MATLAB EXPO 2018

Developing Algorithms for Robotics and Autonomous Systems

Dhirendra Singh
Abhishek Roy

Key Takeaway of this Talk

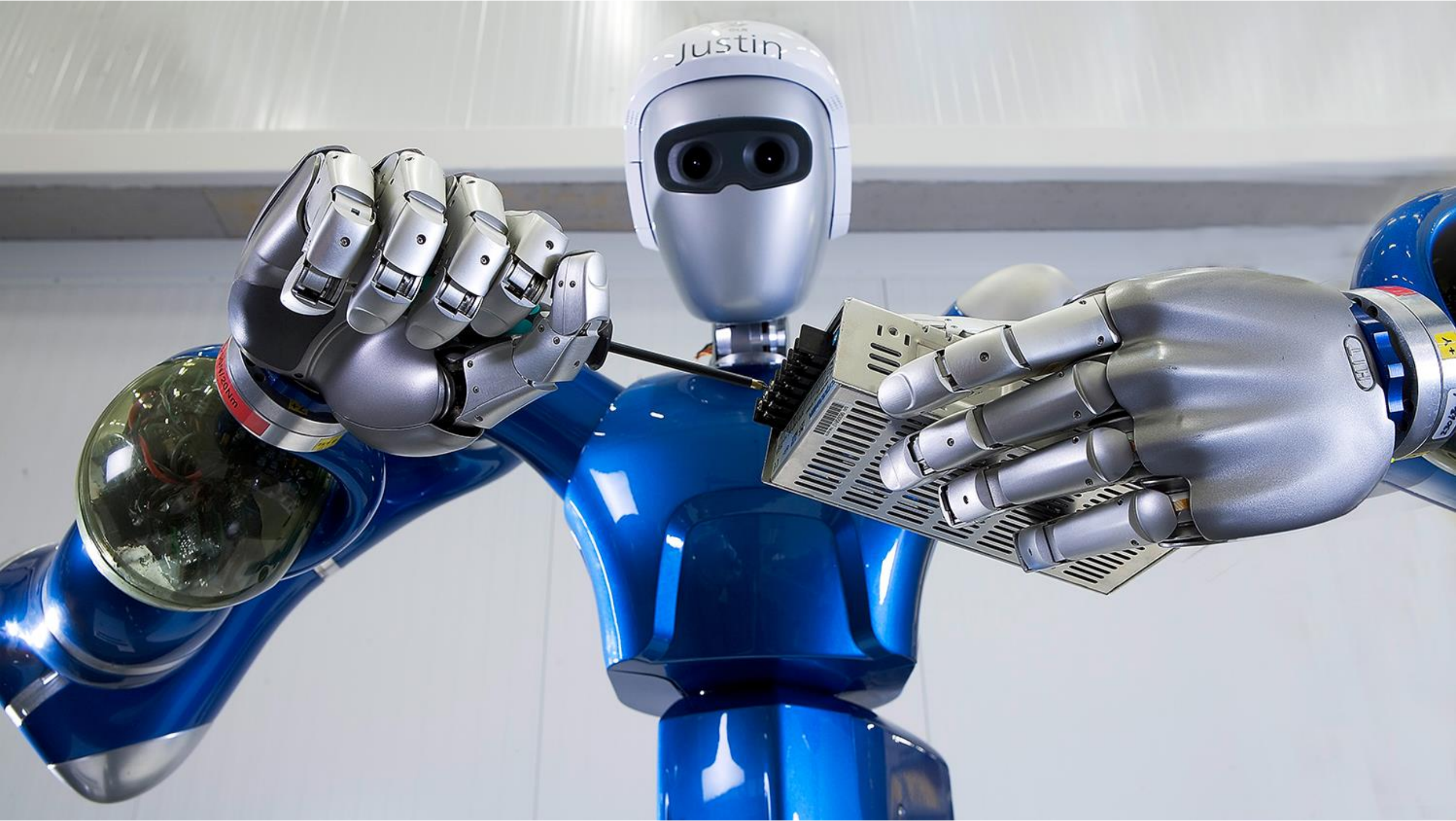
Success in developing an autonomous robotics system requires:

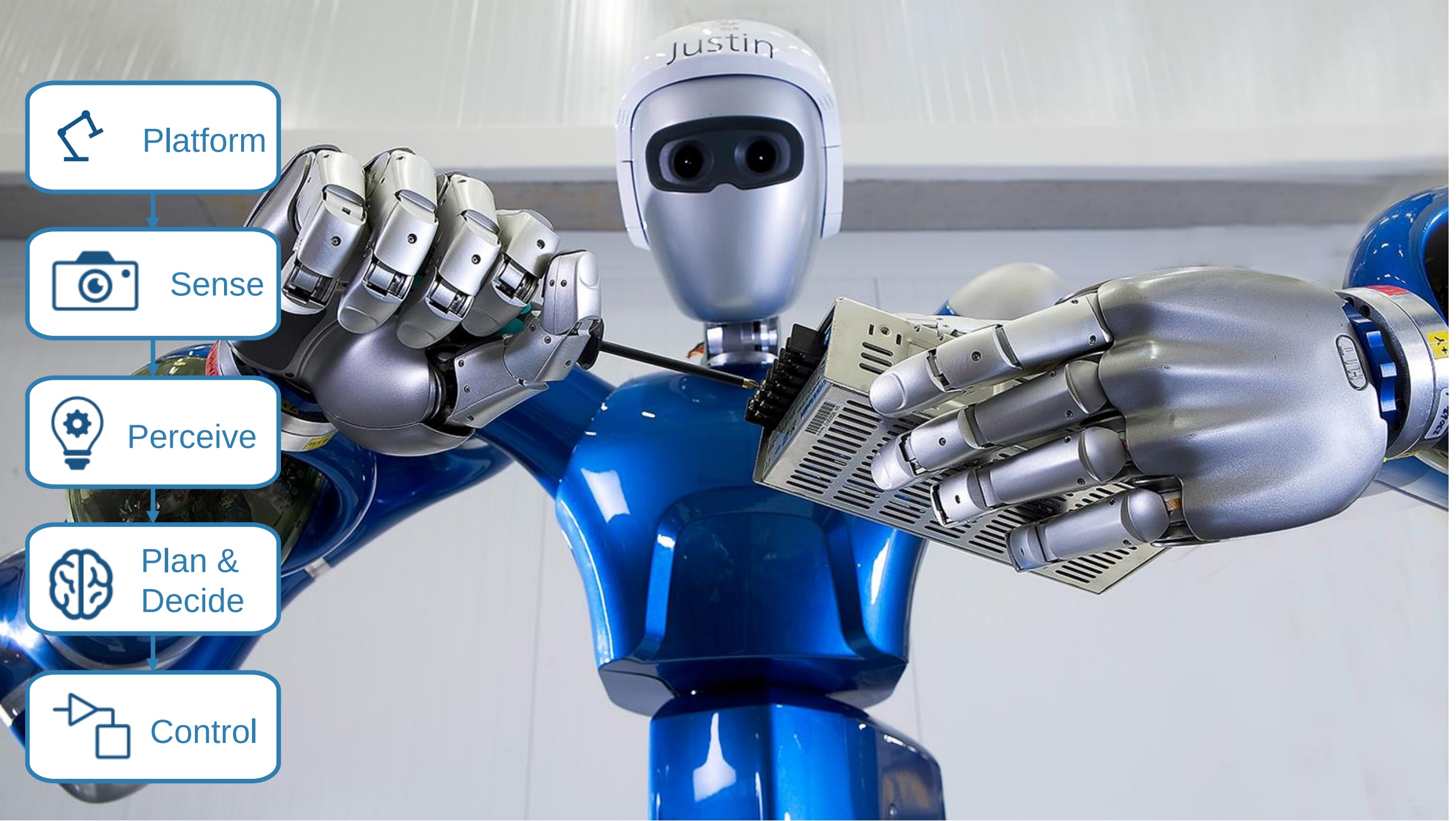
1. Multi-domain simulation
2. Trusted tools which make complex workflows easy and integrate with other tools
3. Model-based design

Challenges with Autonomous Robotics Systems

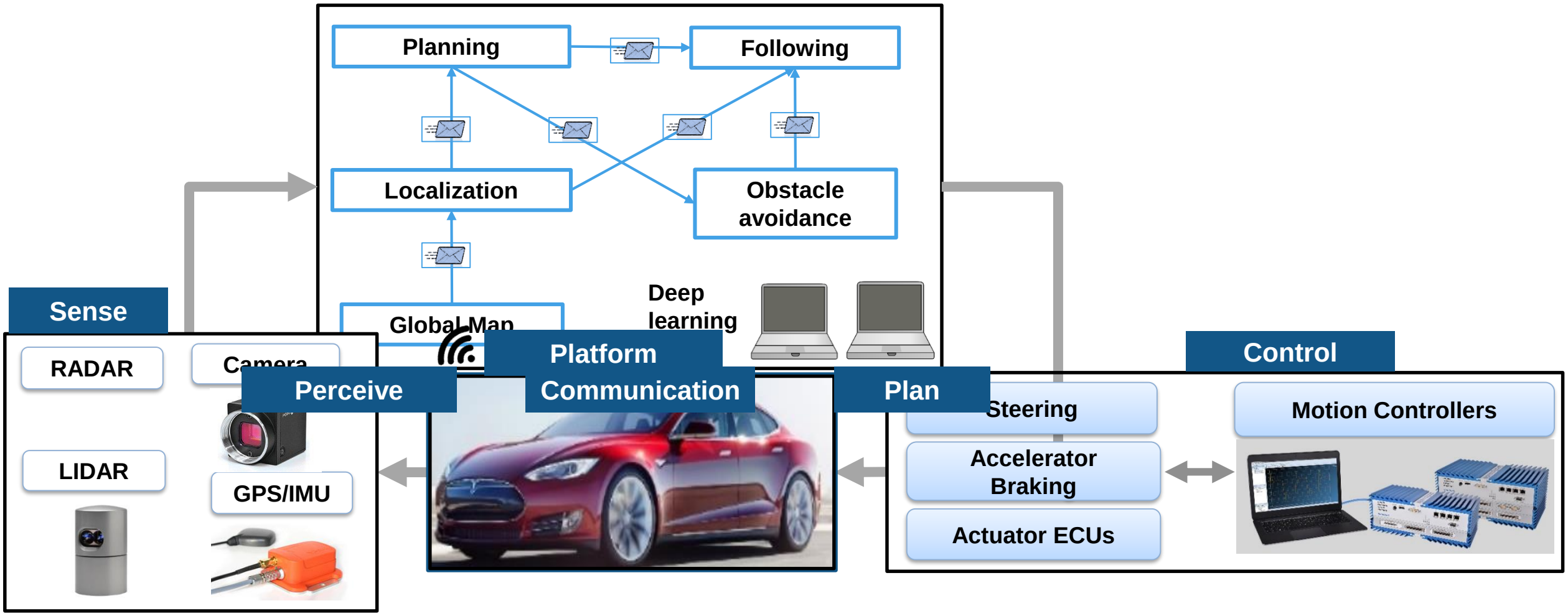
- Applying Multidomain Expertise
- Complexity of Algorithms
- End-to-End workflows
- Technical Depth and System Stability
- IP Protection

What does success look like?

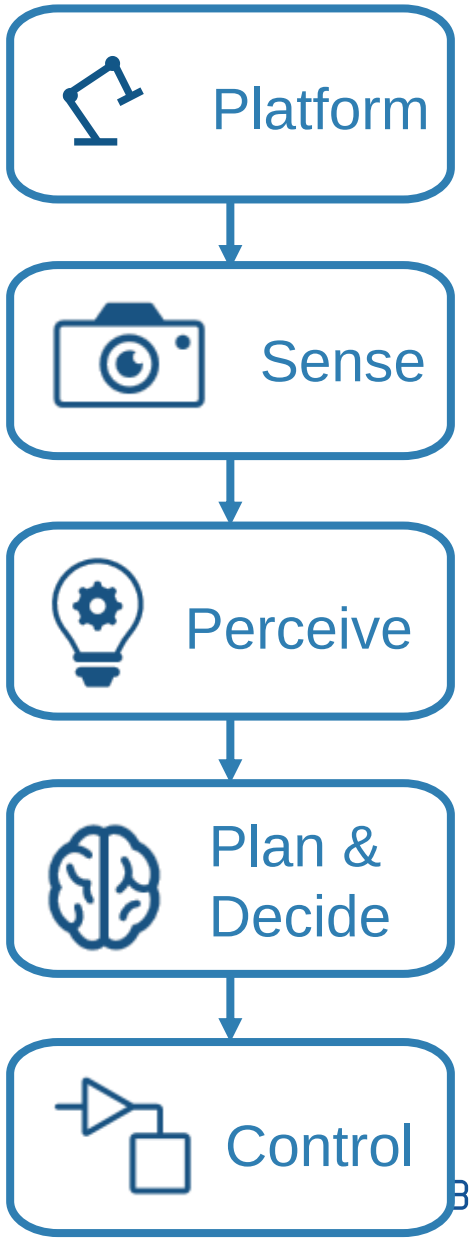

Justin

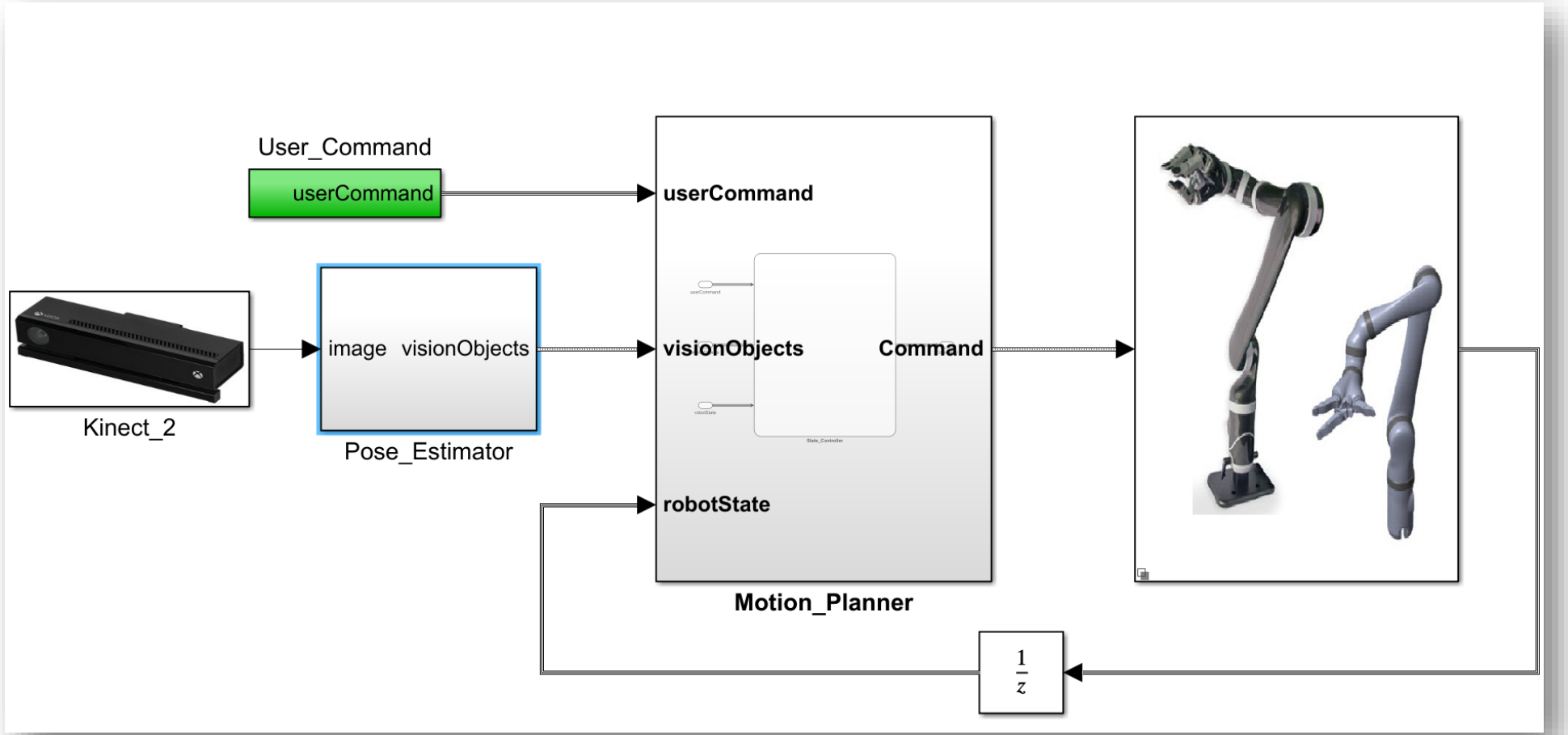

Justin
Platform
Sense
Perceive
Plan &
Decide
Control

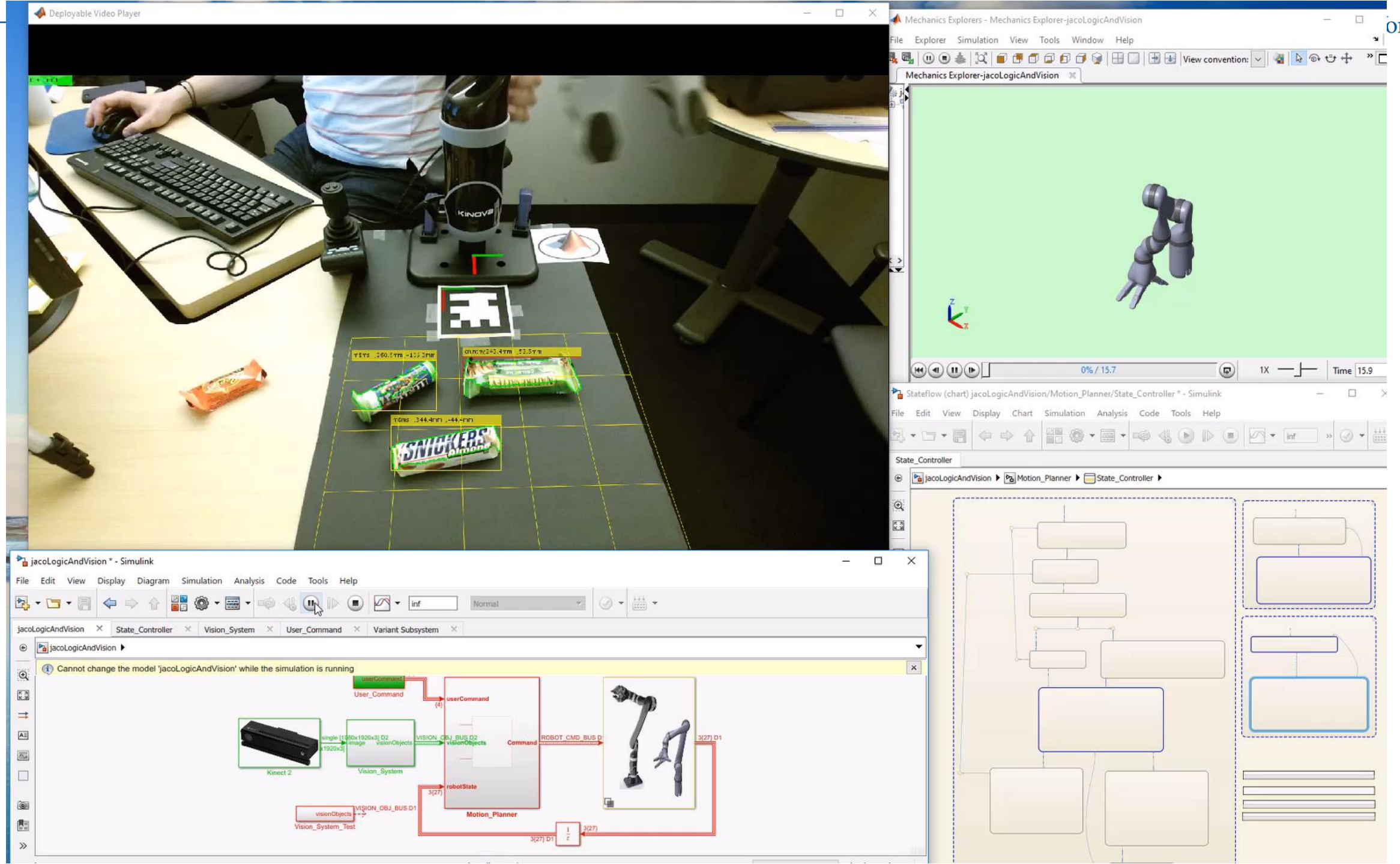
Another Example: Self-Driving Cars



Today: Design Pick and Place Application






Deployable Video Player
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File Explorer Simulation View Tools Window Help
Mechanics Explorer-jacoLogicAndVision
View convention:
0% / 15.7
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Stateflow (chart) jacoLogicAndVision/Motion_Planner/State_Controller * - Simulink
File Edit View Display Chart Simulation Analysis Code Tools Help
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jacoLogicAndVision
Motion_Planner
State_Controller
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jacoLogicAndVision
State_Controller
Vision_System
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VISION_OBJ_BUS.D2
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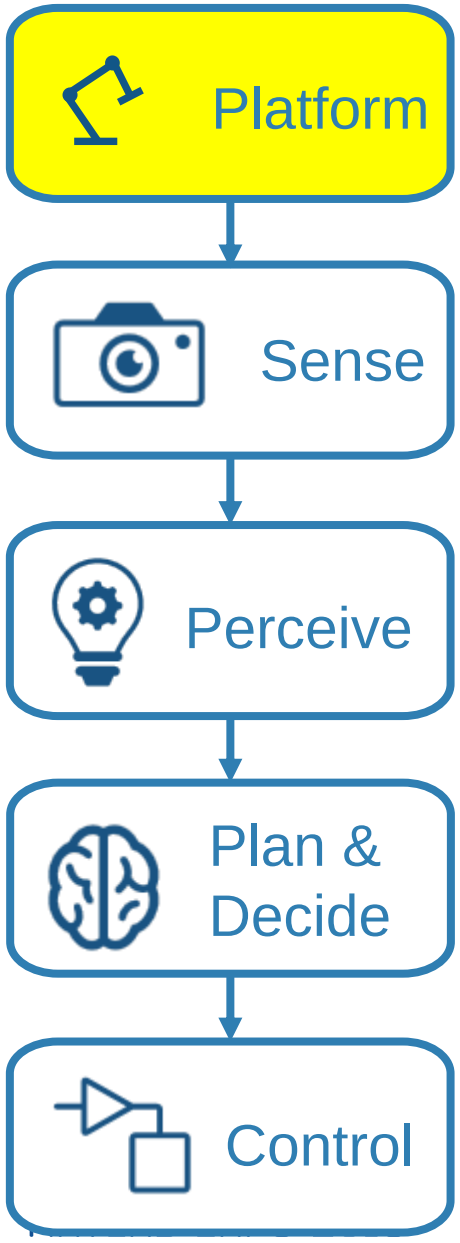
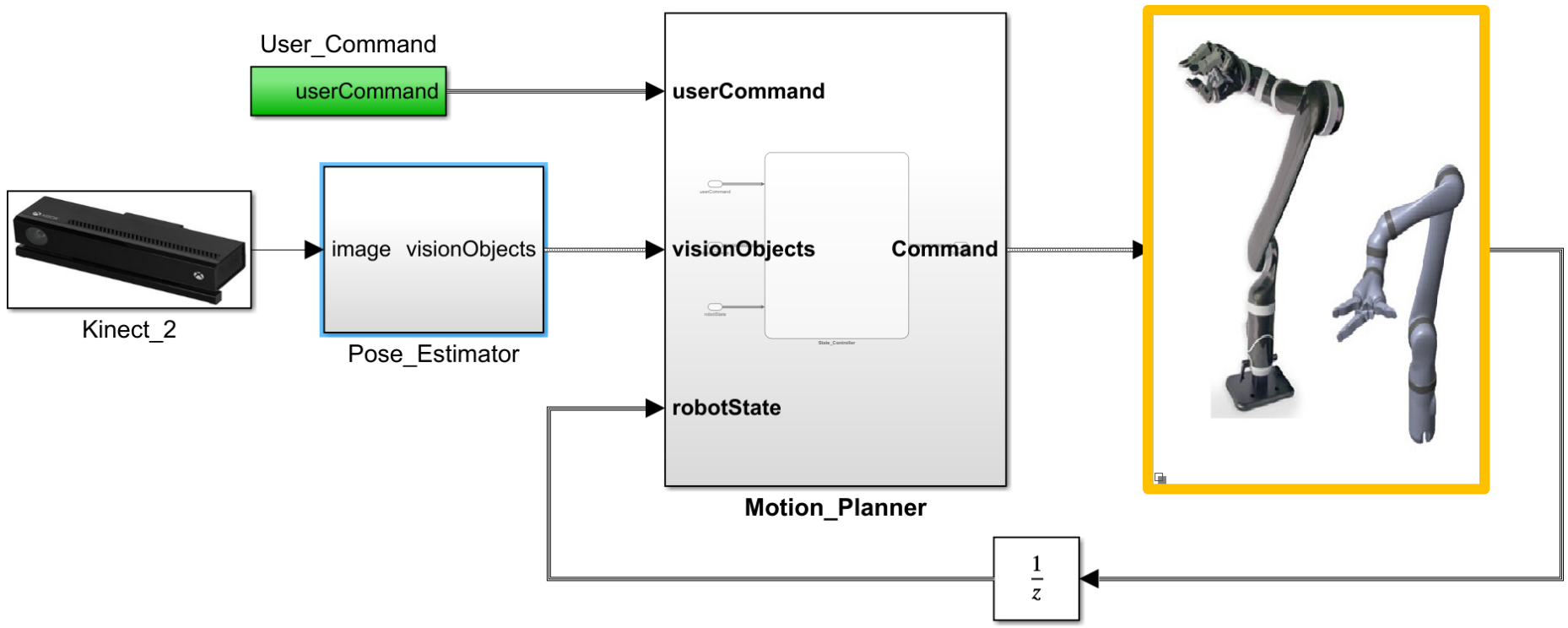
visionObjects
VISION_OBJ_BUS.D1
Vision_System_Test

Today: Design Pick and Place Application





Platform Design

How to create a model of my system that suits my needs?

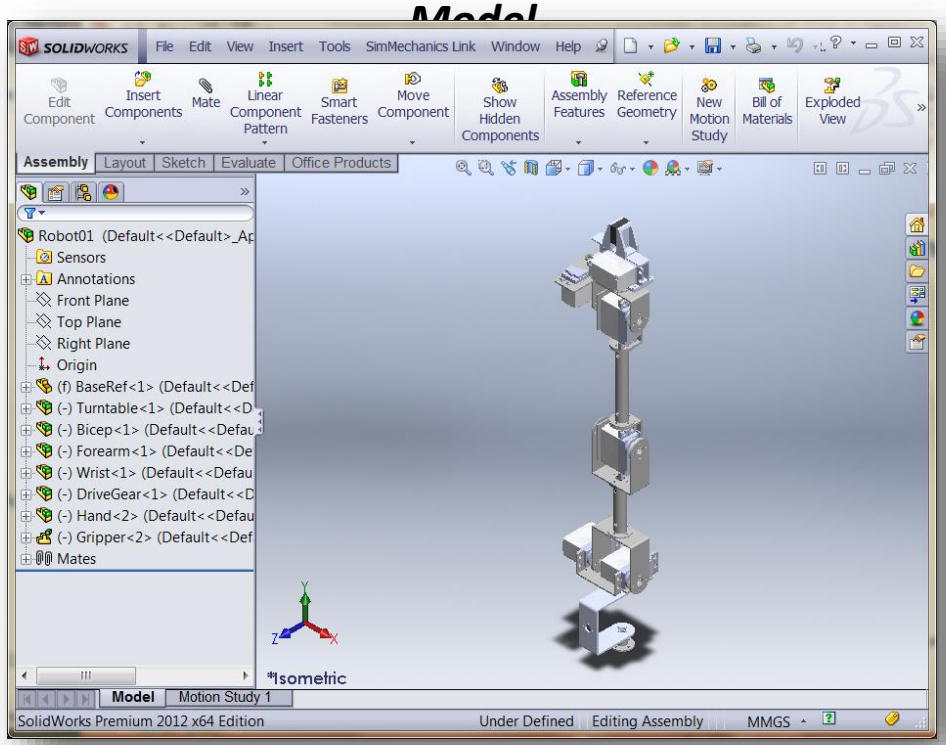
Mechanics

Actuators

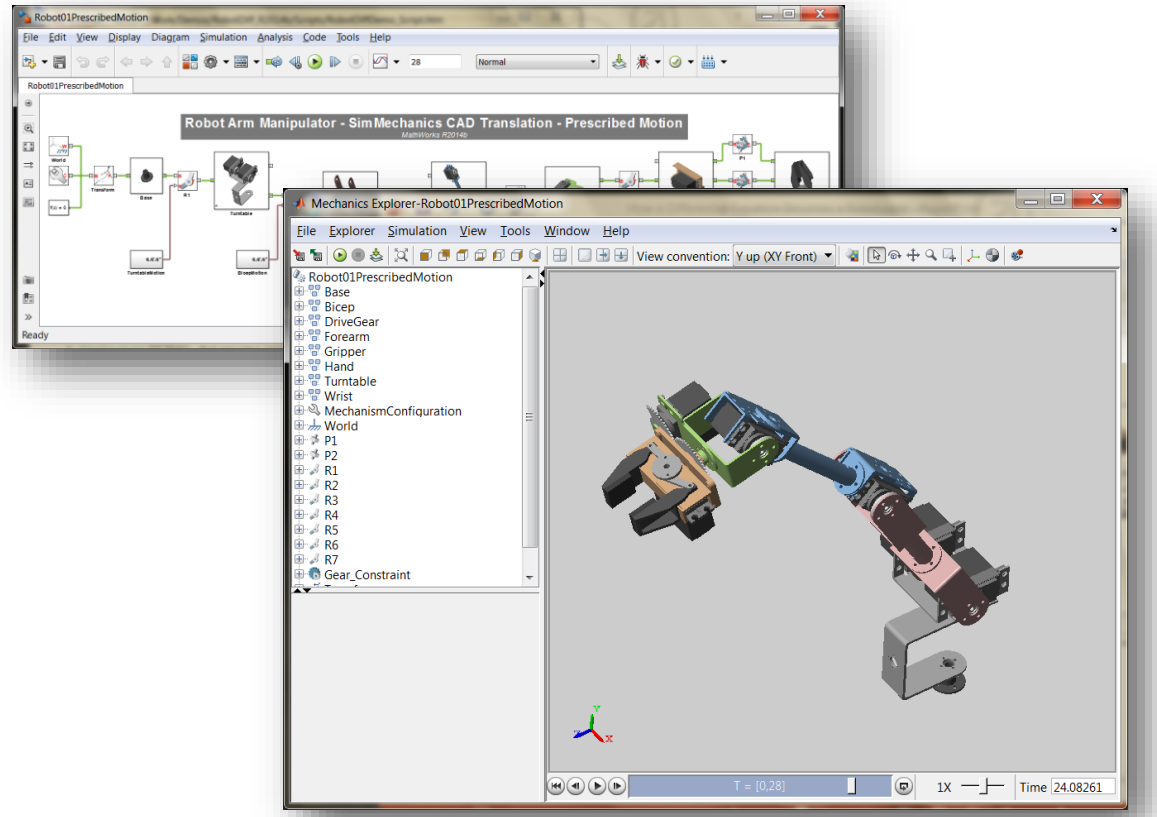
Environment

Mechanics: Import models from common CAD Tools

SolidWorks Model

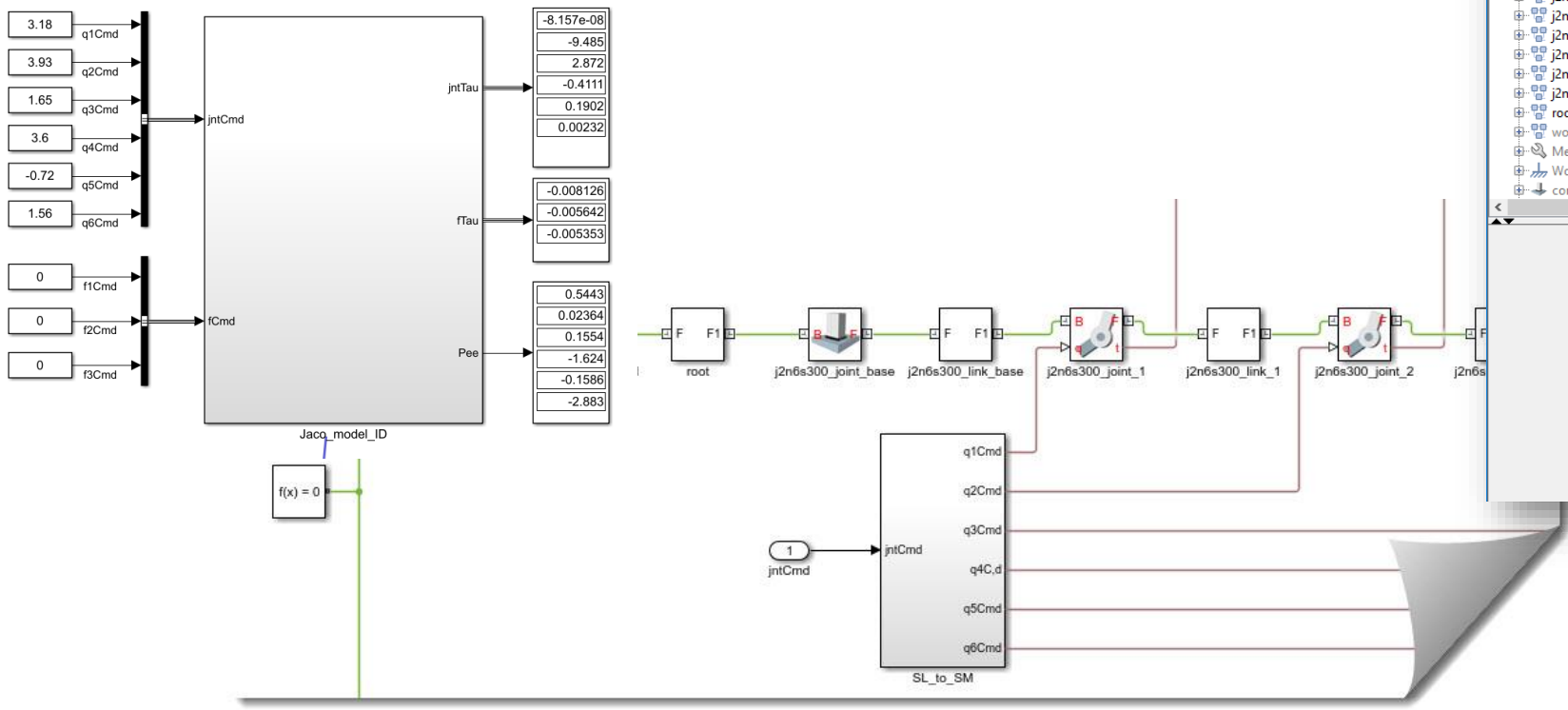


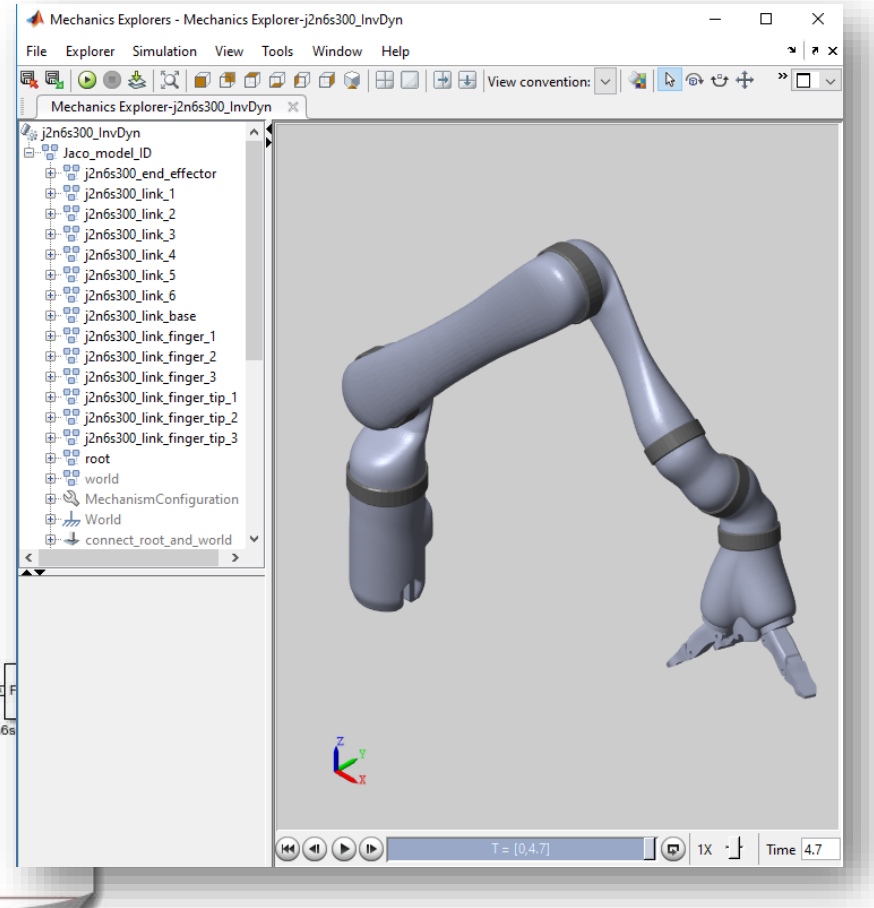
Simscape Multibody Model



Mechanics: One line import from URDF

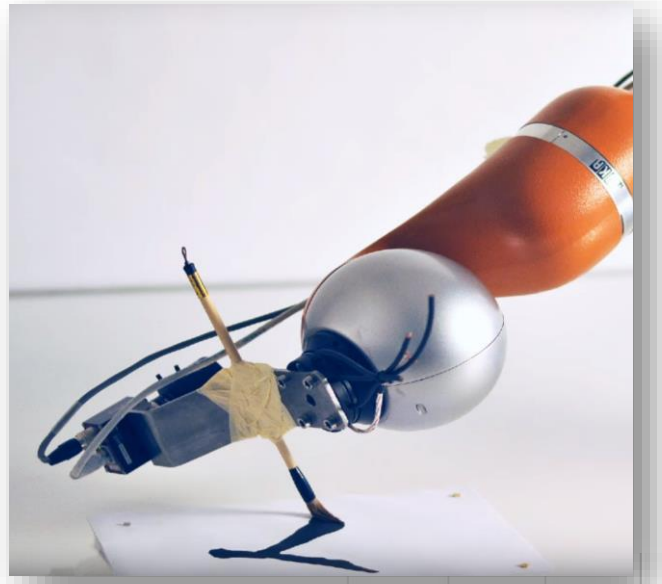
```
%% Import robot from URDF
smimport('j2n6s300_standalone_stl.urdf');
```





Demo

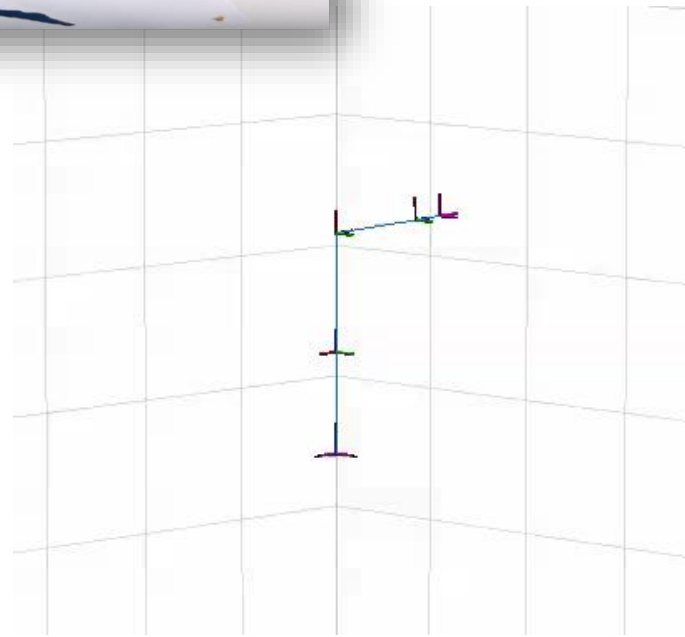
Rigid Body Tree Dynamics



R2017a

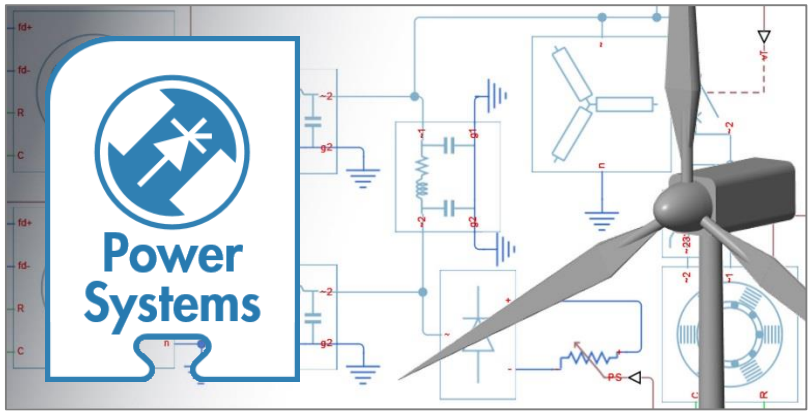
Compute rigid body tree dynamics quantities

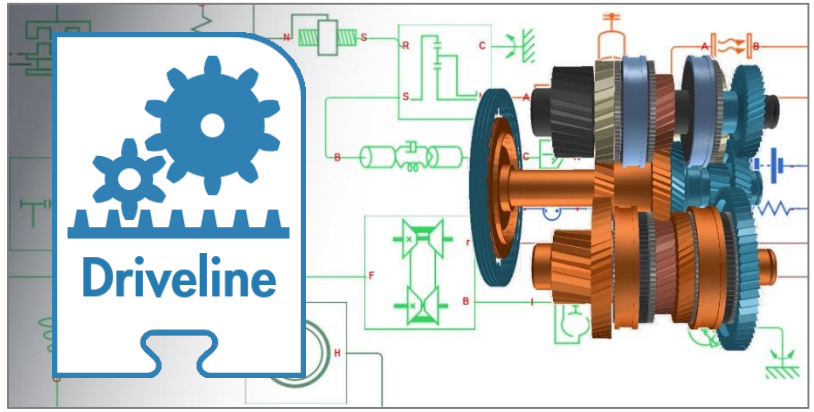
- Specify rigid body inertial properties
- Compute for the rigid body tree
  - Forward dynamics
  - Inverse dynamics
  - Mass matrix
  - Velocity product
  - Gravity torque
  - Center of mass position and Jacobian

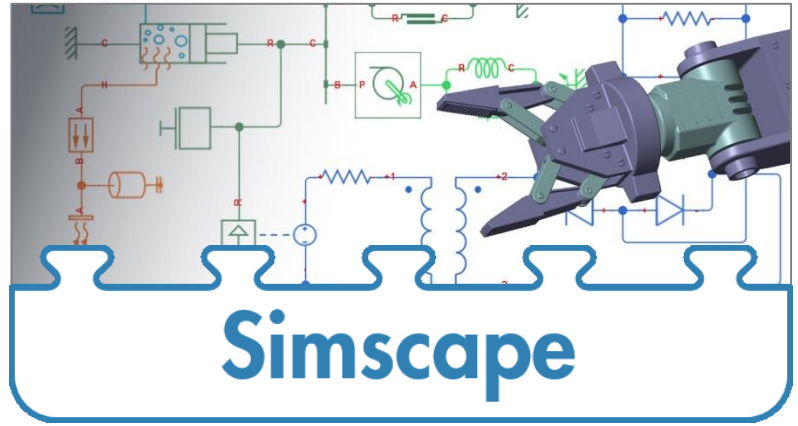


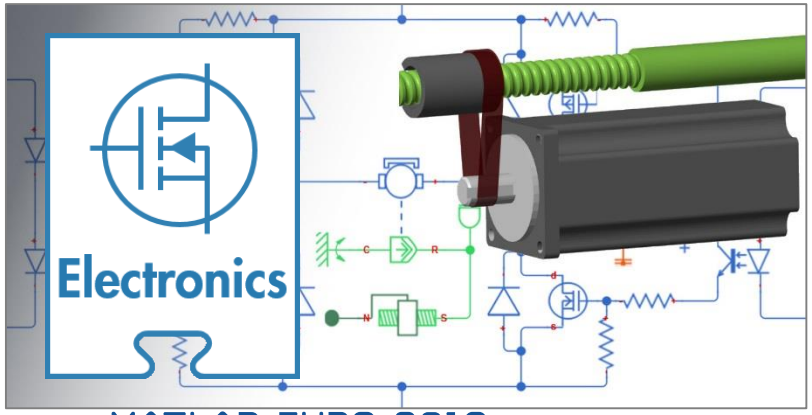
```
» load exampleRobots.mat
» lbr.DataFormat = 'column';
» q = lbr.randomConfiguration;
» tau = inverseDynamics(lbr, q);
```

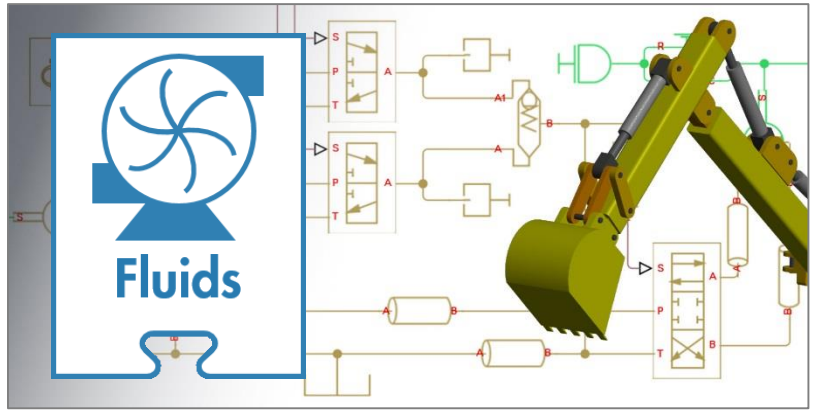
Actuators: Model other domains

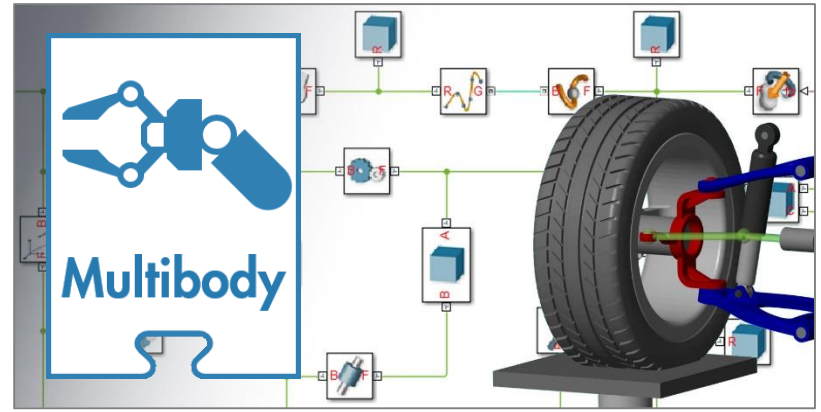




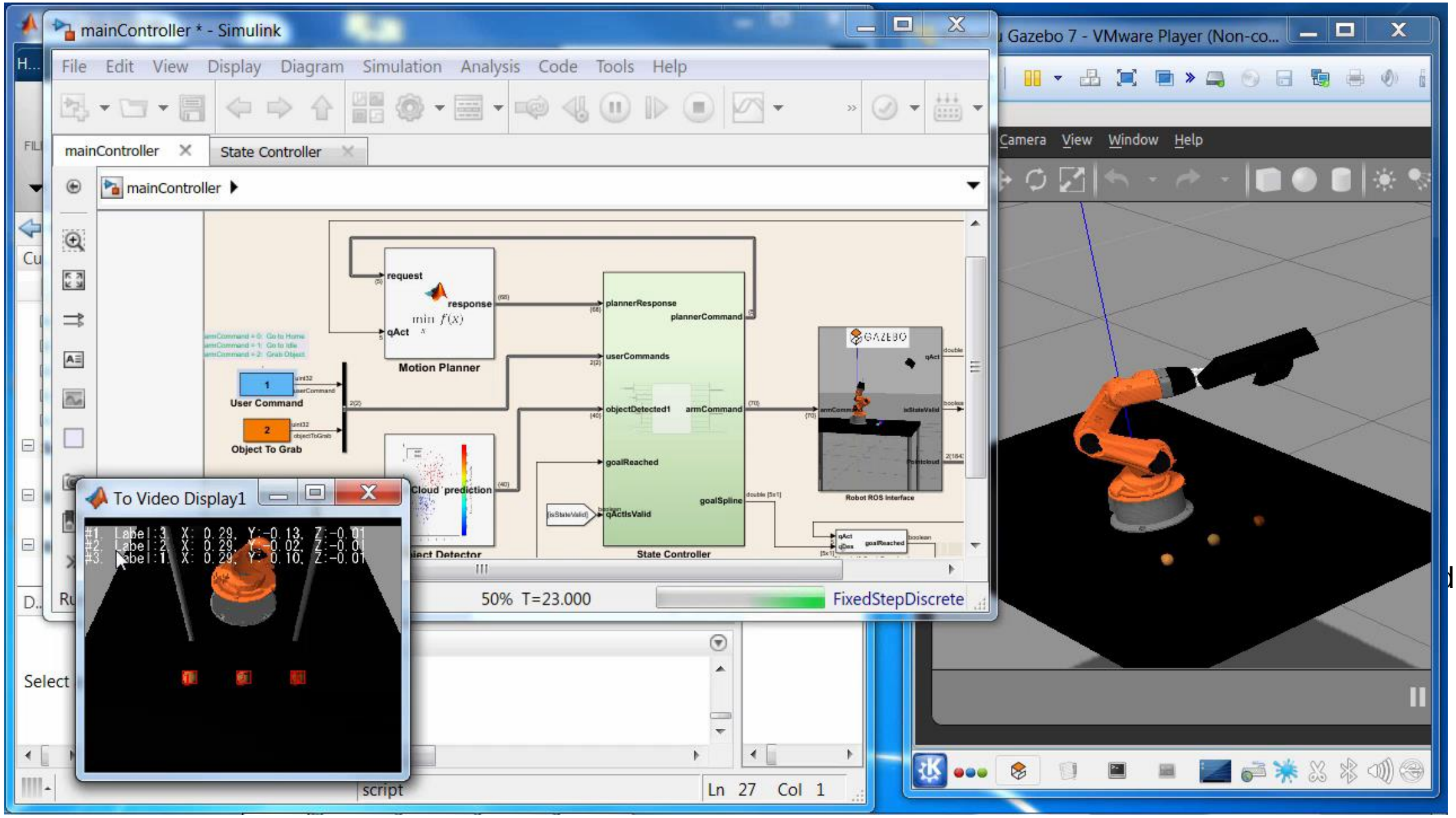




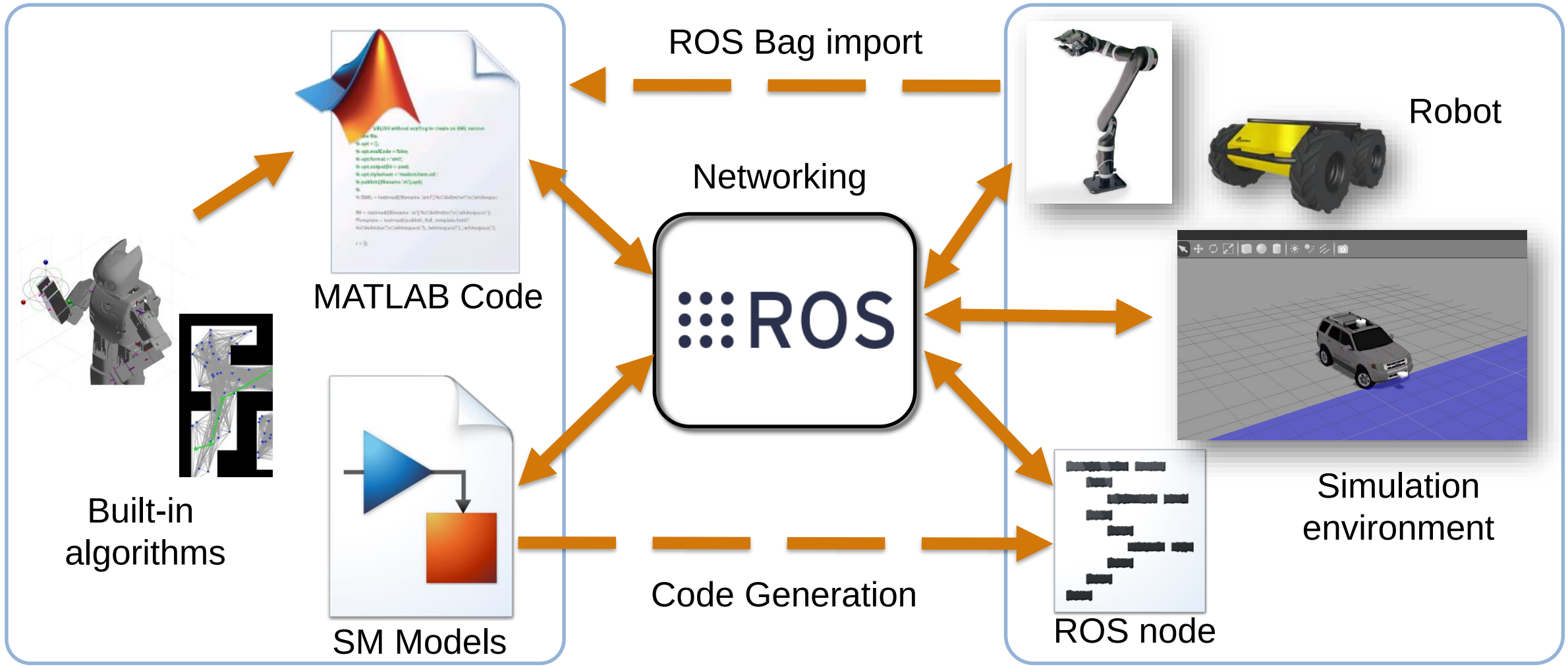




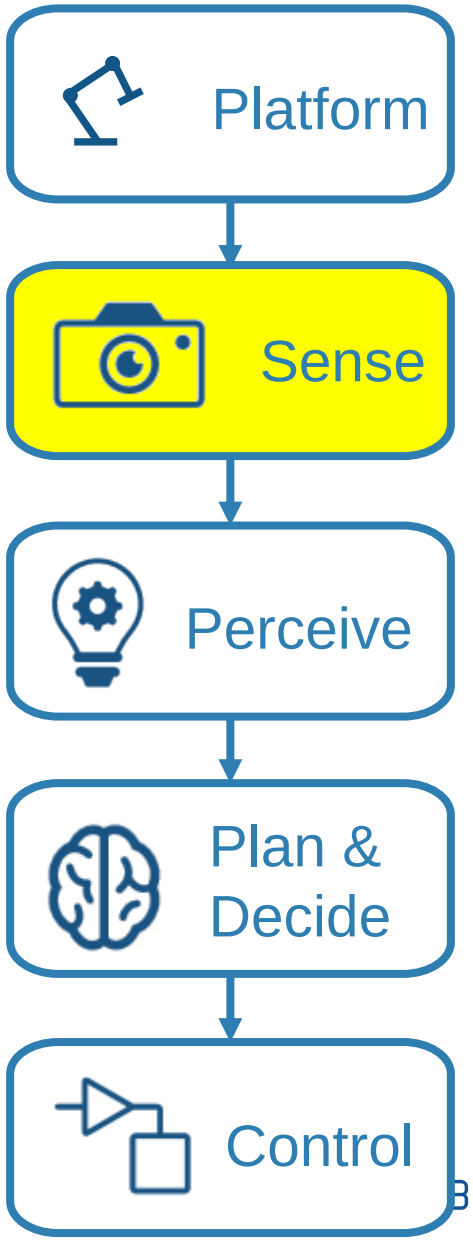
Environment: Connect to an external robotics simulator

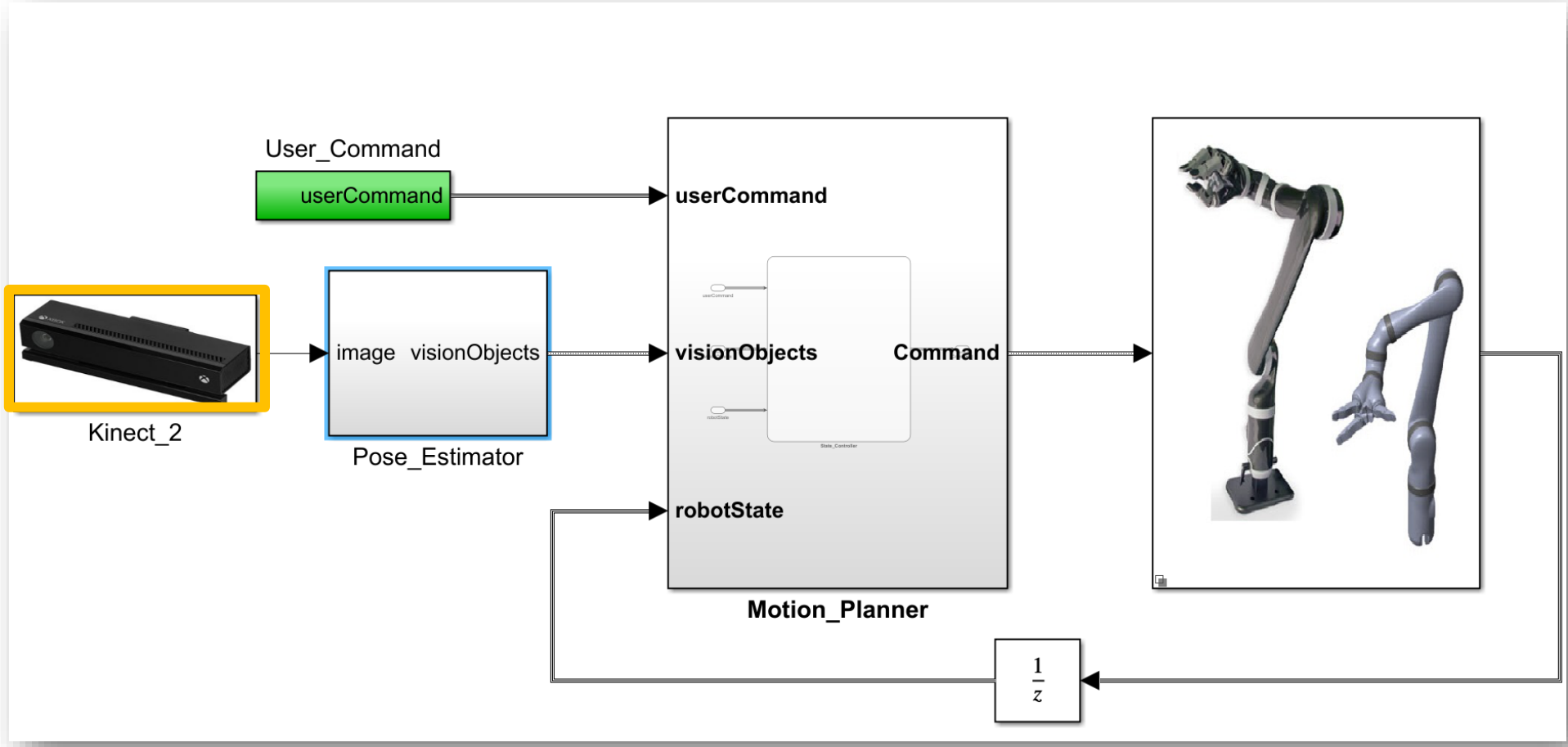


Environment: Connect MATLAB and Simulink with ROS



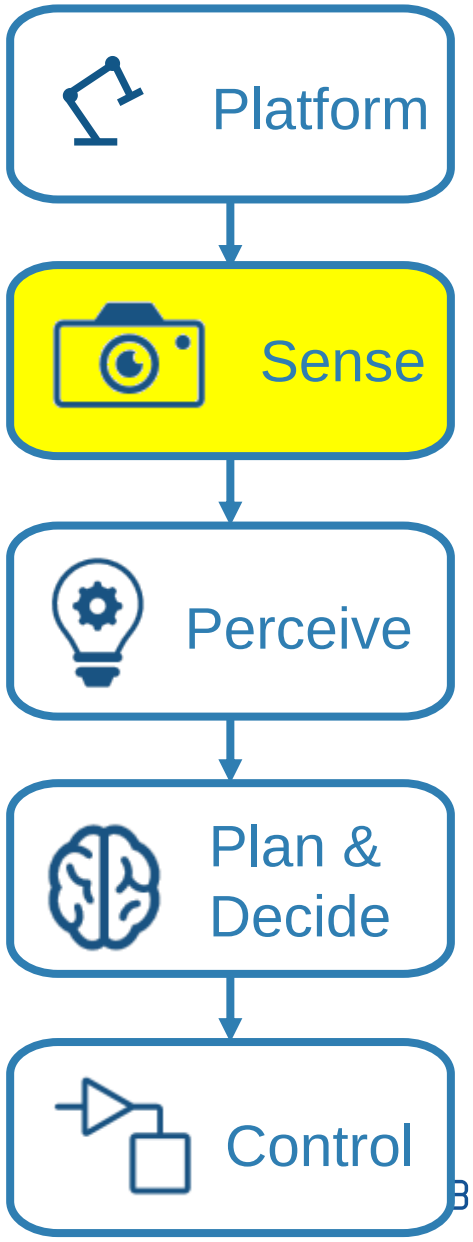
Design Pick and Place Application



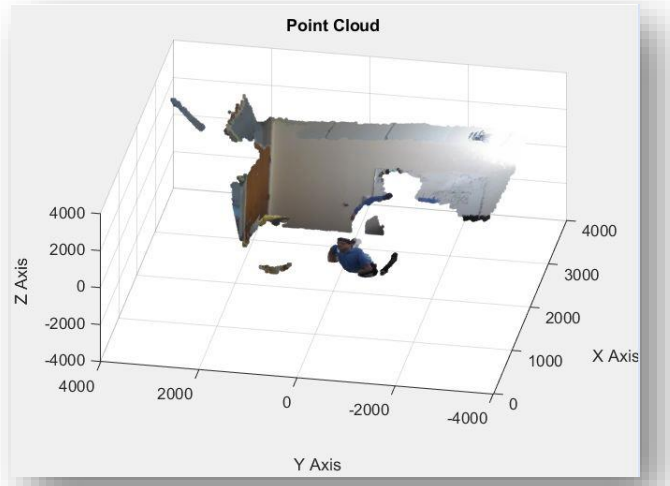


Demo

Design Pick and Place Application



- **Support for Common Sensors**
- **Image analysis**
- **Apps**
- **Image enhancement**
- **Visualizing Point Clouds**



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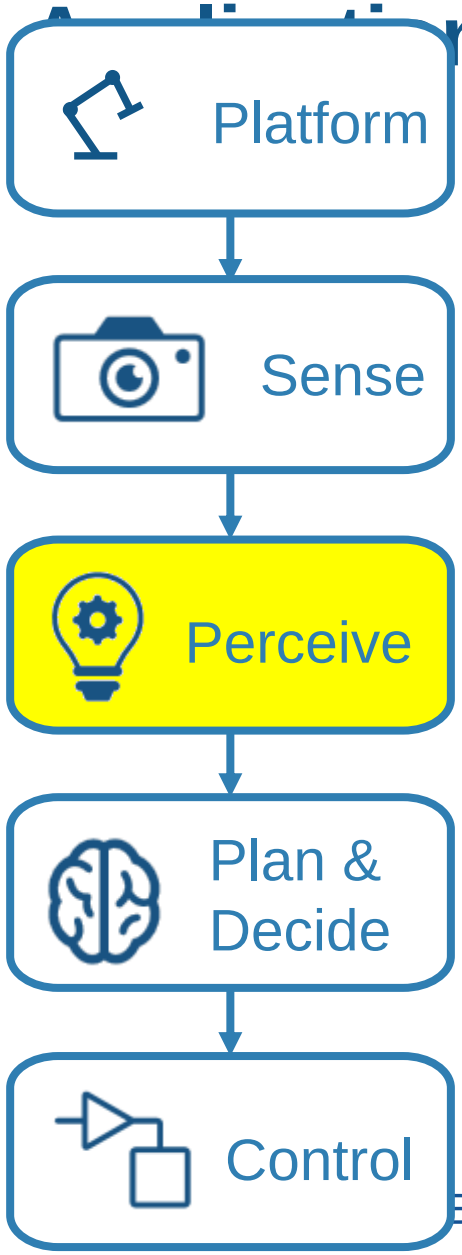
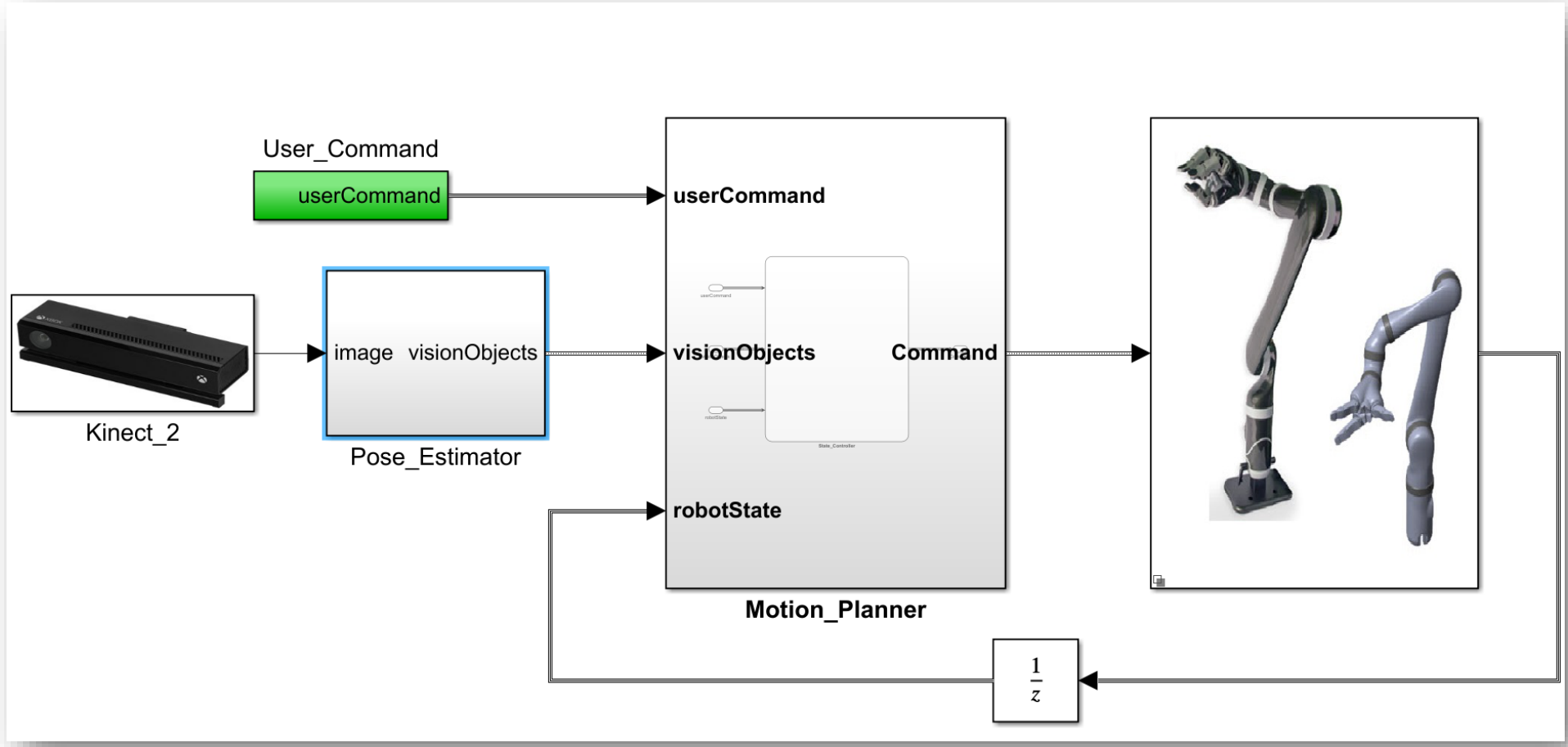
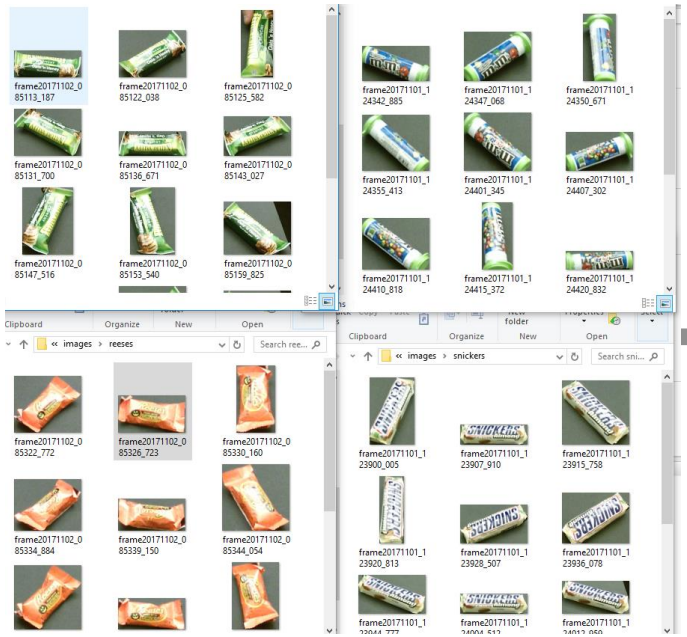




Object Classifier and Pose Estimator

Images

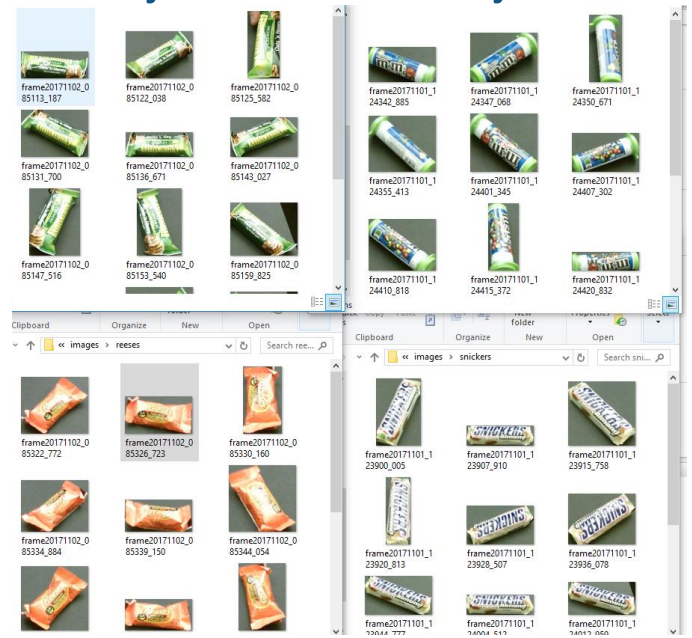


Pose Estimator

Labels and Poses

Object 1

Object 2

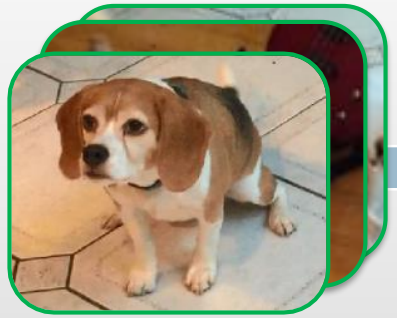


Object 3

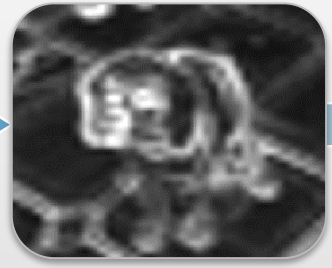
Object 4

MATLAB makes machine learning easy and accessible

Traditional Machine Learning approach



Traditional Feature Extraction



Classification

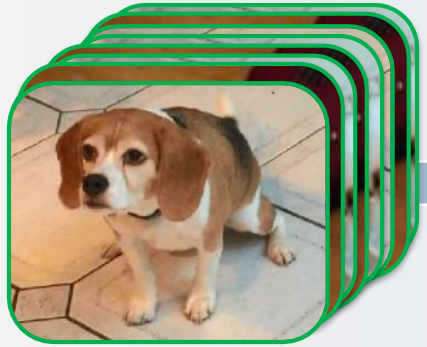
Machine Learning

Dog ✓

Boy ✗

Bicycle ✗

Deep Learning approach



Convolutional Neural Network (CNN)

Learned features

End-to-end learning

Feature learning + Classification

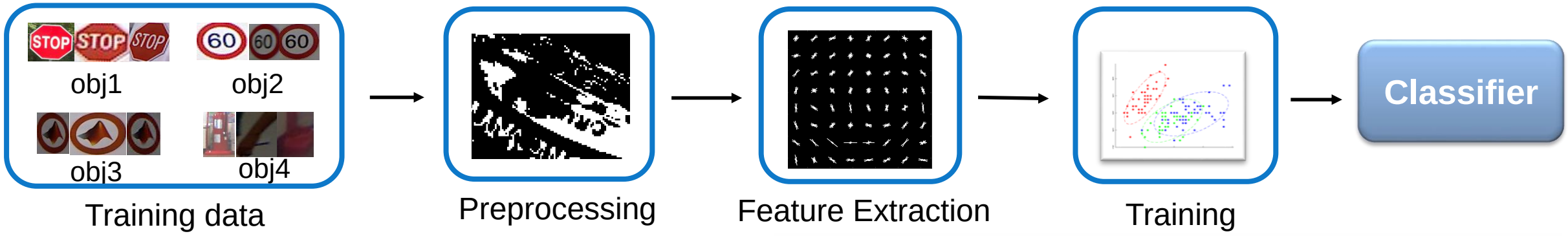
[95%]

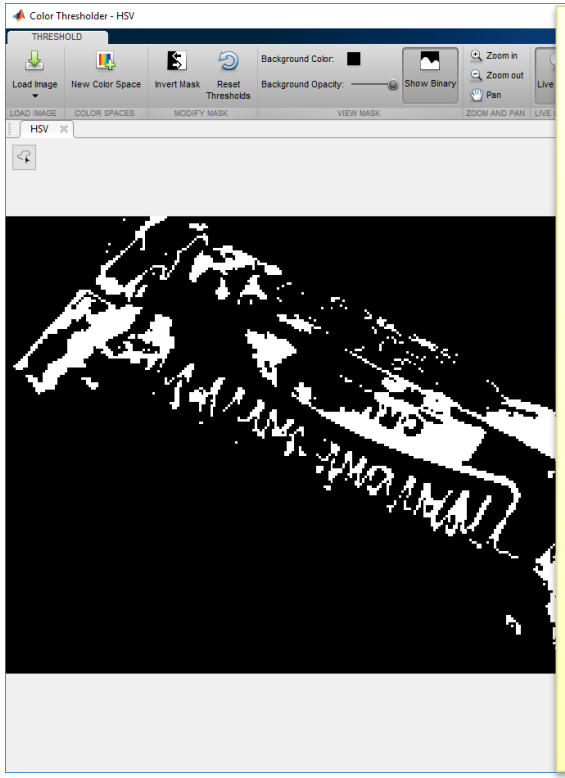
Dog ✓

Boy ✗

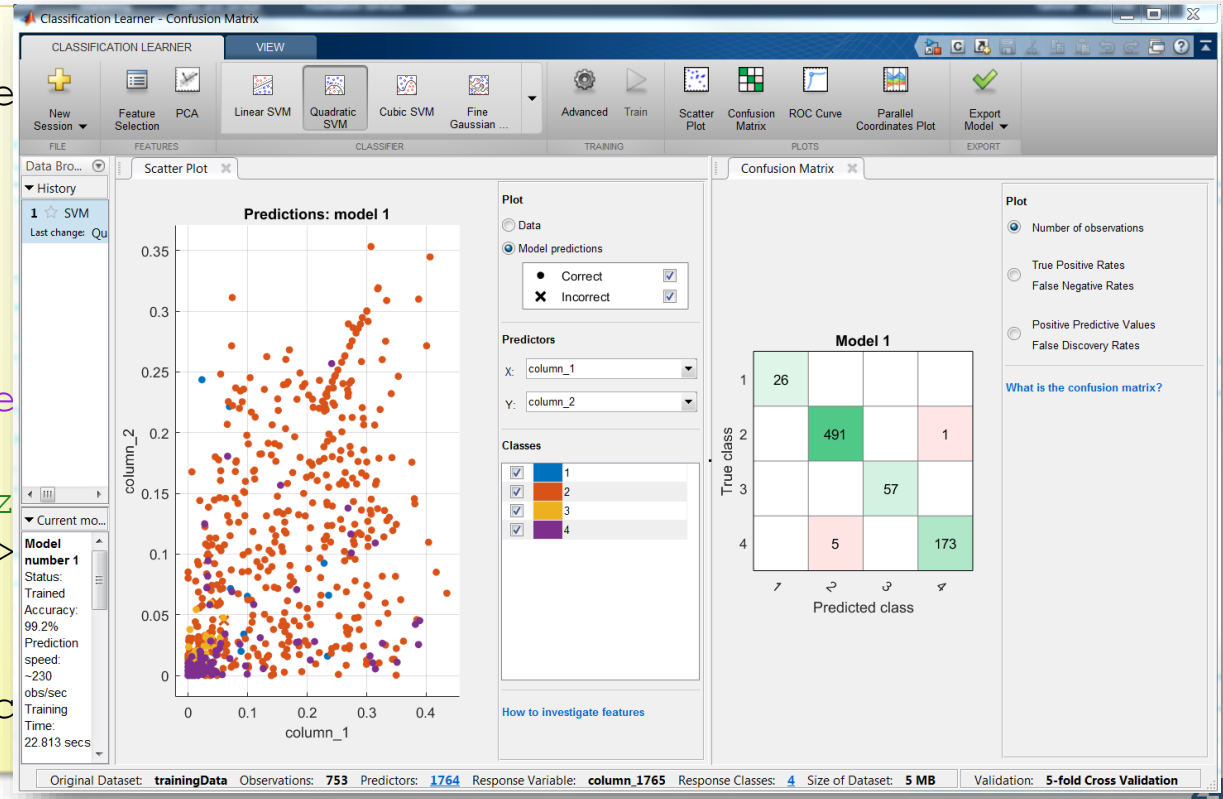
Bicycle ✗

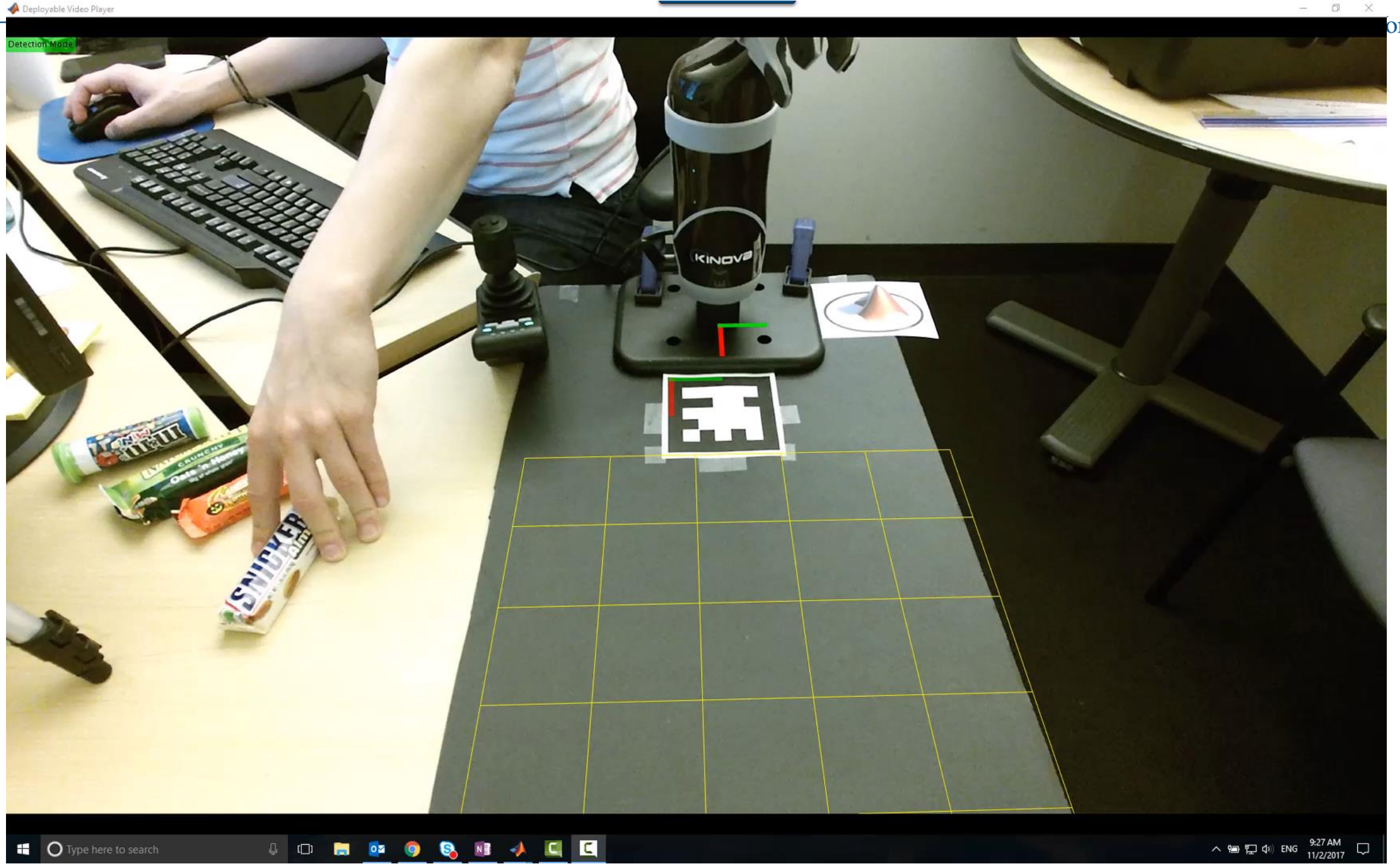
Complex workflows made easy with MATLAB






```
% 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
```

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Detection Mode
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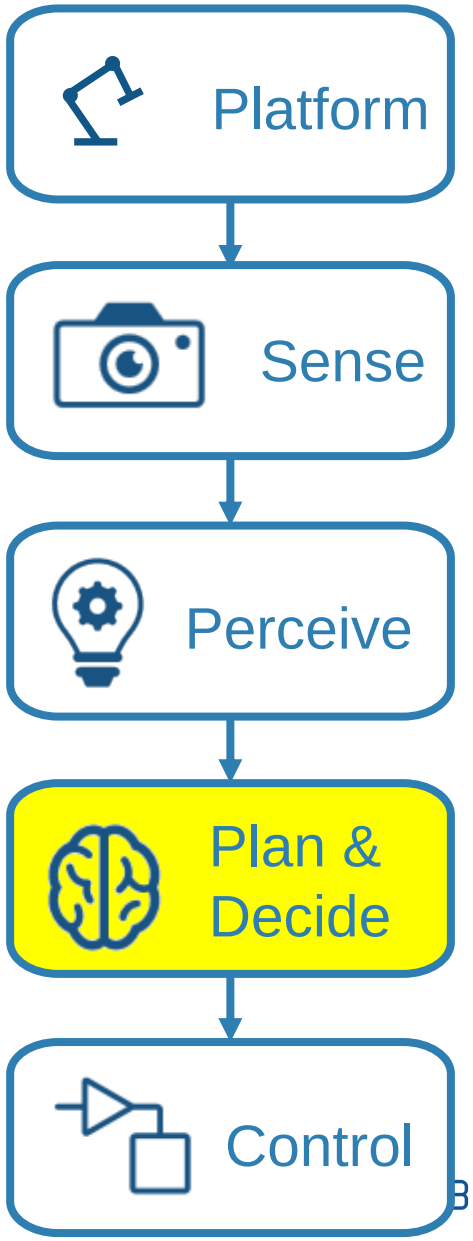
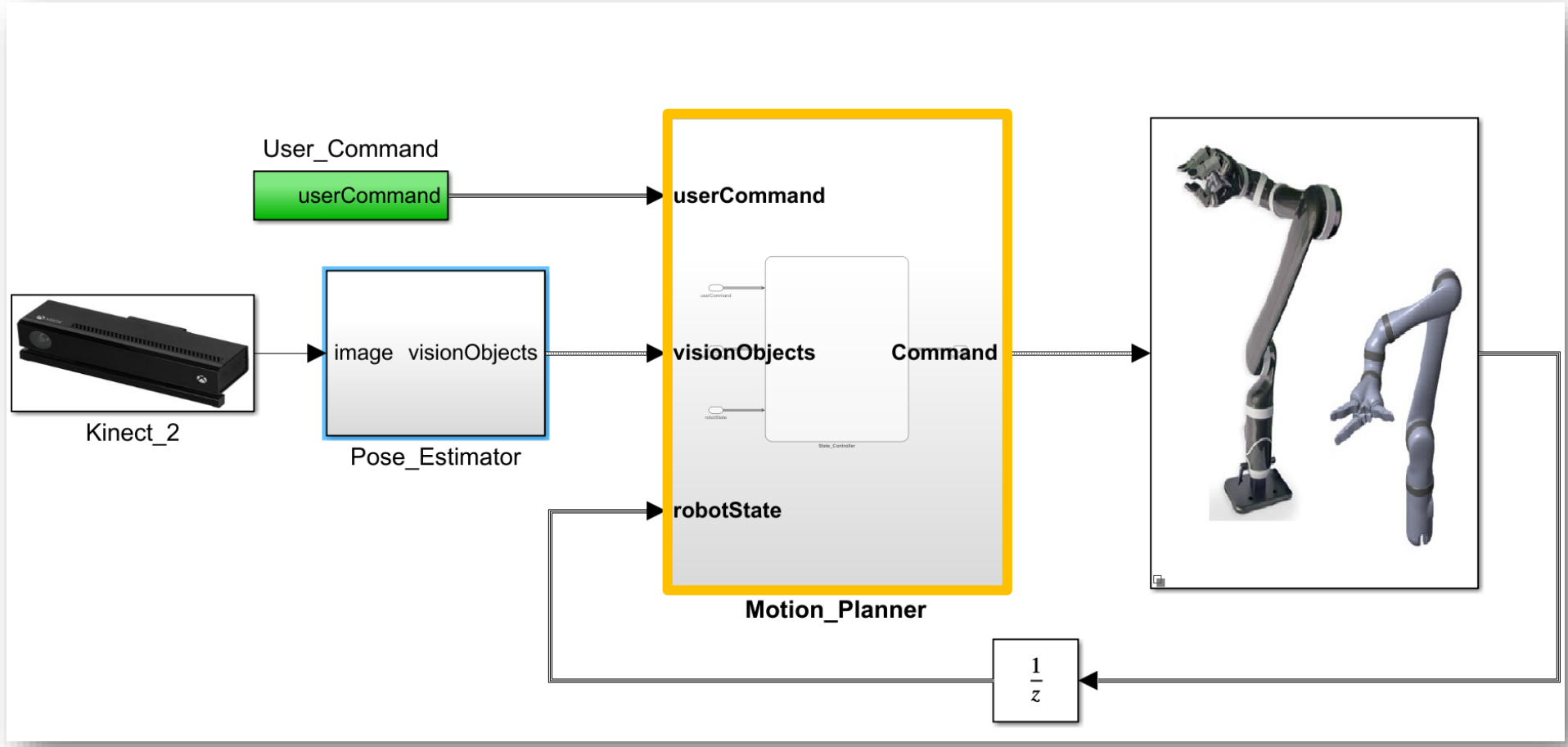
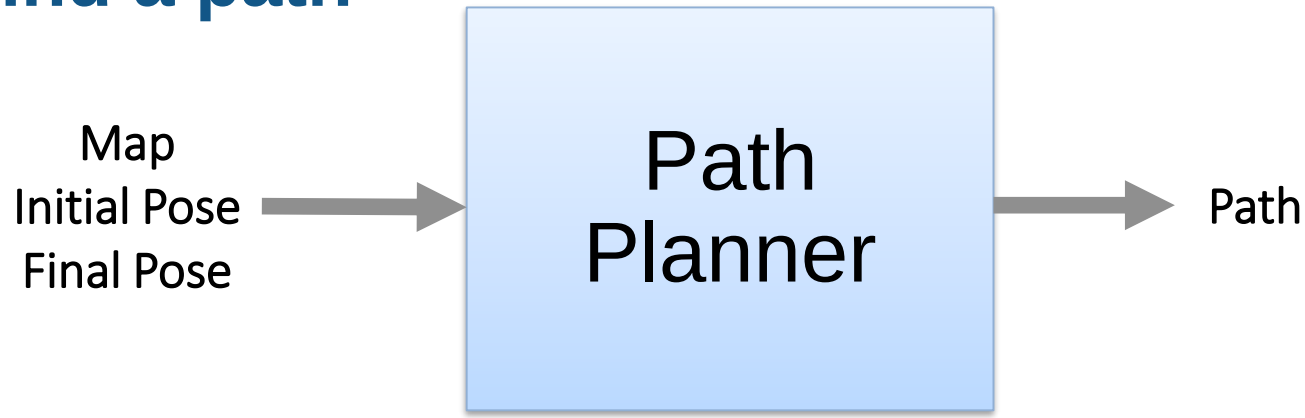
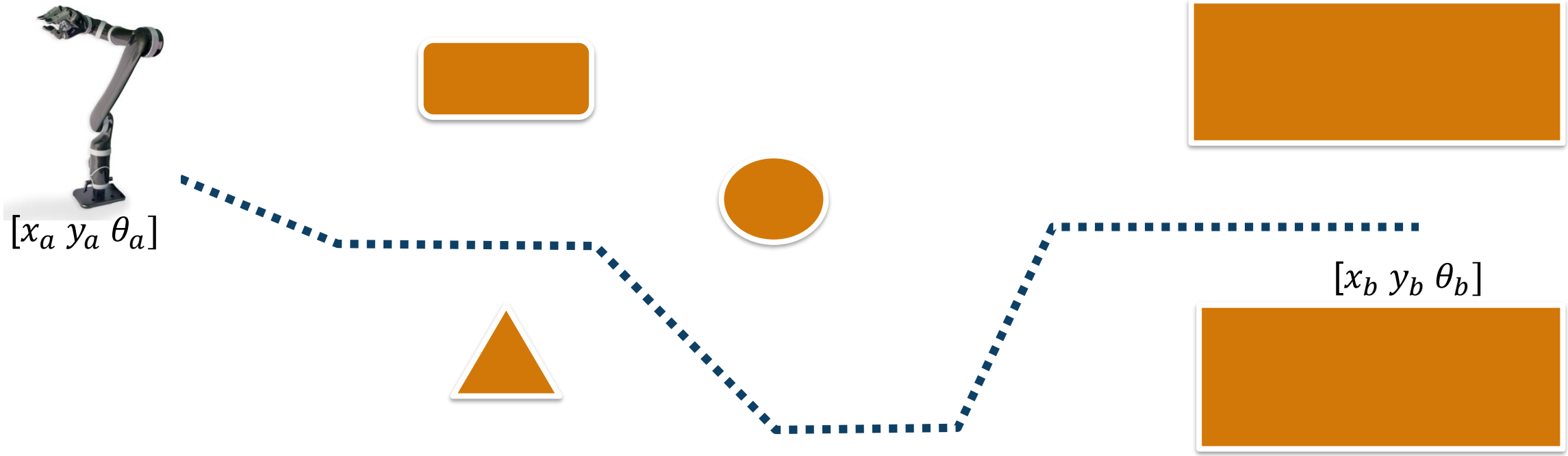
Design Pick and Place Application



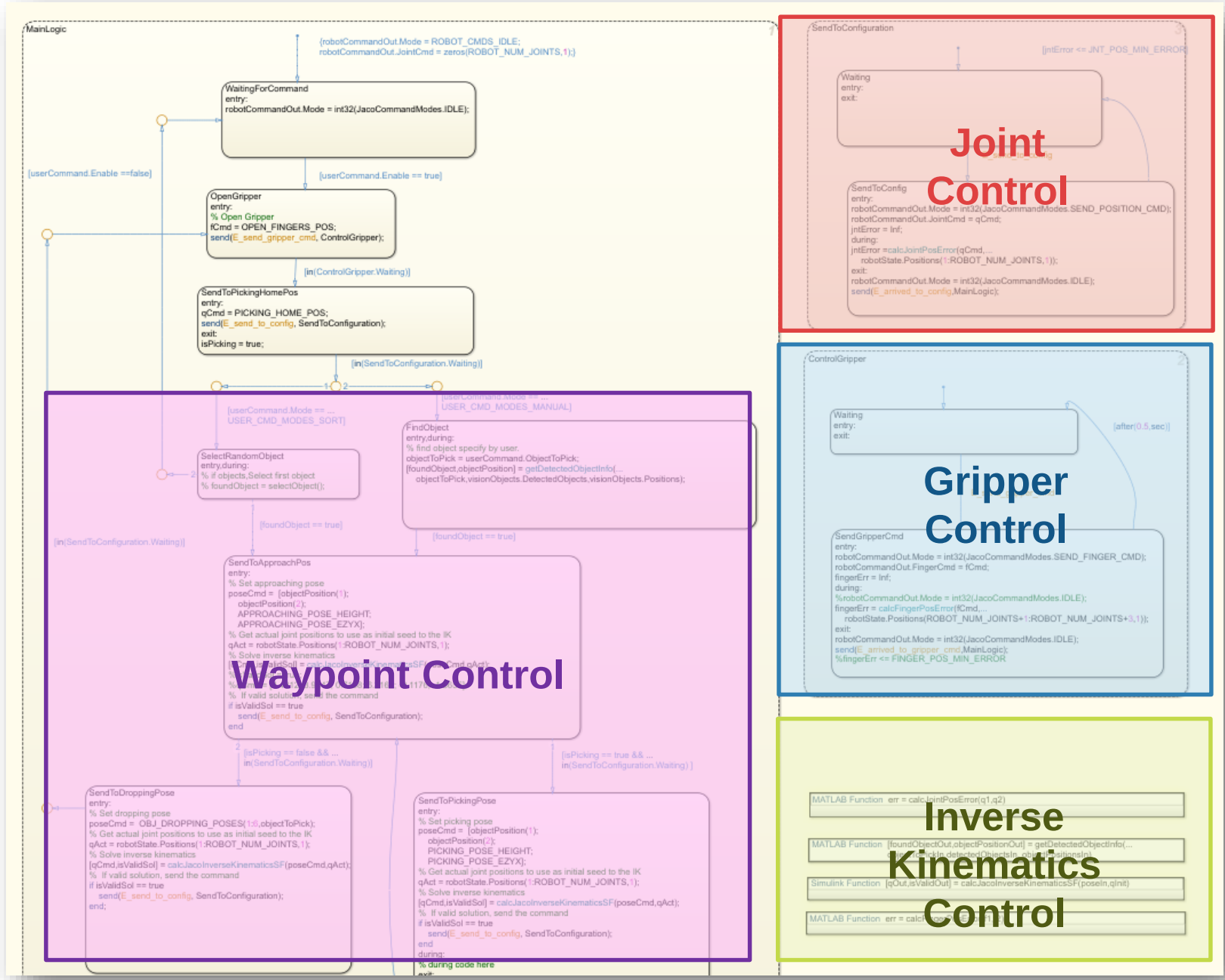


Planning: Find a path

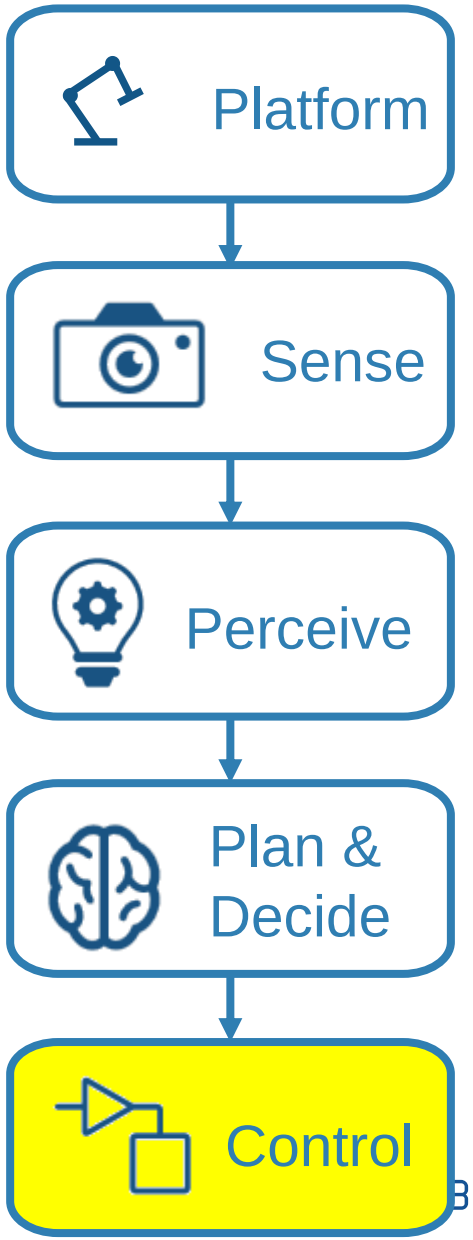


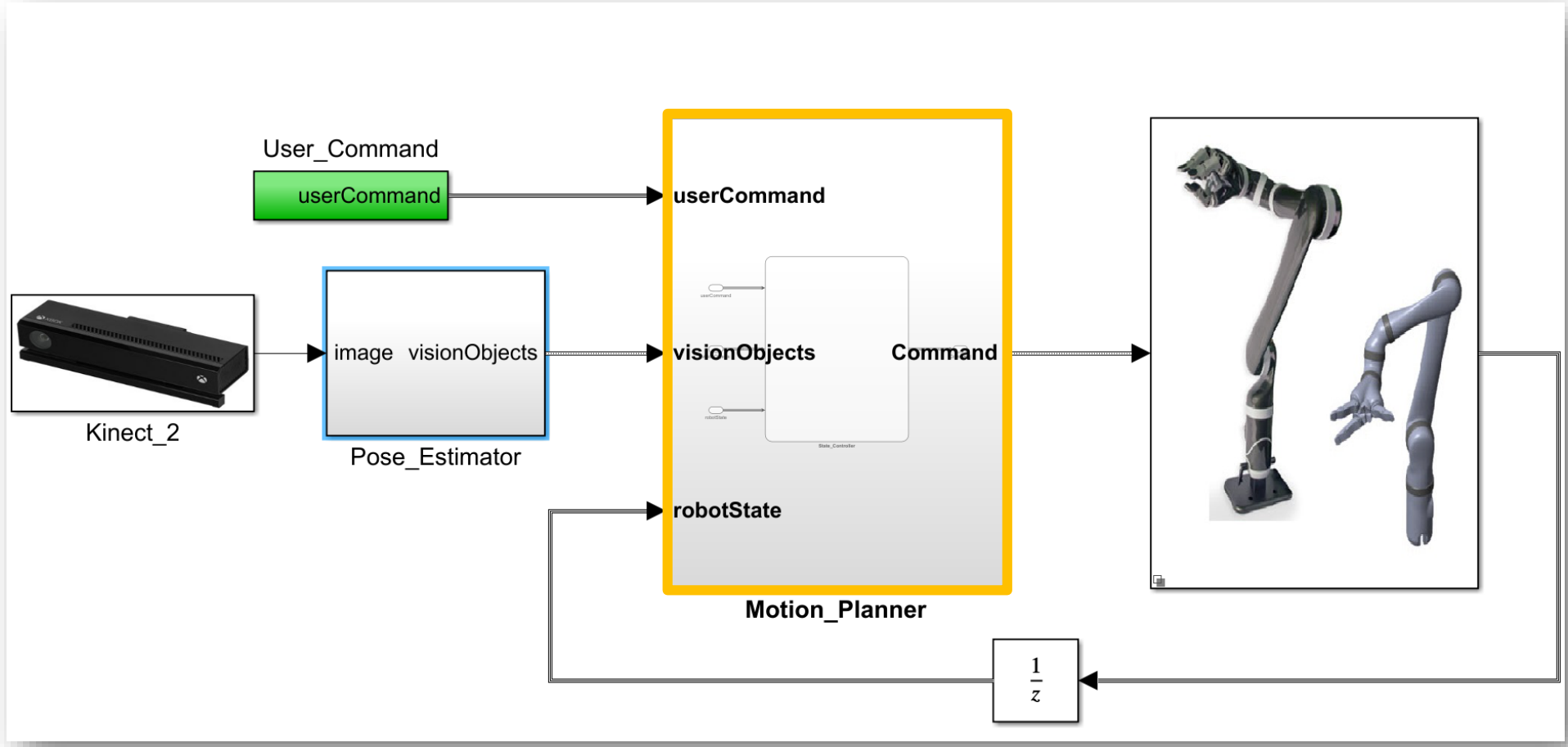


Plan with Stateflow



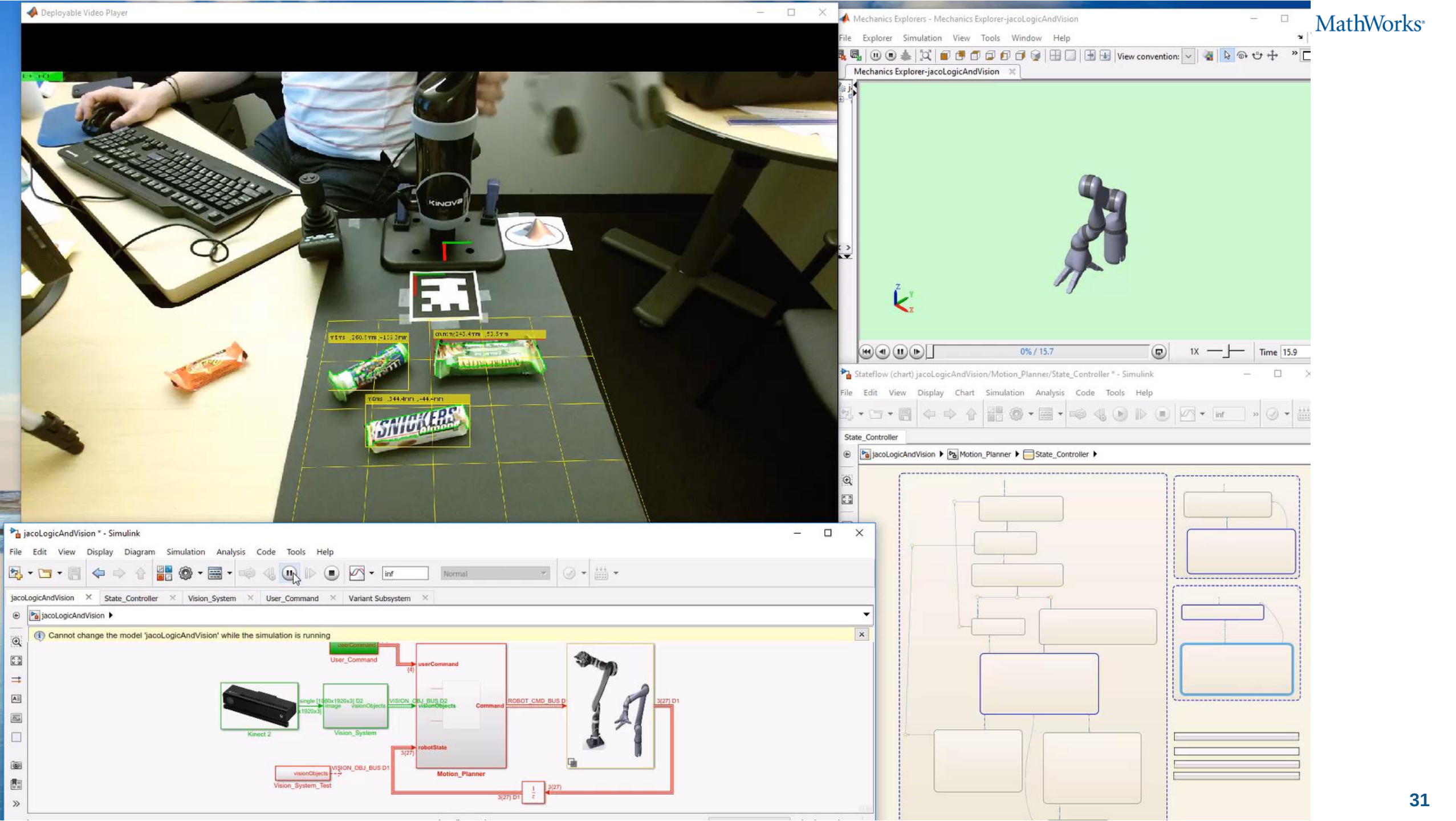
Design Pick and Place Application





Explore Built In Functions: Inverse Kinematics

```
% Create ik solver object
ik = robotics.InverseKinematics('RigidBodyTree',jaco2n6s300)
% Disable random restarts
ik.SolverParameters.AllowRandomRestart = false;
% Parameters to pass to the solver
weights = [1, 1, 1, 1, 1, 1];
q_init = 0.1*ones(numel(q_home),1);
```


Deployable Video Player
Mechanics Explorers - Mechanics Explorer-jacoLogicAndVision
File Explorer Simulation View Tools Window Help
View convention:
Mechanics Explorer-jacoLogicAndVision
0% / 15.7
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Time 15.9
Stateflow (chart) jacoLogicAndVision/Motion_Planner/State_Controller * - Simulink
File Edit View Display Chart Simulation Analysis Code Tools Help
State_Controller
jacoLogicAndVision
Motion_Planner
State_Controller
jacoLogicAndVision * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
jacoLogicAndVision
State_Controller
Vision_System
User_Command
Variant Subsystem
Cannot change the model 'jacoLogicAndVision' while the simulation is running
User_Command
userCommand
Kinect 2
Vision_System
VISION_OBJ_BUS D2
visionObjects
Command
ROBOT_CMD_BUS D
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robotState
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visionObjects
VISION_OBJ_BUS D1
Vision_System_Test
Motion_Planner
3(27) D1
3(27)

Key Takeaway of this Talk

Success in developing an autonomous robotics system requires:

- Multi-domain simulation
- Trusted tools which make complex workflows easy and integrate with other tools
- Model-based design

German Aerospace Center (DLR) Robotics and Mechatronics Center Develops Autonomous Humanoid Robot with Model-Based Design

DLR's humanoid robot Agile Justin autonomously performing a complex construction task.

Challenge

Develop control systems for a two-armed mobile humanoid robot with 53 degrees of freedom

Solution

Use Model-Based Design with MATLAB and Simulink to model the controllers and plant, generate code for HIL testing and real-time operation, optimize trajectories, and automate sensor calibration

Results

- Programming defects eliminated
- Complex functionality implemented in hours
- Advanced control development by students enabled

"Model-Based Design and automatic code generation enable us to cope with the complexity of Agile Justin's 53 degrees of freedom. Without Model-Based Design it would have been impossible to build the controllers for such a complex robotic system with hard real-time performance."

Berthold Bäuml
DLR

Link to user story

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

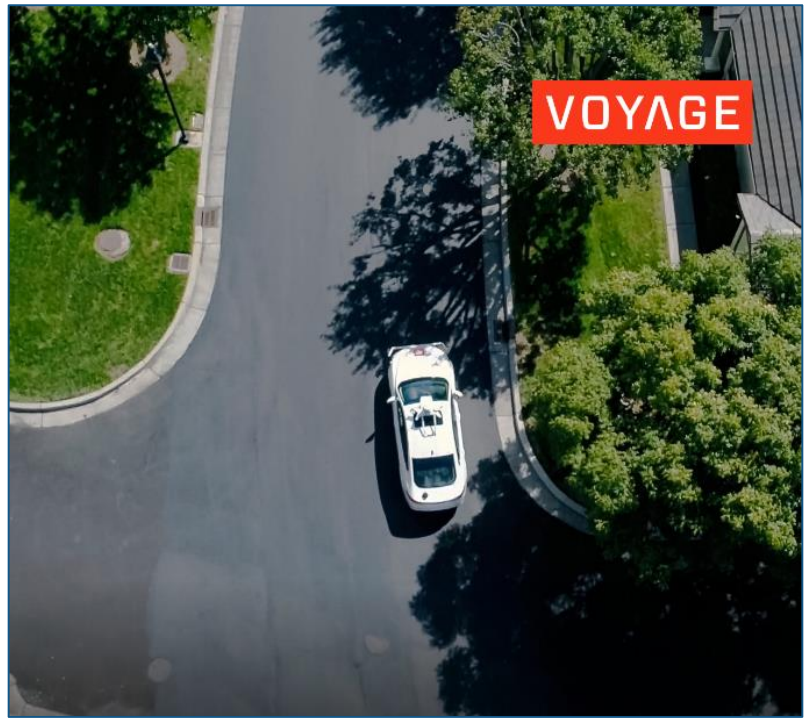
Develop a controller for a self-driving car to follow a target velocity and maintain a safe distance from obstacles

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 MATLAB 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

Link to user story

User Story: Bipedal Robot

The Challenge

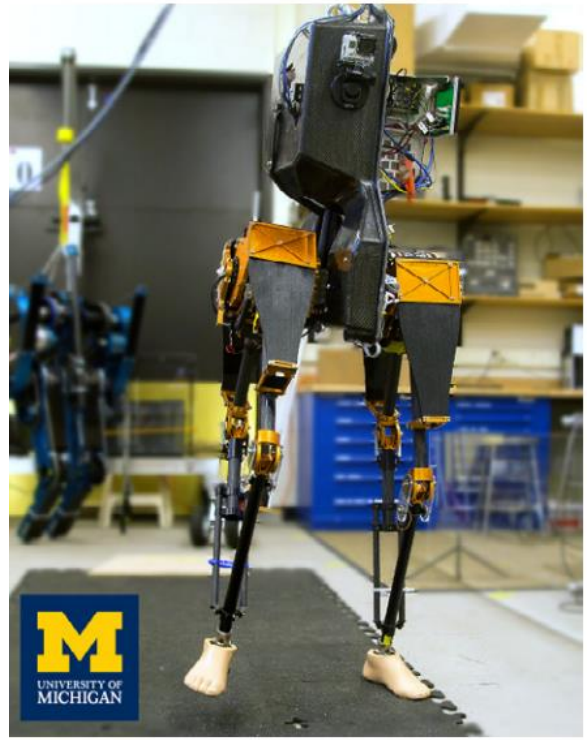
Develop a control system for an underactuated bipedal robot with 13 degrees of freedom

The Solution

Use Model-Based Design with MATLAB and Simulink to model the legs and torso, develop and simulate the control algorithms, and generate code for the real-time implementation

The Results

- Controller development accelerated
- Focus on high-level objectives maintained
- Approach adopted at other institutions



"When other researchers see that we've gone directly from controllers developed in MATLAB and Simulink to a real-time implementation with Simulink Real-Time, they get pretty excited. The approach we took is now being used in other departments at the University of Michigan and by robotics researchers at other universities, including MIT and Oregon State University."

- Prof. Jesse Grizzle, University of Michigan

Festo Develops Innovative Robotic Arm Using Model-Based Design

The Festo Bionic Handling Assistant. Image © Festo AG.

Challenge

Design and implement a control system for a pneumatic robotic arm

Solution

Use Simulink and Simulink PLC Coder to model, simulate, optimize, and implement the controller on a programmable logic controller

Results

- Complex PLC implementation automated
- Technology and innovation award won
- New business opportunities opened

"Using Simulink for Model-Based Design enables us to develop the sophisticated pneumatic controls required for the Bionic Handling Assistant and other mechatronic designs. With Simulink PLC Coder, it is now much easier to get from a design to a product."

Dr. Rüdiger Neumann
Festo

Link to user story

Preceyes Accelerates Development of World's First Eye-Surgery Robot Using Model-Based Design

Challenge

Develop a real-time control system for robot-assisted surgical procedures performed within the human eye

Solution

Use Model-Based Design with MATLAB and Simulink to model and simulate the control system and use Simulink Coder and Simulink Real-Time to deploy it to a real-time target

Results

- Development Core controller developed by one engineer
- Patient safety assured
- Road map to industrialization set

Link to user story

The PRECEYES Surgical System. Image copyright and courtesy Preceyes.

"MATLAB and Simulink provided a single platform that supported our complete workflow and all the components and protocols we needed for our robotic system. That enabled us to quickly develop a safe, real-time device, ready for clinical investigation."

- Maarten Beelen, Preceyes

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% Thank you
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