Applying AI to Enable Autonomy in Robotics Using MATLAB

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MathWorks’ DCRG project
User Study - roboticists interested in AI to learn how they are using it

Where is AI used in robotics?

- Perception
- Planning
- Control
- Others

What challenges have engineers encountered?

- Getting real data
- Labelling
- AI modelling and simulation tools
- AI in production
- AI in repair
- IP and model sharing
- Delay in approval, testing, prototyping, production
Commercial robotics customers: *Where is AI being used in Robotics?*

- Perception
- Planning
- Control
- others
Commercial robotics customers are using AI more for *Perception* than elsewhere
Safety, robustness, and certifications matter for production. Traditional algorithms have an advantage over AI in this regard.

“We want to limit whatever the neural net – or even (for) teleop.... whatever action is commanded there. We want to make sure that it[Robot]'s not stupid. Or even if it’s stupid, we want to make sure it’s not dangerous.”

(MathWorks Customer)
UX researched roboticists interested in AI to learn how they are using it

60 data sources mentioning AI and Robotics (Commercial and Gov only)

Where is AI used in robotics?

- Perception
- Planning
- Control
- others

What challenges have engineers encountered?

- Getting clean data
- Labeling
- AI modeling and simulation tools
- AI in product
- AI in production
- Implementation
- Deployment, Testing, Production, Con subjected
What pains and challenges have engineers encountered?
What **pains and challenges** have engineers encountered?

- **Data**
  - Not enough data
  - Data complexity

- **AI Model**
  - Incomplete AI modeling tools
  - Can’t integrate with other systems

- **AI Expert**
  - No data scientists
  - No AI expertise

- **Business**
  - Poor ROI
  - Production concerns
Autonomous system design workflow

Autonomous algorithms:

- **Perceive**
- **Plan**
- **Control**
- **Deploy**
- **Platform**

System Modeling
Autonomous system design workflow

1. Perception
   - Perceive

2. System Modeling
   - Plan
   - Control

3. Deployment
   - Deploy

4. Platform
   - Platform
Developing pick & place application using cobot
How to get data for training?

- Synthetic data generation with simulator
- Data acquisition with hardware
Generate synthetic data to improve your datasets

- **Semantic Segmentation from Unreal for UAV**
  - UAV Toolbox
  - Simulink

- **Lidar Sensor Model: Simulate lidar sensor and generate point cloud data**
  - Lidar Toolbox

- **Gazebo Co-simulation with a Pretrained Deep Learning Model to Detect Recyclable Parts**
  - Robotics System Toolbox
  - ROS Toolbox
Automated labeling apps save you weeks to months

- Synthetic data generation with CAD models
- Train object detector
- Correct wrong labels
- Automated labeling with actual images
Start with a complete set of algorithms and pre-built models

Object Detection with YOLOv4

Instance Segmentation with Mask R-CNN

Semantic Segmentation with U-Net

Deep Learning Toolbox
Image Processing Toolbox
Computer Vision Toolbox
Access AI models from the broader AI community

- TensorFlow
- TensorFlow Lite
- Caffe
- TensorFlow Importer
- PyTorch Importer
- PyTorch
- ONNX
- Other Frameworks
- Deep Learning Toolbox
- Other

Deep Learning Toolbox
Autonomous system design workflow
Pre-built AI model is ready to use for perception in UAV application

1. Obtain drone captures images and convert into orthophotos
2. Pass through semantic segmentation network
3. Combine output labels to get final 2D map

Deep Learning Toolbox
UAV Toolbox
Computer Vision Toolbox
Navigation Toolbox
AI model for motion planning in UAV application

Define takeoff and landing locations

Exploit AI sampler to inform sample-based path planning

Path planned in a feasible time

Deep Learning Toolbox
Navigation Toolbox
Autonomous system design workflow

- Perceive
- Plan
- Deploy
- Platform
- System Modeling
Obstacle avoidance with reinforcement learning

Define lidar sensor model → Define RL agent → Training in simple env. → Scale up to realistic env. → Validation

Training within a simple map

After training within a simple map

Visualized in a realistic environment

Reinforcement Learning Toolbox, Robotics System Toolbox, Automated Driving Toolbox
Autonomous system design workflow

Simulation and Testing in System-Level

Perceive → Plan → Control

Deploy → Platform

System Modeling
Use AI within entire systems

Robot Platform (Simulation or Real HW)

Platform

Robot Dynamics

Sensor Models

Sensing (Simulation or Real HW)

Perceive

Plan

Control

Platform
Validation of AI models in end-to-end simulation
Easy to change the robot hardware

Robotics System Toolbox Support Package for Universal Robots UR Series Manipulators allows user to connect to and control Universal Robots Cobots over ROS.
Autonomous system design workflow

- Perceive
- Plan
- Control
- Deploy
- Platform
- System Modeling
Deploy to target with zero coding errors

Code Generation

- CPU
  - Any CPU
  - No Library needed

- GPU
  - oneDNN
  - Library

- µC
  - ARM Compute
  - Library

- FPGA
  - NXP
  - Linux
  - Instrument
Deploy to Jetson device as CUDA ROS node
ASTRI Accelerates Development of Robotic Manipulation System Using MBSE Digital Twin

“The integration of MATLAB, Simulink, and Deep Learning Toolbox gave us the confidence to move forward with the MBSE digital twin project.”

– Dr. T. John Koo, ASTRI

**Challenge**
Reduce development time, manual processes, and costs

**Solution**
Adopt model-based systems engineering and develop a digital twin with MATLAB, Simulink, and Deep Learning Toolbox

**Results**
- Integration time reduced by 40%
- Issues resolved in the design stage
- Teams worked collaboratively
Autonomous system design workflow
Why MATLAB for AI in Robotics?

- Synthetic Training Data Generation
- Object Identification & Mapping
- Motion Planning & Controls
- System Level Testing & Deployment
Challenges using AI for your robots:

- **Model Complexity**
  - Object Detection with YOLOv4
  - Instance Segmentation with Mask R-CNN
  - Semantic Segmentation with U-Net

- **Data Complexity**
  - Simulation
  - Image Labeler
  - Video Labeler
  - Lidar Labeler
  - Signal Labeler

- **AI Expertise**

Solutions with MATLAB

- Pre-trained models
- System-level Simulation, testing, & Deployment

Interoperability with other OS AI models:

- Keras
- Caffe
- PyTorch
- Caffe2
- maxnet
- Chainer

Robotics Expertise vs. AI
Challenges using AI for your robots:

- **Data Complexity**
- **Model Complexity**
- **AI Expertise**

**Business**

- Pre-trained models
- System-level Simulation, testing, & Deployment

Interoperability with other OS AI models

Robotics Expertise vs. AI
Get Started with AI in MATLAB

**Onramp**

- Deep Learning Onramp
  - Get started quickly using deep learning methods to perform image recognition.
  - Details and launch

- Machine Learning Onramp
  - An interactive introduction to practical machine learning methods for classification problems.
  - Details and launch

- Reinforcement Learning Onramp
  - An interactive introduction to reinforcement learning methods for control problems.
  - Details and launch

**Videos**

- Deep Learning Tech Talk
  - Why choose deep learning?
  - MATLAB Tech Talks

- Reinforcement Learning Tech Talk
  - Overview for engineers!
  - MATLAB Tech Talks

**Webinars**

- AI for robotics
- AI for Simulink Users
- Deploy Deep Neural Networks