YASKAWA

Implementation verification of picking system for industrial robot using ROS and MATLAB®

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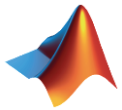
Environmental & Social Systems Div.
YASKAWA ELECTRIC CORPORATION



Source : https://jp.mathworks.com/products/simulink.html

Source: : http://wiki.ros.org Source: http://gazebosim.org/

Speaker Introduction

My job

- Controller development for plants
- Especially on HMI for operators
- Specializes in software development



My authored book on ROS

- **M.Morita** et al., “ROS Robot Programming for practical robotics development”, Morikita Publishing Co., Ltd., 2018.
- I mainly wrote application sections such as OpenCV, PCL, Pluginlib, rostest, industrial_ci and so on...

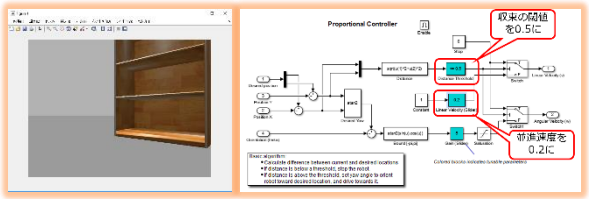
OpenCV
Source : https://opencv.org/

pcl
Source : http://pointclouds.org/

Travis CI
Source : https://travis-ci.org/

- Also wrote **MATLAB integration**

MATLAB
Simulink



1st prize seller on Amazon JP (Robotics category)

Source : https://images-na.ssl-images-amazon.com/images/I/51joyPVM8tL.jpg

Source: http://wiki.ros.org/Robots/CIR-KIT-Unit03

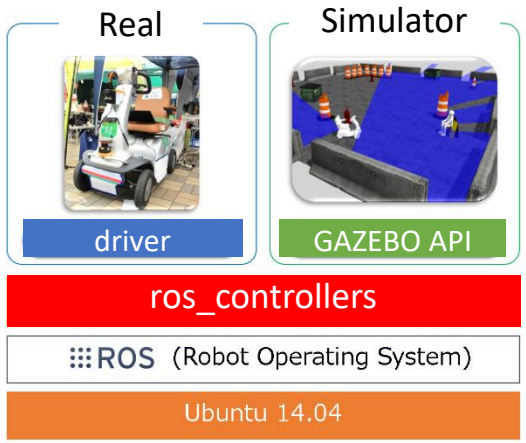
ROS commits experiences and contributions (Hobby)

Autonomous drive

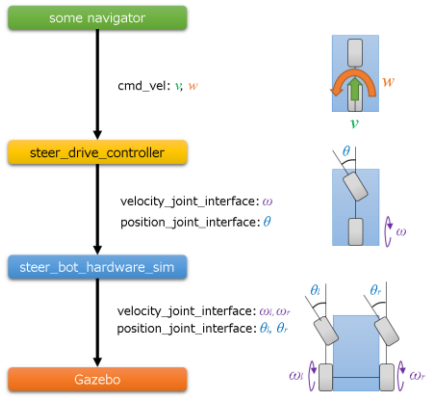
- ackermann_steering_controller

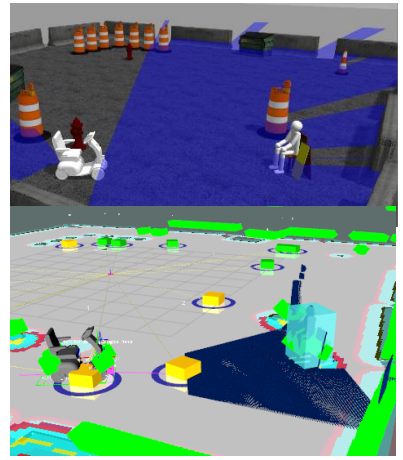
  First author

  Sent PR to ros_controllers repo & already merged!

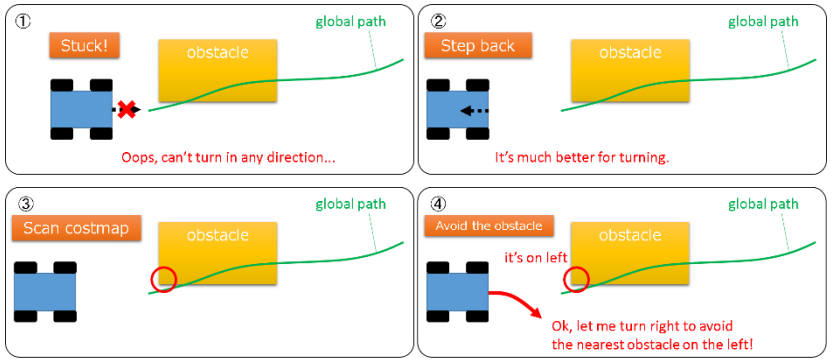


- steer_bot_hardware_sim (plugin)

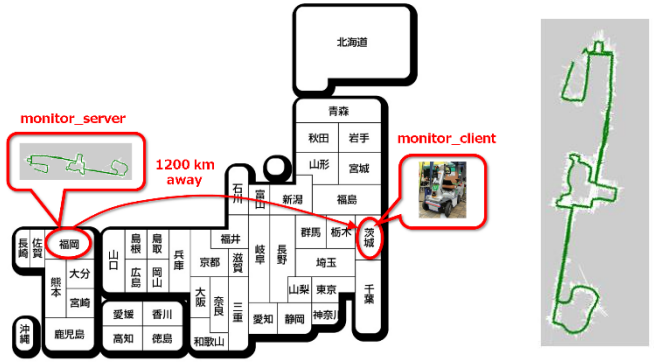




- stepback_and_rotate_recovery (pluigin)



- Remote monitoring with integrating ROS & OpenVPN



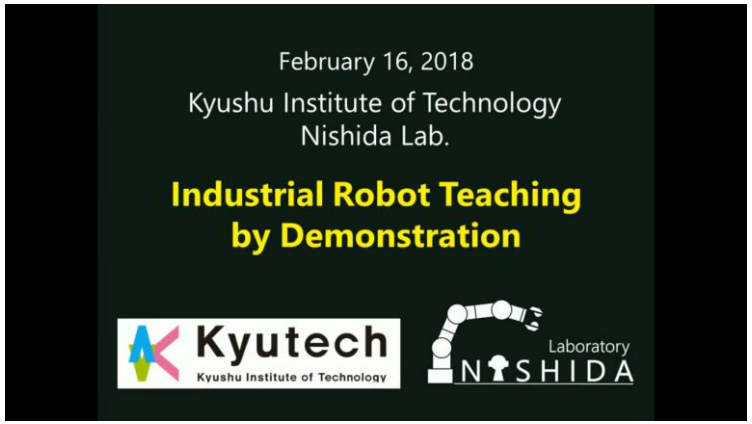
ROS industrial robot apps through my Ph.d program

Easy to use industrial robots

- Construction of industrial robot (teach-less) interactive UI with Pepper (voice+tablet)

- Industrial robot operation from a remote place (teach-less)

- Industrial robot operation from demonstration



- Improving the layout of industrial robots using 5G network

Outline

1. Motivation

- Robotics System Toolbox™
- What's ROS-Industrial?
- Pros for ROS+MATLAB

2. Sample Apps

- Pick & Place App Overview
- Detail on each functions

3. Impression as a User

- Pros
- Cons
- Future work

YASKAWA × MATLAB/Simulink × ROS GAZEBO

Motivation

YASKAWA

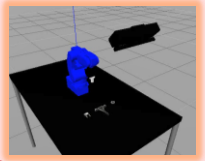
- Unique technologies with advantages
- Limited resources for new technology introduction and verification

In-house tech.

Open Innovation

ROS

- Easy combination of advanced technologies
- Unevenness of the available functions

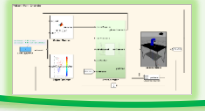


OSS

Expanding advanced functions and quality that are lacking with OSS alone

MATLAB/Simulink

- Secure quality that could be difficult to be provided by only installing OSS
- Advanced technology utilization not provided by ROS alone



Commercial Tool

Possibility of innovation through integration of

In-house tech. × **OSS** × **Commercial Tool**

I introduce the combination verification of OSS × Commercial Tool

High potential of Robotics System Toolbox

MATLAB/Simulink

Source : https://www.mathworks.com/products/matlab.html

Various Toolboxes

Data Analytics
Demonstrates how to use MATLAB for large-scale data, machine learning, and analysis in an enterprise environment.

Wireless communication
See how MATLAB can help you develop algorithms and perform wireless system simulations.

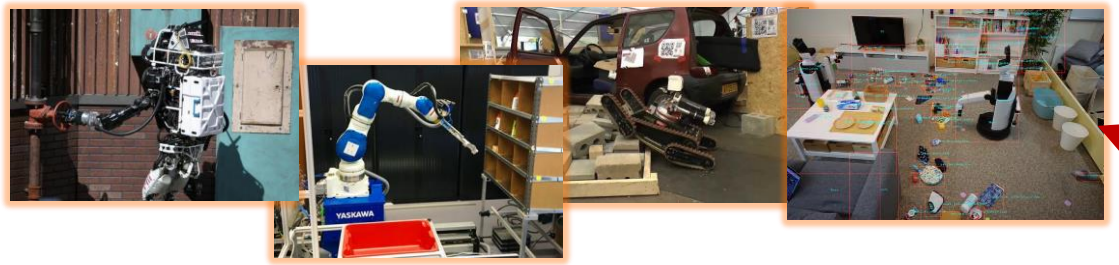
Deep Learning | Computer Vision | Signal Processing | Econometrics and Risk Management | Robotics | Control System

Workspace

```
rosinit('master_host')

sub = rossubscriber('/chat', @callback)

pub =
rospublisher('/chat','std_msgs/String')
```



ROS Network

ROS GAZEBO

Source : http://news.mit.edu/2015/mit-team-places-sixth-darpa-robotics-challenge-0608
Source : https://www.tudelft.nl/en/2016/tu-delft/team-delft-wins-amazon-picking-challenge/
Source : https://youtu.be/1Zpw2288VMQ
Source : https://projects.preferred.jp/tidying-up-robot/

Difficulty of adopting ROS at the manufacturer 1) Technical Issue

ROS GAZEBO

Source : http://news.mit.edu/2015/mit-team-places-sixth-darpa-robotics-challenge-0608
Source : https://www.tudelft.nl/en/2016/tu-delft/team-delft-wins-amazon-picking-challenge/
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Chainer TensorFlow OpenCV pcl

Python, C++, Java

Technical issue:
・It is difficult to employ engineers who can handle the latest OSS libraries and various programming languages

Source : https://www.preferred-networks.jp/ja/pfn-logo
Source : https://www.tensorflow.org/
Source : https://www.irasutoya.com/2016/04/blog-post_78.html

Customers to deliver value to

But not easy…

Source : https://pictarts.com/01-illustration/00011-free-art.html

Difficulty of adopting ROS at the manufacturer 2) Strategic Issue

ROS GAZEBO

Source : http://news.mit.edu/2015/mit-team-places-sixth-darpa-robotics-challenge-0608
Source : https://www.tudelft.nl/en/2016/tu-delft/team-delft-wins-amazon-picking-challenge/
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Source : https://projects.preferred.jp/tidying-up-robot/

Chainer TensorFlow OpenCV pcl

Python, C++, Java

Strategic issue:
・Conflicts between the use of OSS and intellectual property protection.
・Less precedent usage of OSS in development especially among traditional makers.

Source : https://www.irasutoya.com/2019/03/blog-post_877.html

Customers to deliver value to

But not easy…

Source : https://pictarts.com/01-illustration/00011-free-art.html

Difficulty of adopting ROS at the manufacturer 2) Strategic Issue

ROS GAZEBO

Source : http://news.mit.edu/2015/mit-team-places-sixth-darpa-robotics-challenge-0608
Source : https://www.tudelft.nl/en/2016/tu-delft/team-delft-wins-amazon-picking-challenge/
Source : https://youtu.be/1Zpw2288VMQ
Source : https://projects.preferred.jp/tidying-up-robot/

MATLAB/Simulink

- Software installation experience: more than **100,000** companies, governments, universities
- Customer base: More than **185** countries
- MATLAB Users: Over **4 Million** Worldwide
- MATLAB Central File Exchange Downloads: Over **3 Million** Files
- Number of contributors to the MATLAB Central app: more than **525,000** worldwide
- Number of third-party solutions created with MATLAB / Simulink: **500+**
- MATLAB Number of Books: More than **2,000** in **27** languages

Customers
to deliver value to

Source : https://pictarts.com/01-illustration/00011-free-art.html

Difficulty of adopting ROS at the manufacturer 1) Solution

ROS GAZEBO

Source : http://news.mit.edu/2015/mit-team-places-sixth-darpa-robotics-challenge-0608
Source : https://www.tudelft.nl/en/2016/tu-delft/team-delft-wins-amazon-picking-challenge/
Source : https://youtu.be/1Zpw2288VMQ
Source : https://projects.preferred.jp/tidying-up-robot/

MATLAB/Simulink

Solution:
1. Many MATLAB engineers exist in manufacturers
2. MATLAB resources are also accumulated a lot there

Source : https://www.irasutoya.com/2019/05/blog-post_67.html

Technical issue:
・It is difficult to employ engineers who can handle the latest OSS libraries and various programming languages

Customers to deliver value to

Possible!

Source : https://pictarts.com/01-illustration/00011-free-art.html

Difficulty of adopting ROS at the manufacturer 2) Solution

Source : http://news.mit.edu/2015/mit-team-places-sixth-darpa-robotics-challenge-0608
Source : https://www.tudelft.nl/en/2016/tu-delft/team-delft-wins-amazon-picking-challenge/
Source : https://youtu.be/1Zpw2288VMQ
Source : https://projects.preferred.jp/tidying-up-robot/

MATLAB/Simulink

Solution:
1. Interfacing ROS thru MATLAB increases product reliability
2. MATLAB-based product development is often experienced

Source : https://www.irasutoya.com/2013/07/blog-post_5717.html

Strategic issue:
・Conflicts between the use of OSS and intellectual property protection.
・Less precedent usage of OSS in development especially among traditional makers.

Customers to deliver value to

Possible!

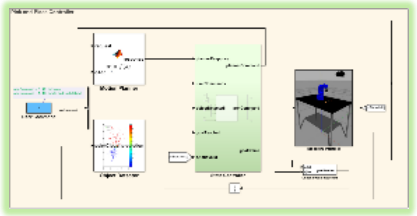
Source : https://pictarts.com/01-illustration/00011-free-art.html

That's why I started to watch on MATLAB & ROS integration!

Robotics System Toolbox

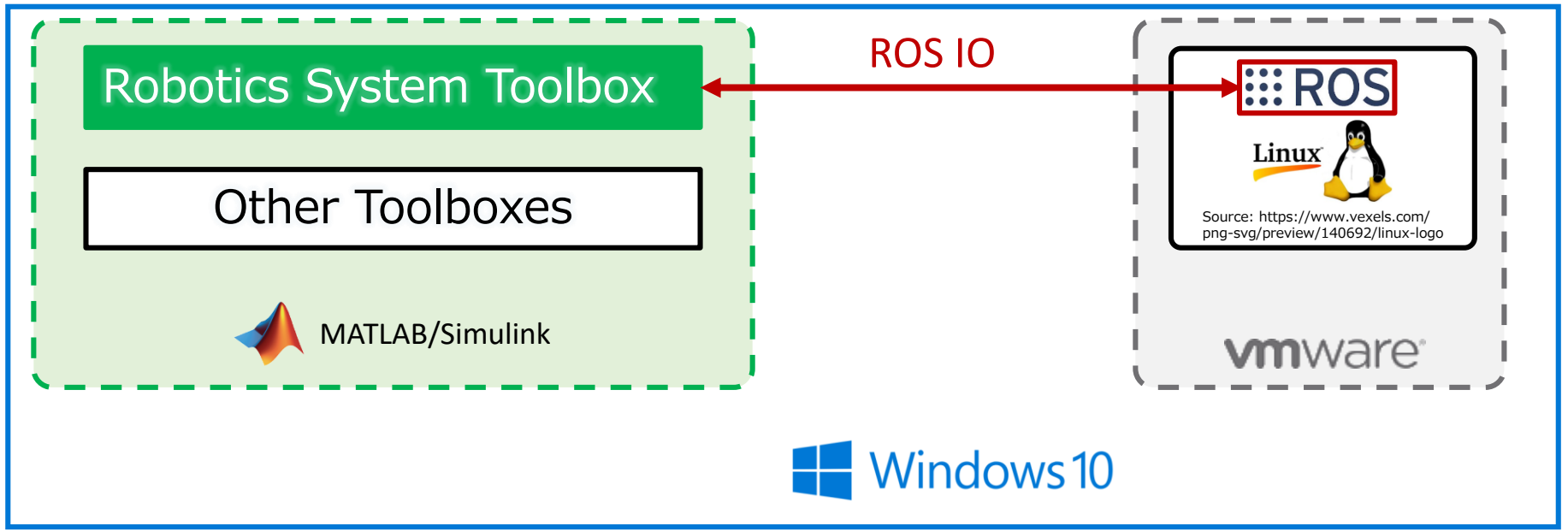
Robotics System Toolbox

MATLAB
Simulink



- Includes various algorithms and functions essential for robotics
- Added interface for linking MATLAB® / Simulink® and ROS

Usage in the demo



Development of ROS for industrial application

ROS-Industrial (ROS-I)

Source:
https://rosindustrial.org/ric/current-members

- Consortium to promote industrial application of ROS
- Over 60 global companies such as manufacturers, users and plants participate

Yaskawa U.S.A

Motoman's repository of ROS-Industrial

Free published in GitHub repository ROS

- Driver, 3D CAD model, visualization tool correspondence, etc.

GP12/7/8

MH5/12/50

MotoMINI

SDA10F/10D

SIA5D/10D/20D

Reference: GitHub

ROS-Industrial Motoman meta-package (http://wiki.ros.org/motoman)

motoman | ros-industrial | ros | urdf | moveit

508 commits | 8 branches | 7 releases | 24 contributors

Branch: kinetic-devel | New pull request | Create new file | Upload files | Find file | Clone or download

shaun-edwards Merge pull request #253 from gavanderhoorn/cleanup_manifests ... Latest commit 80c5299 on 13 Nov 2018

motoman	all: fix grouping of elements in manifests.	3 months ago
motoman_driver	driver: sort source list JTA node.	3 months ago
motoman_gp12_support	support: harmonise build scripts.	3 months ago
motoman_gp7_support	support: harmonise build scripts.	3 months ago
motoman_gp8_support	support: harmonise build scripts.	3 months ago
motoman_mh12_support	support: harmonise build scripts.	3 months ago
motoman_mh50_support	support: harmonise build scripts.	3 months ago
motoman_mh5_support	support: harmonise build scripts.	3 months ago
motoman_motomini_support	all: fix grouping of elements in manifests.	3 months ago
motoman_msgs	Order dependencies.	3 months ago
motoman_sda10f_moveit_config	Order dependencies.	3 months ago
motoman_sda10f_support	support: harmonise build scripts.	3 months ago
motoman_sia10d_support	support: harmonise build scripts.	3 months ago
motoman_sia10f_support	support: harmonise build scripts.	3 months ago
motoman_sia20d_moveit_config	Order dependencies.	3 months ago
motoman_sia20d_support	support: harmonise build scripts.	3 months ago
motoman_sia5d_support	support: harmonise build scripts.	3 months ago

Source: https://github.com/ros-industrial/motoman

Pros of ROS implementation at the manufacturer

ROS features

- Communication library → Focus on application development
- Development and operation tools → Graph, 3D Viewer, Simulator, Compiler
- High-performance library → Also functions at academic level
- Ecosystem → Easy to share and install apps

Easy benchmarking

- Free access to advanced technologies available with ROS

Easy combination verification

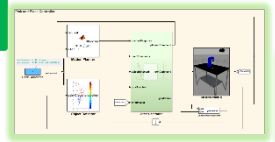
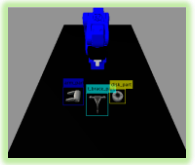
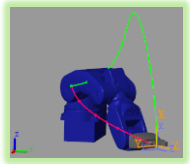
- Sensor / actuator compatible with ROS can be easily introduced
- Interworking can be expected with simple settings by using the ROS network

Reduction of development man-hours Efficiency of advanced function benchmark etc.

Advantages of Introducing Robotics System Toolbox

Robotics System Toolbox Features

MATLAB
Simulink

- Maternal MATLAB is multi-platform
- Can interact with other toolboxes and scripts

Easy combination verification with existing models

- Works with MATLAB / Simulink assets accumulated in-house
- Mainstream OS among manufacturers:ROS verification is possible based on Windows

Easy to build various applications

- By combining various toolboxes of MATLAB, it is easy to develop advanced technology-based applications that are difficult to build with ROS alone

Perform verification with sample application

Outline

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- Pros
- Cons
- Future work

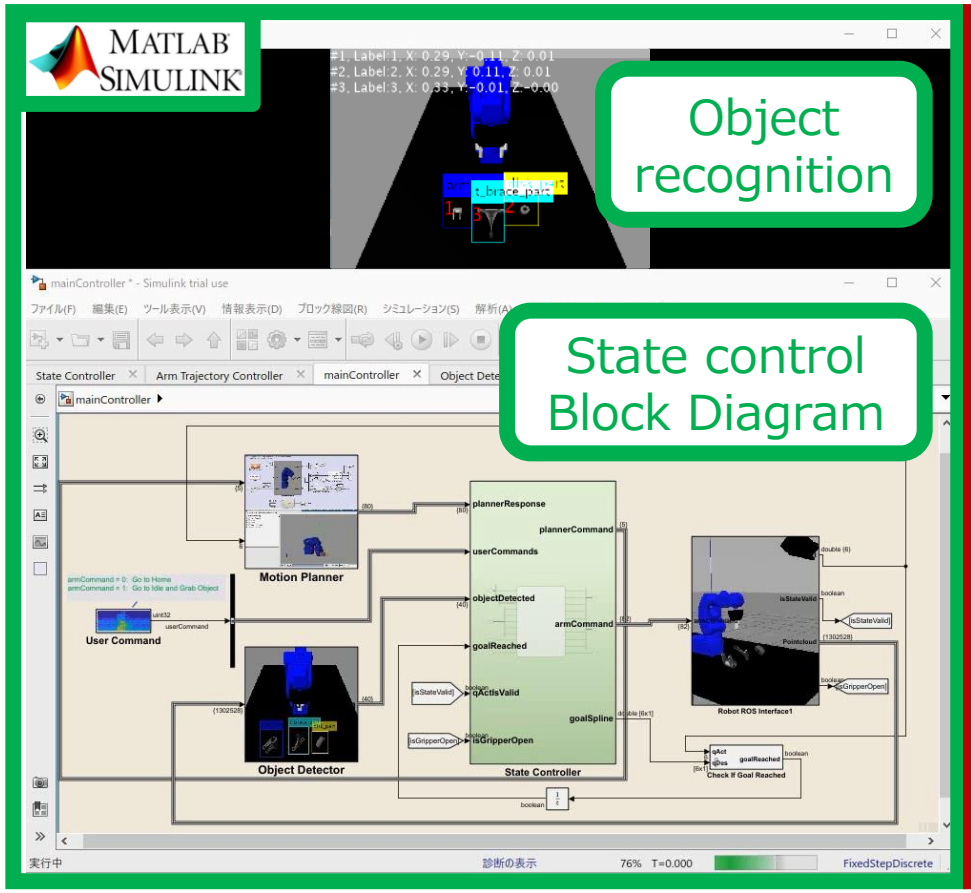
YASKAWA × MATLAB/Simulink × ROS GAZEBO

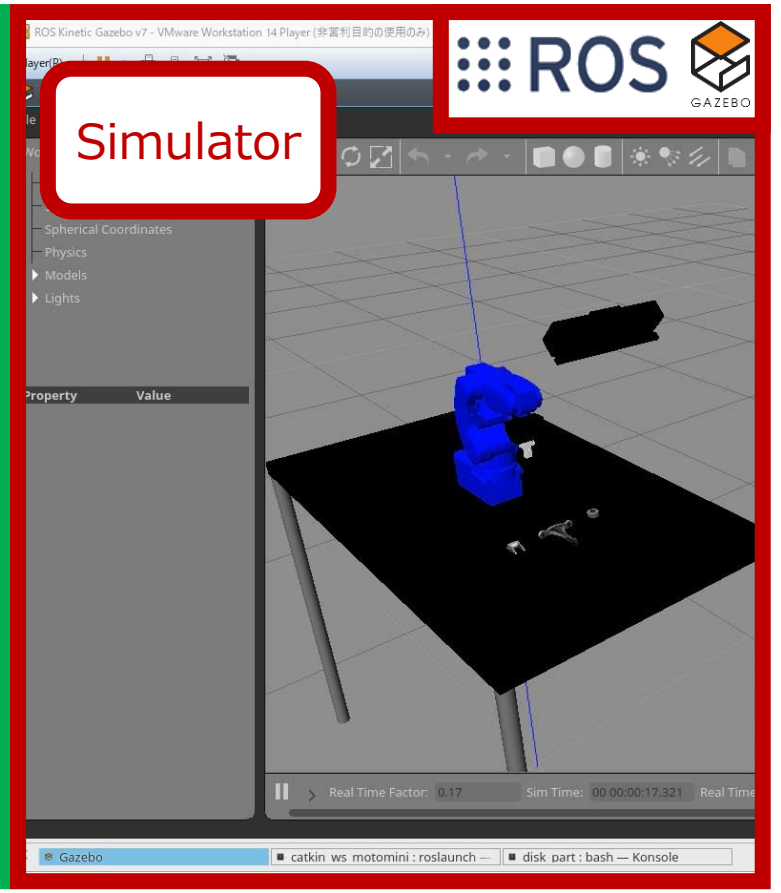
App demo video

Example based system construction

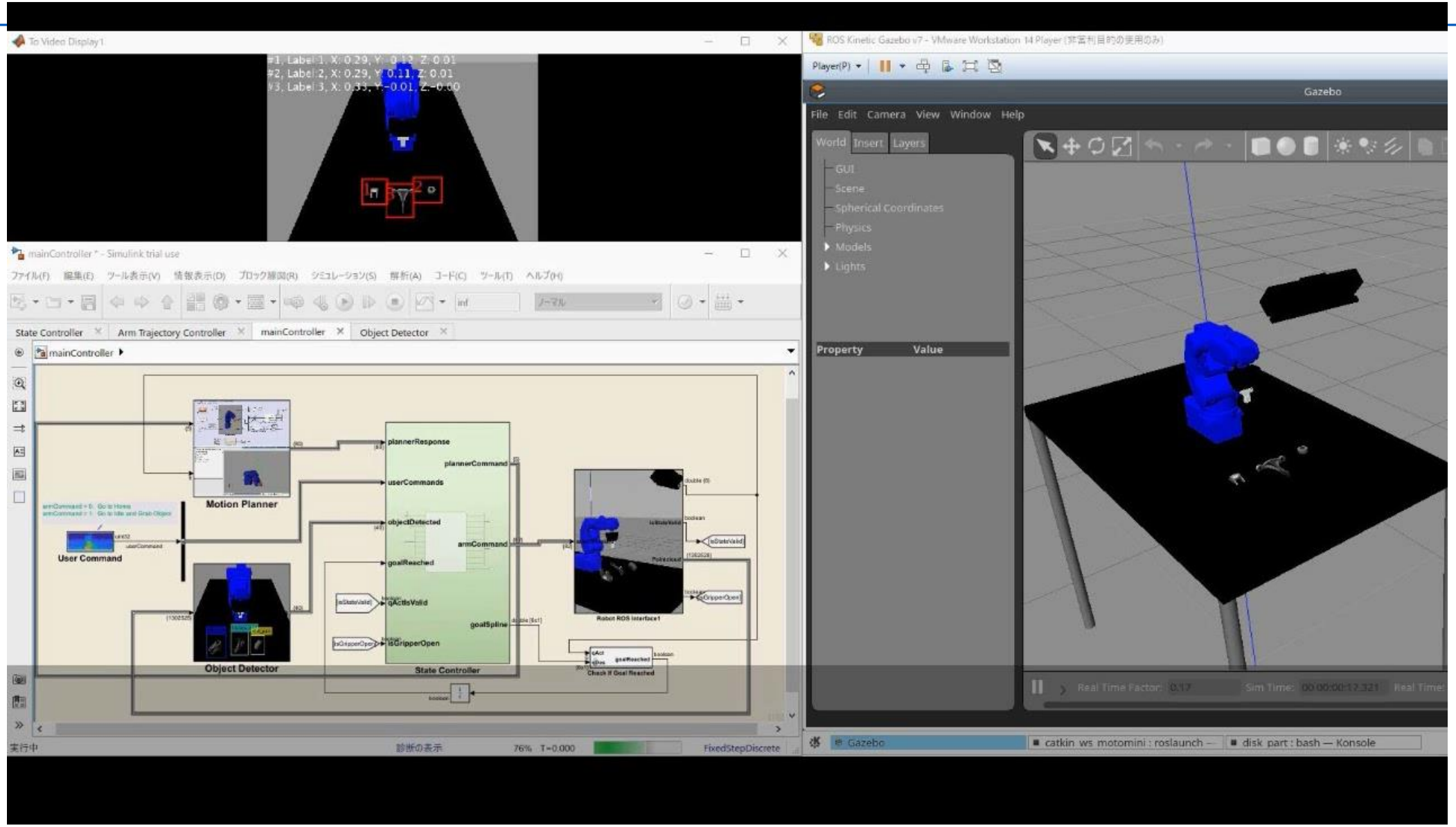
MATLAB Simulink

- Build a system based on Example provided by Mathworks
- KUKA youBot → **Yaskawa MotoMINI**, SVM → **YOLOv2**





App demo video

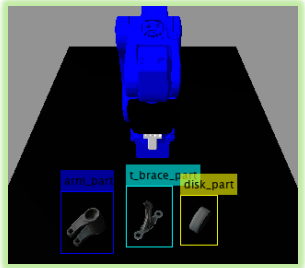


Sample application summary

Object recognition + position estimation

MATLAB Simulink

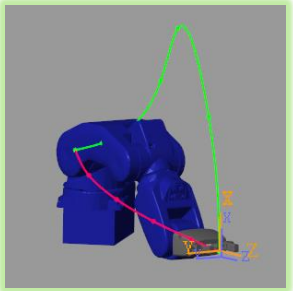
- Object recognition by deep learning based on RGBD sensor information
- Estimate the position of a 3D object



Path plan + pick & place

MATLAB Simulink

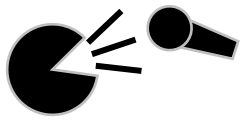
- Plan the trajectory from the robot's current posture to the recognized object position
- Control the robot based on the planned trajectory and carry out pick and place



Voice input

MATLAB Simulink

- Voice input with microphone
- Control the robot according to the instructions



MotoMINI simulation

ROS

- Utilize MotoMINI model provided by ROS-I
- Use simulator (Gazebo)

Build sample application only with MATLAB function + open source

Sample app overview

Flow of explanation

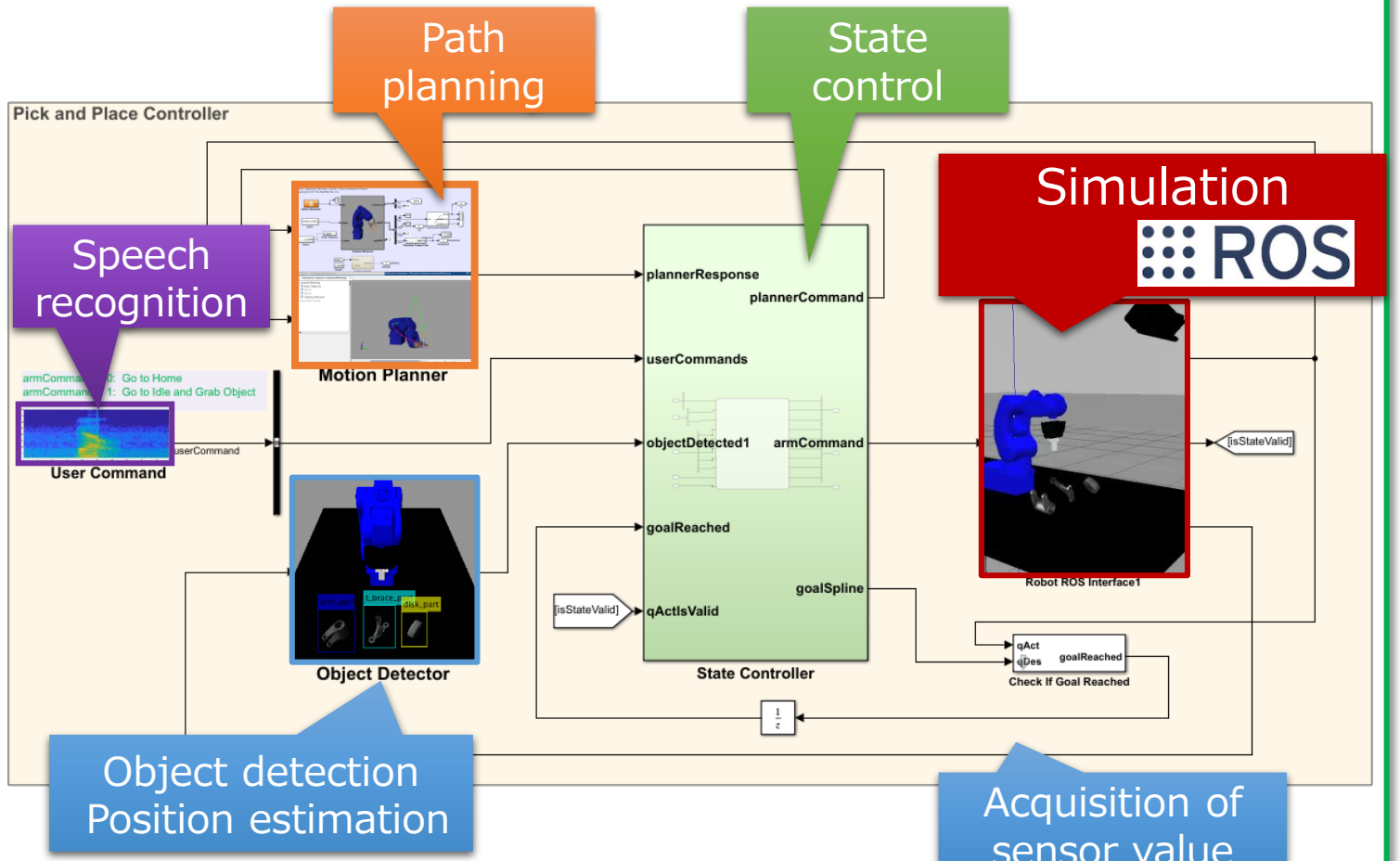
1. Object detection
Position estimation

2. Path planning

3. Speech recognition

4. State machine

Block diagram (Simulink model)



Sample app overview : 1. Object detection

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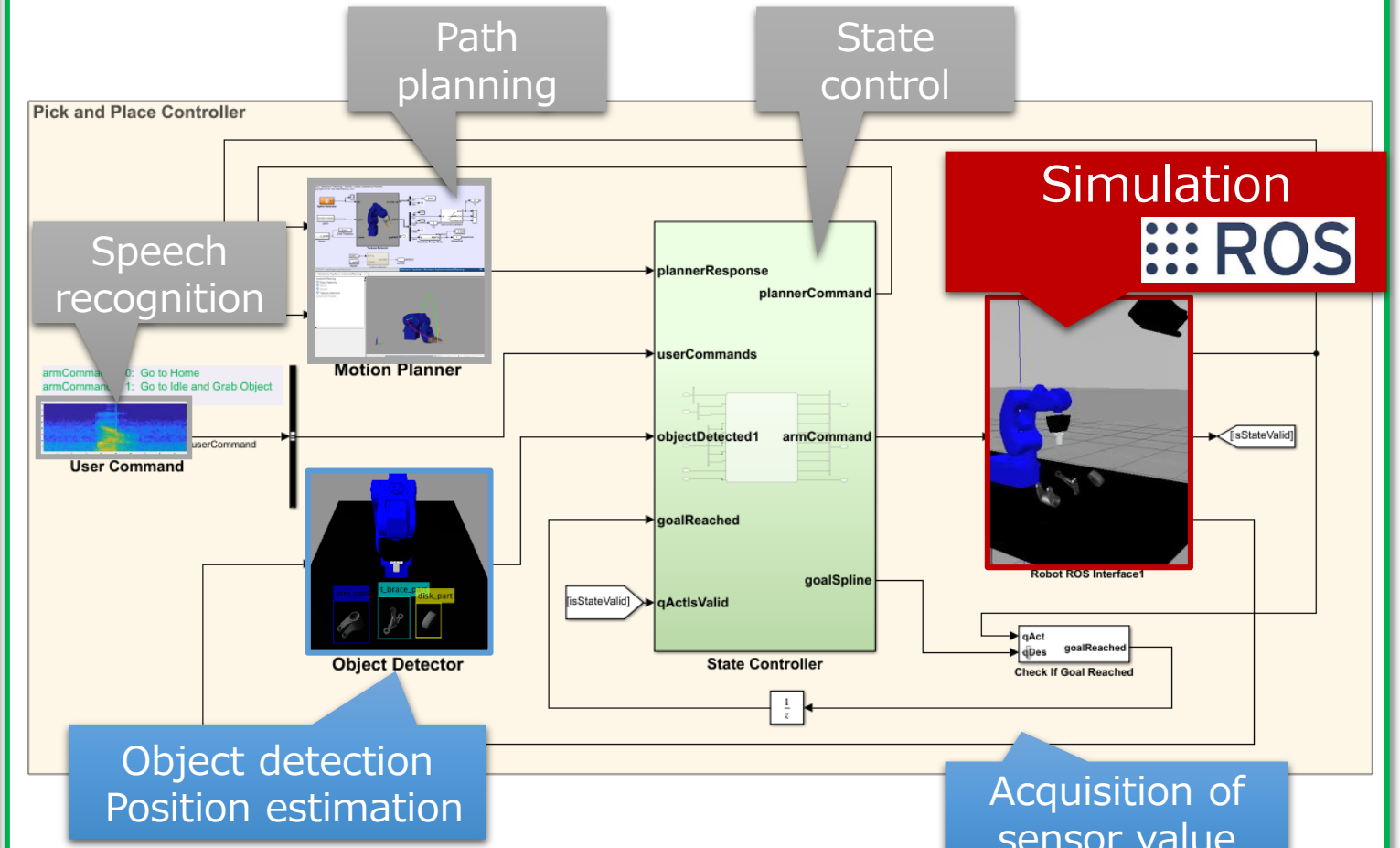


Flow of object detection + position estimation

ROS -> MATLAB conv.

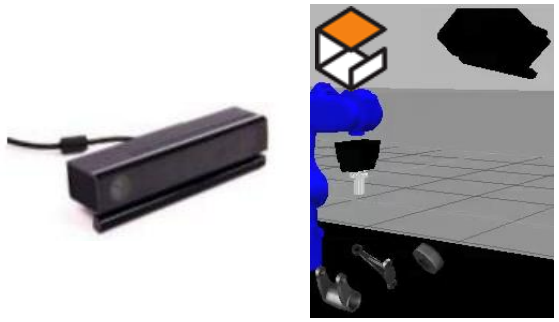
Object detection result

Object position

Path planning

Sensor info. ROS

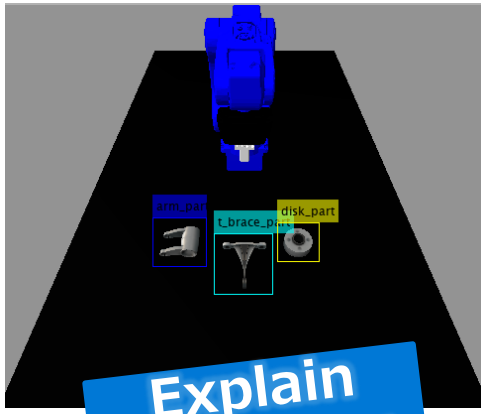
- Real or simulator



Robotics System Toolbox™

Object detection

- Use RGB image
- Detect by YOLOv2



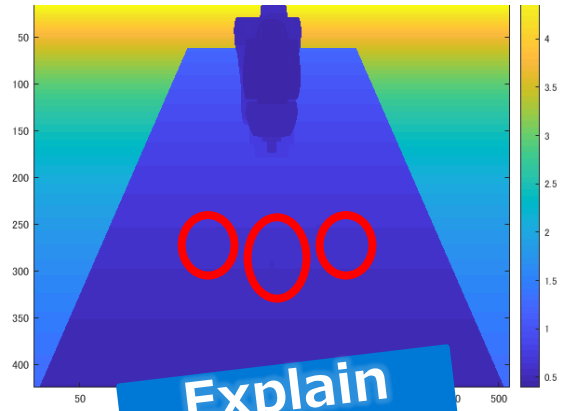
Explain from now

Deep Learning Toolbox™
Computer Vision Toolbox™

MATLAB
Simulink

Position estimation

- Use depth image
- Get 3D position



Explain from now

Image Processing Toolbox™
Computer Vision Toolbox™

MATLAB
Simulink

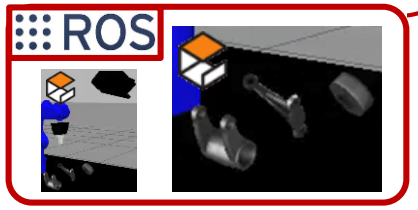
Object recognition with deep learning (YOLOv2)

Flow of object recognition by YOLOv2

MATLAB Simulink

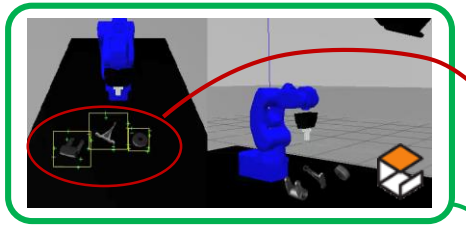
Learning

Image Acquisition



Robotics System Toolbox™
Image Processing Toolbox™

Labeling

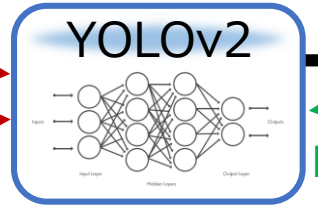


Robotics SystemToolbox™

Input image

Anchor

Feature extraction + learning



Deep Learning Toolbox™

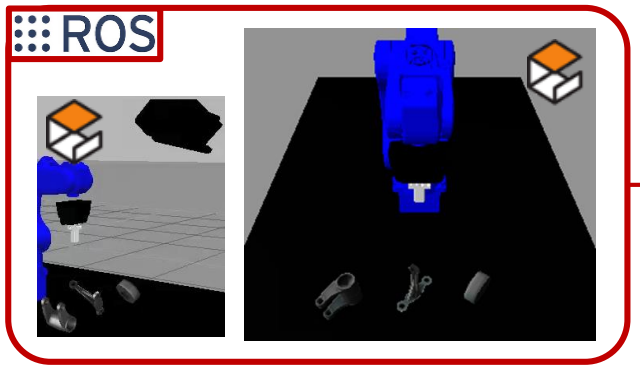
Learned model

Label

To Recognition

Recognition

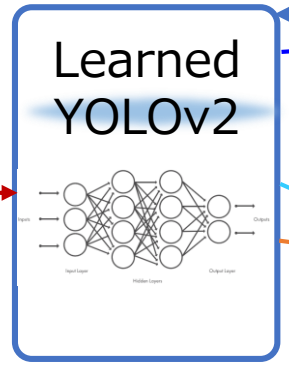
Image Acquisition



Robotics System Toolbox™

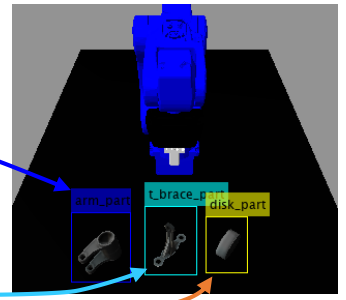
Input image

End to End Network



Deep Learning Toolbox™

Bounding box estimation



Extract work

To position estimation

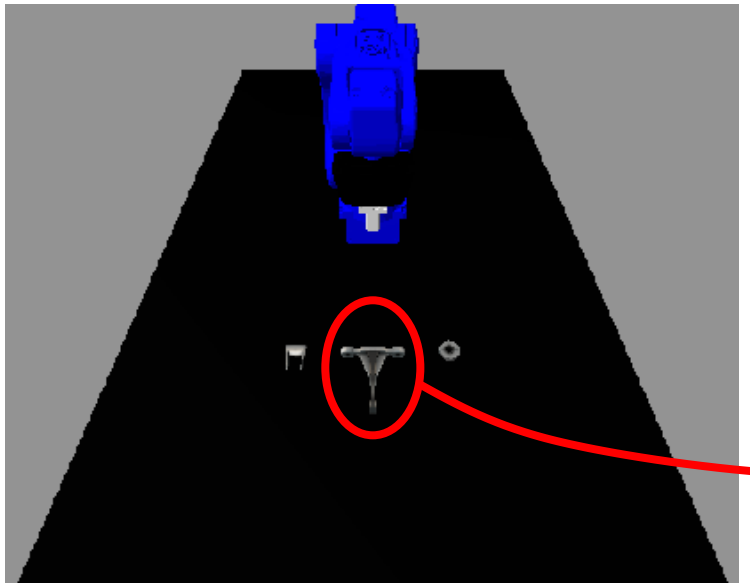
Position estimation with point cloud

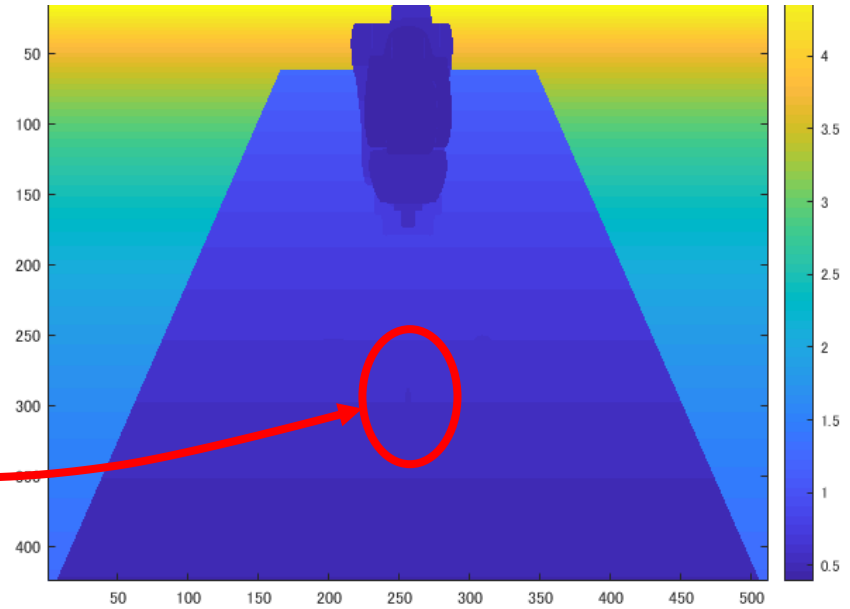
Position estimation by point cloud

MATLAB
Simulink

Computer Vision Toolbox™

- Use of both RGB image and depth image data by RGBD sensor





Object detection
with RGB image

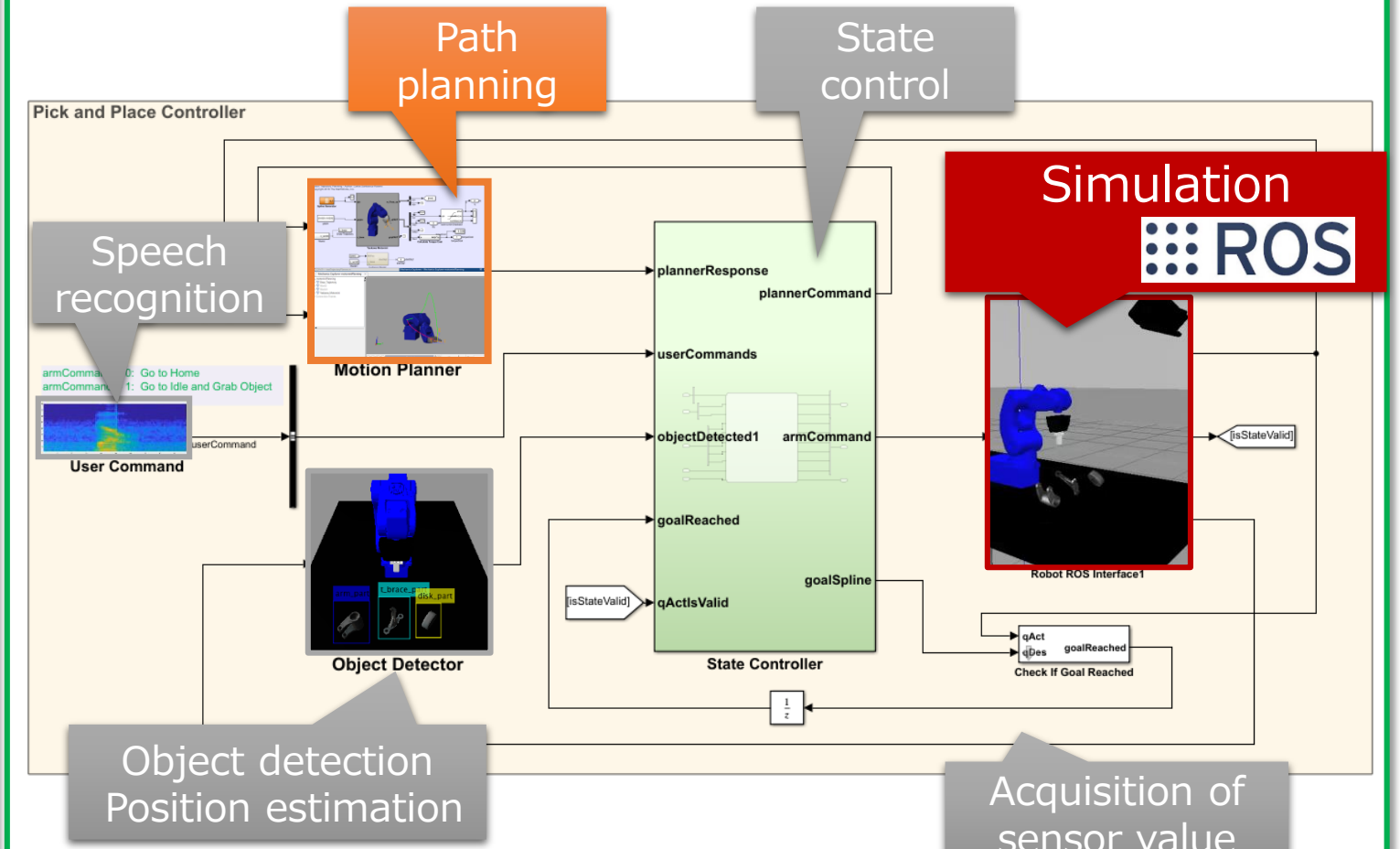
Get the depth of the corresponding
position in the depth image

Sample app overview : 2. Path planning

Flow of explanation

1. Object detection Position estimation
2. Path planning
3. Speech recognition
4. State machine

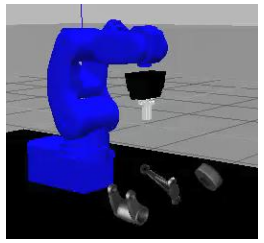
Block diagram (Simulink model)



Path planning flow

Setting ROS

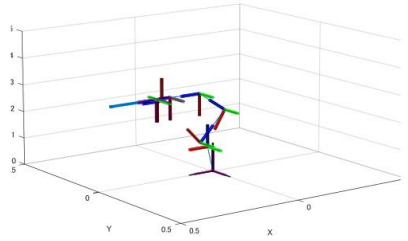
- Robot config (URDF, CAD)



ROS->MATLAB import

Tree MATLAB Simulink

- Easy access to ROS config data

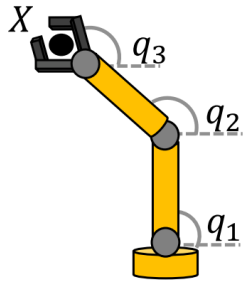


Robotics System Toolbox™

Kinematics Parameter

IK MATLAB Simulink

- Hand start / end point specification
- Calculate joint angle

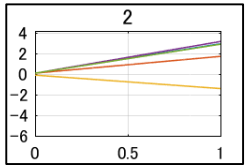


Robotics System Toolbox™

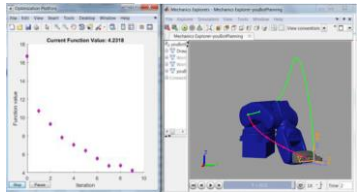
Initial posture / final posture (joint angle expression)

Path planning MATLAB Simulink

- Initial joint angle path (Linear interpolation)

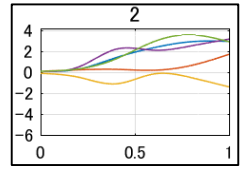


- Optimization



Simscape™ Multibody™
Optimization Toolbox™

- Optimal joint angle path (Spline interpolation)

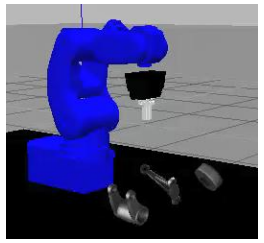


ROS

Path planning flow

Setting ROS

- Robot config (URDF, CAD)



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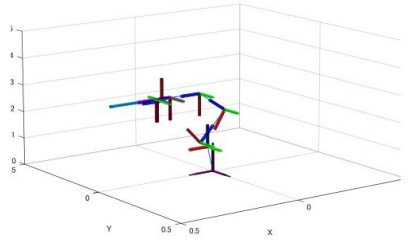
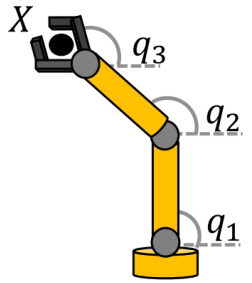


Robotics System Toolbox™

Kinematics Parameter

IK MATLAB Simulink

- Hand start / end point specification
- Calculate joint angle



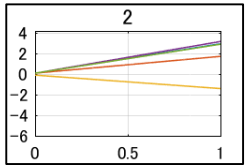
Robotics System Toolbox™

Initial posture / final posture (joint angle expression)

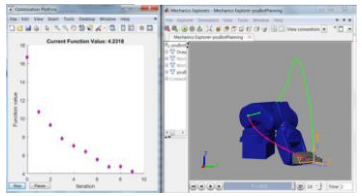
Path planning MATLAB Simulink

Explain from now

- Initial joint angle path (Linear interpolation)

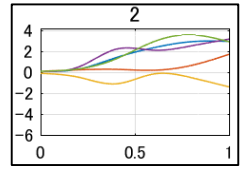


- Optimization



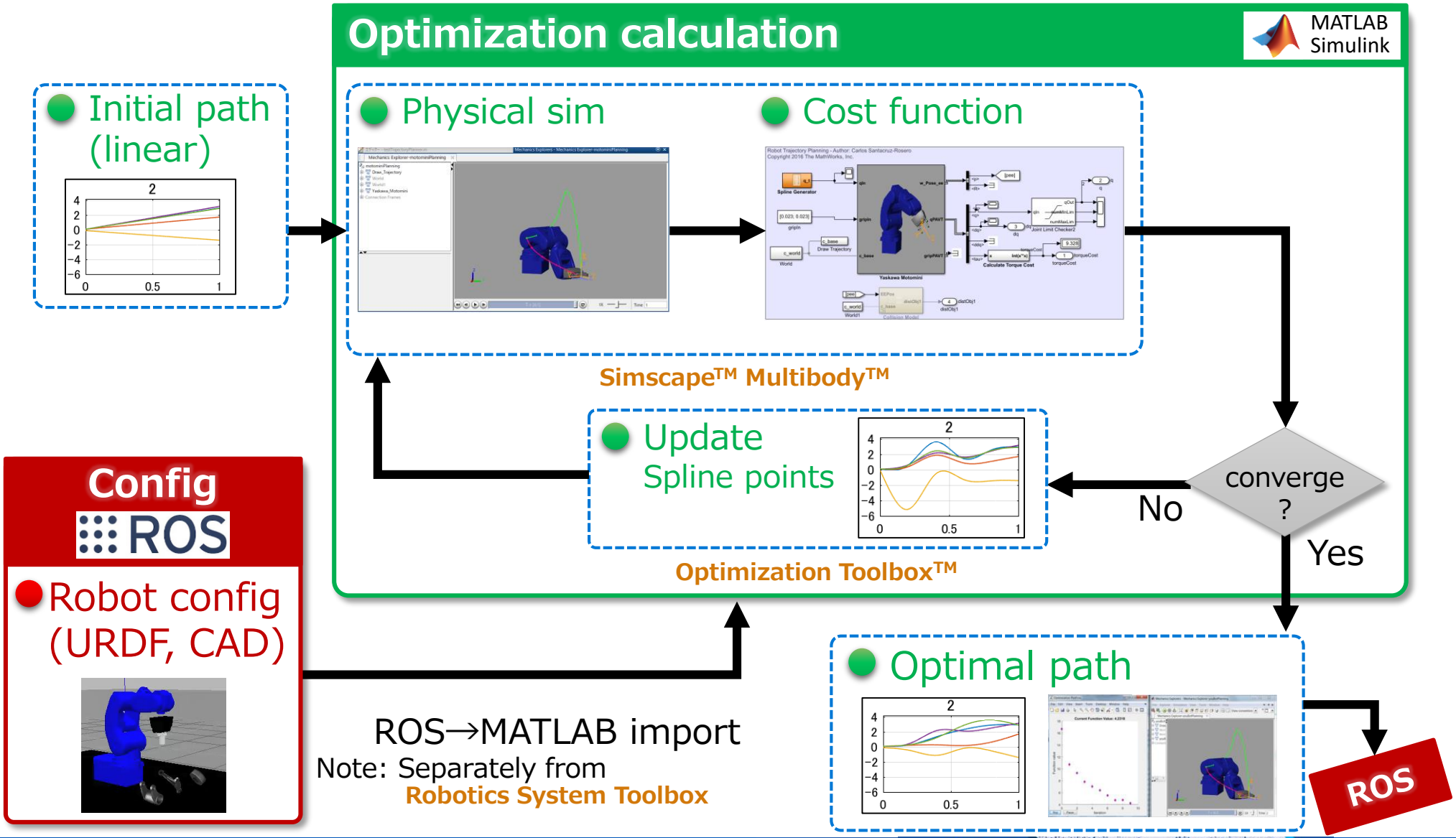
Simscape™ Multibody™ Optimization Toolbox™

- Optimal joint angle path (Spline interpolation)



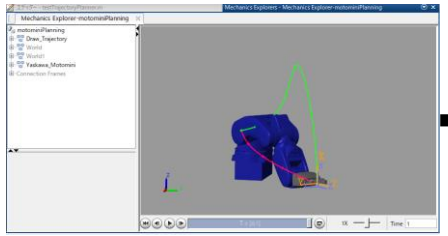
ROS

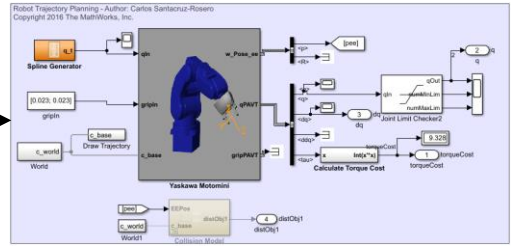
Optimization overview



Optimization overview: Main points

- Physical sim
- Cost function



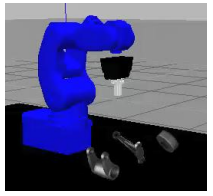


Simscape™ Multibody™

Config

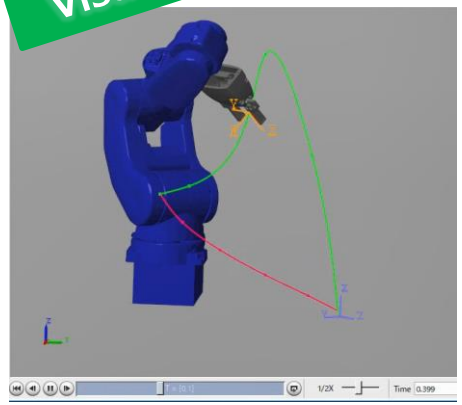
ROS

- Robot config (URDF, CAD)

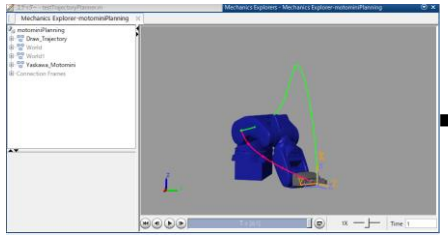


Optimization overview：Main points

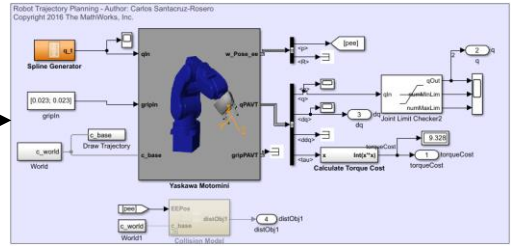
IK simulation
Visualization of 3D motion



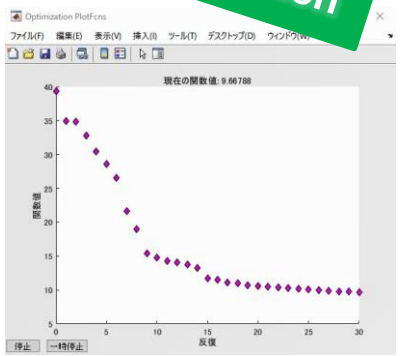
Physical sim



Cost function



Calculate torque by simulation
Total torque cost optimization



Simscape™ Multibody™

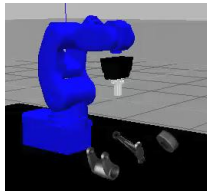
URDF

STL

Config

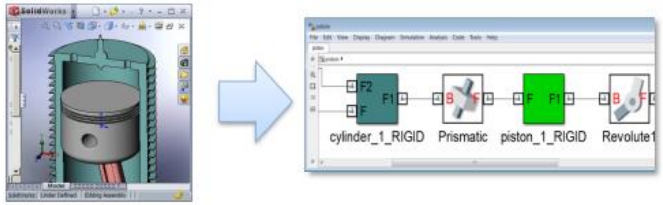
ROS

- Robot config (URDF, CAD)



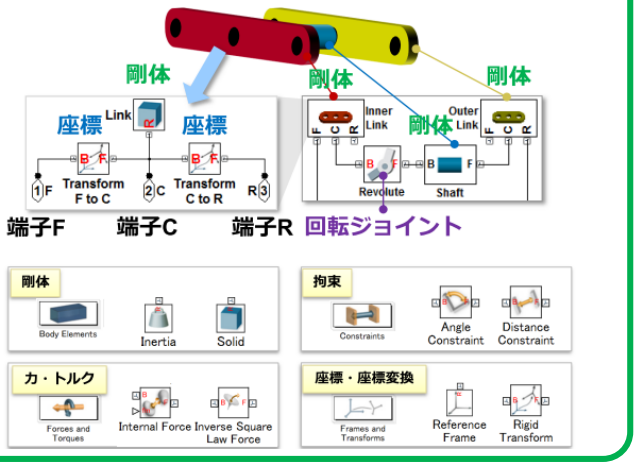
CAD import

MATLAB Simulink



URDF import

MATLAB Simulink



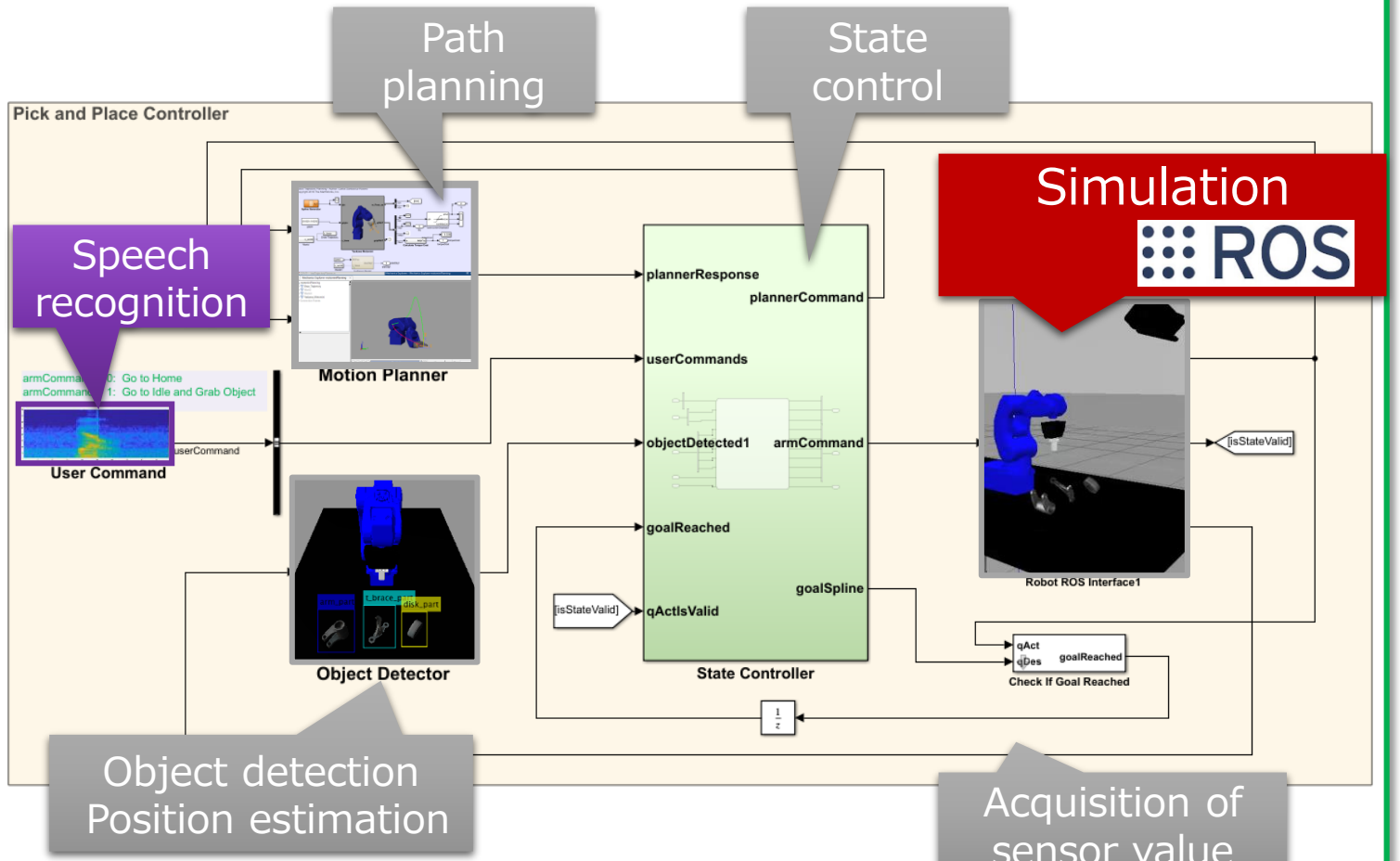
Cooperation is easy by the import function of ROS information

Sample app overview : 3. Speech recognition

Flow of explanation

1. Object detection Position estimation
2. Path planning
3. Speech recognition
4. State machine

Block diagram (Simulink model)



Speech recognition flow

Spectrogram conversion

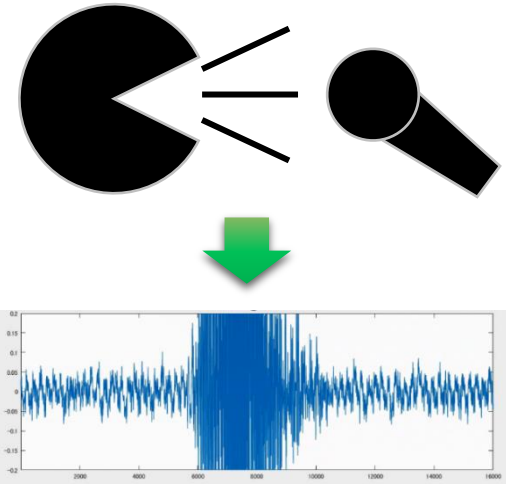
Word recognition result

Operation instruction

State Control

Voice input

- Via mic.
- Acquire sound signal

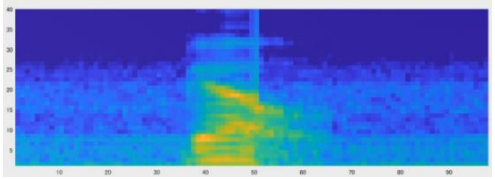


Audio Toolbox™

MATLAB Simulink

Voice recognition

- Spectrogram img
- Word recognition w/t CNN



“go” “right” …

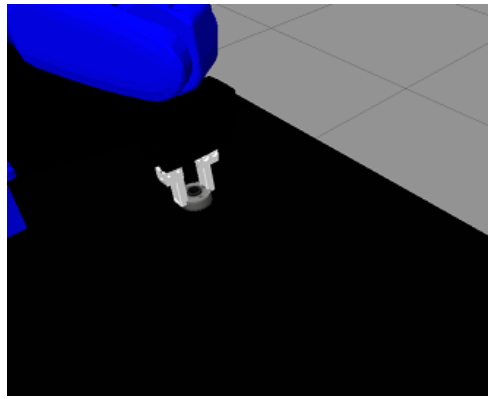
Explain from now

Deep Learning Toolbox™
Audio Toolbox™

MATLAB Simulink

Operation command

- generate motion instruction to hold the specified work



Robotics System Toolbox™

MATLAB Simulink

Speech recognition Using deep learning (CNN)

Flow of speech recognition w/t CNN

MATLAB Simulink

Learning

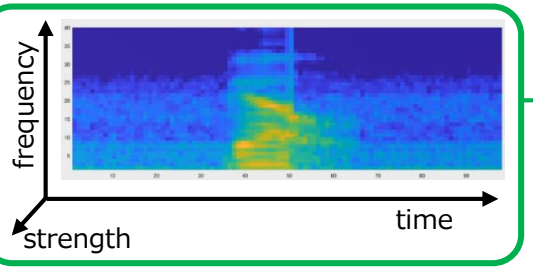
Voice data set

word1 word2 ⋯

Audio Toolbox™

Conv.

Spectrogram image



Audio Toolbox™

Input img

Feature extraction + learning

CNN

Deep Learning Toolbox™

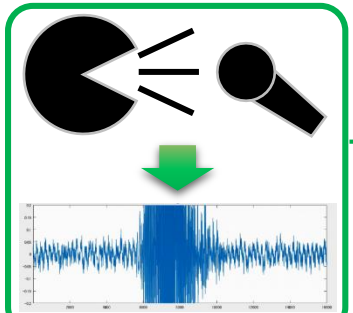
Learned Model

Label

Recognition

Recognition

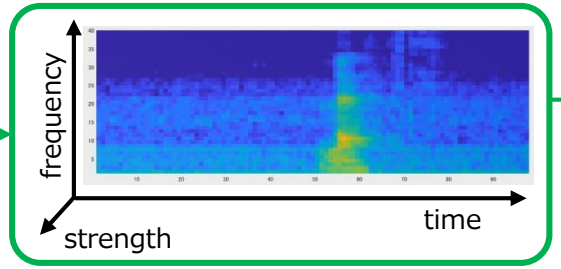
Voice input



Audio Toolbox™

Conv.

Spectrogram image



Audio Toolbox™

Input img

Feature extraction + classification

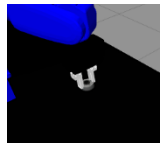
Learned CNN

Deep Learning Toolbox™

Word recognition

Motion: go, stop
Place: left, center, right

Motion instruction generation



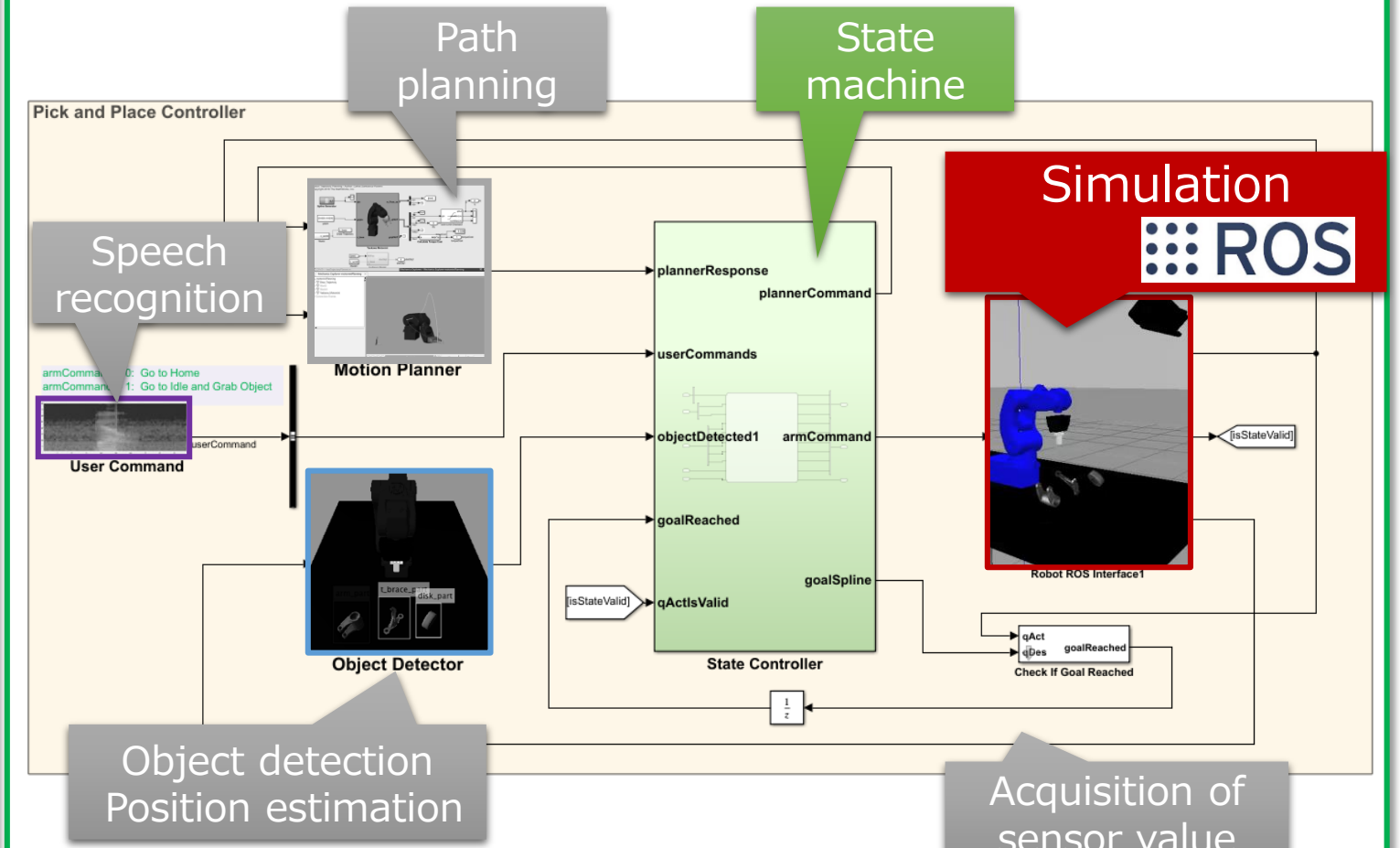
State Control

Sample app overview : 4. State machine

Flow of explanation

1. Object detection Position estimation
2. Path planning
3. Speech recognition
4. State machine

Block diagram (Simulink model)



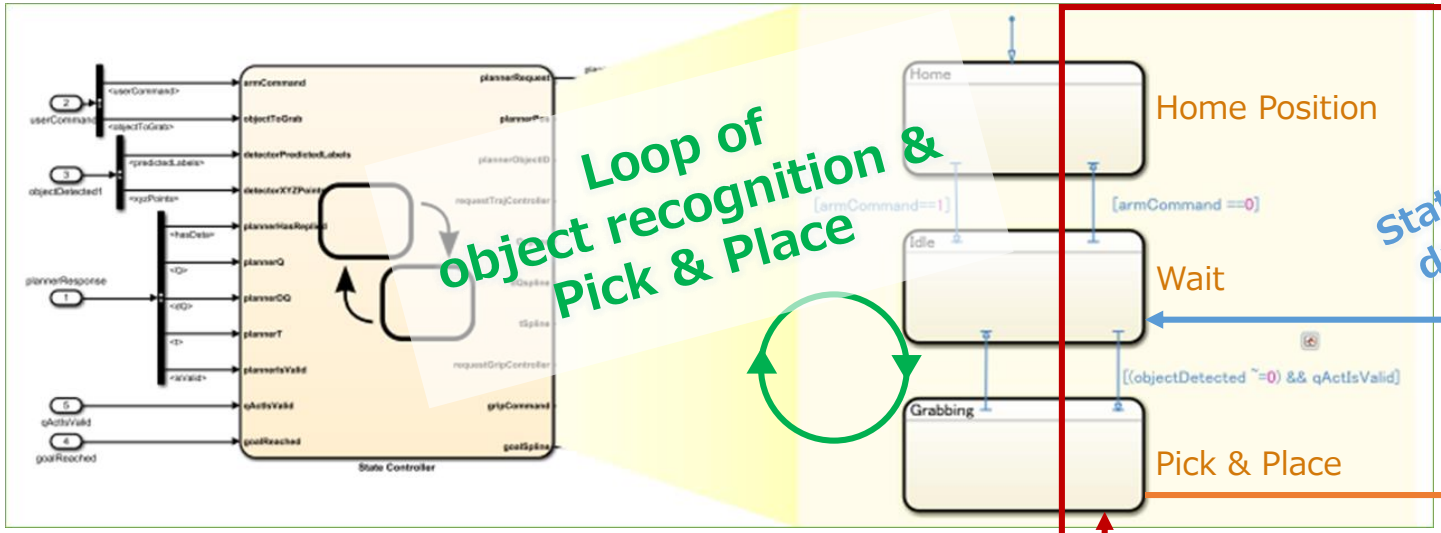
State machine

Control modules by state transition

MATLAB Simulink

Stateflow®

- State management of manipulator

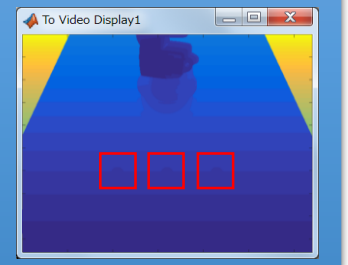


image

ROS

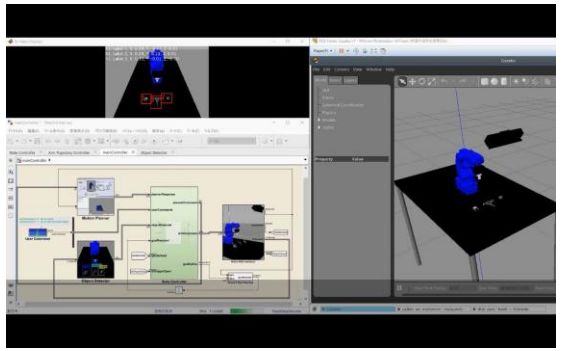
Object Recognition

MATLAB Simulink

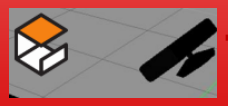


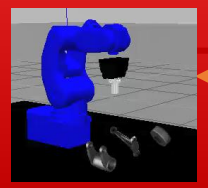
State transition during object detection

Path planning based on object position



ROS





ROS

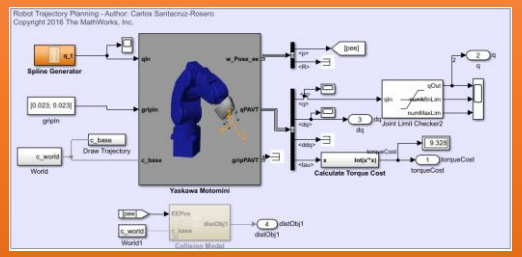
Pick and place Completion

Joint path Open/close

ROS

Path planning

MATLAB Simulink



Outline

1. Motivation

- Robotics System ToolboxTM
- What's ROS-Industrial?
- Pros for ROS+MATLAB

2. Sample Apps

- Pick & Place App Overview
- Detail on each functions

3. Impression as a User

- Pros
- Cons
- Expecting Future work

Impression & Requests as a User of MATLAB

Pros

- Easy collaboration with advanced functions
  → ROS alone can not be handled as easily as MATLAB
- Highly compatible with ROS, such as URDF, TF, Gazebo I/F too.
- Easy to use sequencer and blocking GUI such as StateFlow and Simulink
- Development based on Example enables early startup of prototypes

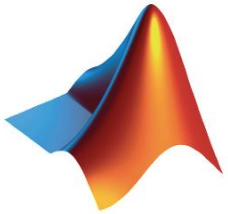
Cons

- Processing takes time → Speeding up with Coder is also possible
- The parts requiring tuning are dispersed when changing the robot
- Some apps require to load the robot model separately for each toolbox

Expecting Future work

- Import MATLAB motor and other models as Gazebo plug-in
- Need a sample where ROS for Windows and MATLAB work together
  → Currently there is only the tutorials where ROS runs on Linux on VM
- Support for ROS 2 and V-REP too!

YASKAWA



MATLAB/Simulink

ROS

GAZEBO

Labeling for YOLOv2

Training data

MATLAB Simulink

- Place works with random sets of position and posture
- Automatically capture parts images with various poses
- Automatically estimate bounding boxes and labels

Gazebo

ROS

- Replace works from MATLAB
- Send images to ROS