2021 February 17th (Wed)

Developing Autonomous Systems with MATLAB® and Simulink®

MathWorks
Industry Manager – Robotics and Autonomous Systems
Fred Noto

Our Customers: Subaru

Advanced Driver-Assistance Systems

Critical safety features for everyone

Detects obstacles, applies brakes, adjusts cruise control, and stays in lane

Our Customers : German Aerospace Center (DLR)

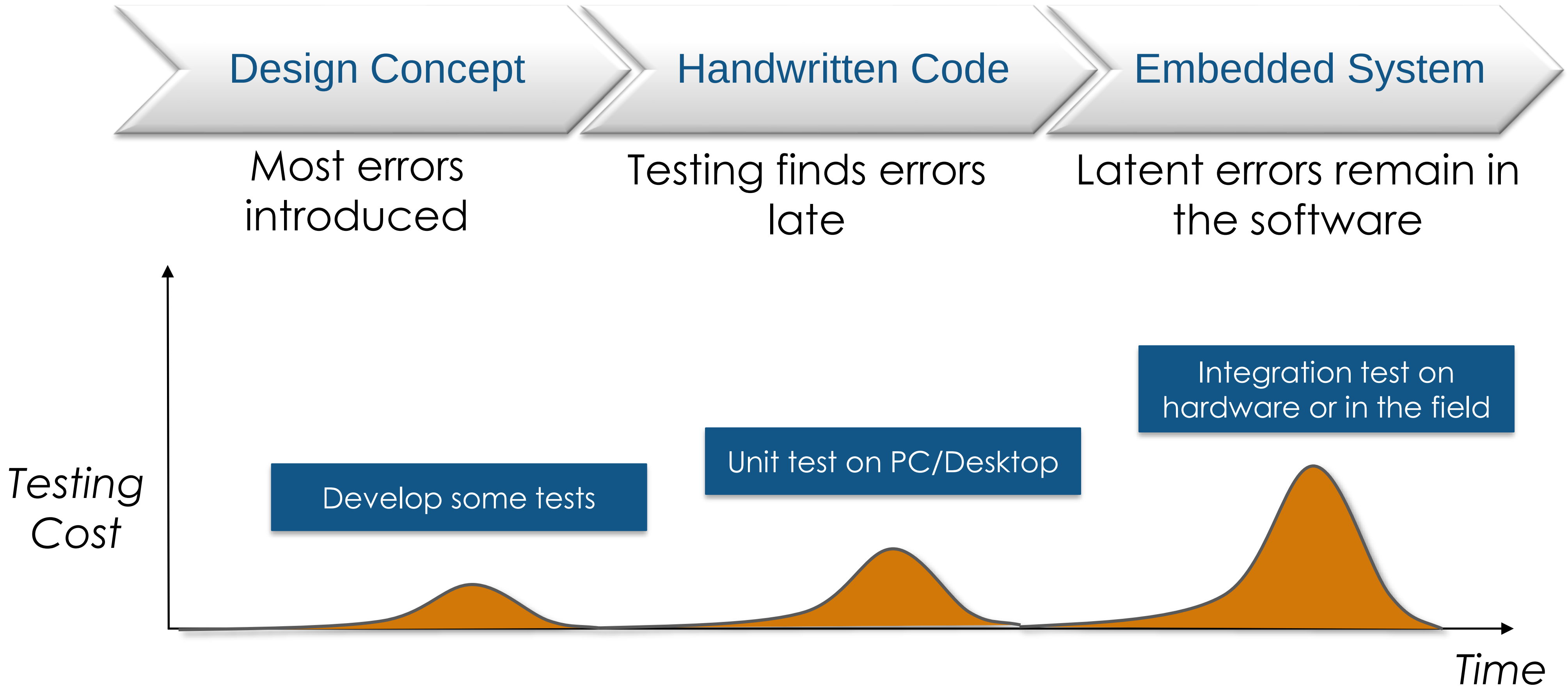
Autonomous Robots

- Senses the environment using stereo cameras and tactile sensors on his skin
- Performs human-like tasks

Autonomous System Development and Deployment Accelerated with MATLAB and Simulink

Traditional Software Development

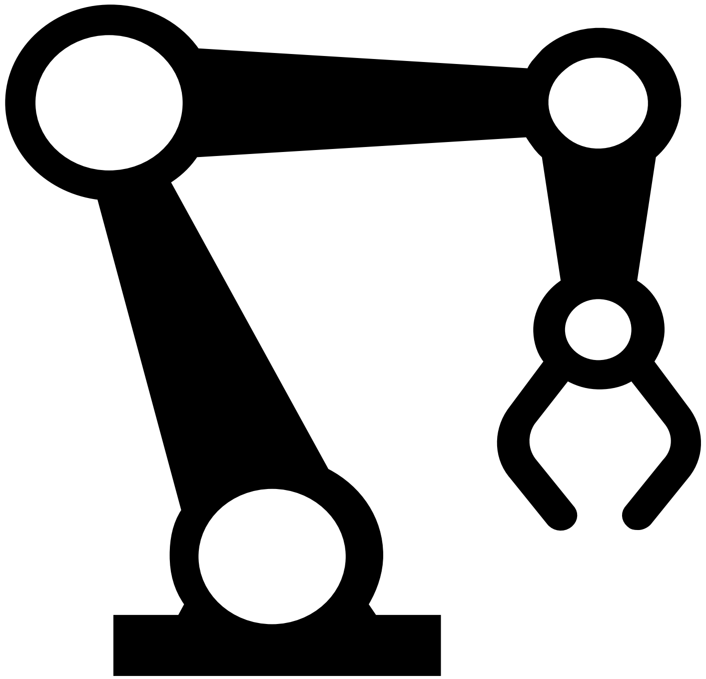
Cost of Finding Errors Increases Over Time



Common Challenges of Autonomous Robotics Development

Applying Multidomain Expertise

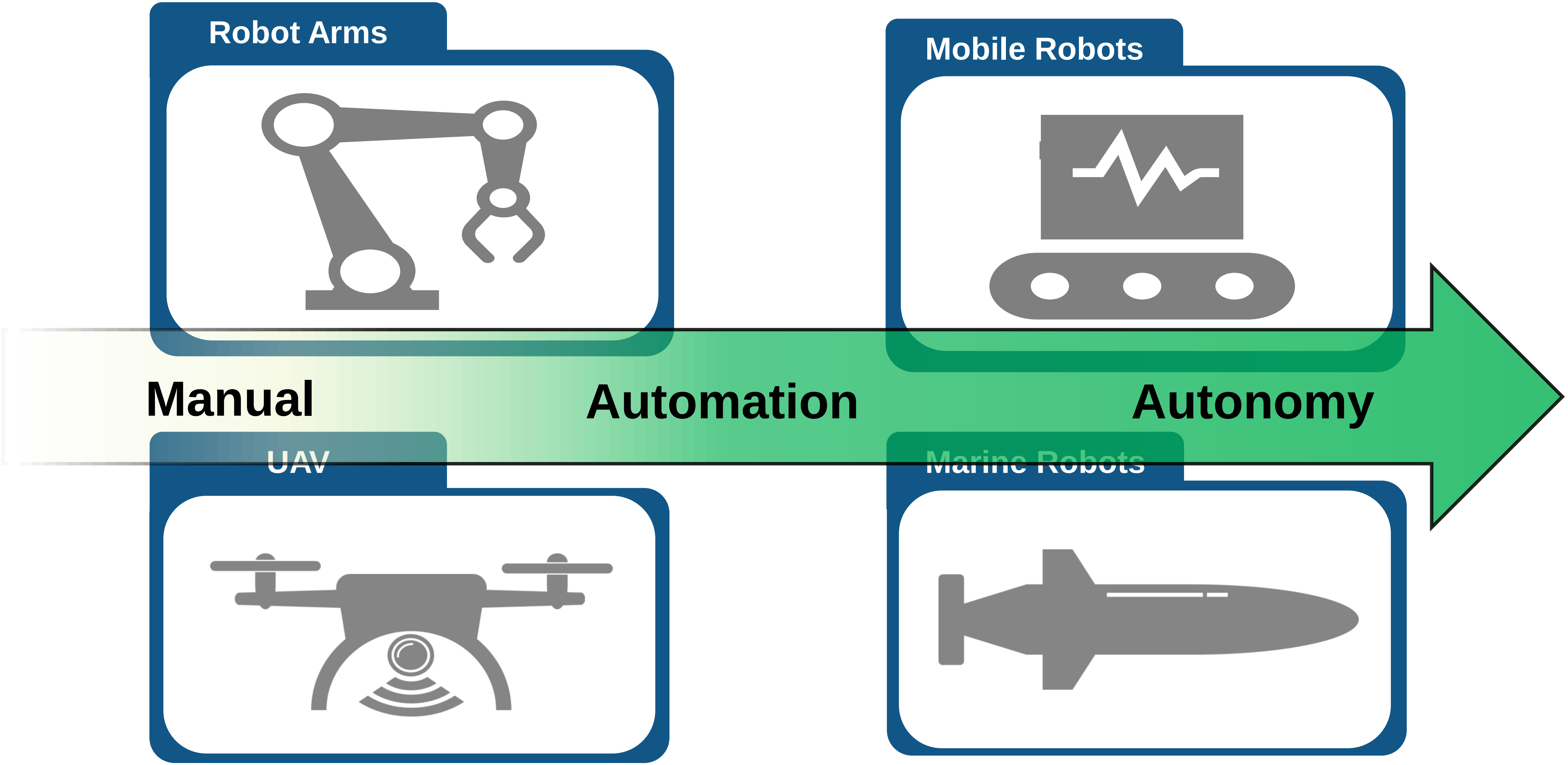
End-to-End workflows



Complexity of Algorithms

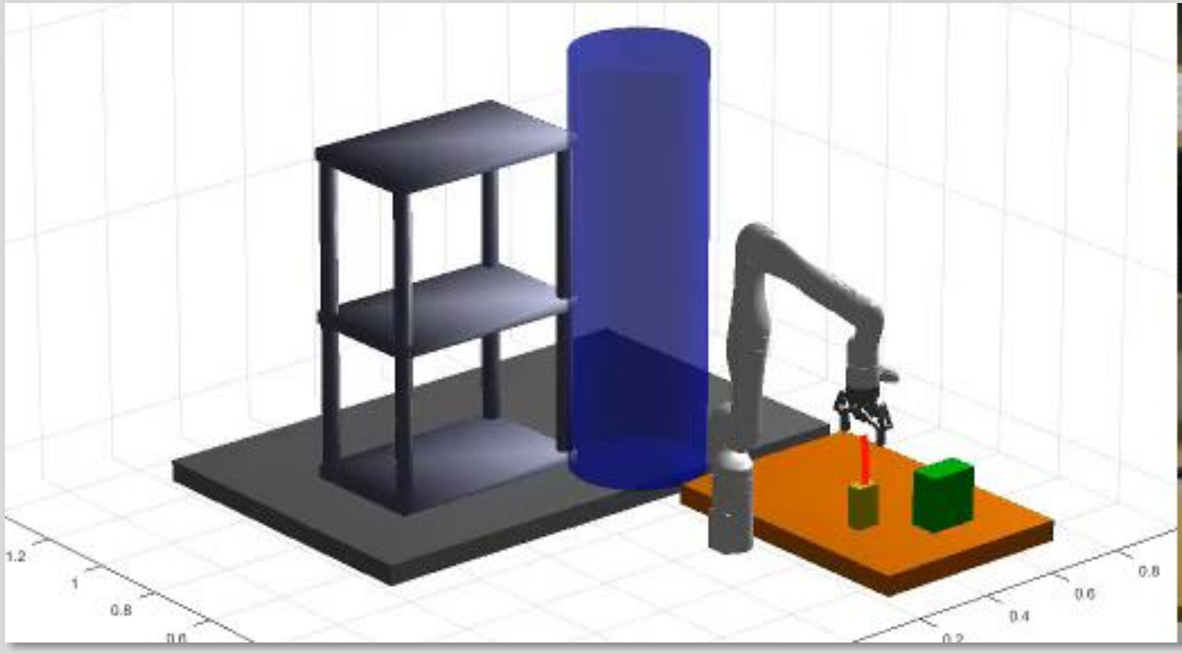
Technical Depth and System Stability

Types of Autonomous Robotics

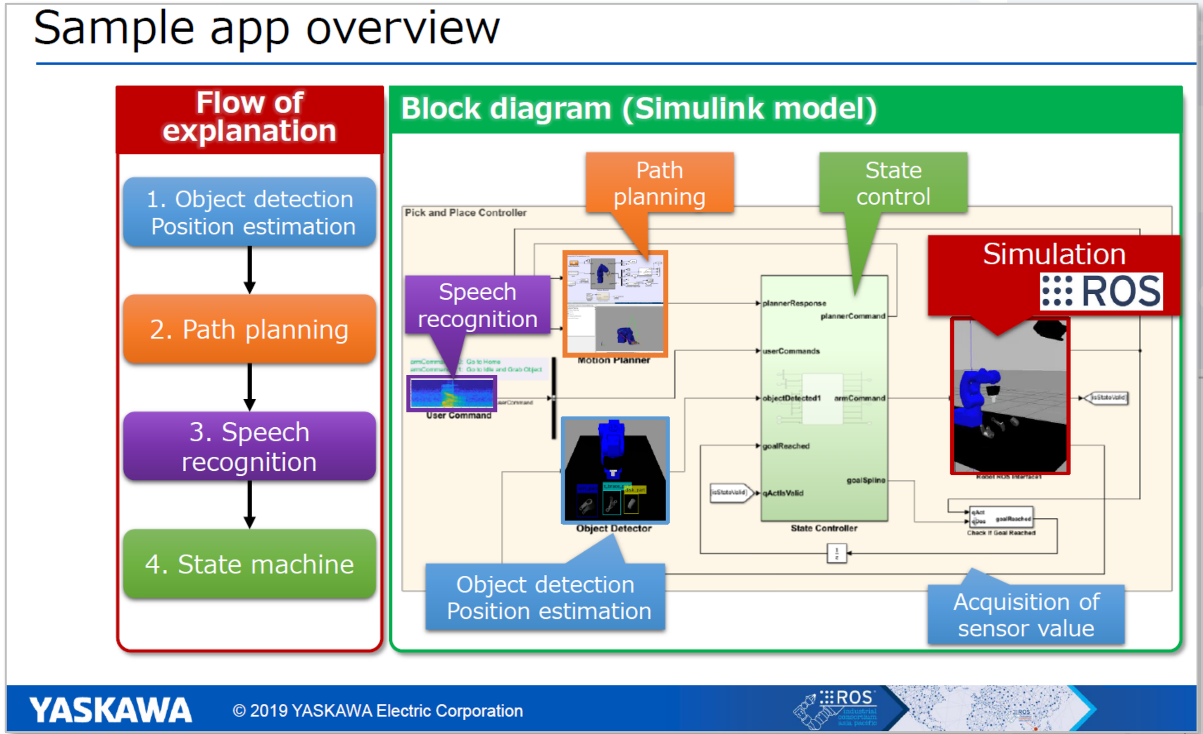


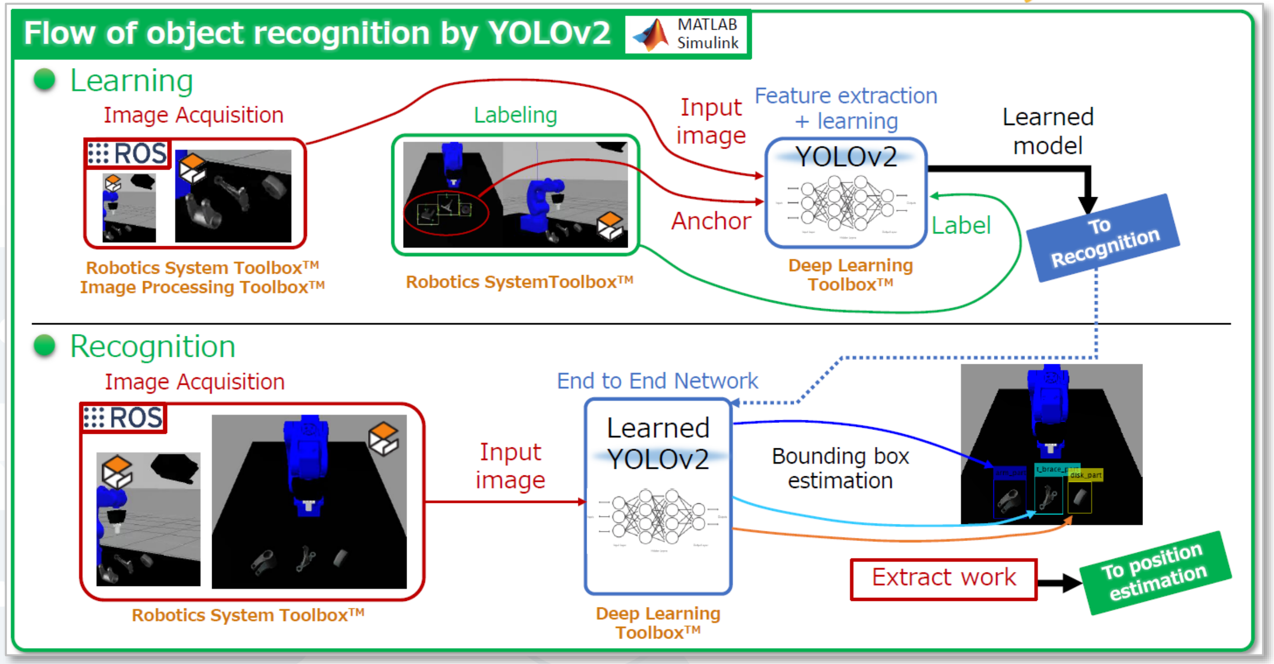
Pick-and-Place Industrial Robots

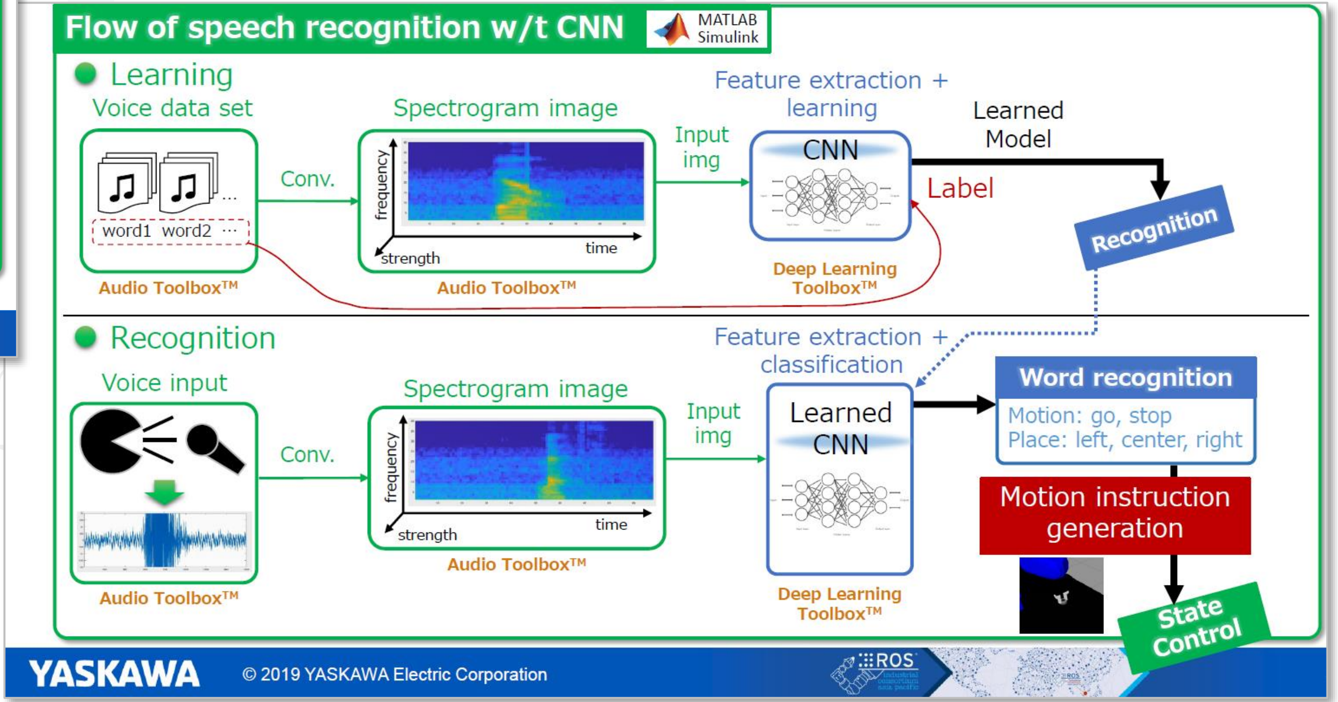
Robot Arms



User Presentation: Yaskawa Electric Corporation





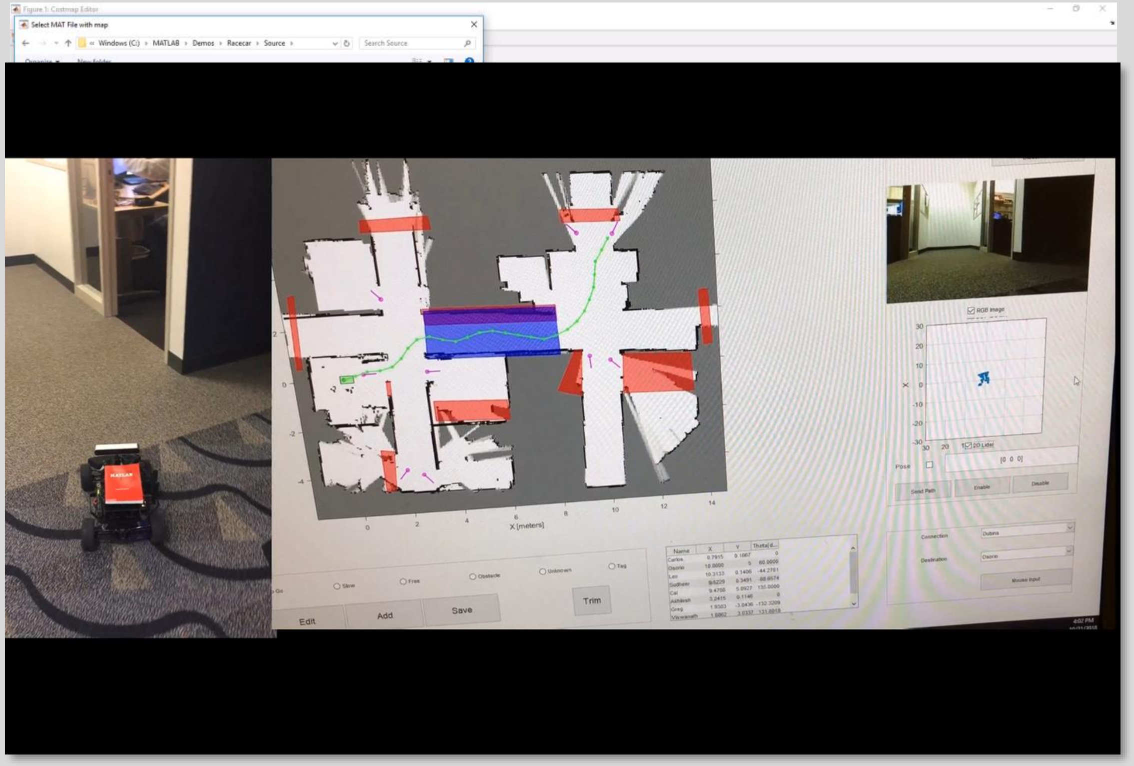


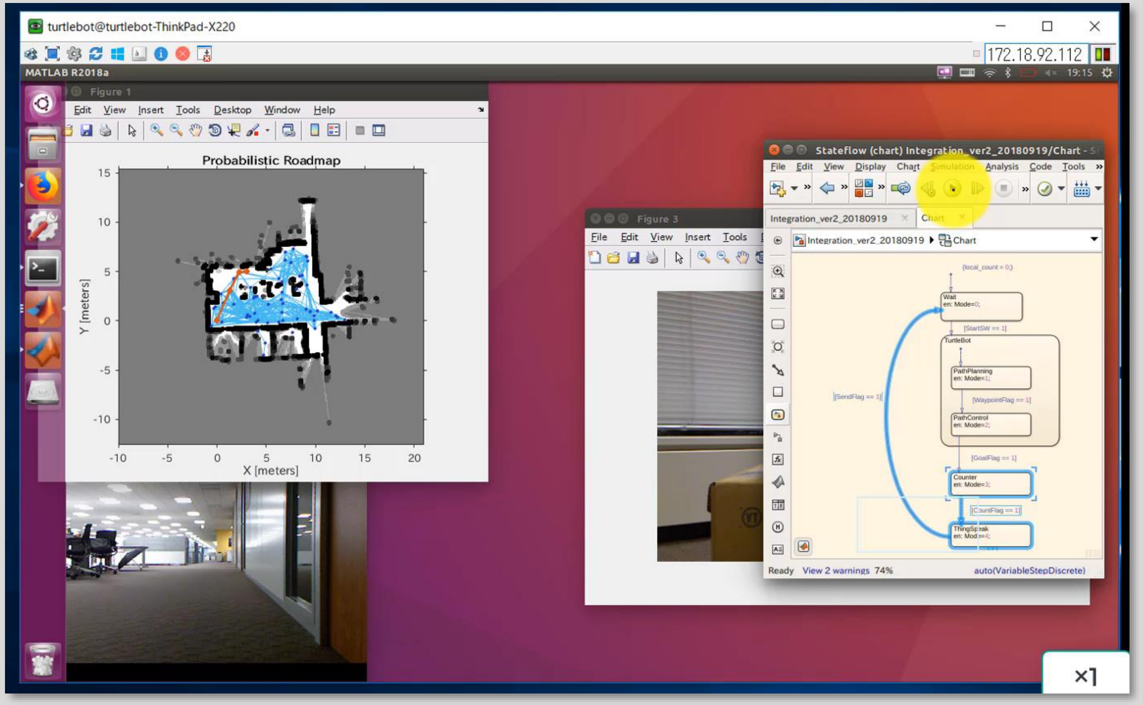
MATLAB EXPO 2019 in Japan

https://www.mathworks.com/content/dam/mathworks/mathworks-dot-com/images/responsive/supporting/products/robotics/implementation-of-verification-of-picking-system-for-industrial-robot-using-ros-and-matlab-yaskawa.pdf

Mobile Robot Delivery and Inventory Management

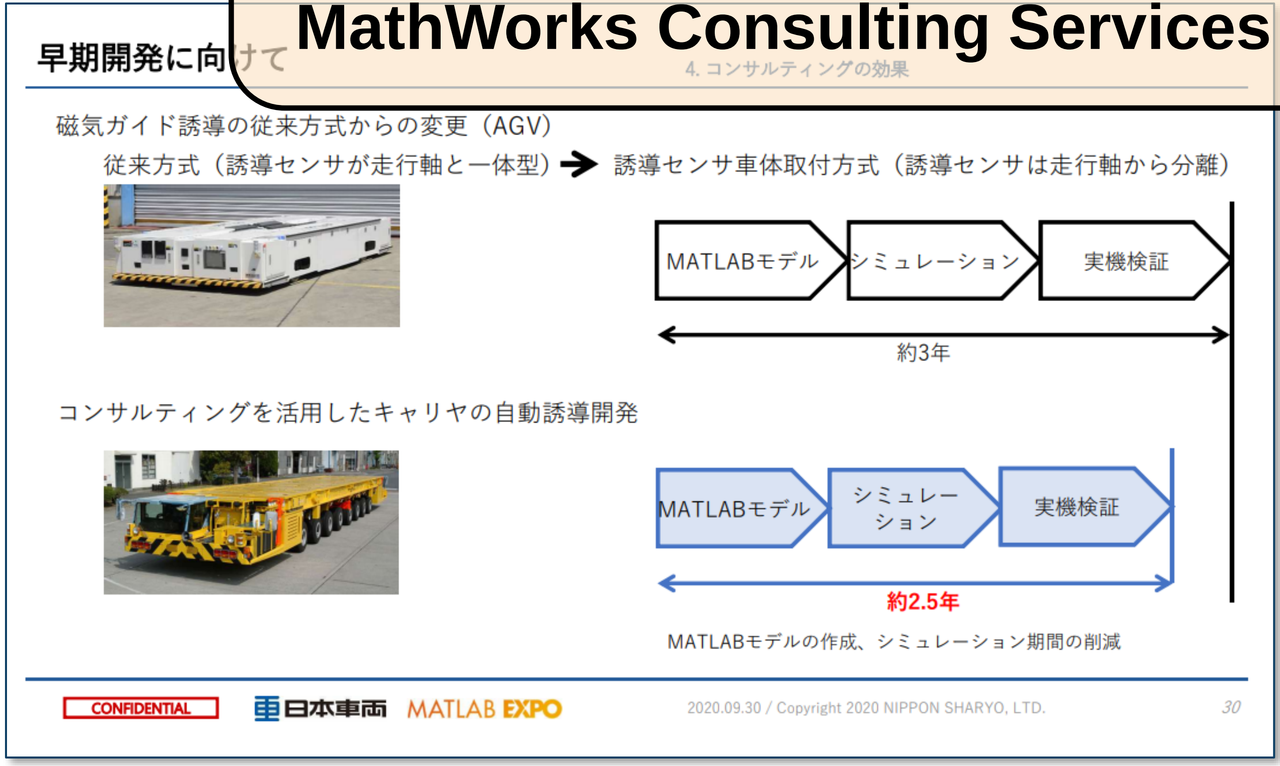
Mobile Robots

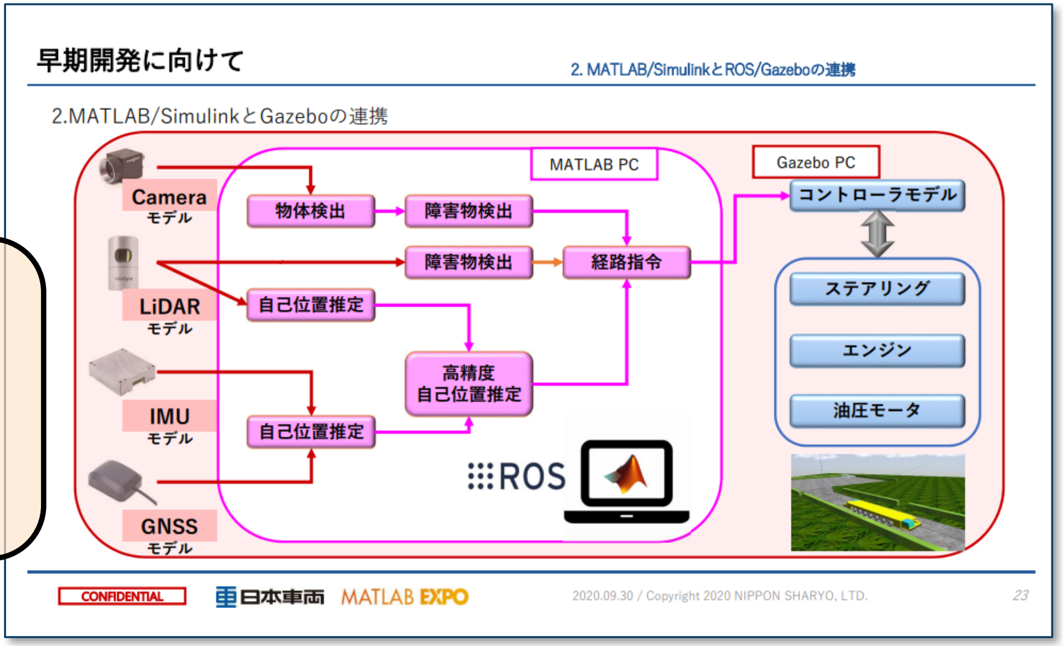




User Presentation: Nippon Sharyo

Development time decreased using MATLAB/Simulink and MathWorks Consulting Services

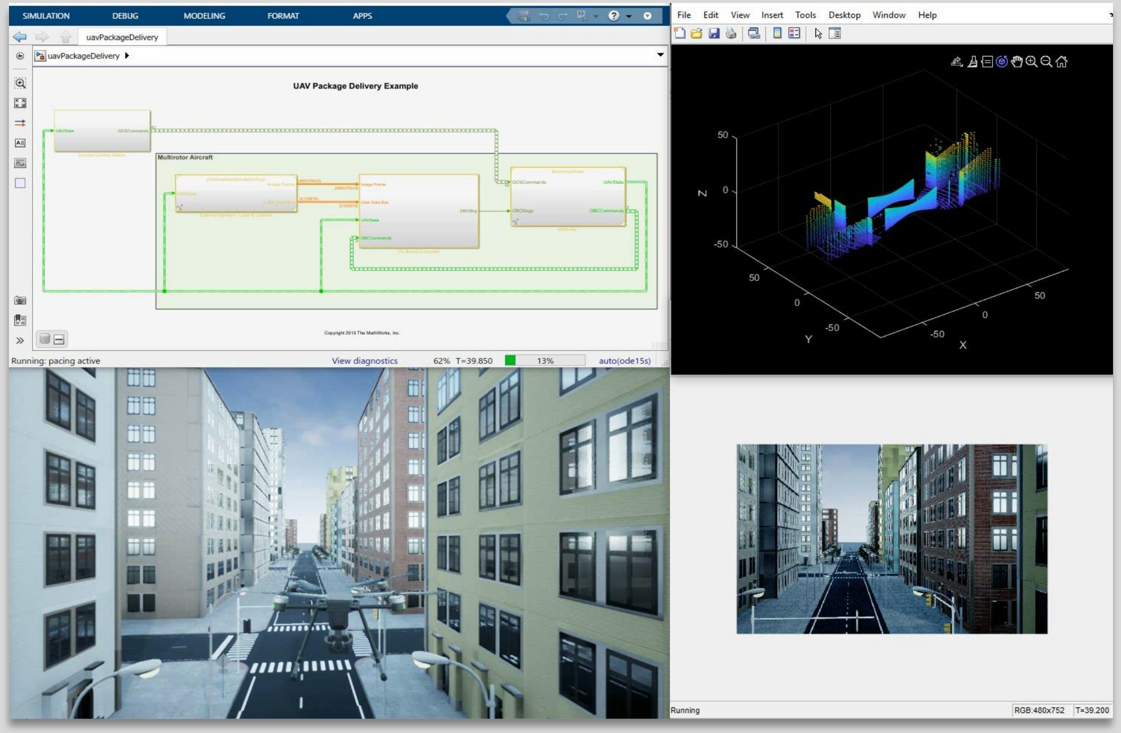




MATLAB EXPO 2020 in Japan
https://www.matlabexpo.com/jp/2020/proceedings.html

Unmanned Aerial Vehicle (UAV) Delivery

UAV



UAV User Stories

[Dynamic Simulation Environment for Testing GNC Algorithms for Multirotor UAVs]

Intel

> "Modeling and simulation with Simulink is the only way that we can get the results we need with the speed and quality that's expected in our industry today. If we had to do everything by hand and rely solely on flight testing, we would require more bug fixing iterations and need more testing time per iteration. The problem would grow intractable. There's no other way."
>
> — *Jan Vervoorst, Intel*

[UAV Flight Control Software Development and Verification with Model-Based Design]

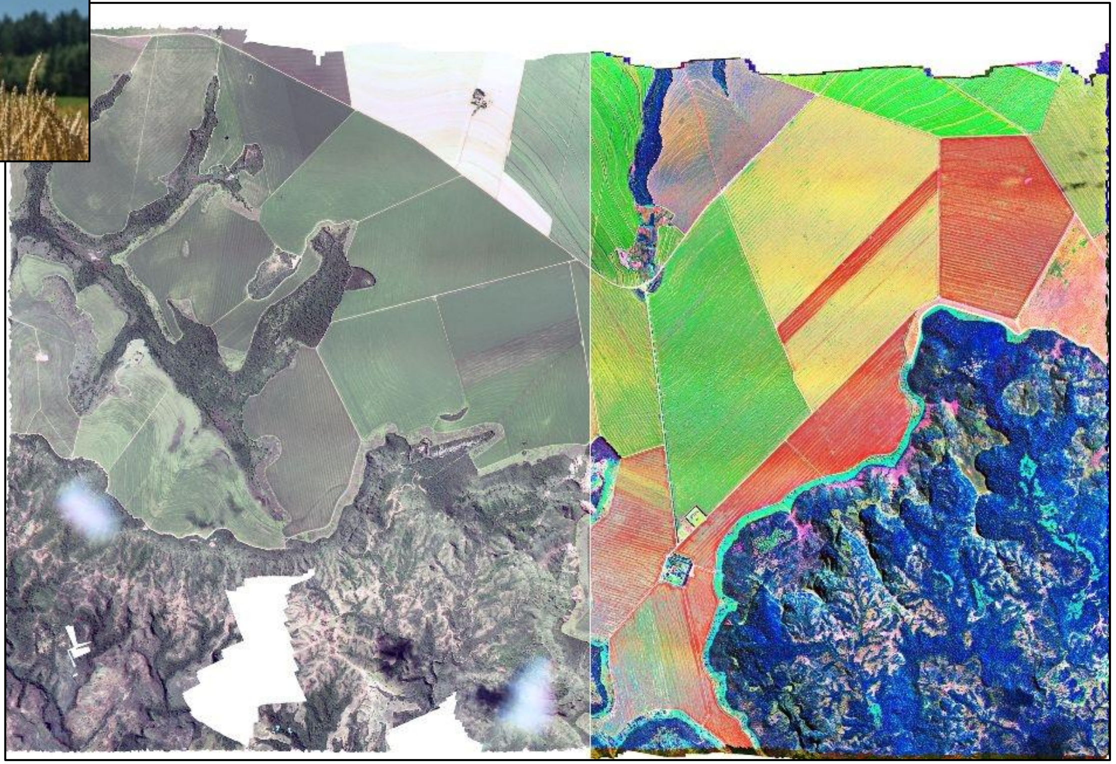
Korean Air

> "The model reuse and efficiency improvements enabled by MATLAB and Simulink save time and lower costs. We estimate a time savings of more than 50% is achievable with Model-Based Design compared with hand-coding, and the advantages of Model-Based Design increase with the complexity of the project."
>
> — *Jungho Moon, Korean Air*

Examples of UAV Usage

Getting into the Weeds:
Farmers Rely on Artificial Intelligence to Boost Production

> "In the next few years, computer vision, machine learning, and robotics will increasingly converge to help growers produce more food, more efficiently, and achieve greater financial returns in the process."
>
> — *Al Eisaian, CEO, IntelinAir*

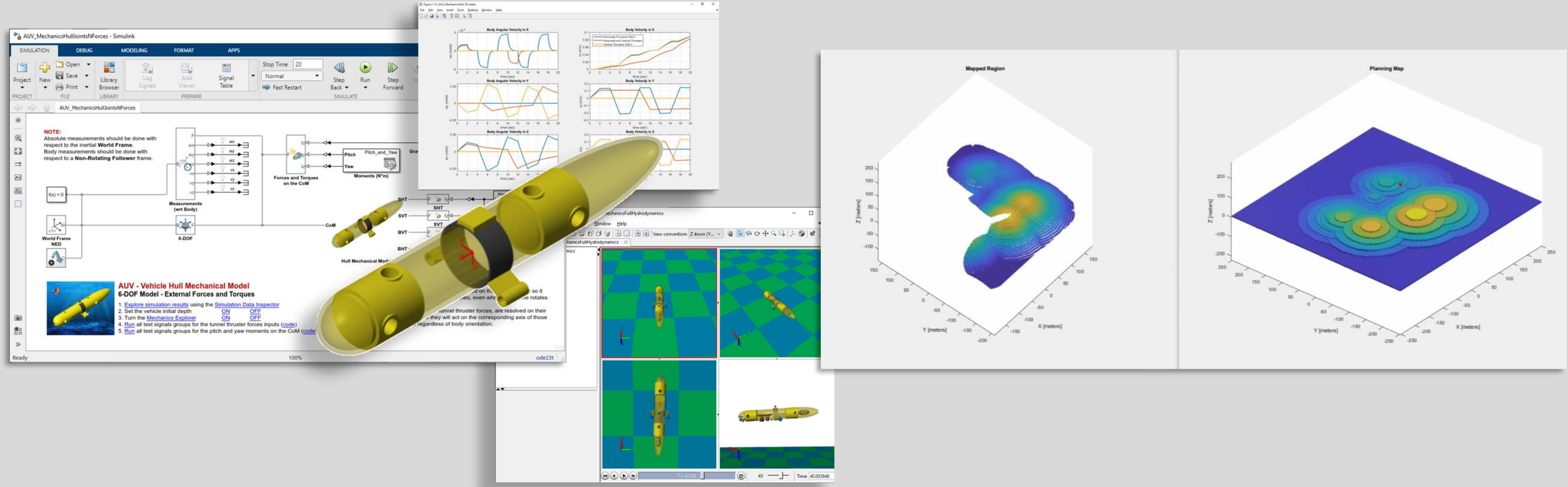


> "It's time-consuming to walk an entire field, but aerial imagery can provide the detailed information needed for both in-season insights and end-of-season guidance on what to change to improve next year's crop. There is a lot of research and development focused on these applications from an agronomic perspective."
>
> — *Dr. Joe Luck, Associate Professor of Biological Systems Engineering, The University of Nebraska-Lincoln*

Link

Marine Robot Mapping

Marine Robots



Startup Use Case: Eelume Snake Robot

Types of Autonomous Robotics

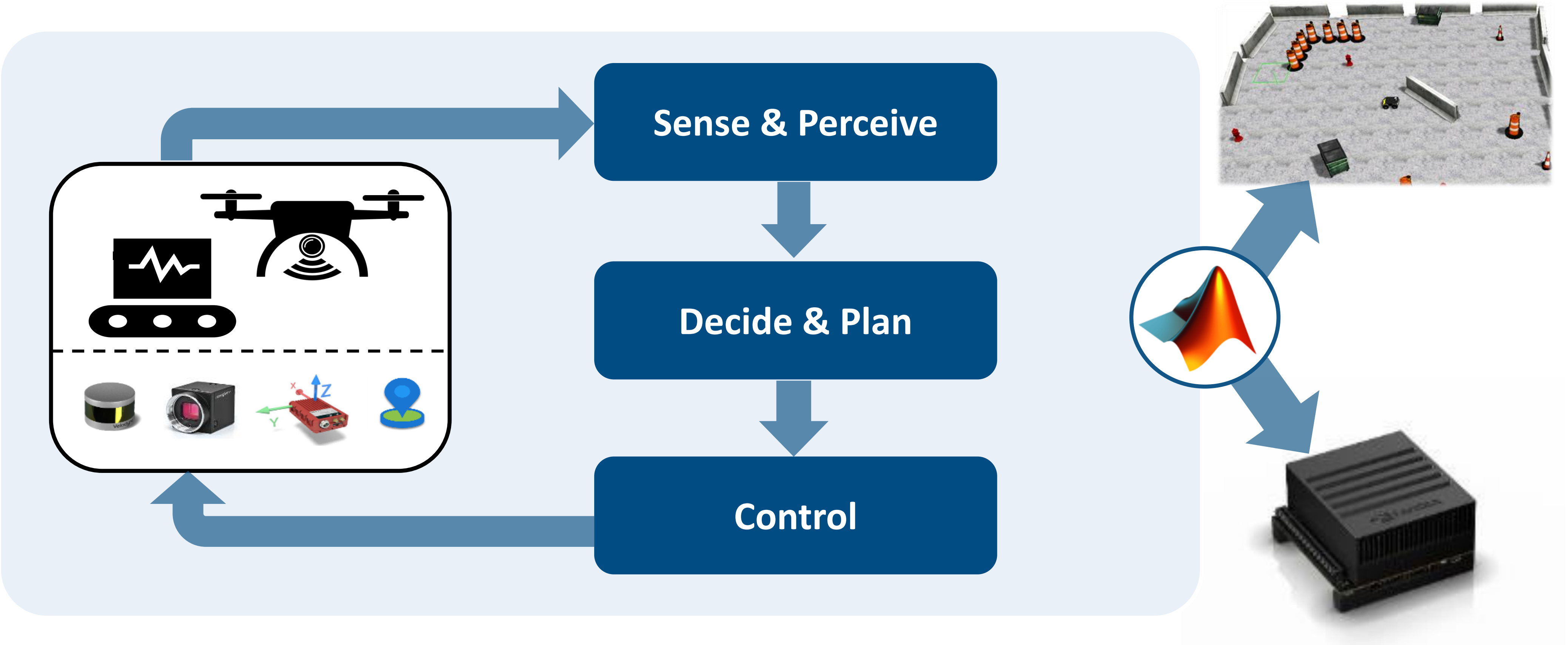
Robot Arms

Mobile Robots

UAV

Marine Robots

Common questions from robotics engineers

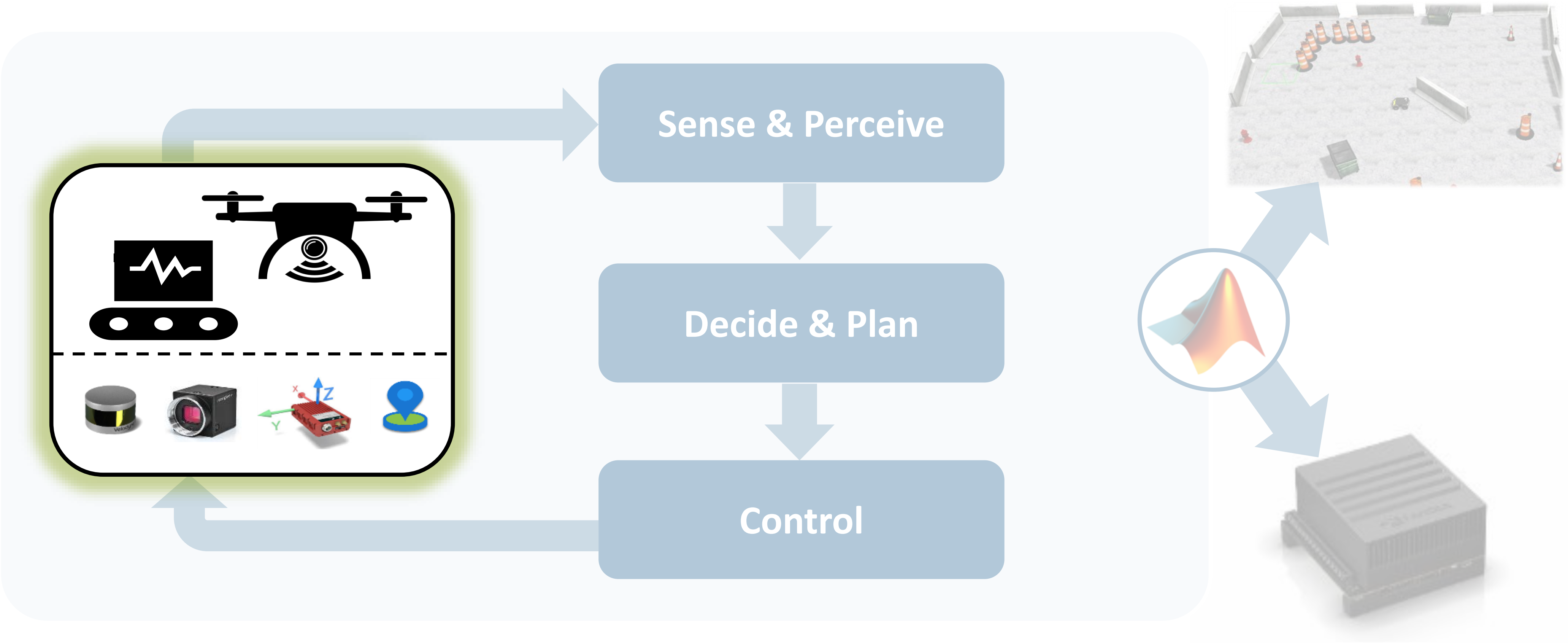


How can I model and simulate robots and sensors?

How can I discover and design autonomous algorithms?

How can I test and deploy robotics applications?

Common questions from robotics engineers



How can I model and simulate robots and sensors?

How can I discover and design autonomous algorithms?

How can I test and deploy robotics applications?

How can I model and simulate robots and sensors?

Robot modeling methods

- Physical model
- Abstract model
- External robot model

Selection based on task

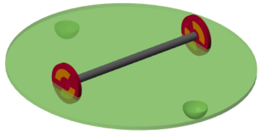
Sensor modeling methods

- Import sensor data
- Sensor simulation model
- External sensor model

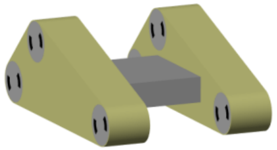
Enable open and closed-loop workflows

Modeling High-Fidelity Robot Dynamics: Physical Modeling

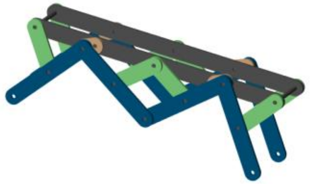
Automobile



Two-wheeled vehicle



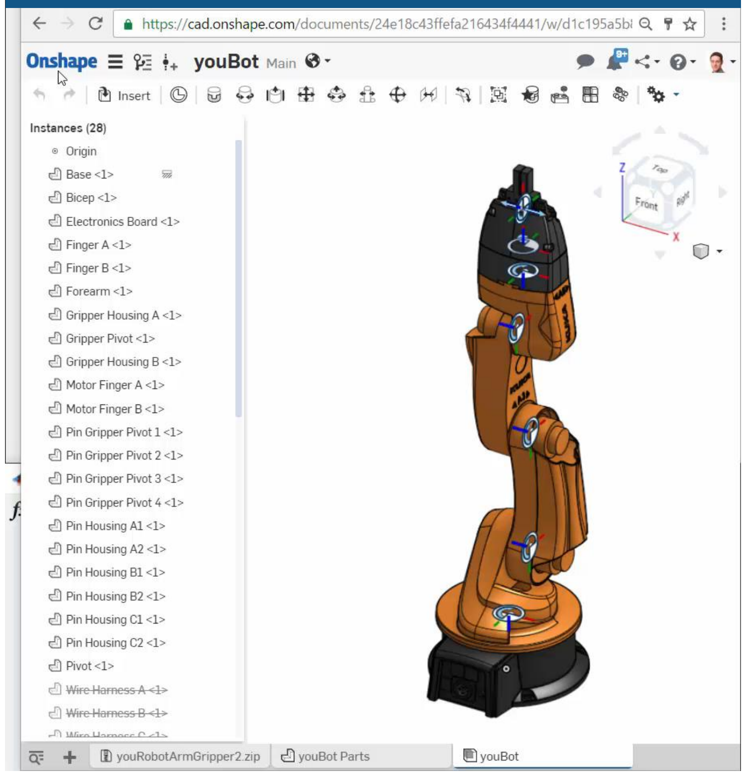
Crawler



Legged

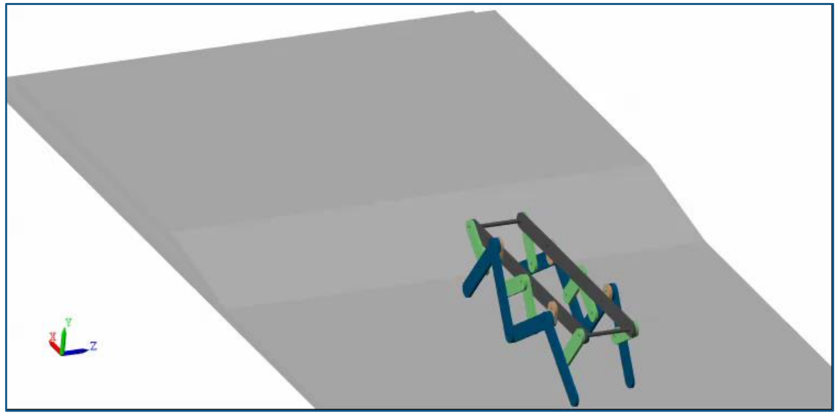
Drone

CAD Import



Contact / Friction

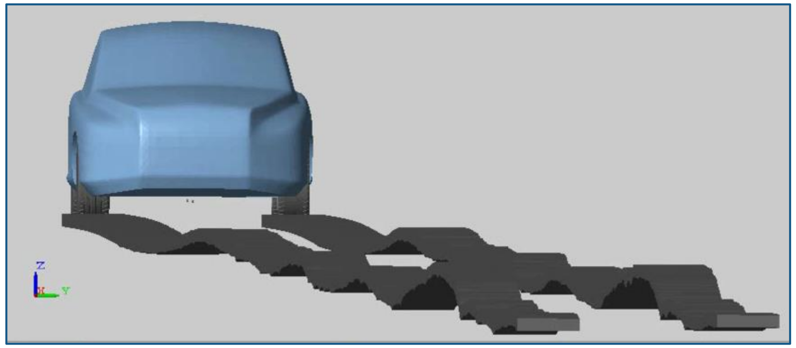
Contact Forces Library



Rough road

Detailed tire model : Delft-Tyre

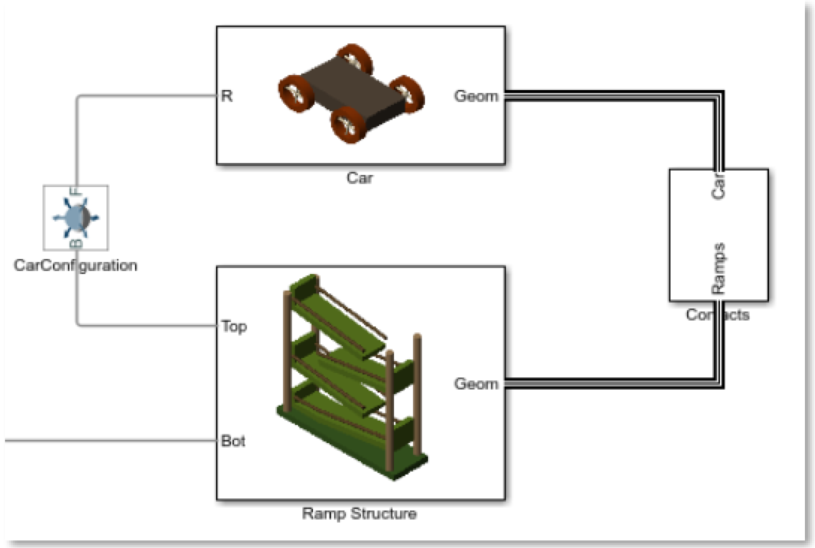
(Provided by TASS International)



Simscape™ Products

Modeling High-Fidelity Robot Dynamics: Simscape Multibody™

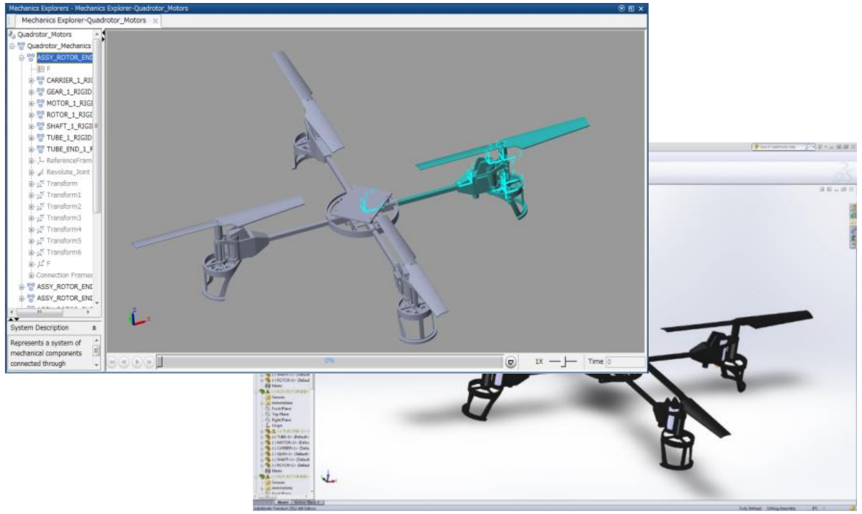
Mobile Robots



Using the Spatial Contact Force Block - Bumper Car

Simscape Multibody™

UAV



Import UAV CAD model

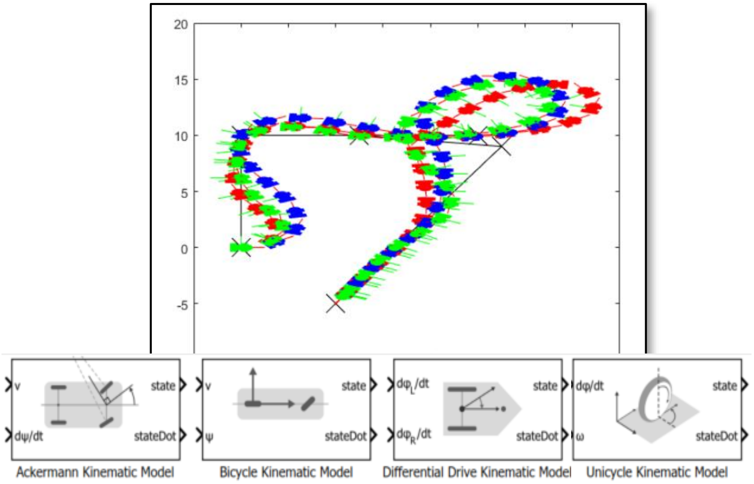
Simscape Multibody

Simscape Electrical™

Aerospace Blockset™

Robot Modeling Methods

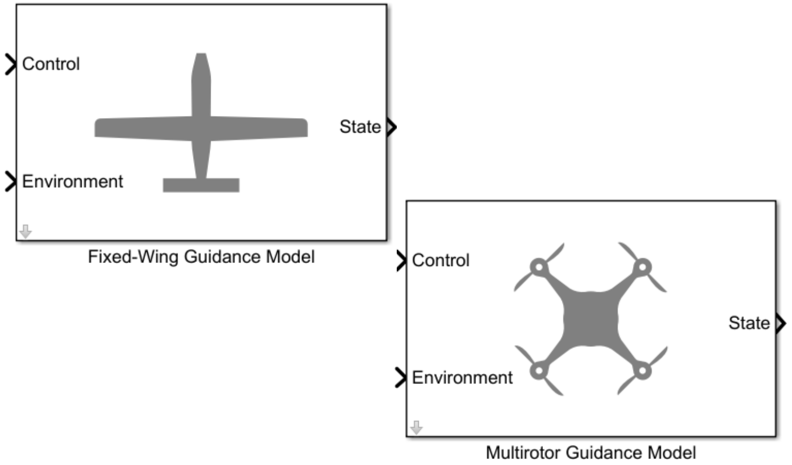
Mobile Robotics Kinematics Models



[Simulate Different Kinematic Models for Mobile Robots]()

Robotics System Toolbox™

UAV Guidance Models



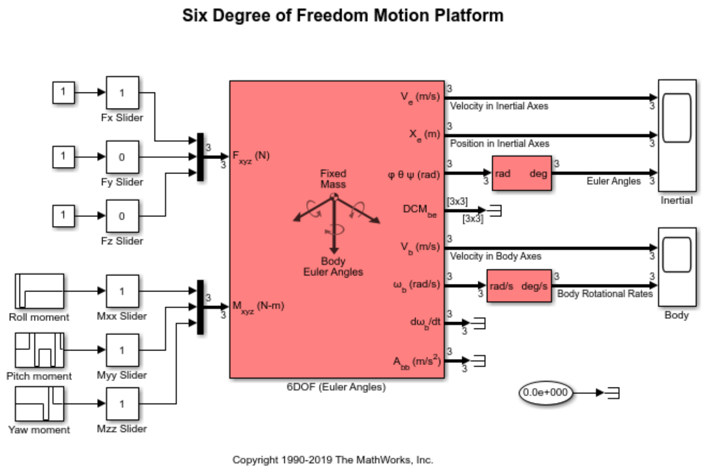
[Approximate High-Fidelity UAV model with UAV Guidance Model block]()

UAV Toolbox

Aerospace Blockset

Control System Toolbox™

Equations of Motion



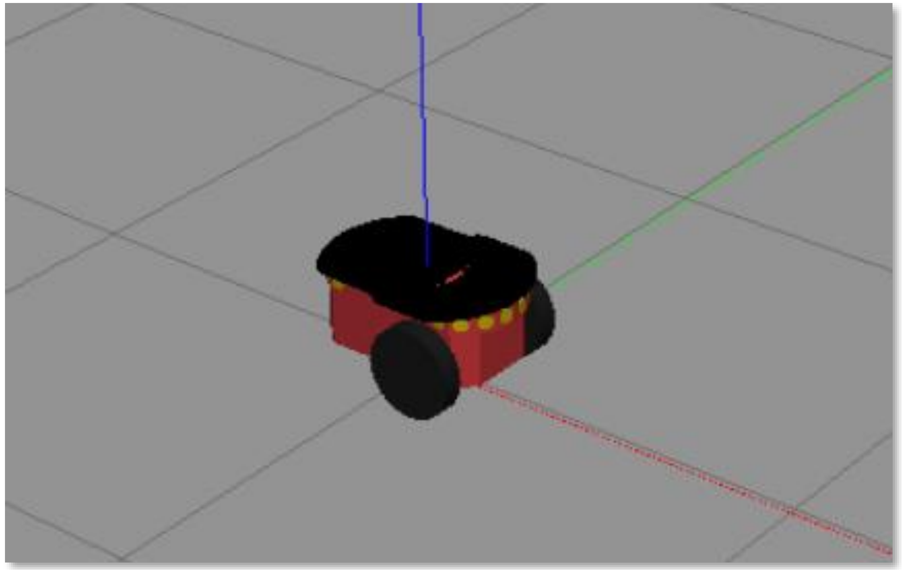
[Six Degree of Freedom Motion Platform]()

Aerospace Blockset

Co-simulating with Gazebo Simulator

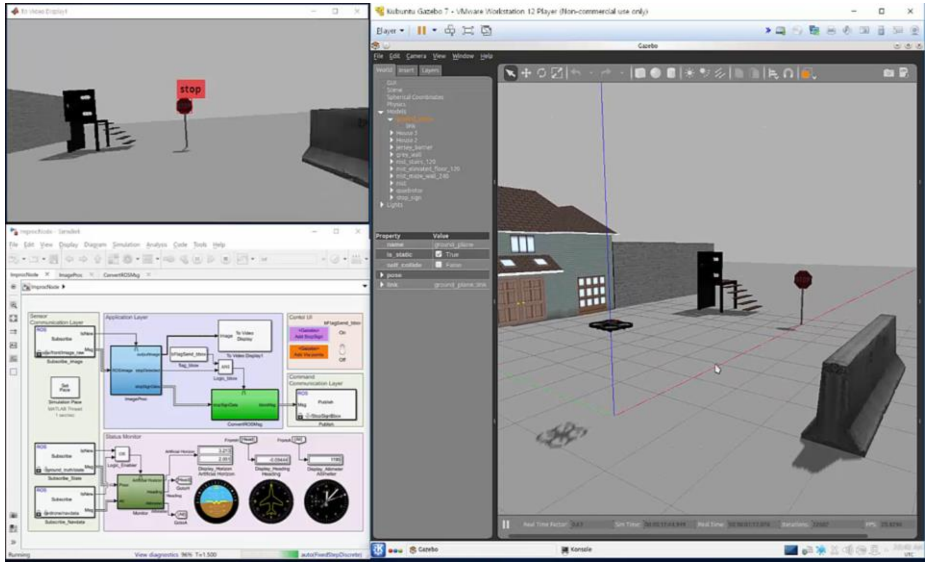
Mobile Robots

UAV



[Control A Differential-Drive Robot in Gazebo With Simulink]

Robotics System Toolbox



Simulink and Gazebo Co-Simulation

Robotics System Toolbox

How can I model and simulate robots and sensors?

Robot modeling methods

- Physical model
- Abstract model
- External robot model

Selection based on task

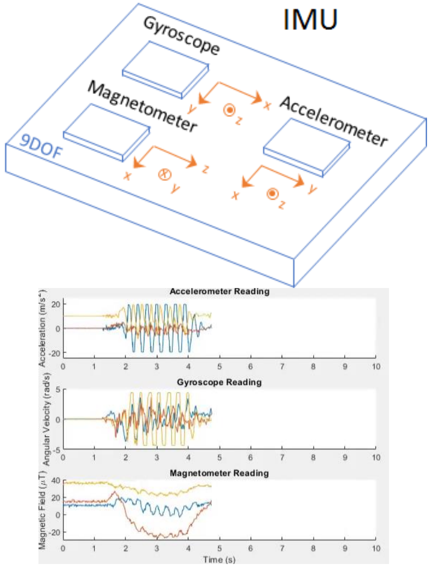
Sensor modeling methods

- Import sensor data
- Sensor simulation model
- External sensor model

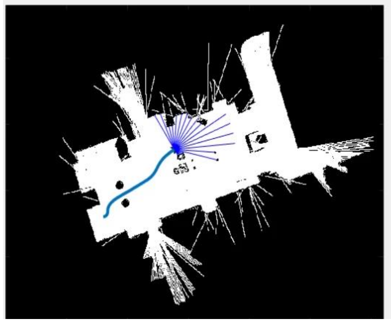
Enable open and closed-loop workflows

Sensor simulations for localization

(IMU / GPS / Altimeter / 2D-LiDAR / GNSS / INS / wheel encoder)



Accelerometer, Gyroscope, Magnetometer

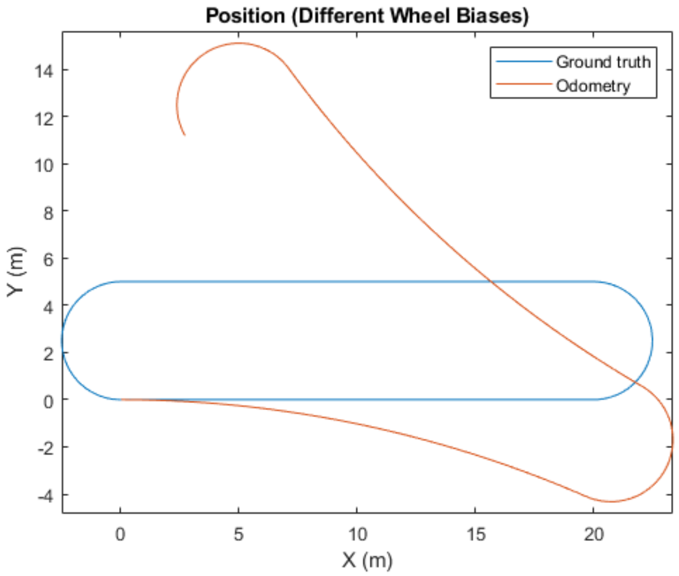


Range sensor (2D LiDAR)

gnssSensor	Simulate GNSS to generate position and velocity readings
altimeterSensor	Altimeter simulation model
gpsSensor	GPS receiver simulation model
imuSensor	IMU simulation model
insSensor	Inertial navigation and GPS simulation model
rangeSensor	Simulate range-bearing sensor readings
wheelEncoderUnicycle	Simulate wheel encoder sensor readings for unicycle vehicle
wheelEncoderBicycle	Simulate wheel encoder sensor readings for bicycle vehicle
wheelEncoderDifferentialDrive	Simulate wheel encoder sensor readings for differential drive vehicle
wheelEncoderAckermann	Simulate wheel encoder sensor readings for Ackermann vehicle
kinematicTrajectory	Rate-driven trajectory generator
timescope	Display time-domain signals
waypointTrajectory	Waypoint trajectory generator
nmeaParser	Parse data from standard NMEA sentences sent from GNSS receivers
gpsdev	Connect to a GPS receiver connected to host computer

Sensor Modeling

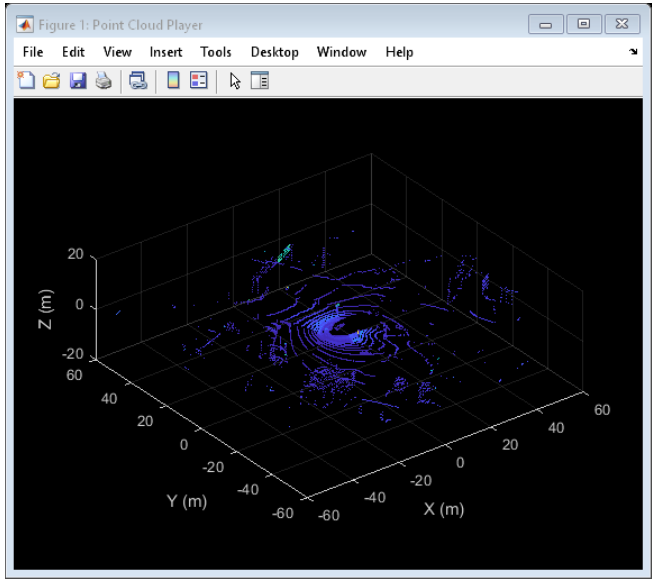
Wheel Encoder



[Wheel Encoder Error Sources]

Navigation Toolbox

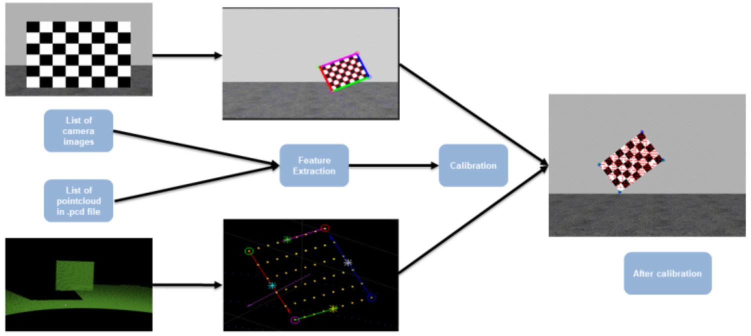
Velodyne Lidar



[Working with Velodyne ROS Messages]

ROS Toolbox

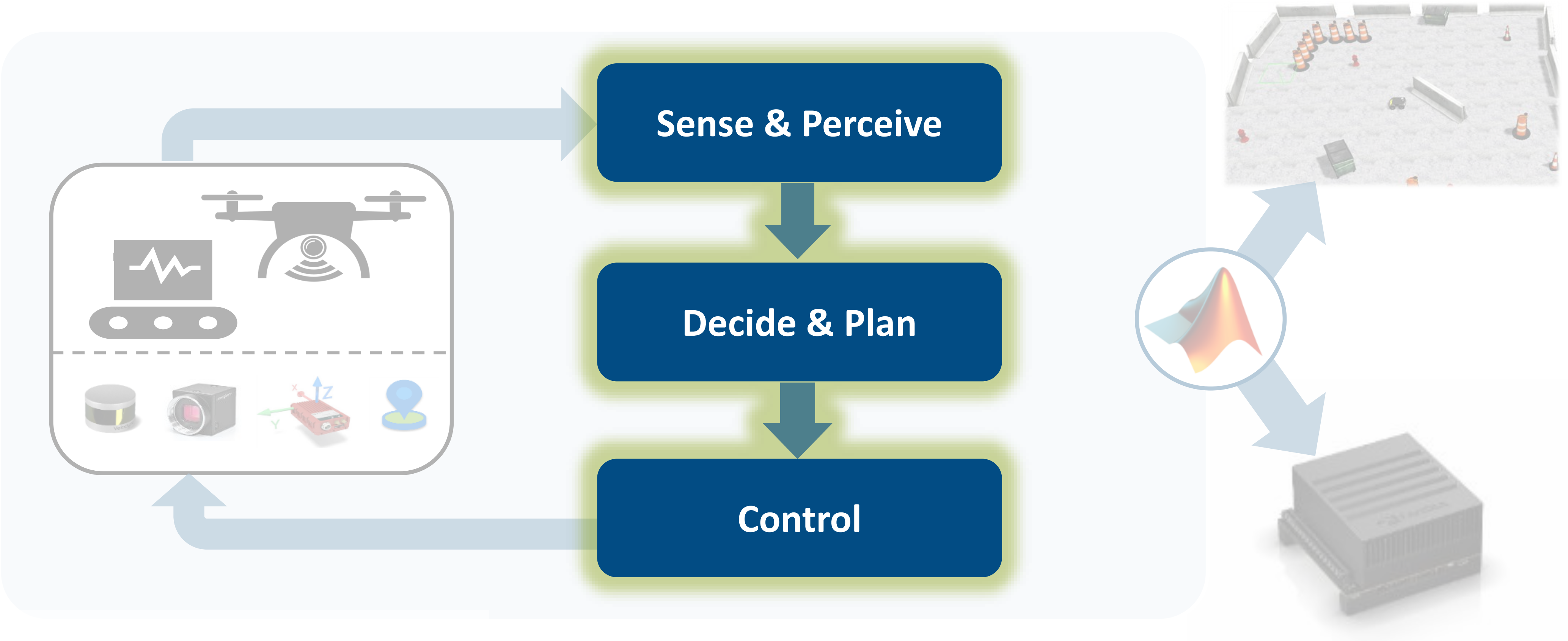
Lidar



[Lidar and Camera Calibration]

Lidar Toolbox™

Common questions from robotics engineers



How can I model and simulate robots and sensors?

How can I discover and design autonomous algorithms?

How can I test and deploy robotics applications?

How can I discover and design autonomous algorithms?

Sensing and Perception

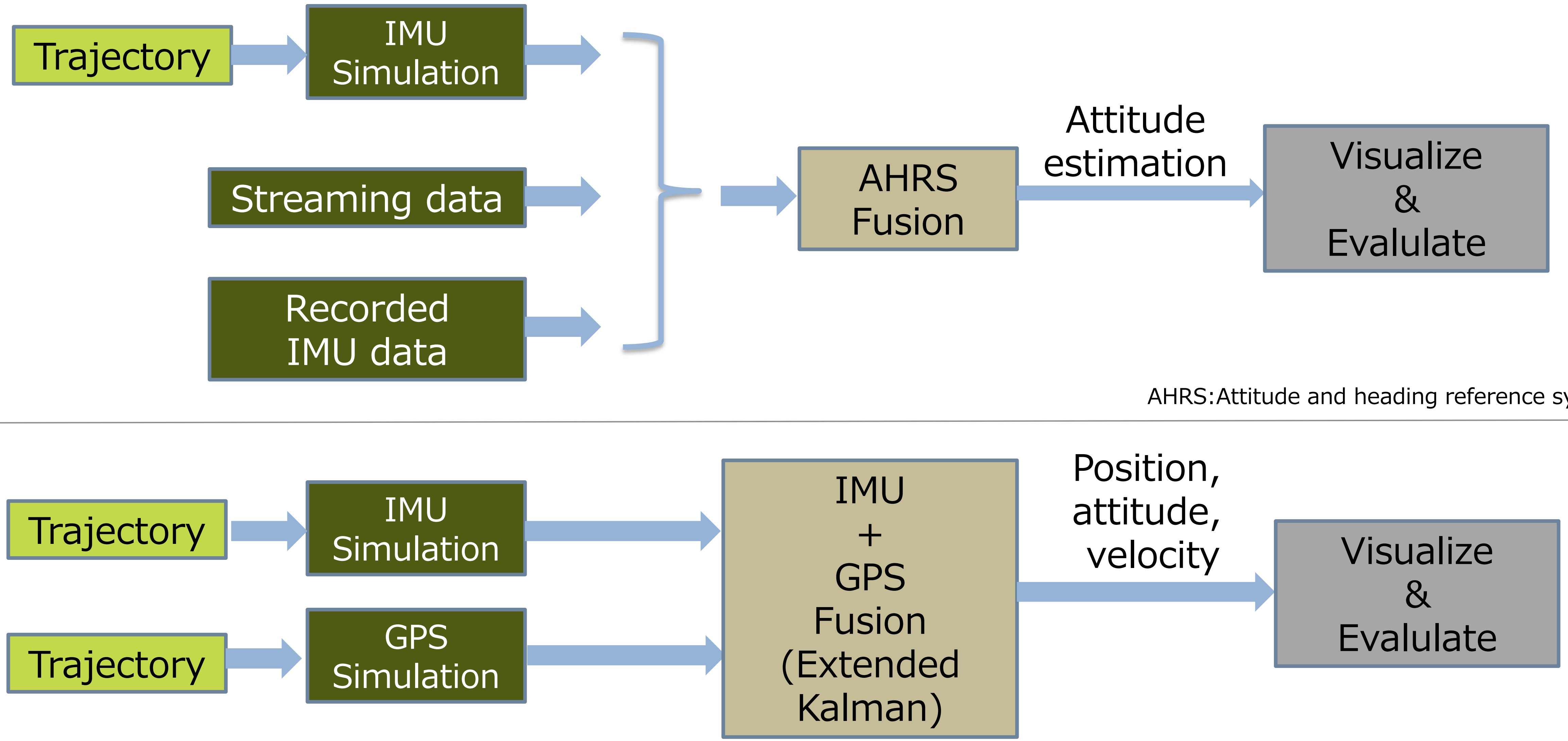
- Load data
- Localization
- Mapping
  SLAM
- Environmental awareness

Planning and Controls

- Decision logic
- Motion planning
- Path following
- Advanced Controls

Developing Localization Algorithms

Sensor Fusion and Tracking Toolbox™



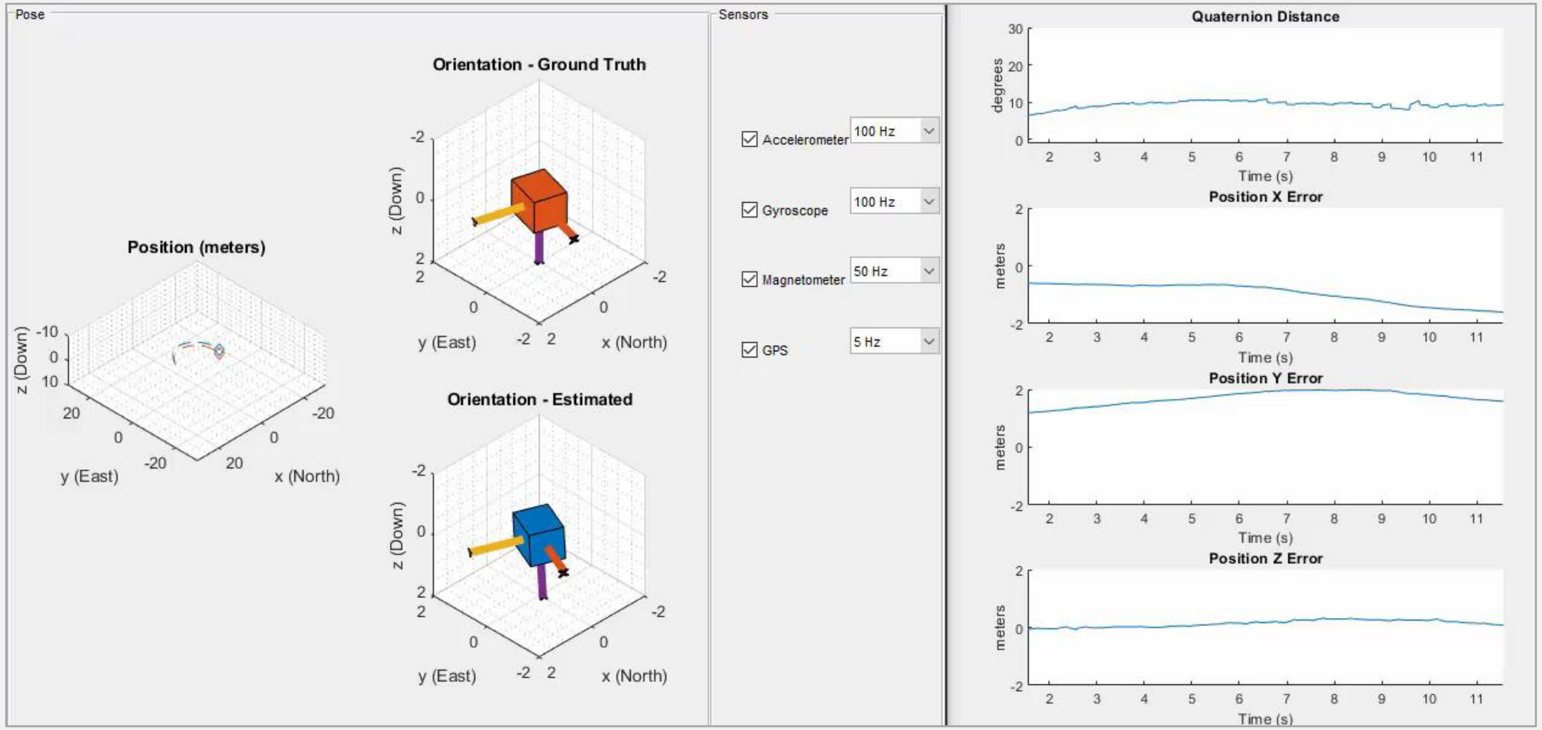
AHRS:Attitude and heading reference system

Tools for Developing Localization Algorithms

IMU + GPS fusion for accurate localization

- Create the filter to fuse IMU + GPS measurements
- Use an extended Kalman filter to track orientation (as a quaternion), position, velocity, and sensor biases

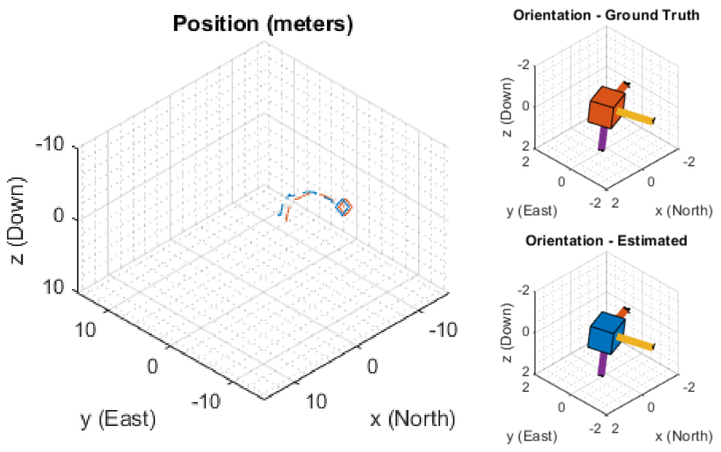
Multi-Sensor Fusion



Sensor Fusion and Tracking Toolbox

Localization, Position/Attitude Estimation with Sensor Fusion

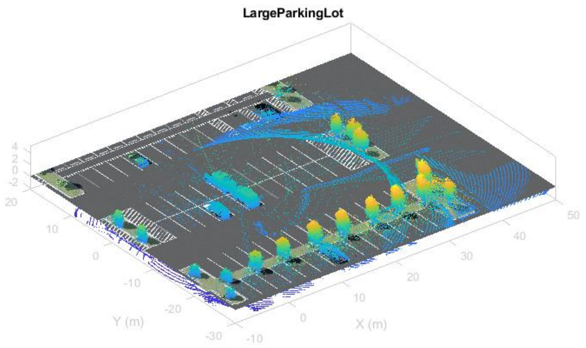
IMU + GPS



IMU and GPS Fusion for Inertial Navigation

Sensor Fusion and Tracking Toolbox

Lidar



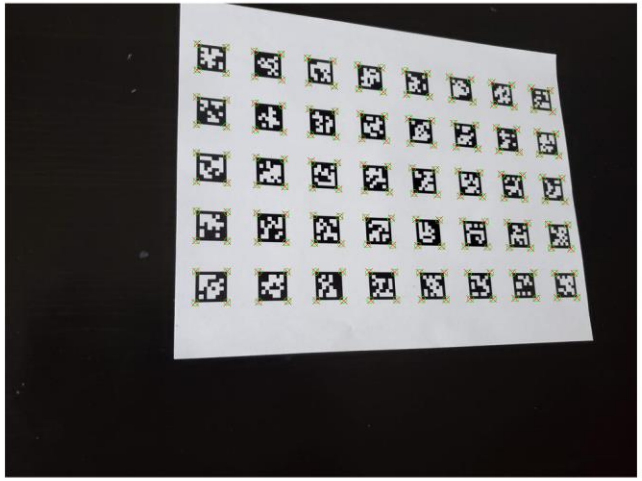
Lidar Localization with Unreal Engine Simulation

Automated Driving Toolbox™

Image Processing Toolbox™

Computer Vision Toolbox™

AprilTag

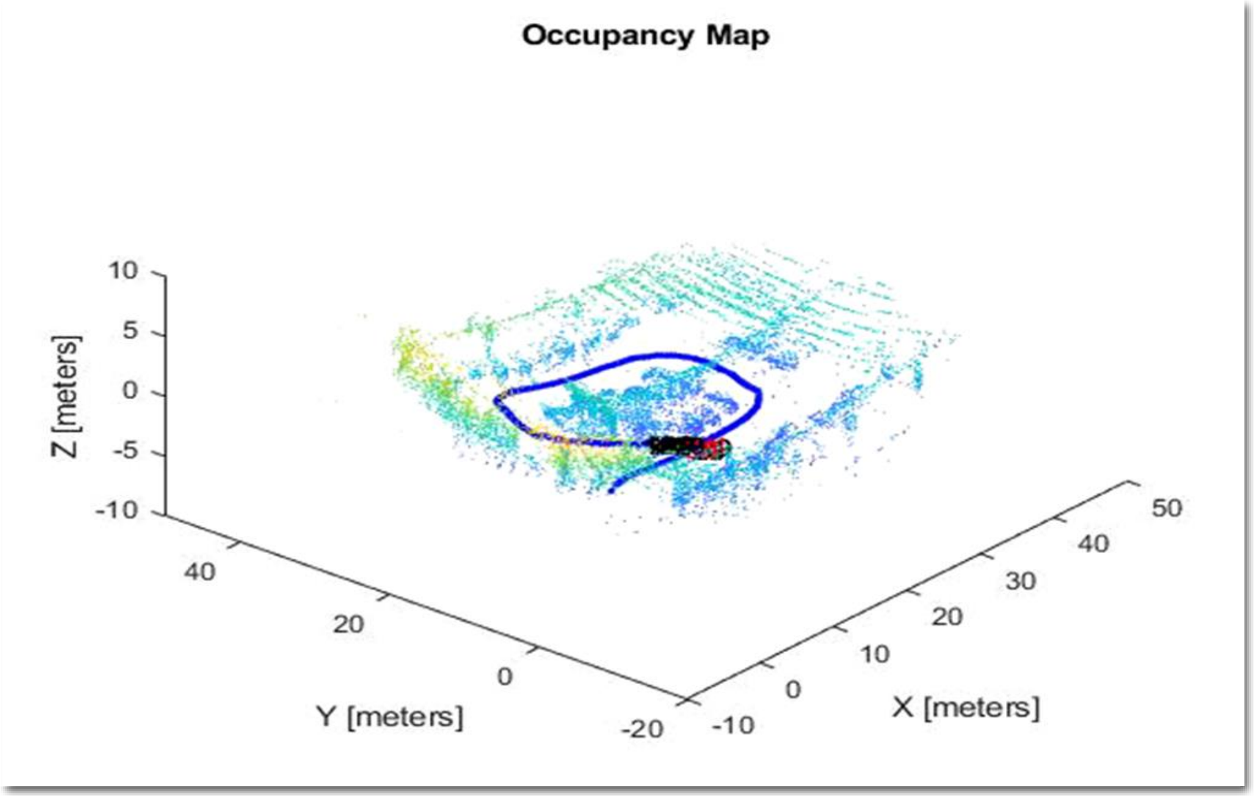


Camera Calibration Using AprilTag Markers

Computer Vision Toolbox

Localization, Mapping, and SLAM

Load data → Synchronize → Offline mapping → SLAM Localization → Obstacle avoidance



- Loop closure estimation
- Trajectory Estimation And Refinement Using Pose Graph Optimization
- Build and Visualize 3-D Occupancy Map

Perform SLAM Using 3-D Lidar Point Clouds

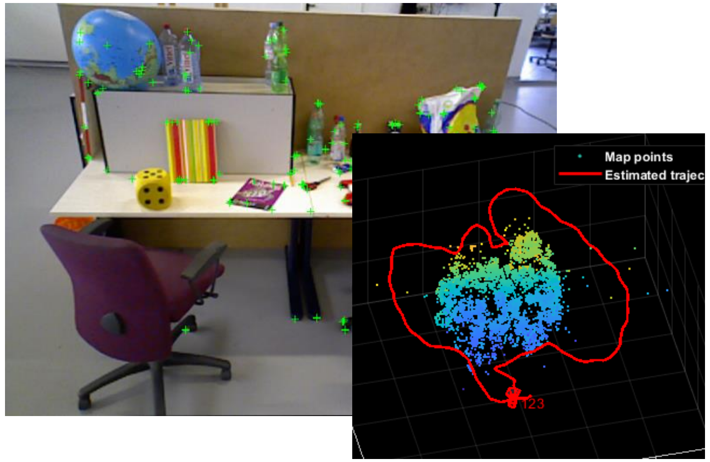
Navigation Toolbox

Computer Vision Toolbox

Design SLAM Algorithms

（Simultaneous Localization and Mapping）

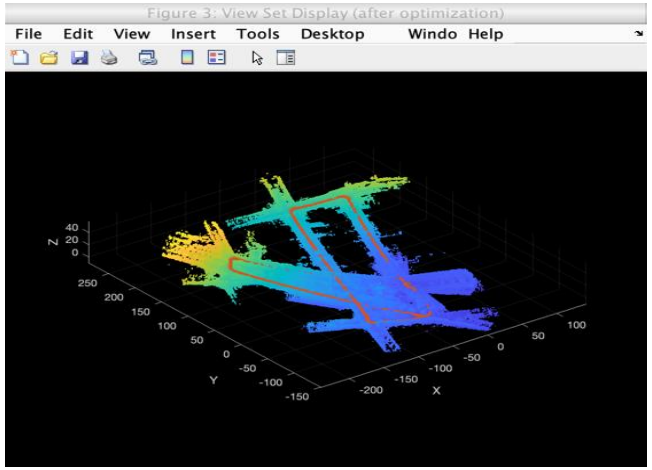
Monocular camera



[Monocular Visual Simultaneous Localization and Mapping]

Computer Vision Toolbox

Lidar (Real data)



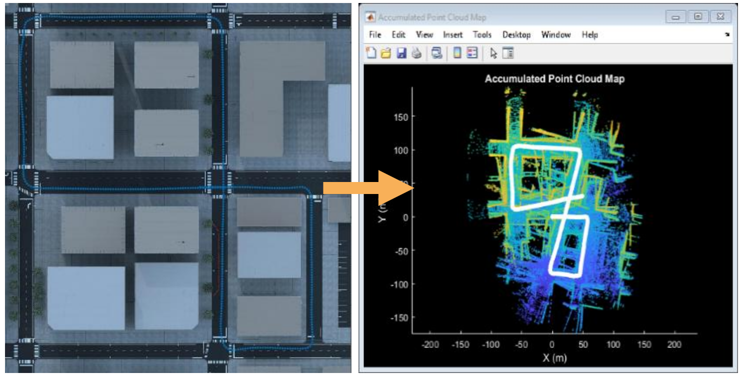
[Build a Map from Lidar Data Using SLAM]

Navigation Toolbox

Automated Driving Toolbox

Computer Vision Toolbox

Lidar (Synthesized data)



[Design Lidar SLAM Algorithm using 3D Simulation Environment]

Navigation Toolbox

Automated Driving Toolbox

Computer Vision Toolbox

Sensing and Perception

Load data → Synchronize → Calibration → Labeling → Training

- Load and augment data
- Preprocess training data
- Define YOLOv3 network
- Train & evaluate model

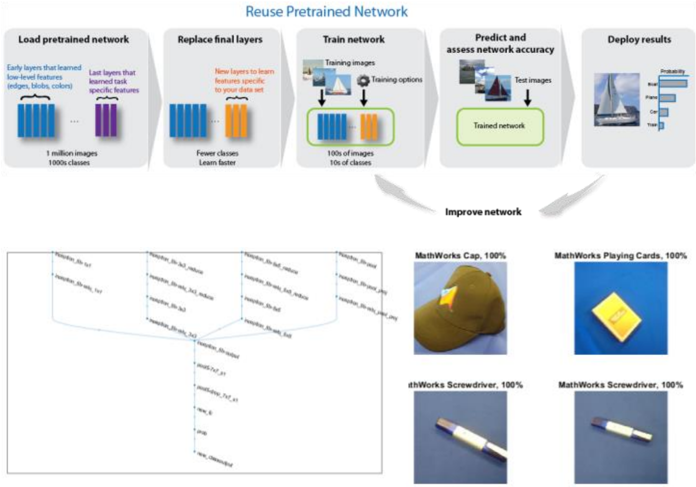
[Object Detection Using YOLO v3 Deep Learning]()

Computer Vision Toolbox

Deep Learning Toolbox™

Computer Vision and Deep Learning

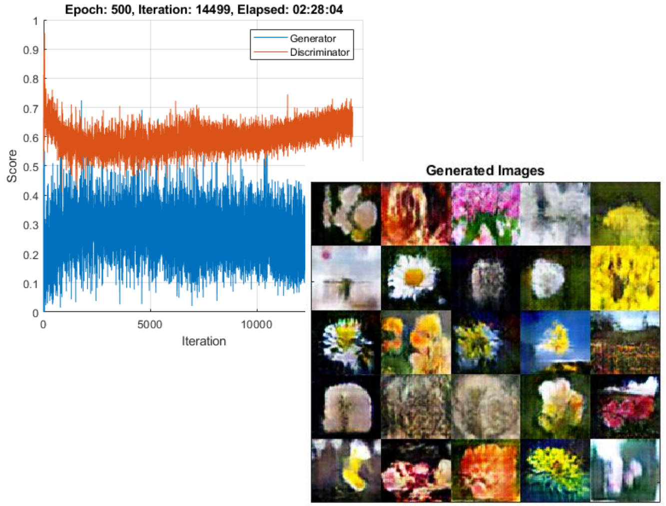
Image classification



[Train Deep Learning Network to Classify New Images]

Deep Learning Toolbox

GAN

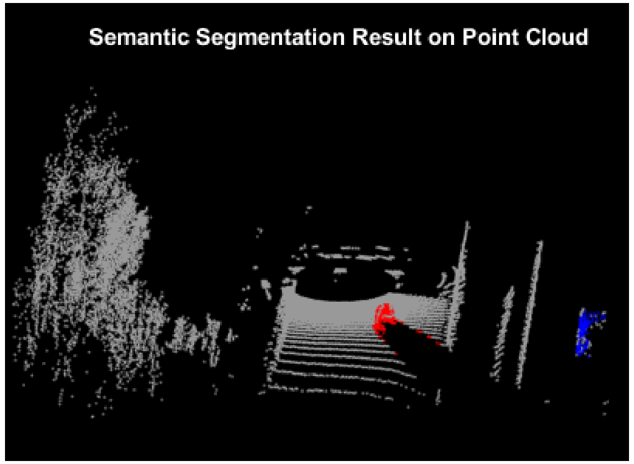


[Train Generative Adversarial Network (GAN)]

Deep Learning Toolbox

Parallel Computing Toolbox™

Detecting Object



[Lidar Point Cloud Semantic Segmentation]

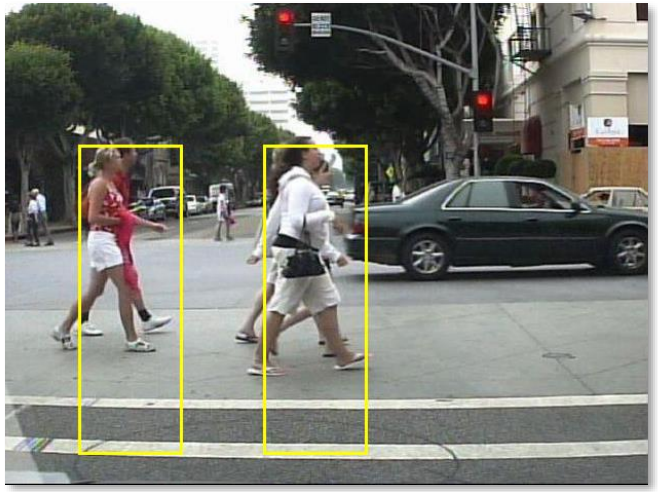
Lidar Toolbox

Deep Learning Toolbox

Computer Vision Toolbox

Other Perception Algorithms

Detecting Humans



[Pedestrian Detection]()

Computer Vision Toolbox

Deep Learning Toolbox

GPU Coder™

Detecting Object

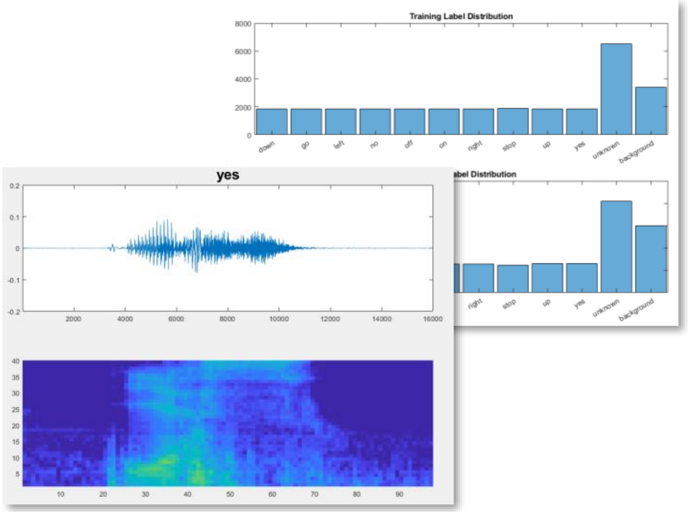
[Vehicle Detection using YOLO v2 Deployed to FPGA]()

Computer Vision Toolbox

Deep Learning Toolbox

Image Processing Toolbox

Speech Command Recognition



[Speech Command Recognition Using Deep Learning]()

Audio Toolbox™

Deep Learning Toolbox

How can I discover and design autonomous algorithms?

Sensing and Perception

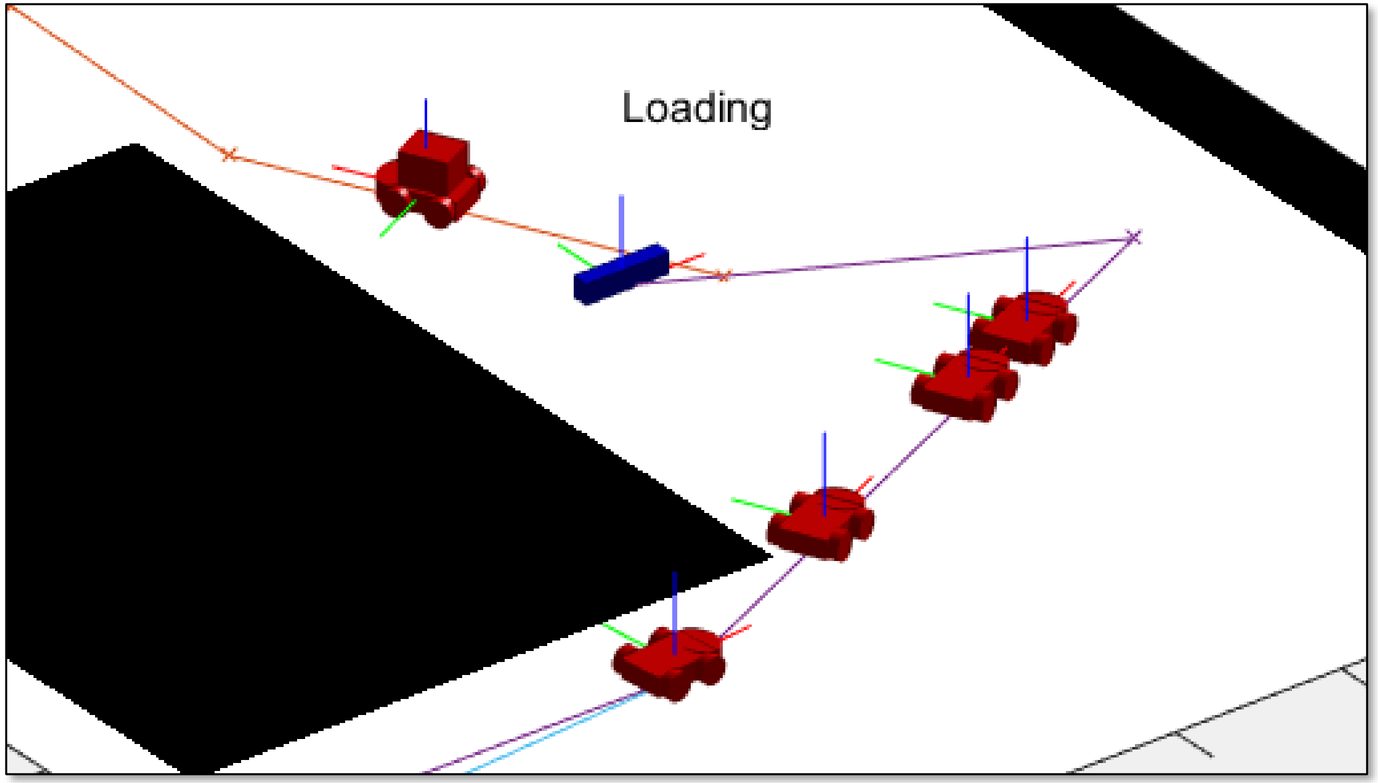
- Load data
- Environmental awareness
- Localization
- Mapping
  SLAM

Planning and Controls

- Decision logic
- Motion planning
- Path following
- Controls

Planning and Control Workflows

Task scheduling → Path planning → Trajectory planning → Path following → Controls



- Central scheduler
- Robot models and controller
- Visualization

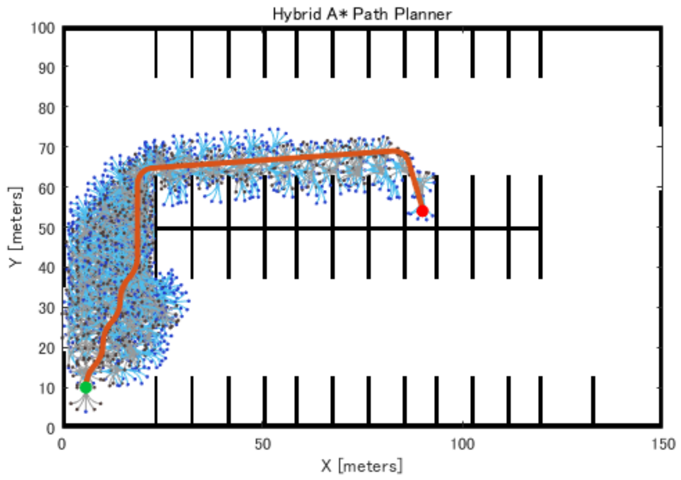
[Control and Simulate Multiple Warehouse Robots]

Robotics System Toolbox

Stateflow®

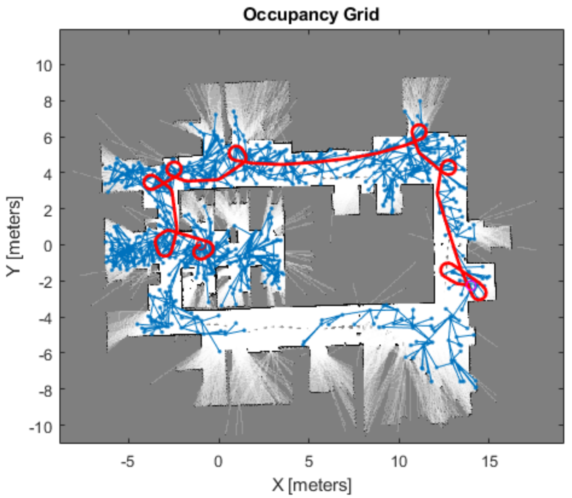
Motion Planning Algorithms

Hybrid A*



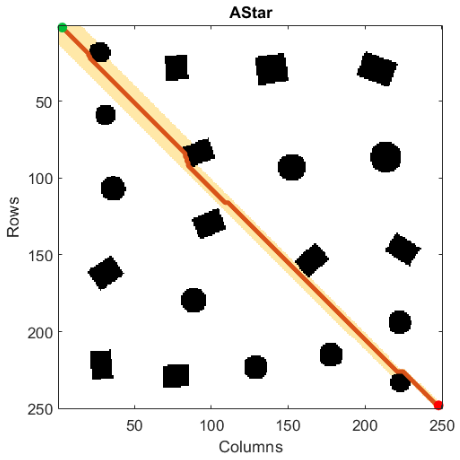
plannerHybridAStar
Navigation Toolbox

RRT、RRT*



Plan Mobile-Robot Paths using RRT
Navigation Toolbox

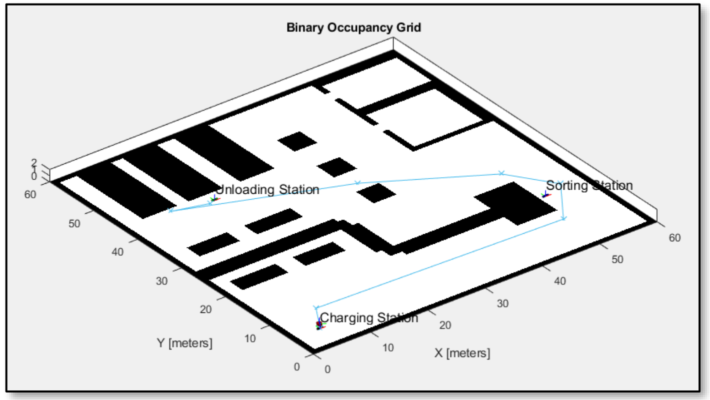
Grid-based A*



plannerAStarGrid
Navigation Toolbox

Task and Motion Planning

Task scheduling

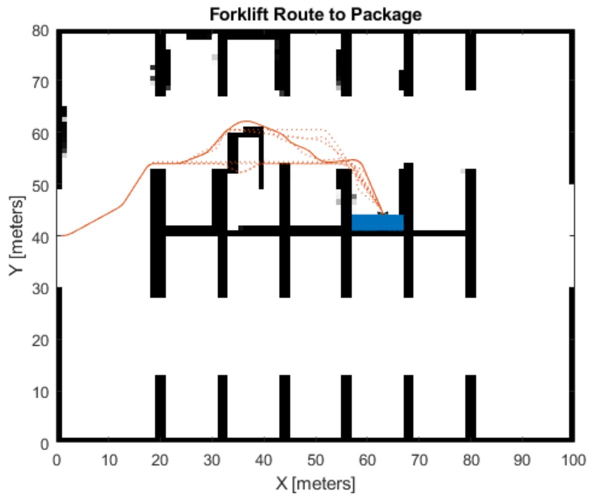


[Execute Tasks for a Warehouse Robot]

Robotics System Toolbox

Stateflow

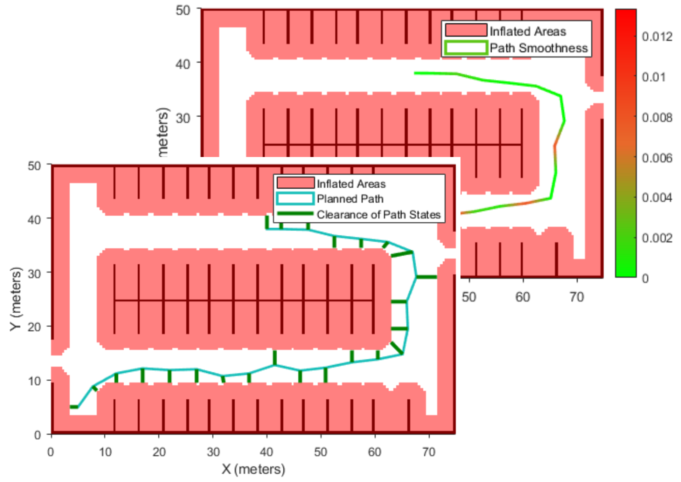
Dynamic replanning



[Dynamic Replanning on an Indoor Map]

Navigation Toolbox

Path metrics

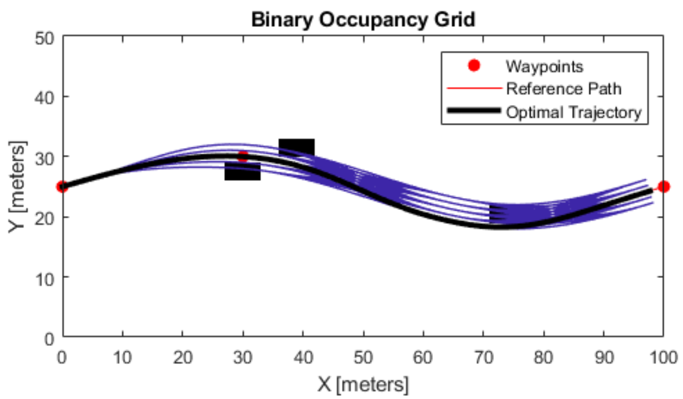


[Evaluate metrics for planned path]

Navigation Toolbox

Mobile Robot Examples: Path Following and Controls

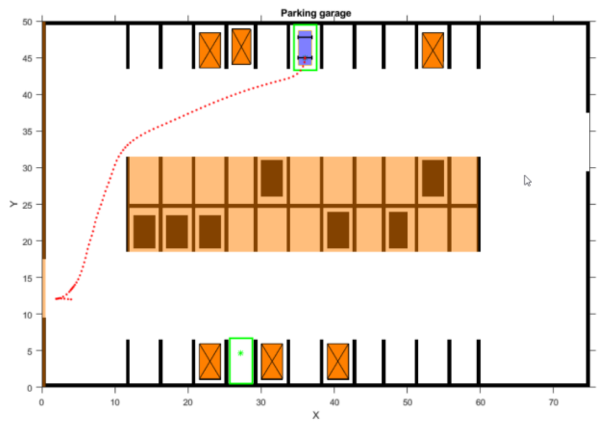
Optimization



[Find optimal trajectory for reference path]

Navigation Toolbox

Nonlinear MPC



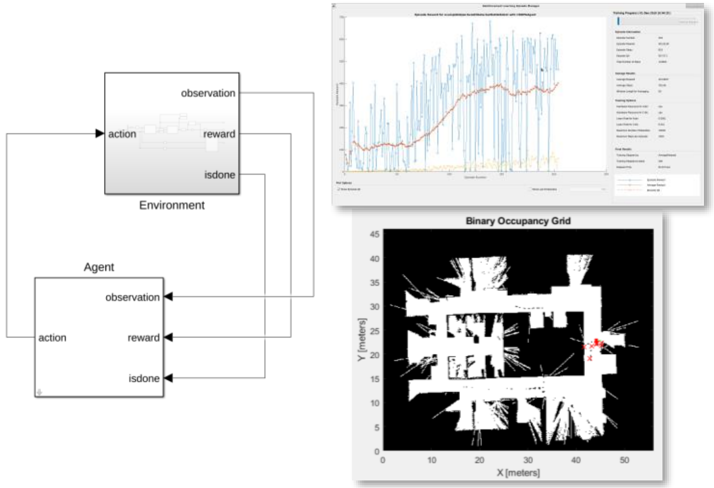
[Parallel Valet using Nonlinear Model Predictive Control]

Automated Driving Toolbox

Model Predictive Control ToolboxTM

Navigation Toolbox

Reinforcement learning



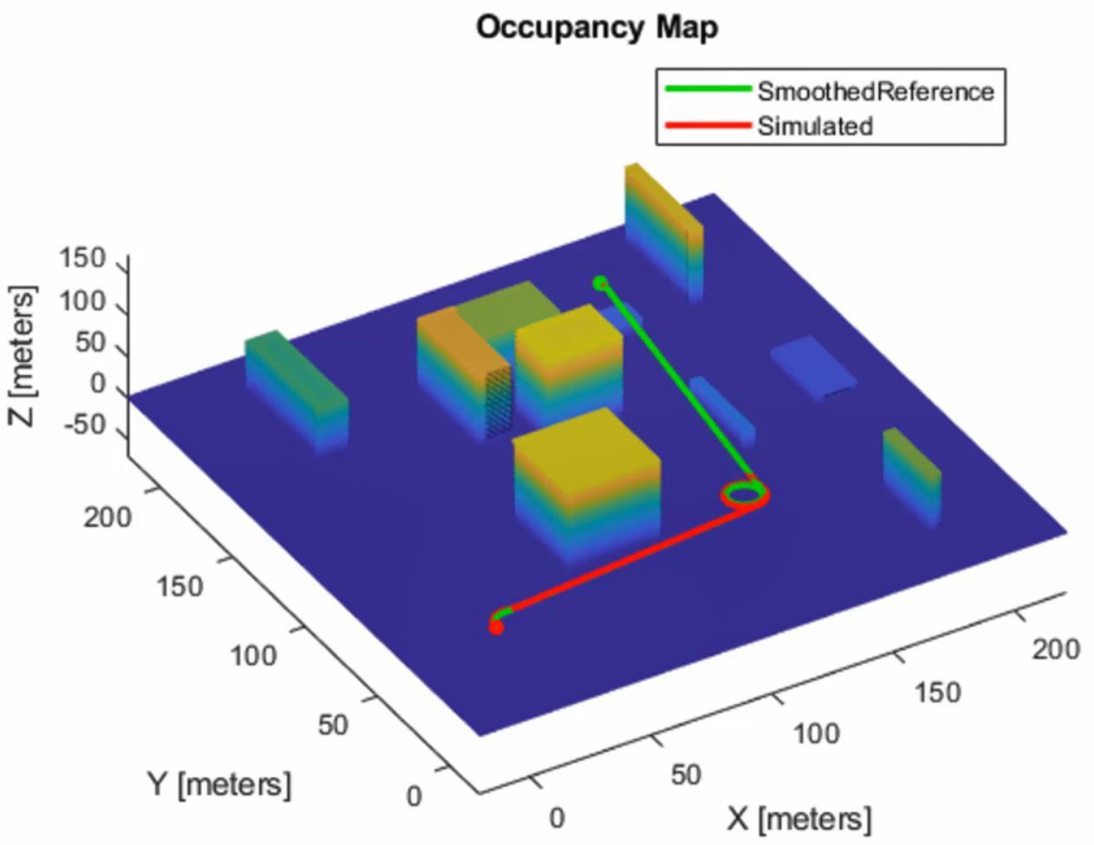
[Avoid Obstacles using Reinforcement Learning for Mobile Robots]

Robotics System Toolbox

Reinforcement Learning ToolboxTM

UAV Example: Planning and Controls

Load map → Define start and goal → Setup state-space → Plan path → Simulation and visualize → Refine path



Plan a smooth path within obstacles

- RRT path planner
- Apply aerodynamic constraints
- Visualize in 3D occupancy map

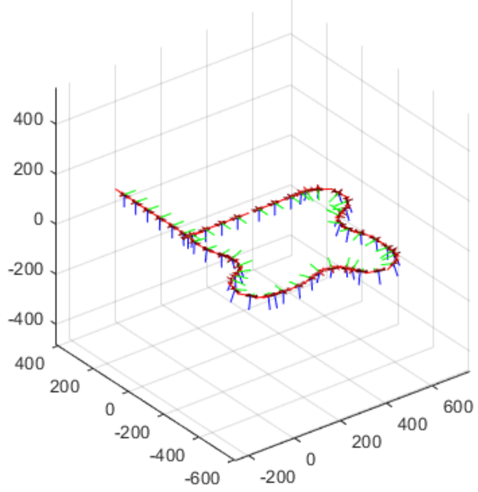
[Motion Planning with RRT for Fixed-Wing UAV]

UAV Toolbox

Navigation Toolbox

UAV Motion Planning

Guidance model



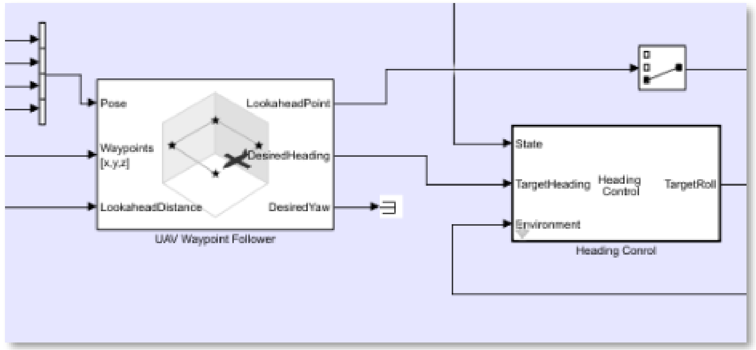
[Approximate High-Fidelity UAV model with UAV Guidance Model block]

UAV Toolbox

Aerospace Blockset

Control System Toolbox

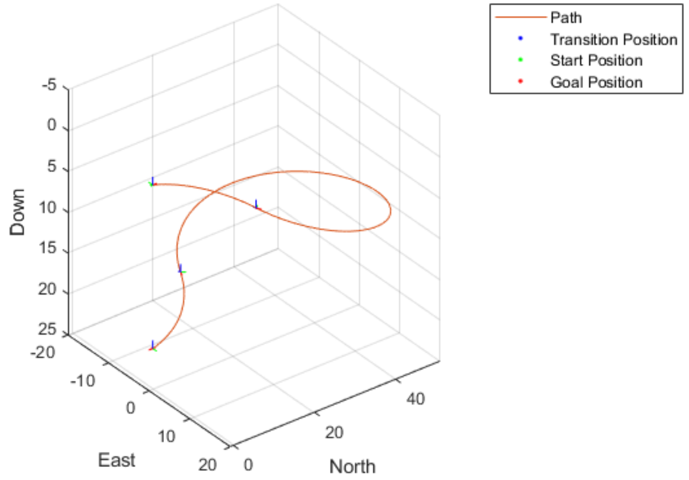
Dynamic path planning



[Tuning Waypoint Follower for Fixed-Wing UAV]

UAV Toolbox

Dubins path



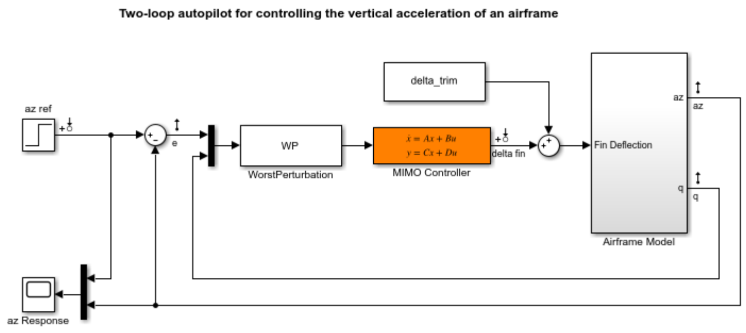
[Dubins Path Connection]

[Dubins Path Segment]

UAV Toolbox

UAV Examples: Path Following and Controls

Robust controls

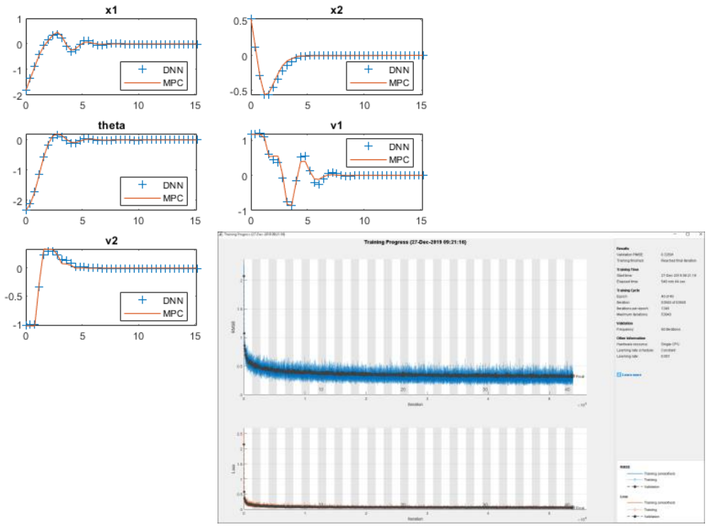


Robust MIMO Controller for Two-Loop Autopilot

Robust Control Toolbox™

Simulink Control Design

Non-linear MPC + Reinforcement learning



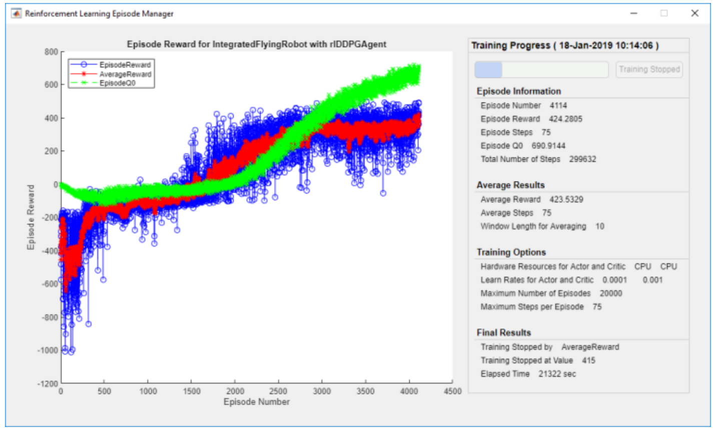
Imitate Nonlinear MPC Controller for Flying Robot

Reinforcement Learning Toolbox

Model Predictive Control Toolbox

Deep Learning Toolbox

Reinforcement learning

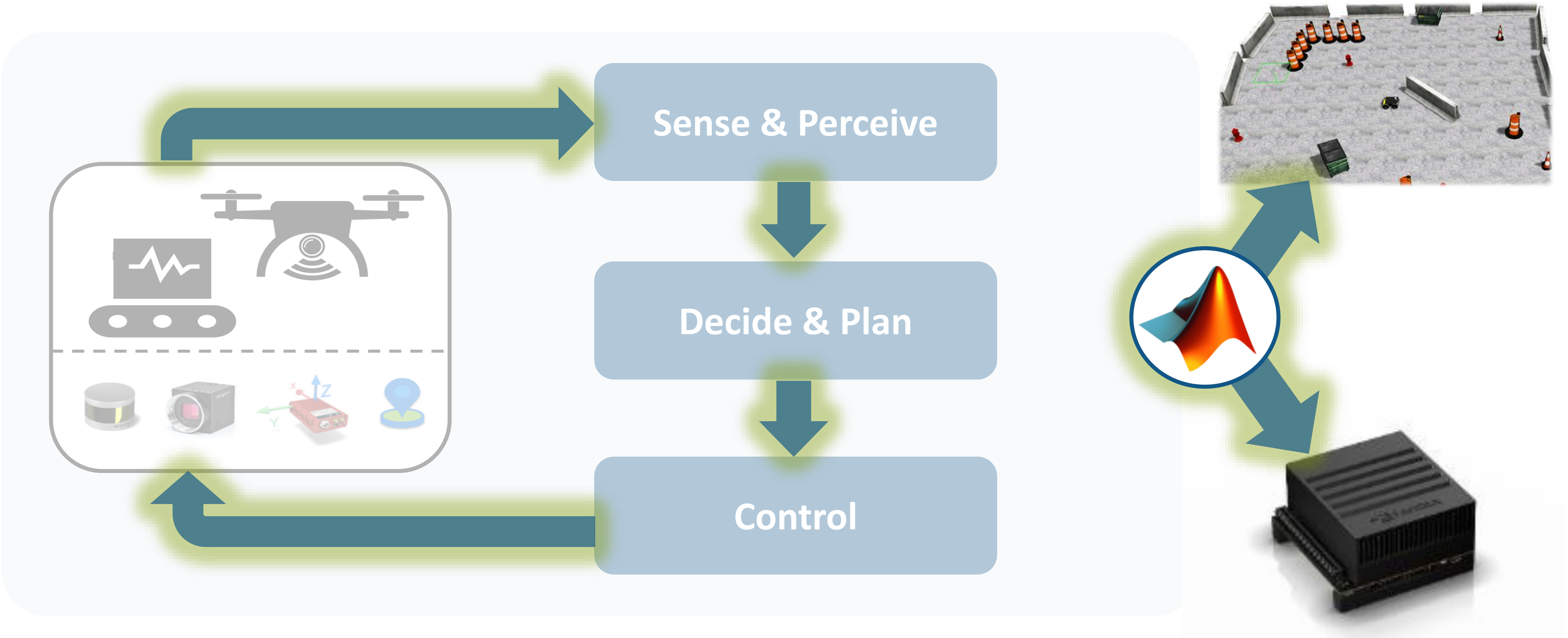


Train DDPG Agent to Control Flying Robot

Reinforcement Learning Toolbox

Deep Learning Toolbox

Common questions from robotics engineers



How can I model and simulate robots and sensors?

How can I discover and design autonomous algorithms?

How can I test and deploy robotics applications?

How can I test and deploy UAV applications?

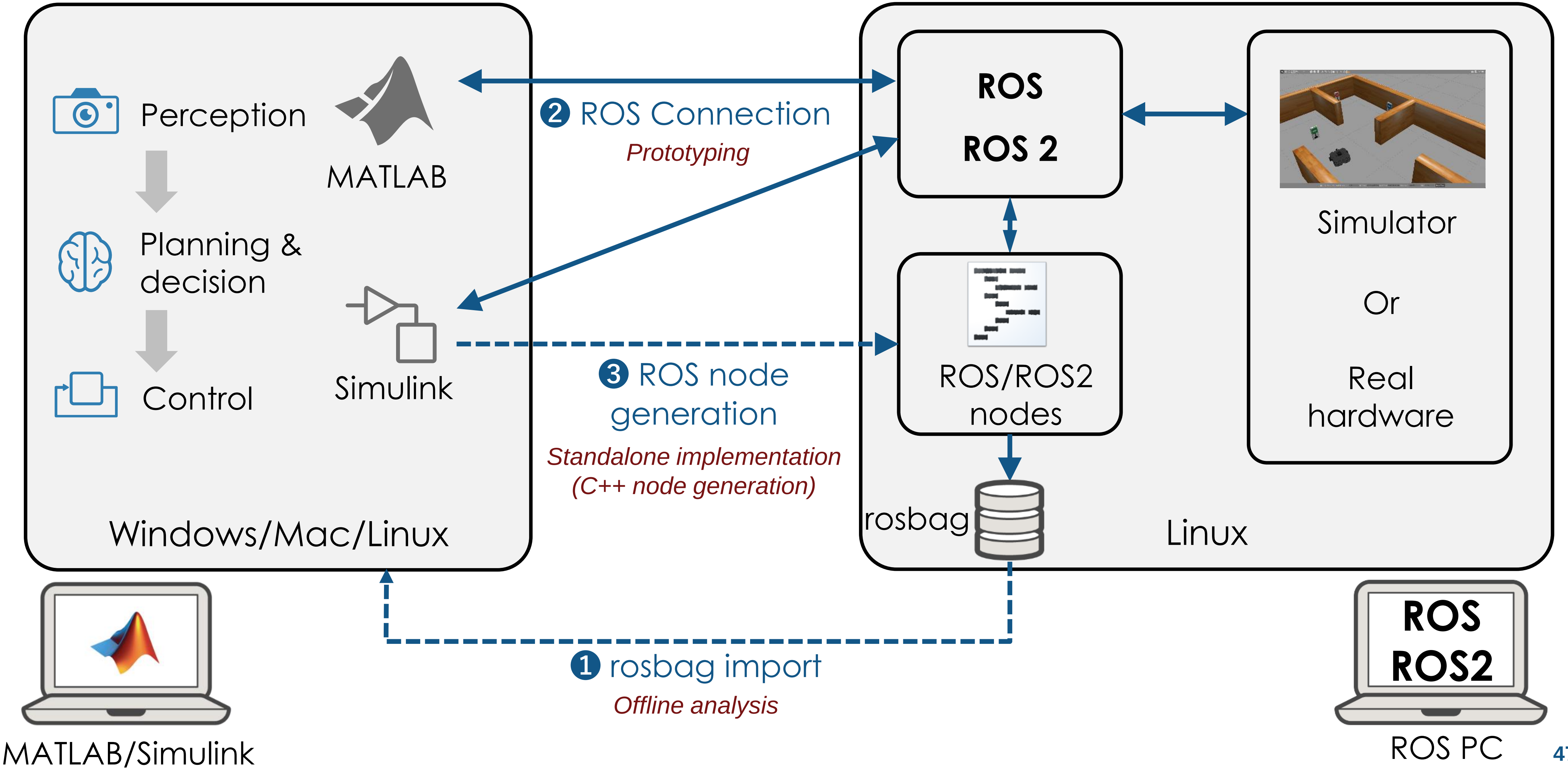
Testing

- MATLAB Simulink
- External simulator
- Automating verification
- Certification

Deployment

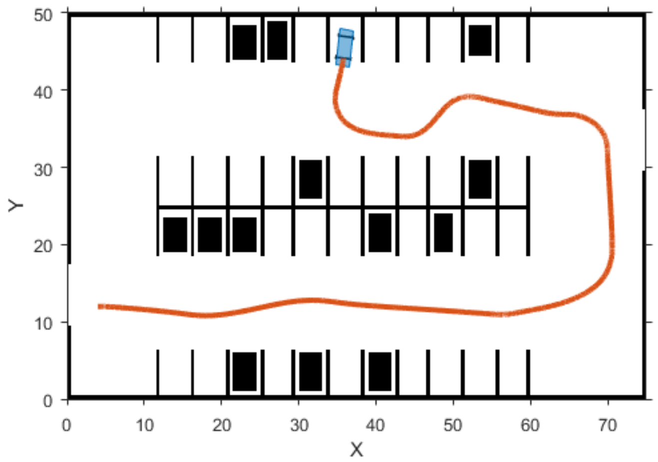
- ROS/ROS2
- MCU DSP
- SoC
- FPGA ASIC
- GPU

Communicate with ROS/ROS2 using MATLAB/Simulink



Gazebo / ROS connectivity

ROS connectivity

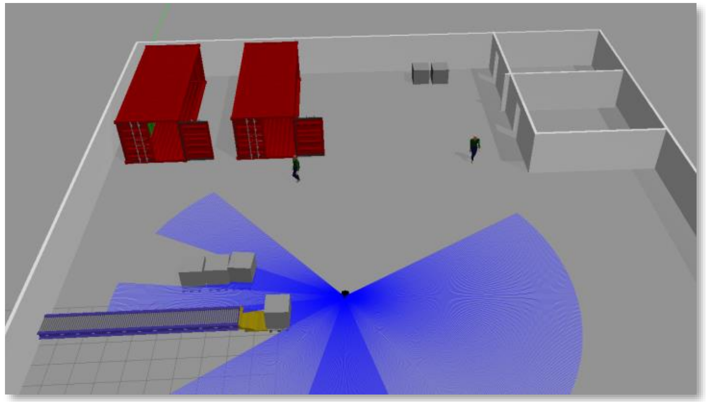


[Automated Parking Valet with ROS in MATLAB]

Automated Driving Toolbox

ROS Toolbox

Gazebo synchronized simulation



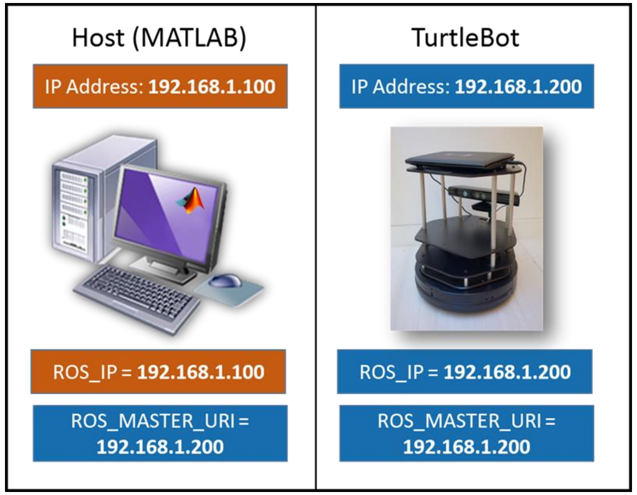
[Simulate a Mobile Robot in a Warehouse Using Gazebo]

Robotics System Toolbox

Navigation Toolbox

Stateflow

Testing with hardware

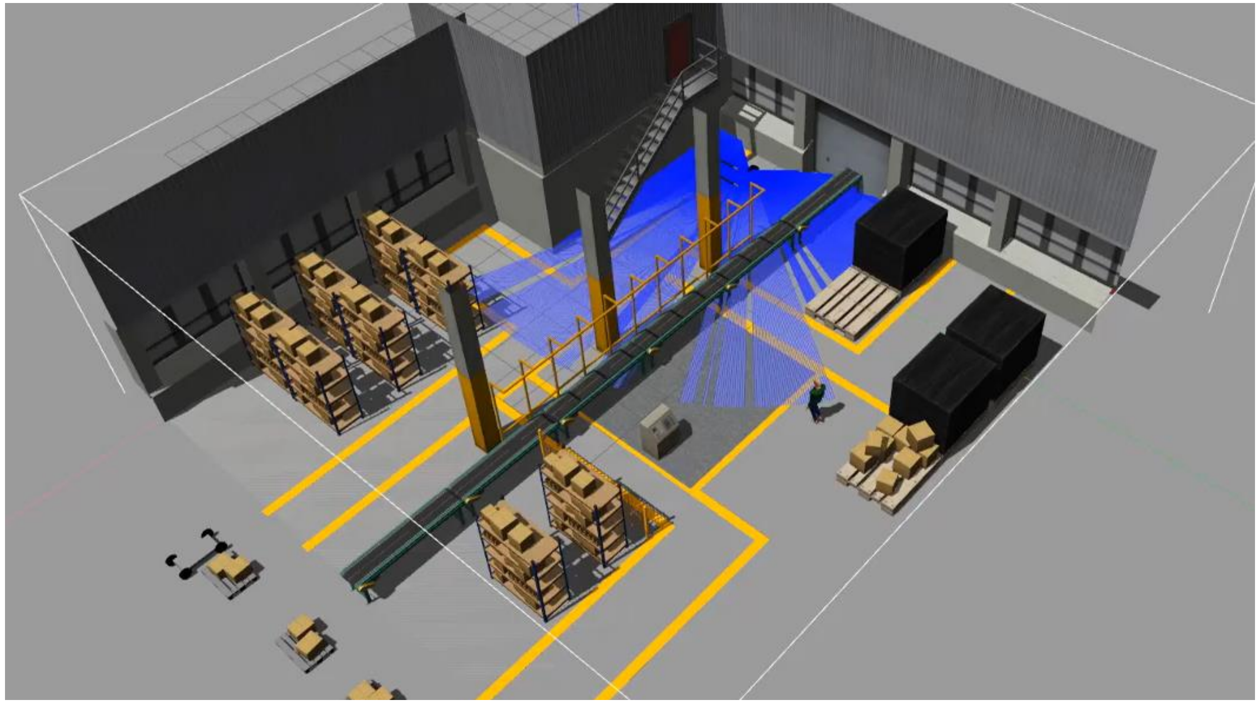


[Get Started with a Real TurtleBot]

ROS Toolbox

Mobile Robot Example: Co-simulation with Gazebo

Task scheduling → Path planning → Trajectory planning → Path following → Controls



- A* path planner
- Vector field histogram (VFH) algorithm to avoid obstacles
- Gazebo co-simulation

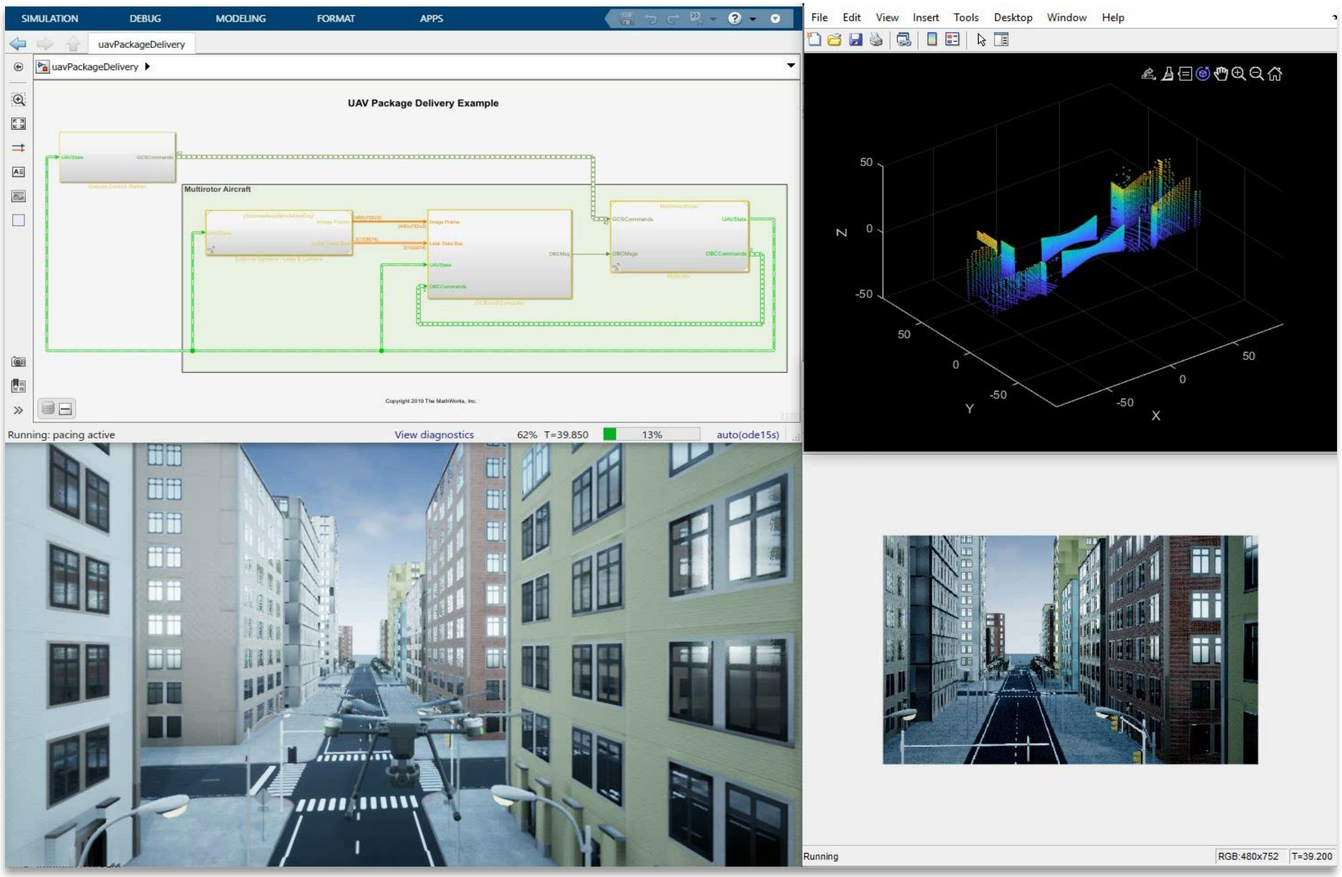
[A* Path Planning and Obstacle Avoidance in a Warehouse]

Robotics System Toolbox

Navigation Toolbox

3D Simulation with Unreal Engine

Design algorithm → Plan mission → Generate scenario → Cuboid simulation → 3D simulation → Increase UAV model fidelity



- Workflow for UAV application development
- Sensor readings for closed-loop simulations
- Variant subsystems for incremental design iterations
- Customizable components

[UAV Package Delivery]

UAV Toolbox

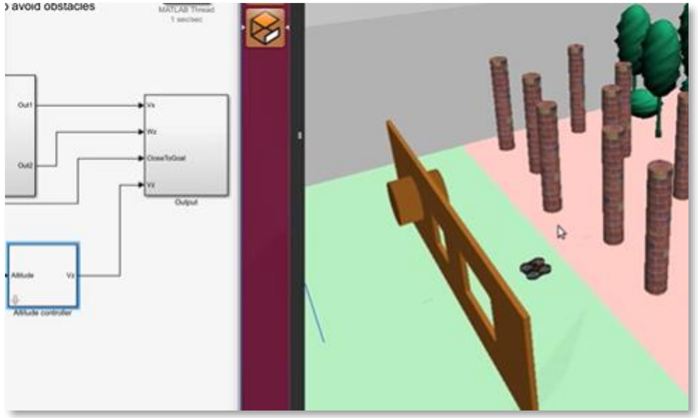
Aerospace Blockset

Navigation Toolbox

Stateflow

Simulator and hardware test

Gazebo simulation



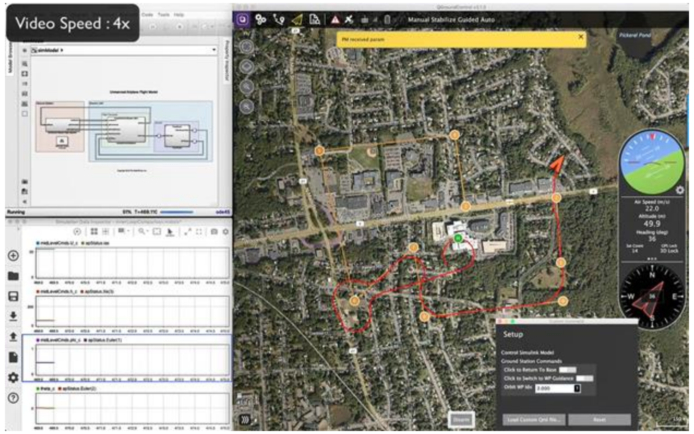
[Simulating Quadcopter Missions with Simulink and ROS]

Robotics System Toolbox

ROS Toolbox

Aerospace Blockset

MAVLink / QGroundControl



[Simulink Drone Reference Application]

UAV Toolbox

Aerospace Blockset

Control System Toolbox

PX4 Autopilots

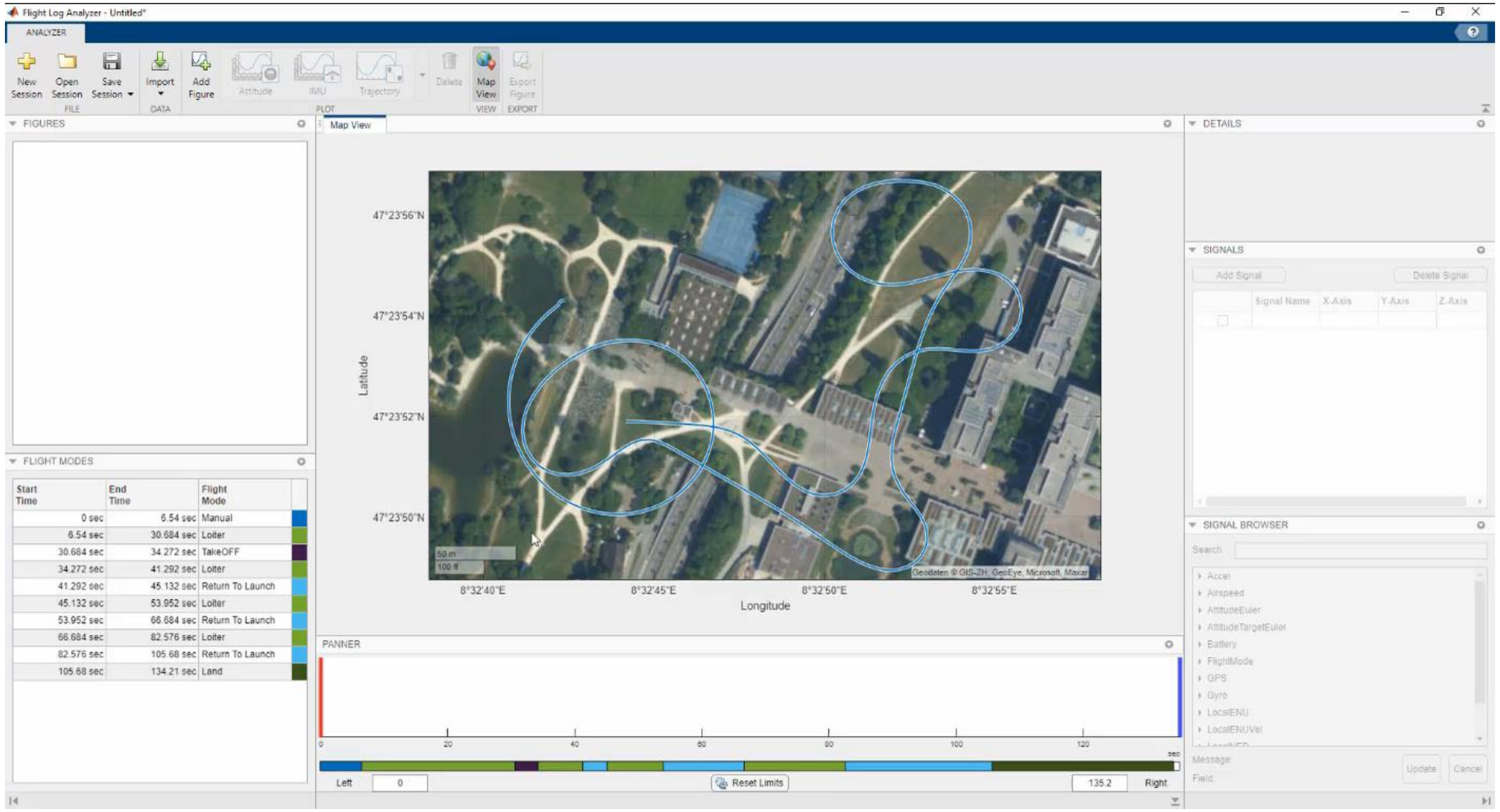
[PX4 Autopilots Support from Embedded Coder]

UAV Toolbox

Embedded Coder™

Flight Log Analysis

Load flight log data → Add predefined plots → Customize plots (optional) → Interactively change plot focus → Export figure



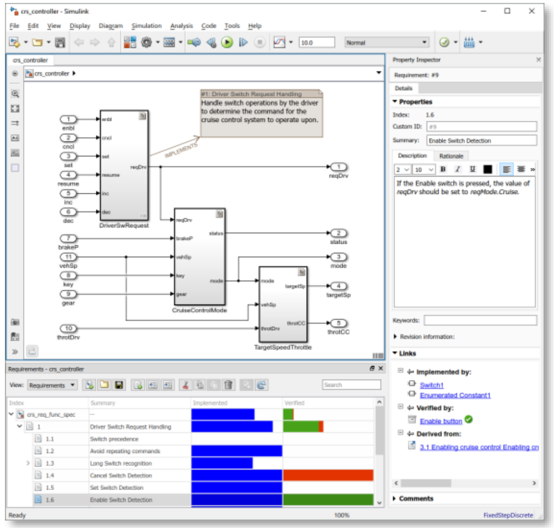
- Create customized series of plots
- Visualize with predefined or custom plots
- Interactively zoom in to data segments of interest
- Save and load sessions

[Flight Log Analyzer App](#)

UAV Toolbox

Automating verification tasks and certification

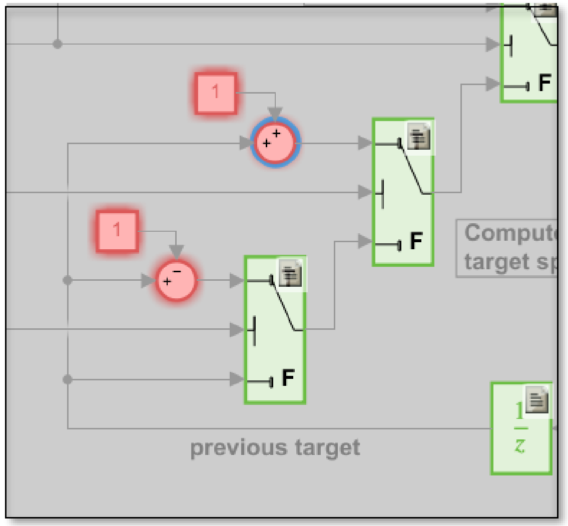
Requirements traceability



[Requirements Definition for a Cruise Control Model](#)

Simulink Requirements™

Test automation



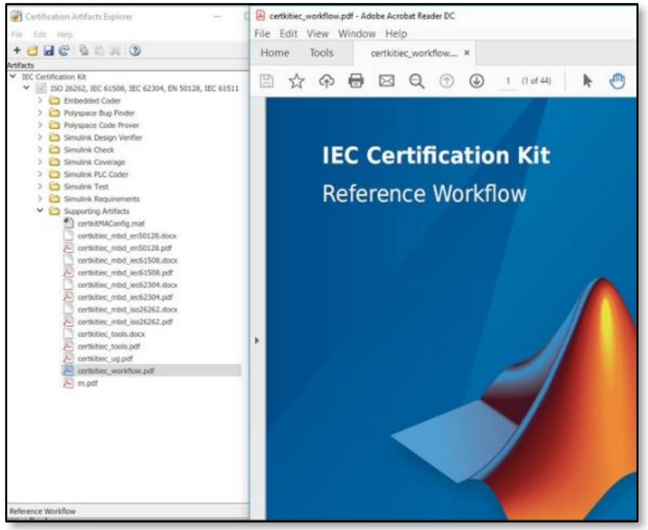
[Test Coverage for Requirements-Based Testing](#)

Simulink Test™

Simulink Coverage™

Simulink Requirements

Certification support



[IEC/ISO](#) and [DO](#) certification

IEC Certification Kit

DO Qualification Kit

How can I test and deploy UAV applications?

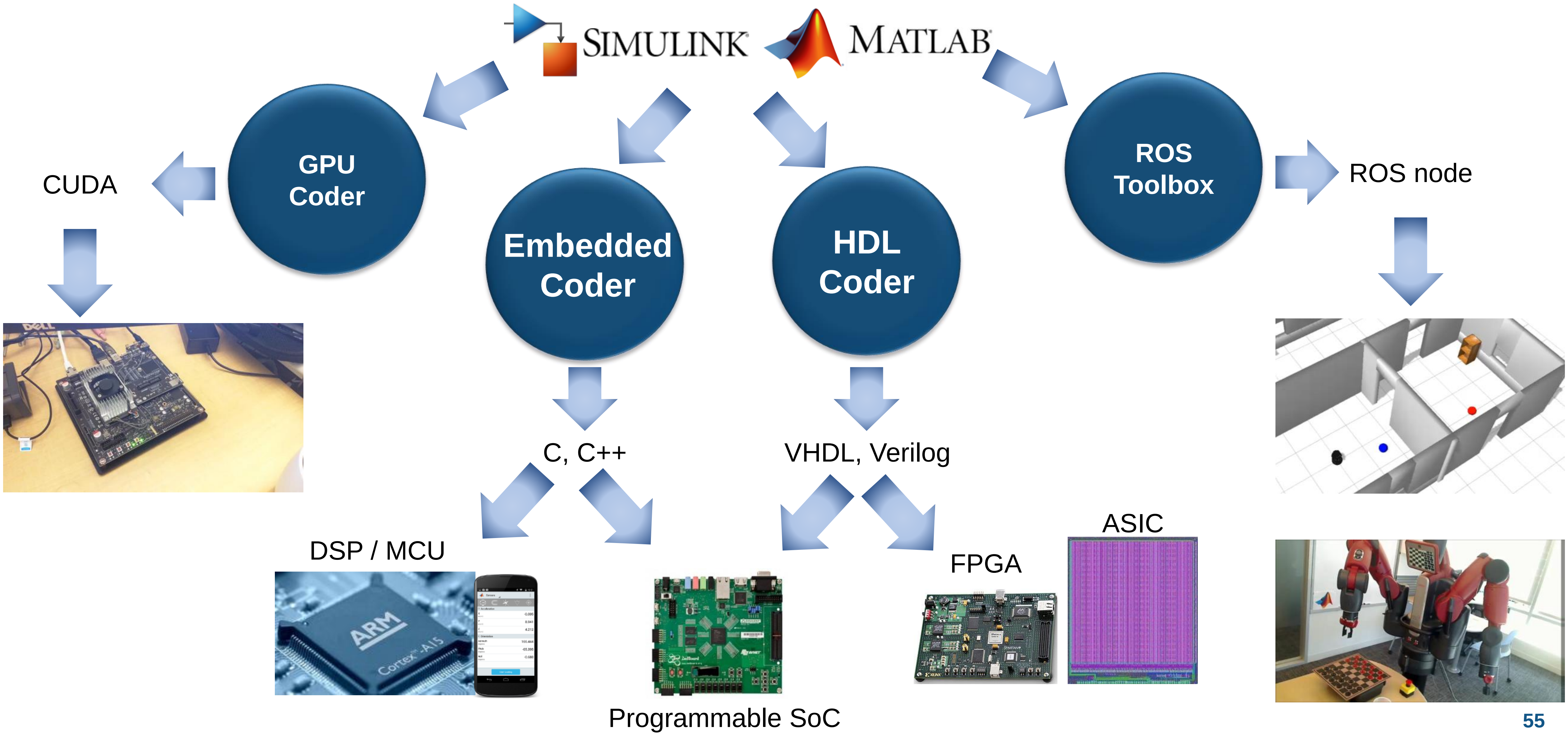
Testing

- MATLAB Simulink
- External simulator
- Automating verification
- Certification

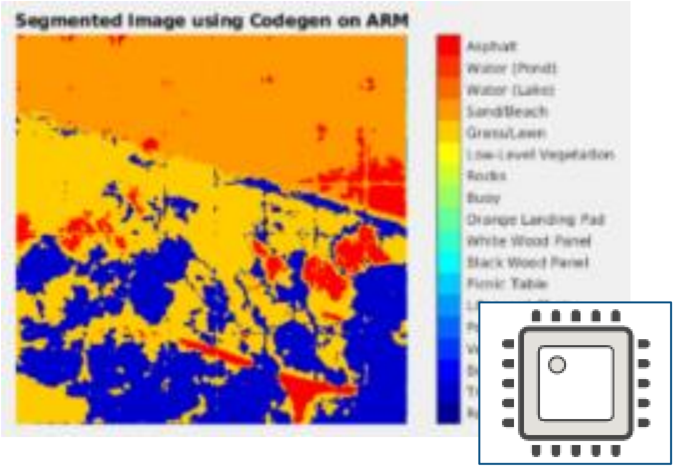
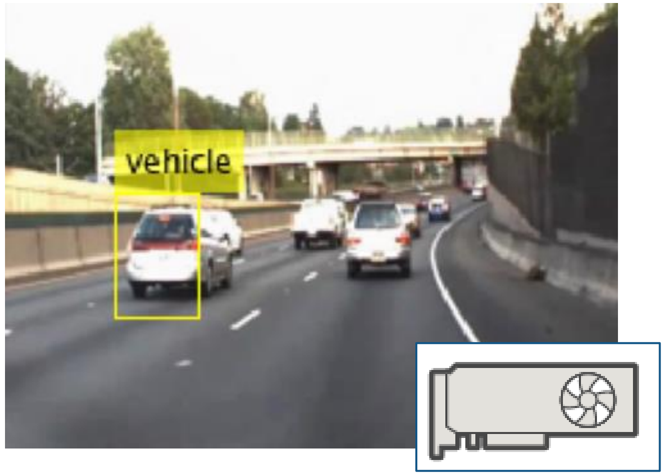
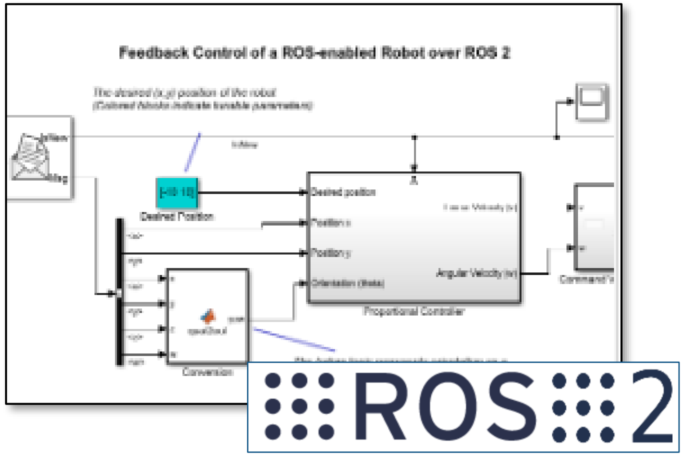
Deployment

- ROS/ROS2
- MCU DSP
- SoC
- FPGA ASIC
- GPU

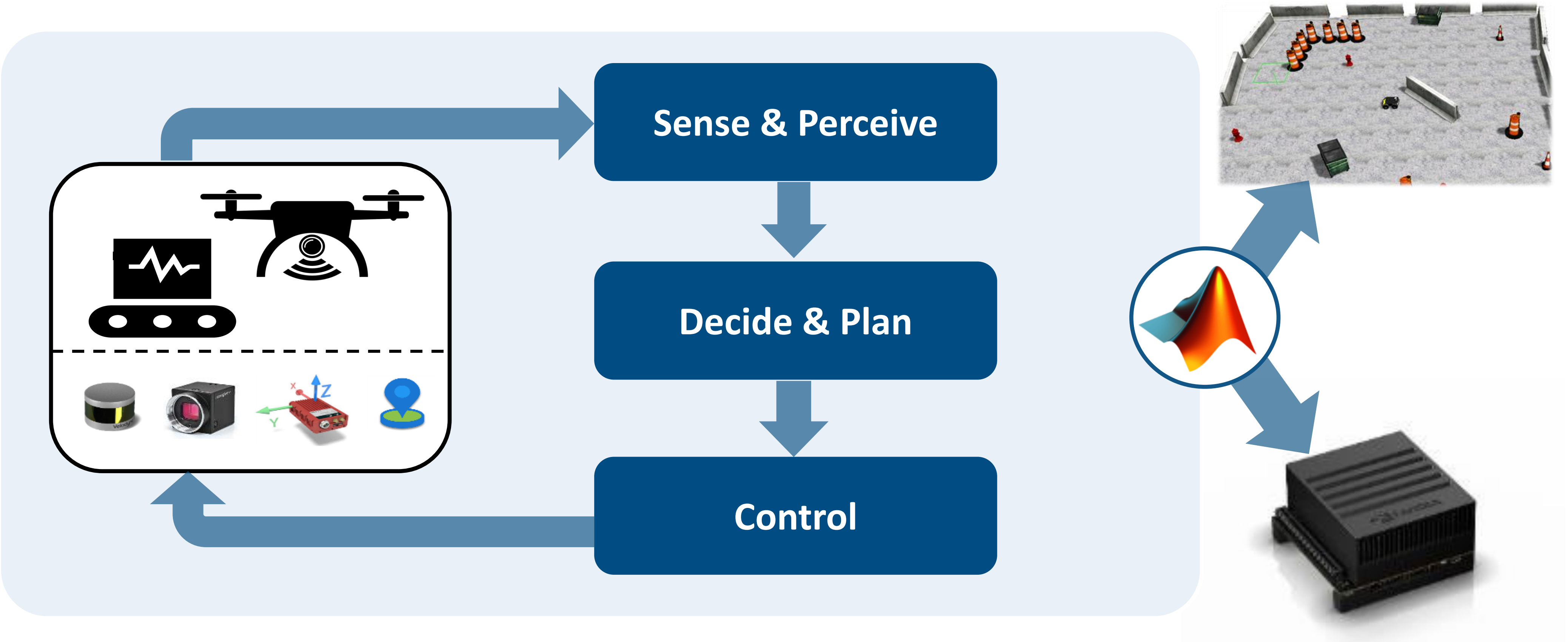
Implement and Prototype Algorithms in Hardware



Automatic Code Generation and Deployment

ARM	NVIDIA GPU	ROS node generation
		
[Code Generation for Semantic Segmentation Application on ARM Neon]()	[Code Generation for Object Detection by Using Single Shot Multibox Detector]()	[Generate a Standalone ROS 2 Node from Simulink®]()
Deep Learning Toolbox	*Deep Learning Toolbox*	*ROS Toolbox*
MATLAB Coder®	*GPU Coder*	*Embedded Coder*

MATLAB and Simulink for Autonomous Robotics Development

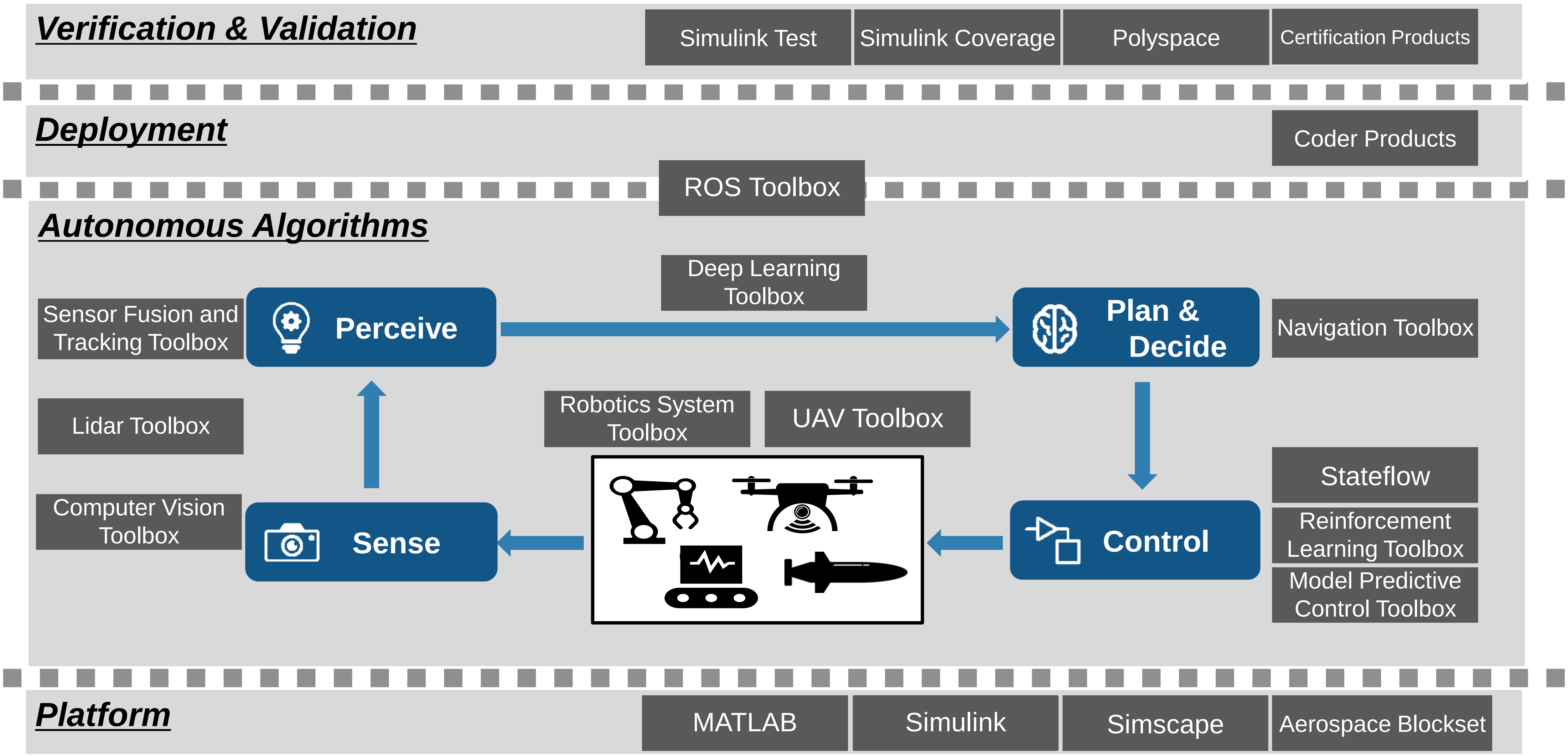


Model and simulate robots and sensor

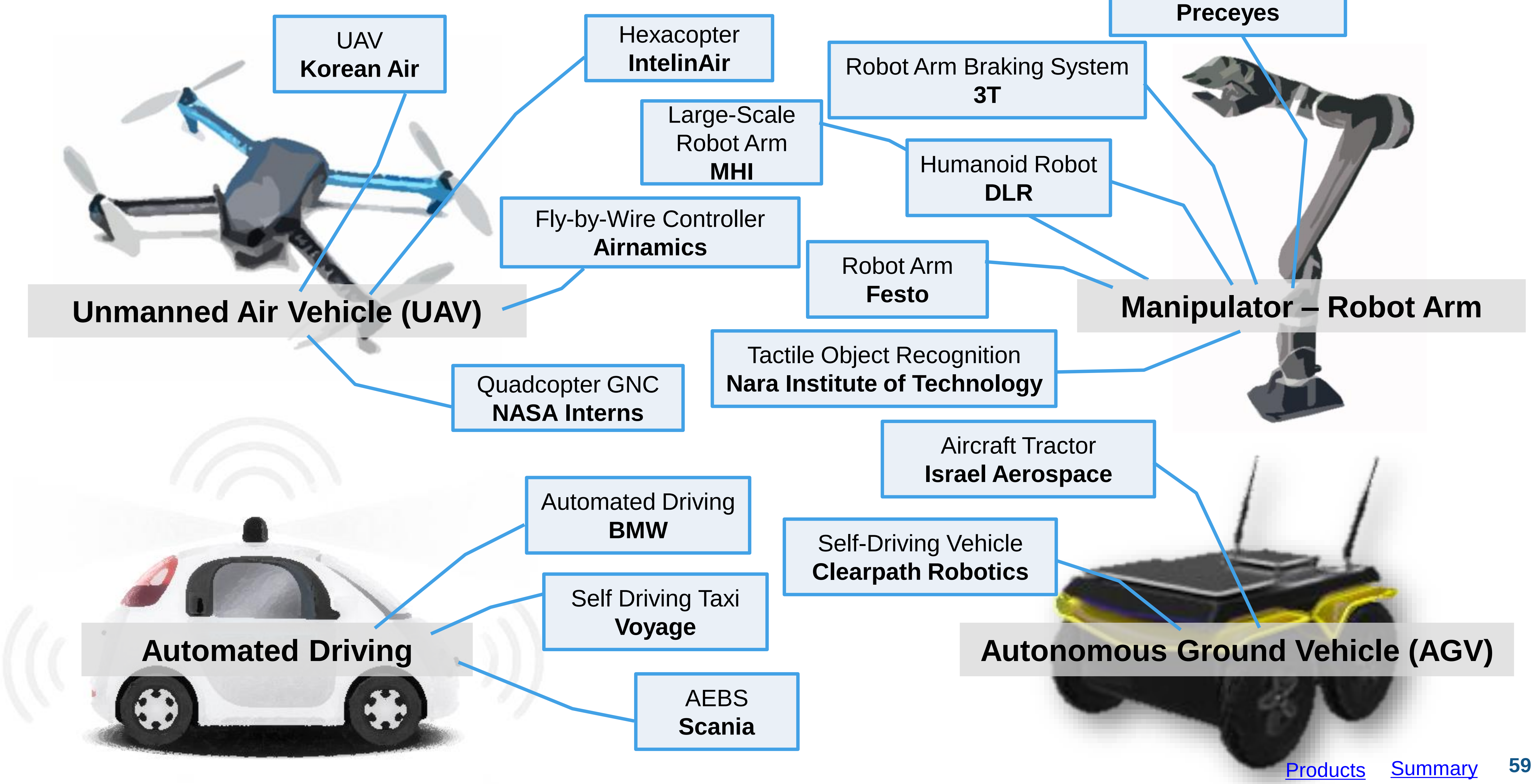
Design and evaluate autonomous algorithms

Test and deploy robotics applications

Model-based design for developing autonomous UAV



User Stories: Robotics and Autonomous Systems

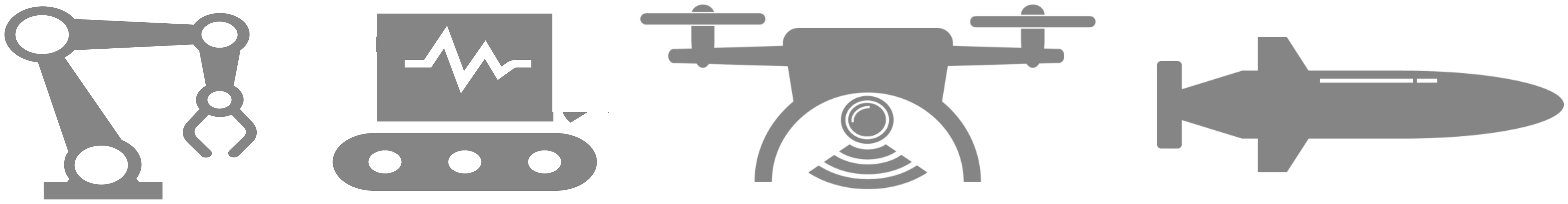


Takeaways

1. Autonomous robotics development workflows with MATLAB and Simulink

2. Integrate platforms and autonomous algorithms for closed-loop simulations with sensor models

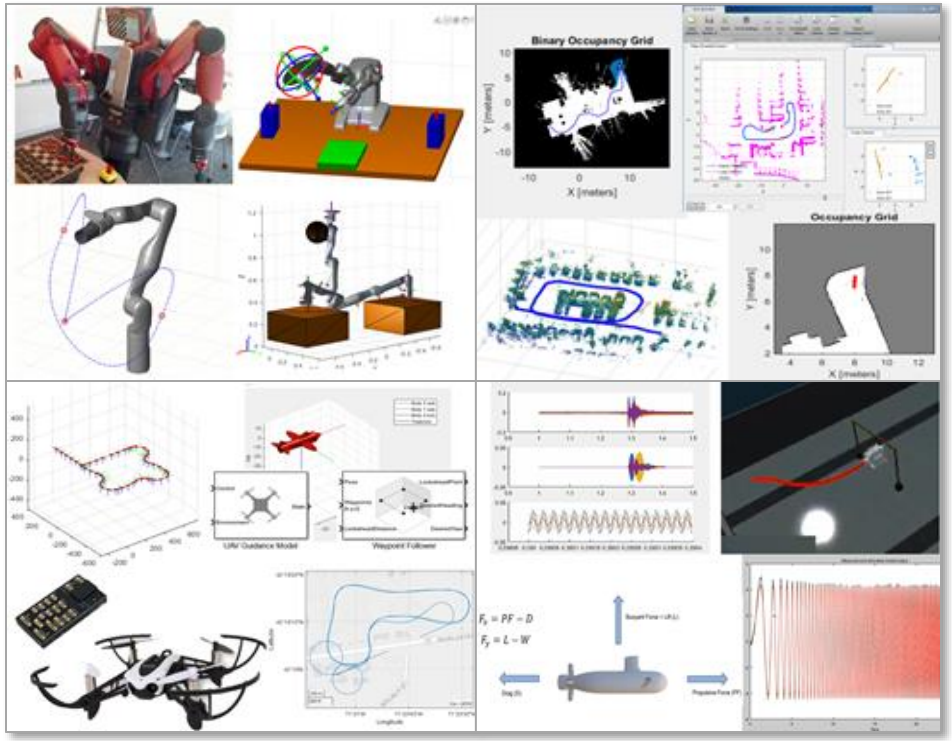
3. Streamline processes from prototyping to production



Next Step: Resources Offer

Email us or indicate via polling if you would like access to these practical resources you can use in your projects

- Free MATLAB trial for Robotics
- MATLAB & Simulink Robotics Github
- Example Files
- Video Series: Autonomous Navigation
- Video: Unmanned Aerial Vehicles using MATLAB and Simulink



Contact Us

MarketingAU@mathworks.com.au

Accelerating the pace of engineering and science