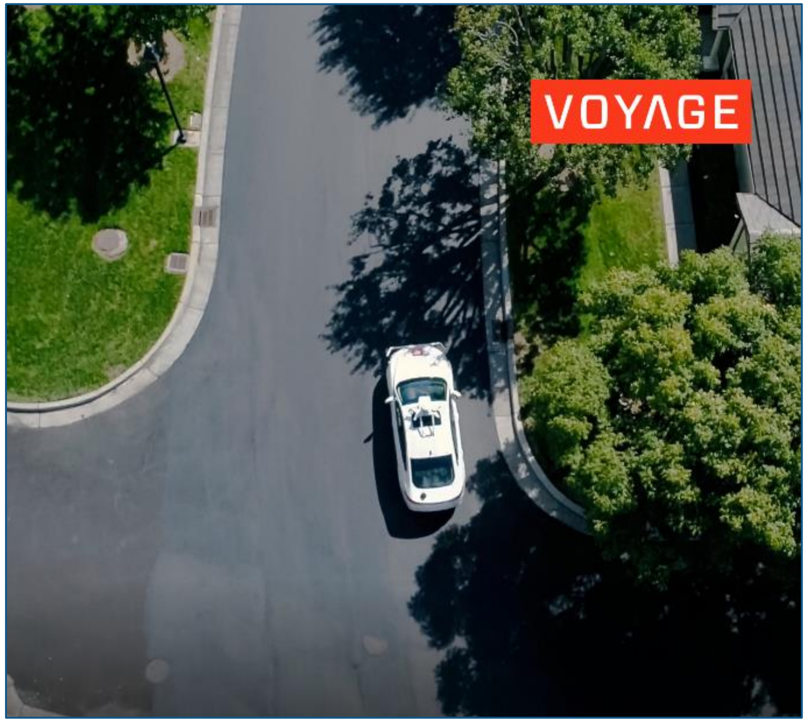
Develop a controller for a self-driving car to follow a target velocity and maintain a safe distance from obstacles

Solution

Use Simulink to design a longitudinal model predictive controller and tuned parameters based on experimental data imported into MATLAB using Robotics System Toolbox. Deploy the controller as a ROS node using Robotics System Toolbox. Generate source code using Simulink Coder into a Docker Container.

Results

- Development speed tripled
- Easy integration with open-source software
- Simulink algorithms delivered as production software



Voyage's self driving car in San Jose, California.

"We were searching for a prototyping solution that was fast for development and robust for production. We decided to go with Simulink for controller development and code generation, while using MATLAB to automate development tasks."

- Alan Mond, Voyage

Key Takeaway of this Talk

Success in developing an autonomous robotics system requires:

1. Multi-domain simulation with newer technologies
2. Trusted tools which make complex workflows easy and integrate with other tools
3. Model-based design provides the flexibility for changing development needs

```
% Thank you
```

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Come talk to us at the Autonomous Navigation Booth!