ROS based Control of a 7-DoF Robot Arm for BMI

Reporter： Zhu Xiaoxiao

Date： 2017.1.27

Self-introduction

- I am a post-doc in the Prof. Cao Qixin's Lab in Shanghai Jiao Tong University (SJTU). The main research areas are machine vision, modularity technology and robot localization.
- Researched in the Prof. Yokoyi's Lab from 2016.7.1~2017.1.31. The research project is an automatic Pick & Place robot arm for the BMI system.

UEC TOKYO

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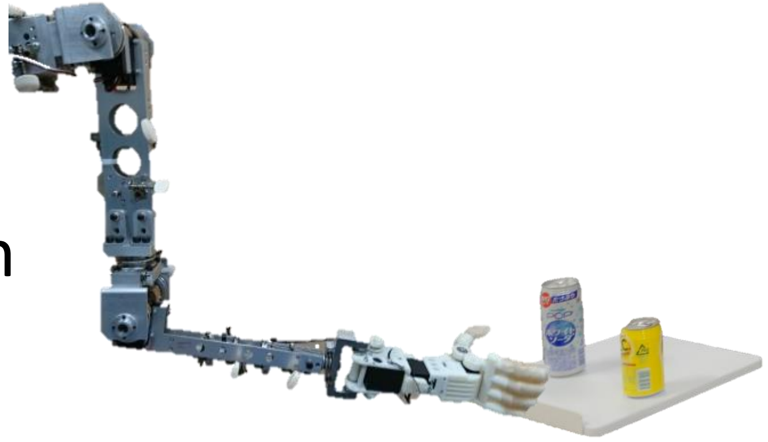

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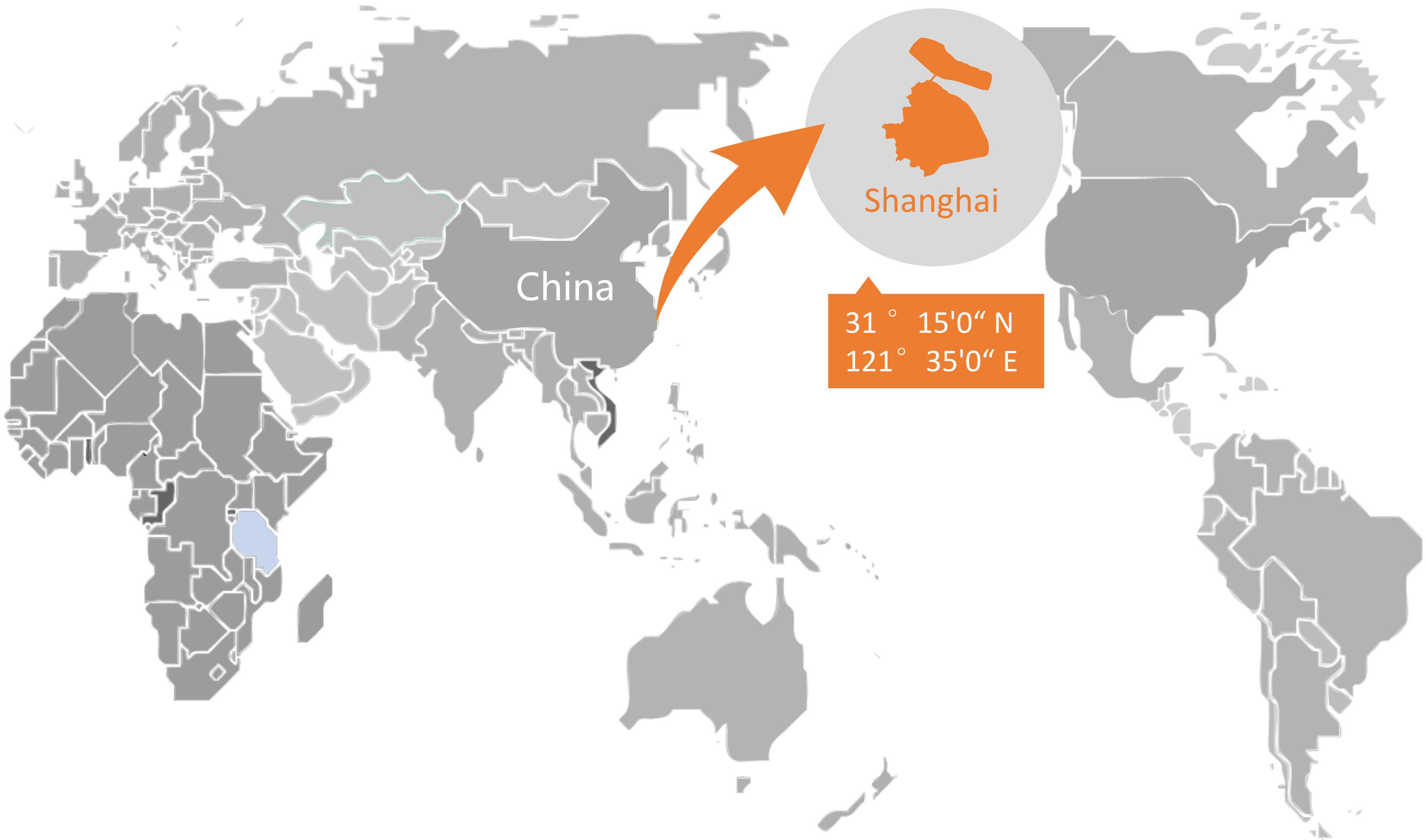

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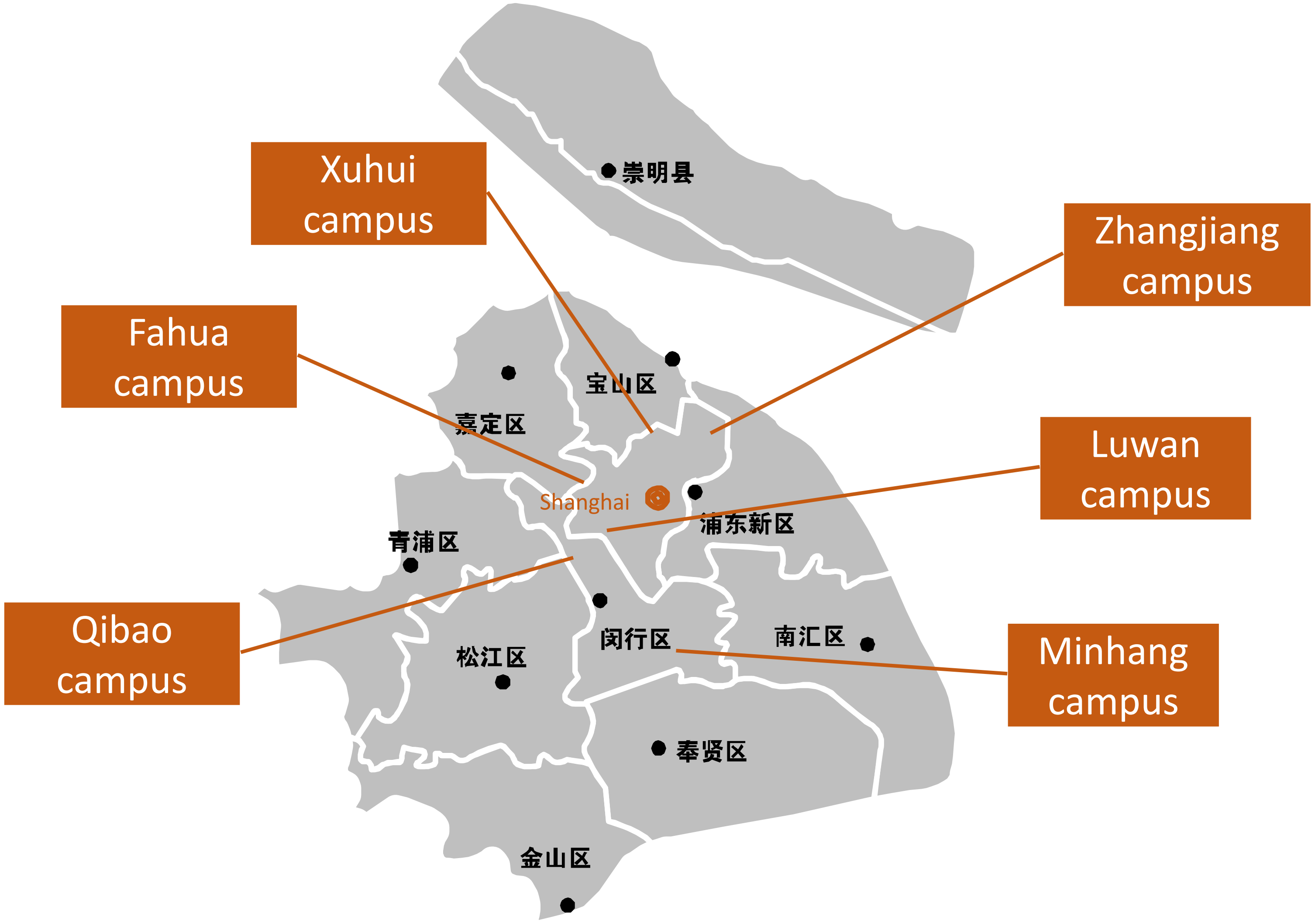


交通大學

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY
2006
Kaixuan gate

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Today SJTU has 62 undergraduate programs covering 9 major disciplines: economics, law, literature, science, engineering, agriculture, medicine, management and arts.

By December 2015, SJTU has had 29 schools/departments, 25 directly-affiliated institutions, 13 affiliated hospitals, with 16,188 undergraduates and 20,347 postgraduates (13,841master degree candidates and 6,506 doctorate degree candidates)， 2,134 overseas students.

Up to 2015, SJTU led the country for the 6th consecutive year in terms of both the project number and the amount of money issued by National Natural Science Foundation of China, ranked second in sponsored research grants. The total number of SCI-cited papers from 2005 to 2014 reaches 35,488, with 308,723 times of citation, ranking the second in China.

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Robotics Institute of SJTU was established in 1985(its predecessor was Robot Laboratory established in 1979). One of the earliest robotics professional research organization in China. The existing 30 teachers , about 60 PhD students, more than 50 master students.

Prof. Ichiro Kato, the father of Japanese humanoid robot, is our honorary director of the Institute during his lifetime.

Shanghai No. 1 is the China 's first teaching-and-replay robot

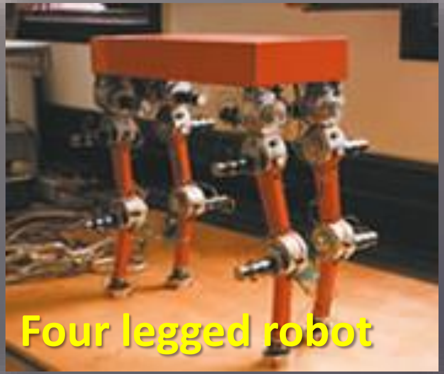
Former President Jiang Zemin was watching the performance of "Shanghai No. 1" on the conference of major science and technology

Former Prime Minister Zhu Rongji in Shanghai watched "Shanghai No. 1" Performance, on "the introduction of digestion Exhibition"

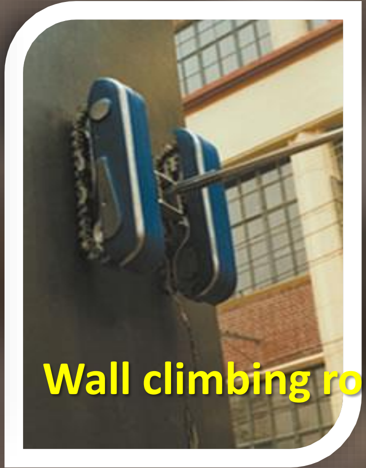
Researching a lot kind of robots

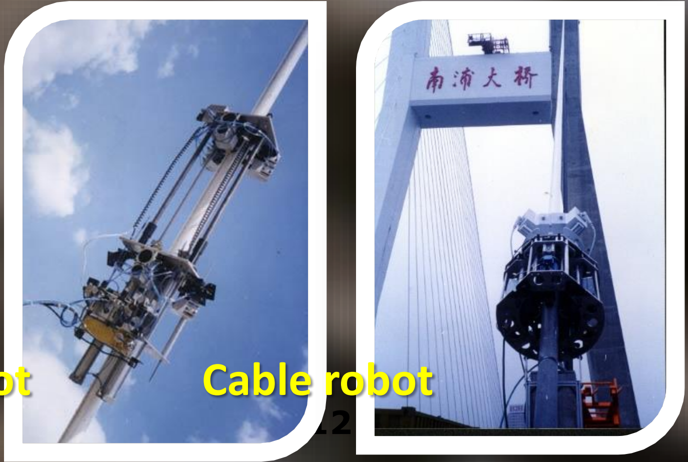

Fire robot


EOD robot

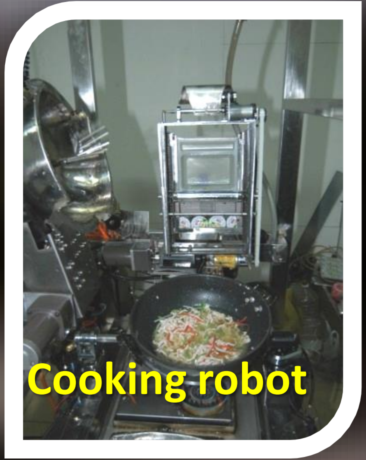

Four legged robot


Electric cleaning robot


Wall climbing robot



Cable robot


Cooking robot

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Prof. Cao's Lab

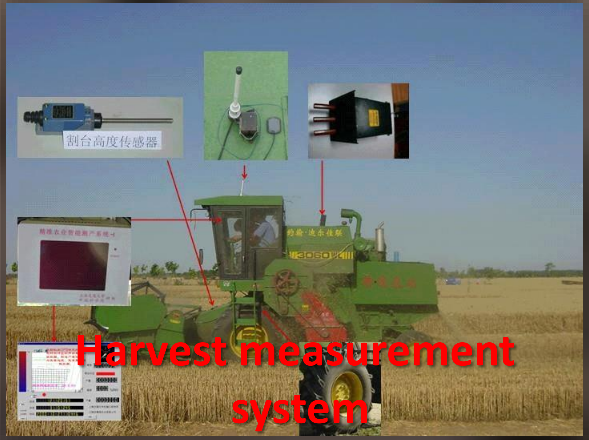
Get the Ph.D. in Agricultural Mechanical Engineering, Kagoshima University, Japan.
And then teaching in SJTU from 1998.
He is the executive deputy director of the Institute of Robotics and the director of the Institute of Biomedical Manufacturing and Life Quality Engineering.

Published more than 70 SCI/EI journal papers, obtained 90 Chinese patents, and 4 Chinese academic awards.

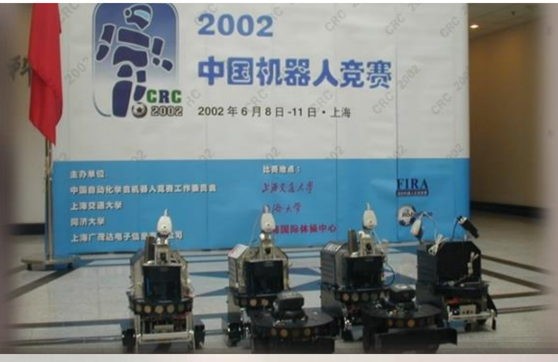
Robots

Agricultural	Competition	Service	Industry	Medical

Robots for Agricultural



Prof. cao, guided students to participate in the NHK 1998 ROBOCON competition in Japan won the mayor Award. And he organized the first china’s robot football competition in 2002. Since 2003, he began as the CCTV National College robot contest evaluation expert



Service robot and special robot

Flute robot

Performing robot

Toy robot

Oil pipeline inspection robot

Lunar rover

Educational robot

Painting robot

Service robot and special robot

科技部国际热核聚变实验堆(ITER)计划专项

MCF装备的智能维护
及远程操控技术研究

（2011GB113005）

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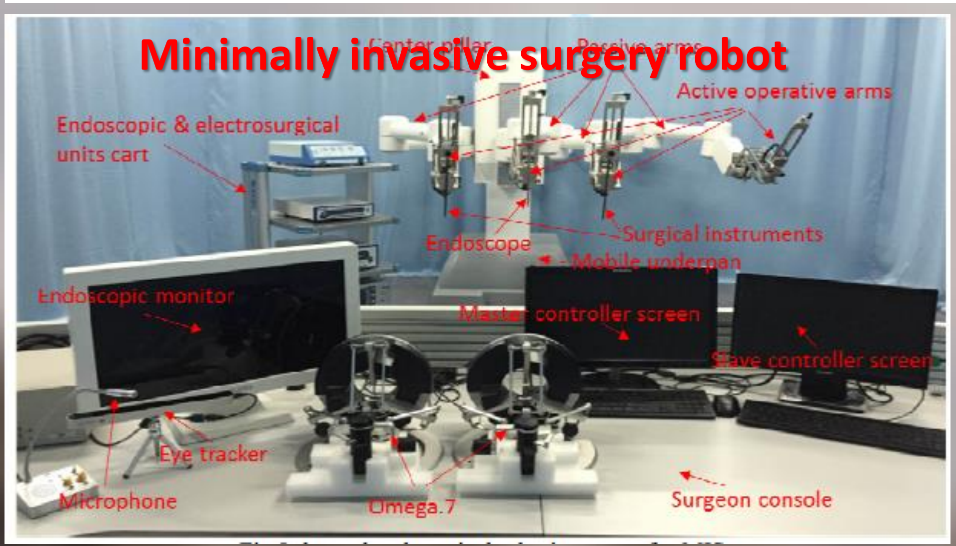
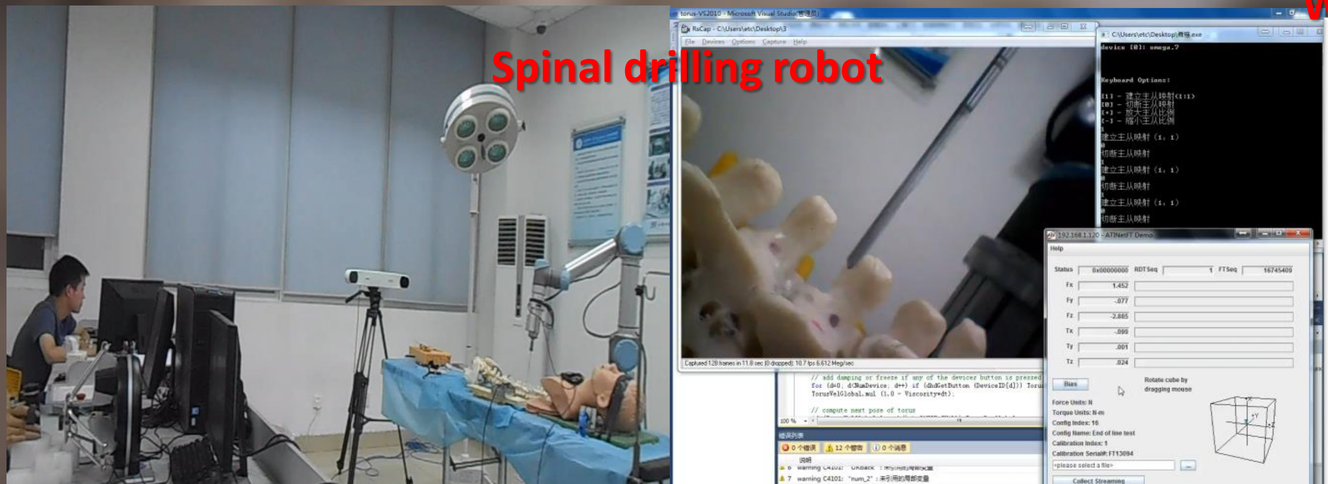
Industrial robot

Medical robots





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You are welcome to SJTU and our lab!

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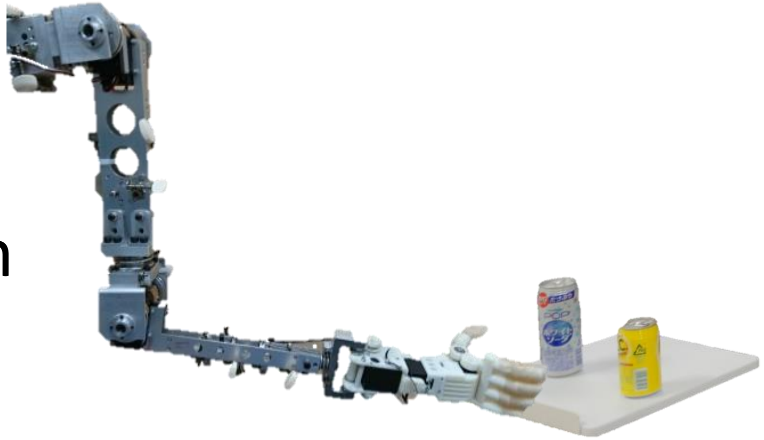
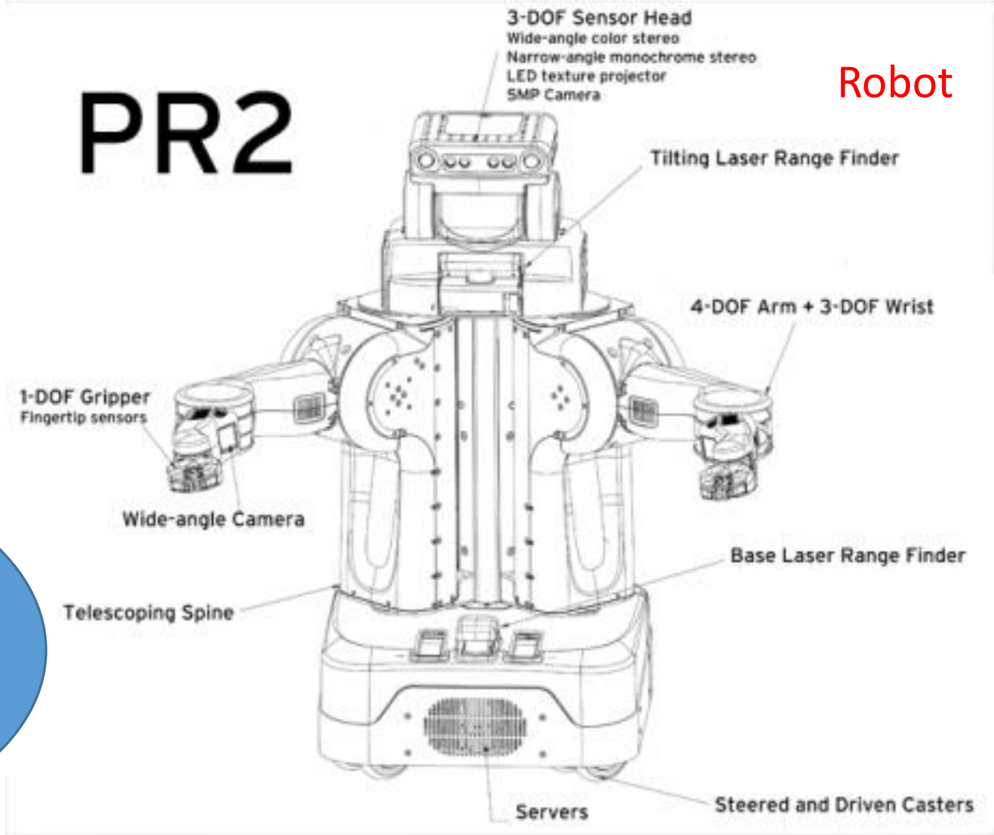


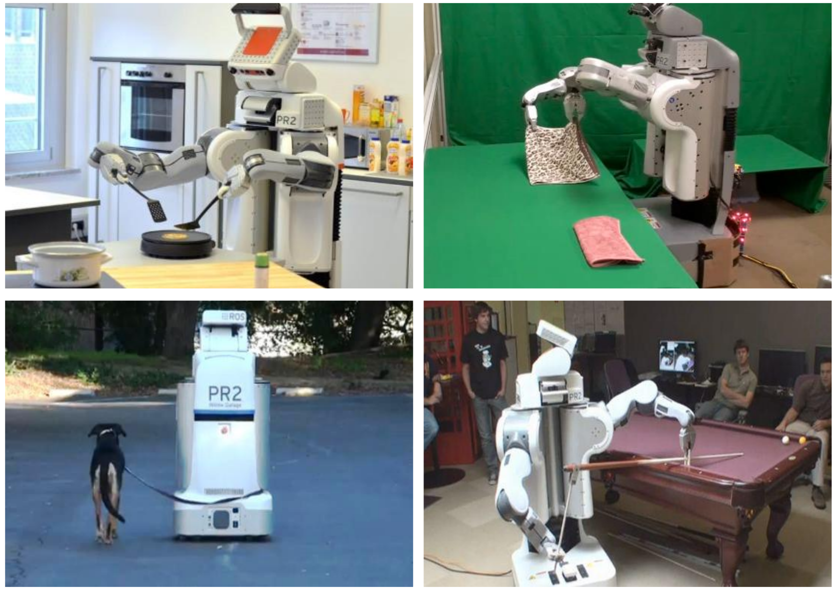
How to develop a robot system？

Develpe a PR2 robot

Robot

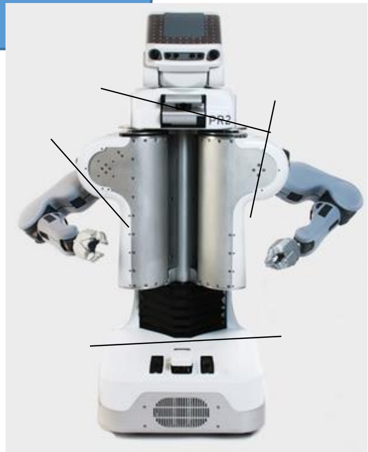


Applications



How to develop a robot system？

Ok， I need a team.
Divide the work



Hardware

Body

Arm

Mobile base

Head

Sensors

⋮

＋

Software

Drivers

Algorithms

System managers

Database

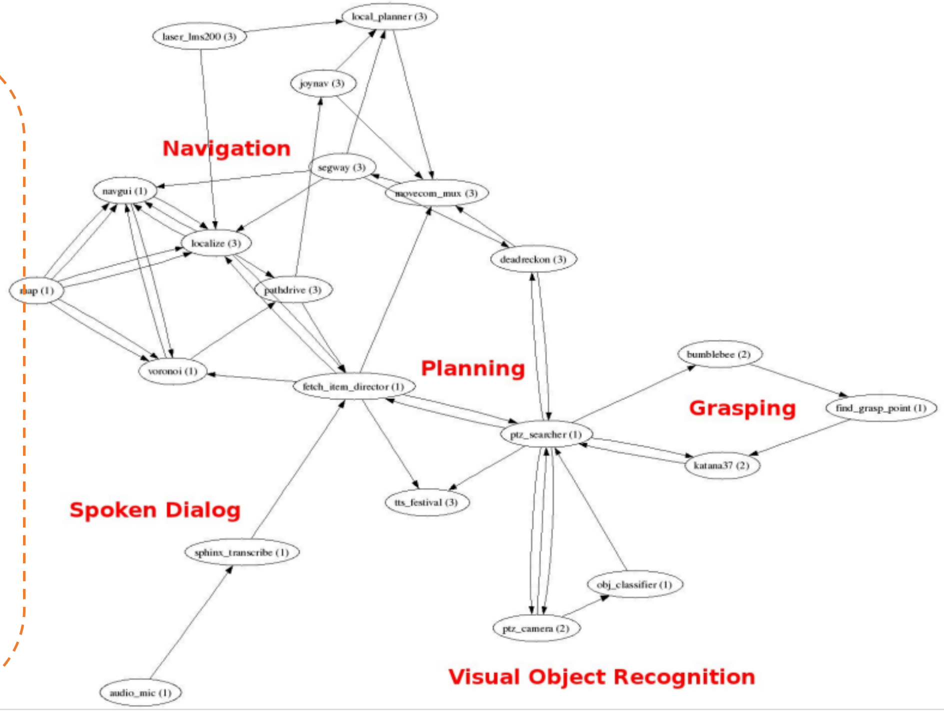
Applications

⋮

How to develop a robot system？

I need to manage the system

Structure clear
Robust
Easy management
Extendable
Easy updating
⋮



How to develop a robot system？

Laziness is human nature

I developed a similar arm
Reuse the design and code

Reuse

How to develop a robot system？

  Divide+Manage+Reuse+…

  Divide+Manage+Reuse+…

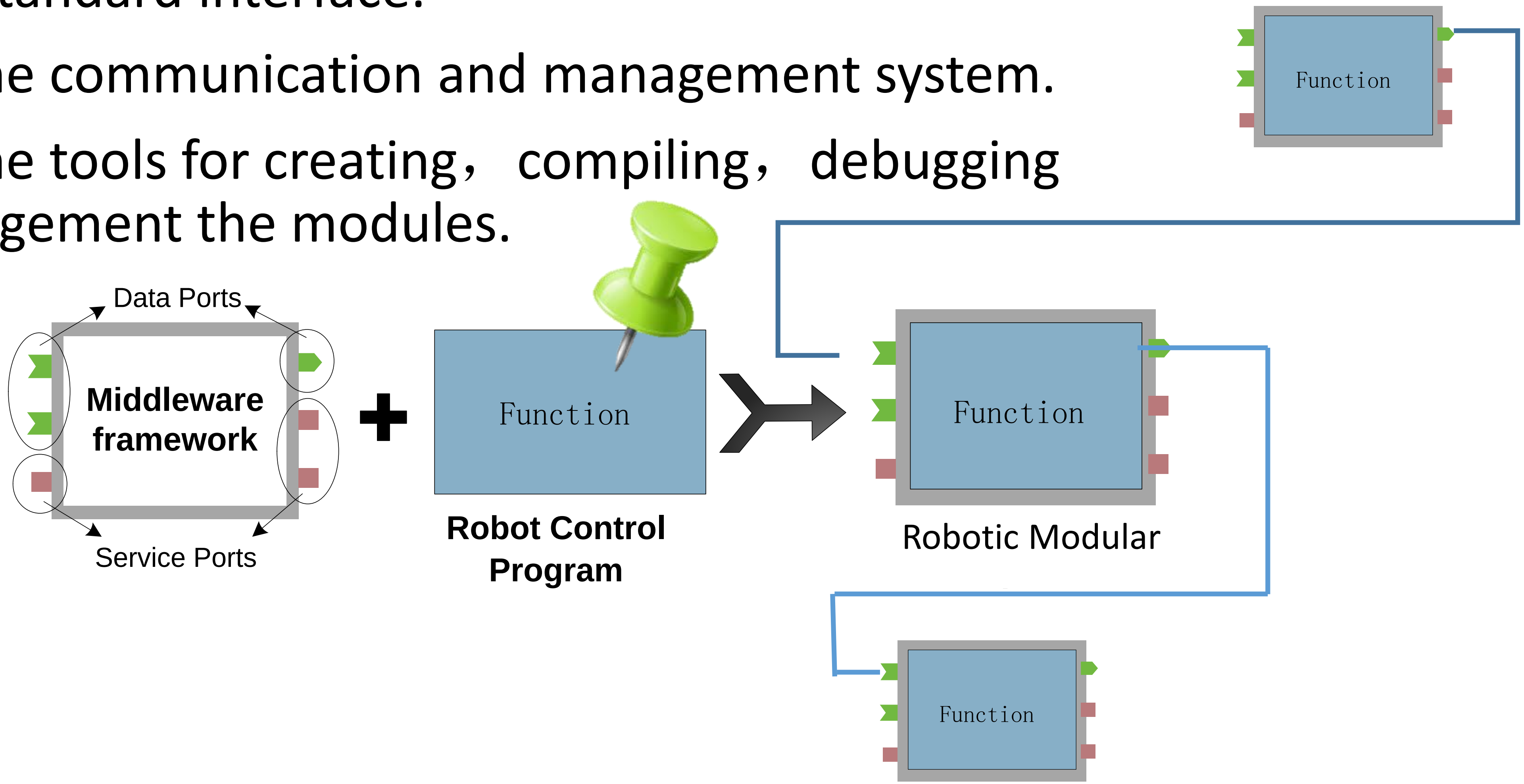
  Divide+Manage+Reuse+…

⋮

→ **Modularity Technology**

Robot modularity technology

- Define a standard interface.
- Provide the communication and management system.
- Provide the tools for creating, compiling, debugging and management the modules.



Robot modularity technology

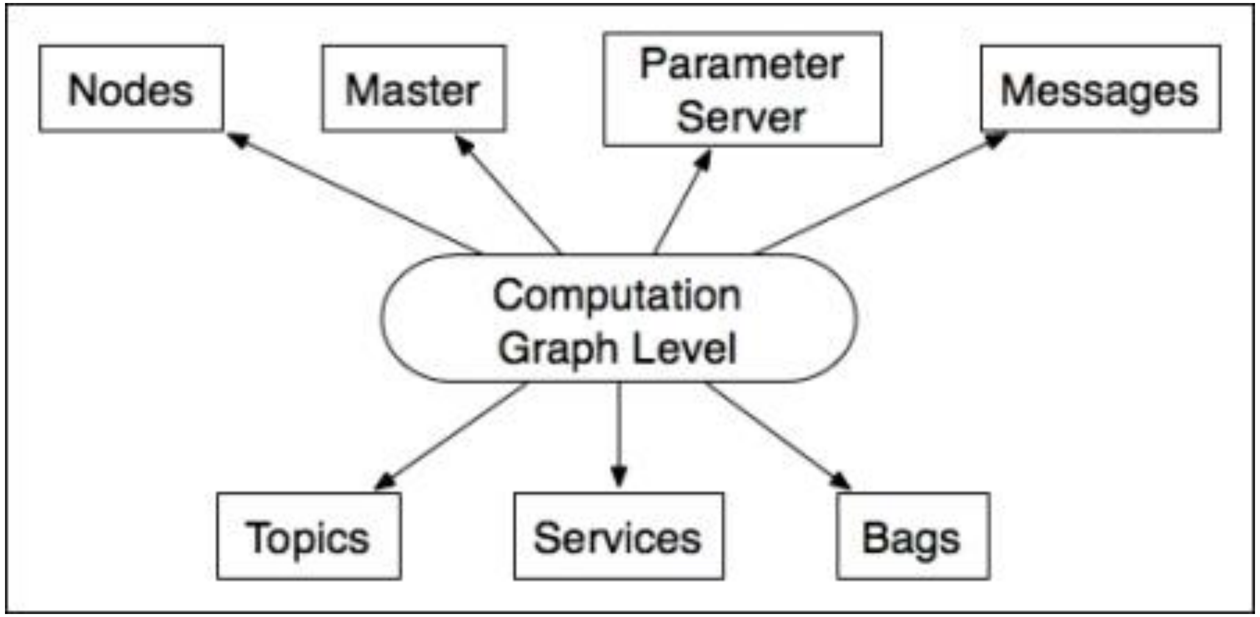
name	orginization	Used standard
OROCOS	K.U. Leuven in Belgium , LAAS Toulouse in France and KTH Stockholm in Sweden, *www.**orocos**.org/*	CORBA
Orca	KTH Stockholm, ***orca**-robotics.sourceforge.net/*	Ice
ROS	Willow Garage , *www.**ros**.org/*	TCPROS
OpenRT M-aist	Object Management Group (OMG) and AIST, *www.**openrtm**.org*	CORBA
Miro, UPnP Robot Middleware, ASEBA, Player / Stage, The PEIS Kernel, OriN, MARIE, RSCA, The Middleware of AWARE, Sensory Data Processing Middleware, Distributed Humanoid Robots Middleware, Layer for Incorporation, WURDE		

ROS(Robot Operating System)

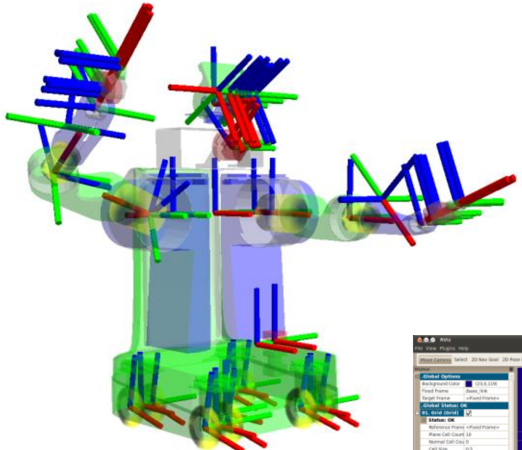
- The ROS is a flexible framework for writing robot software. It is a collection of tools, libraries, and conventions that aim to simplify the task of creating complex and robust robot behavior across a wide variety of robotic platforms.
- ROS is open-source and encourage *collaborative* robotics software development.

Introduction of ROS

Peer-to-peer graph network system

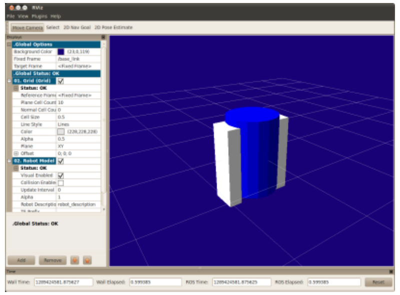


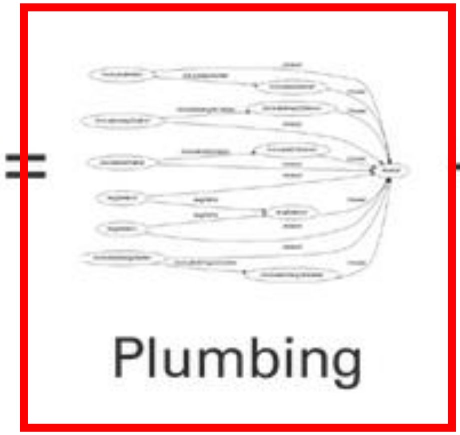
Robot-oriented functionality



Tf

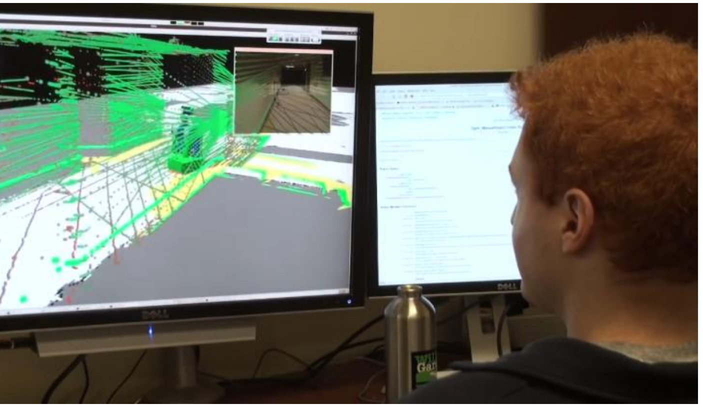
urdf



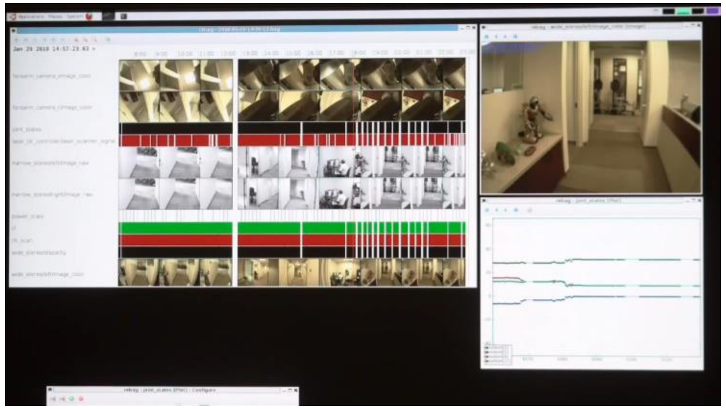


Introduction of ROS

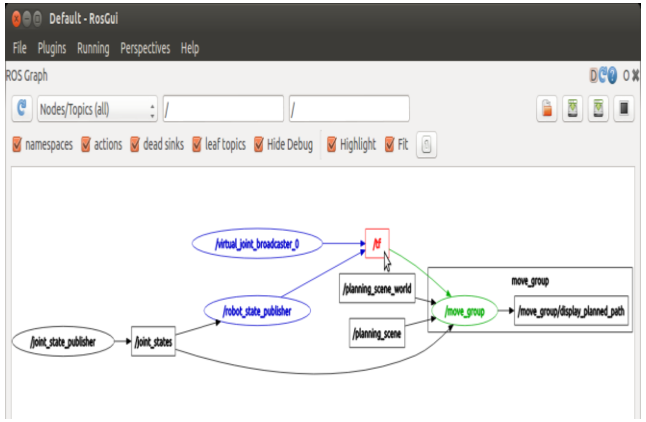
3D visualization



Data recording and playing back



System monitor



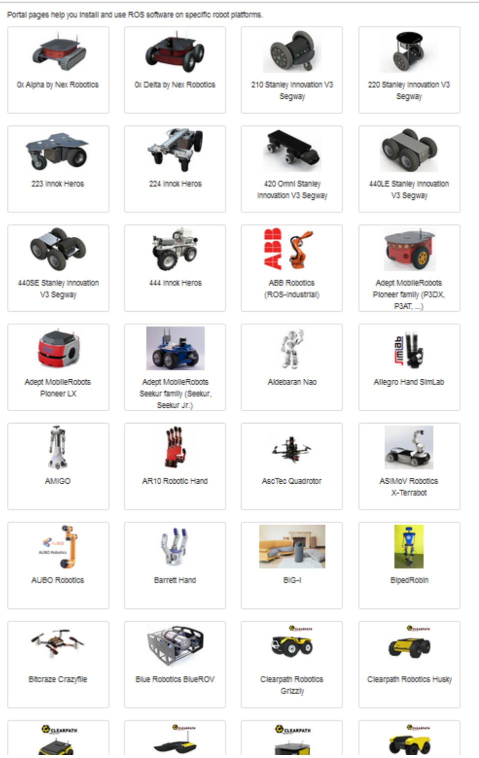
Command Line Tools

Introduction of ROS

- Provide 2500+ function packages.
- Integrated great software

pointcloudlibrary
GAZEBO
OpenCV
ROS industrial
MoveIt!

Robots



Sensors

目录

1. Portals

Portal pages help you install and use ROS software
information about tutorials and documentation of con

2D range finders 3D Sensors

Introduction of ROS

- **ROS wiki**
- **ROS Answer**
- **ROS blog**
- **ROSCon**

Smart factory based on ROS

ROS greatly accelerating the development

fetch robotics

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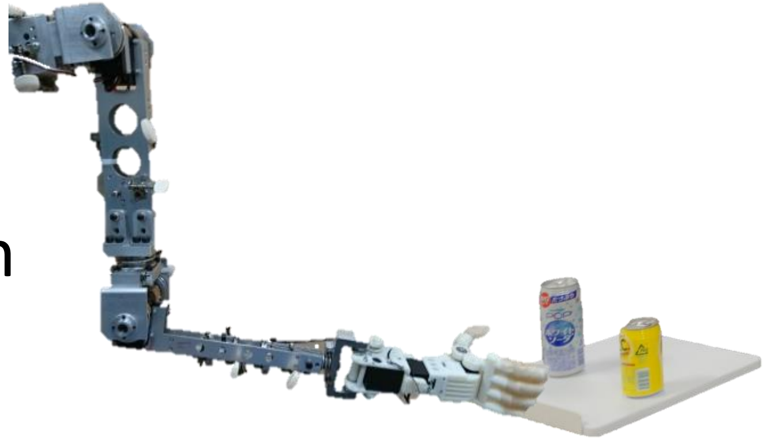


Background

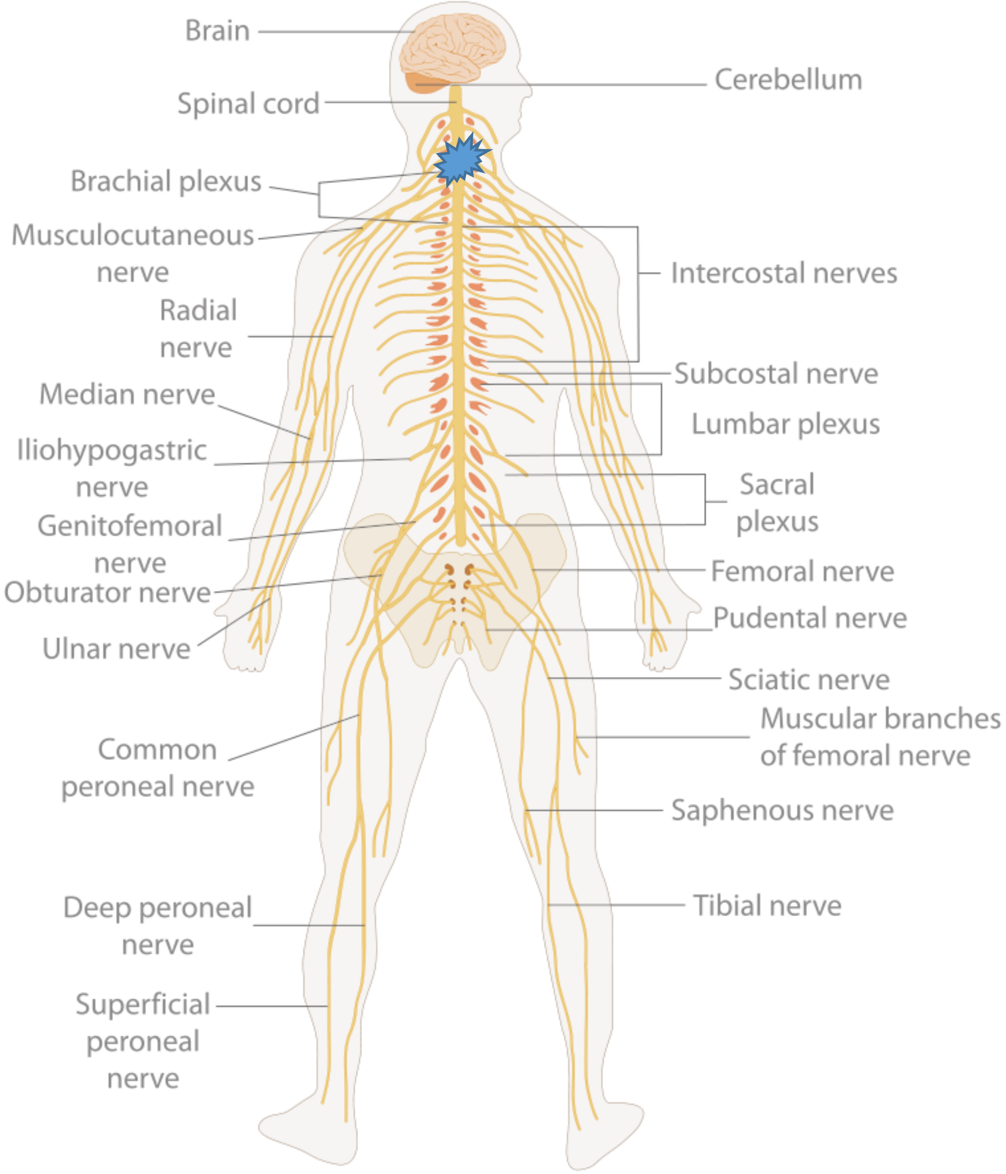
Paralysis (麻痺) is loss of muscle function for one or more muscles.
Reason: damage in the nervous system, such as, stroke, trauma with nerve injury, poliomyelitis, ALS, etc.

ALS(Amyotrophic lateral sclerosis,筋萎縮性側索硬化症)

Stephen William Hawking

2014 ice bucket challenge

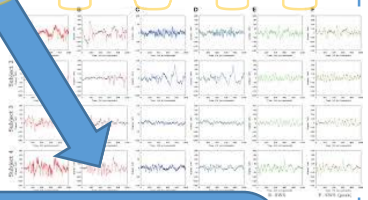
[wikipedia.org]



Brain Machine interface (BMI)

Sensor

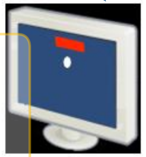
Signal reading

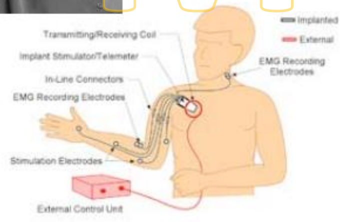


Signal Processing and transformation

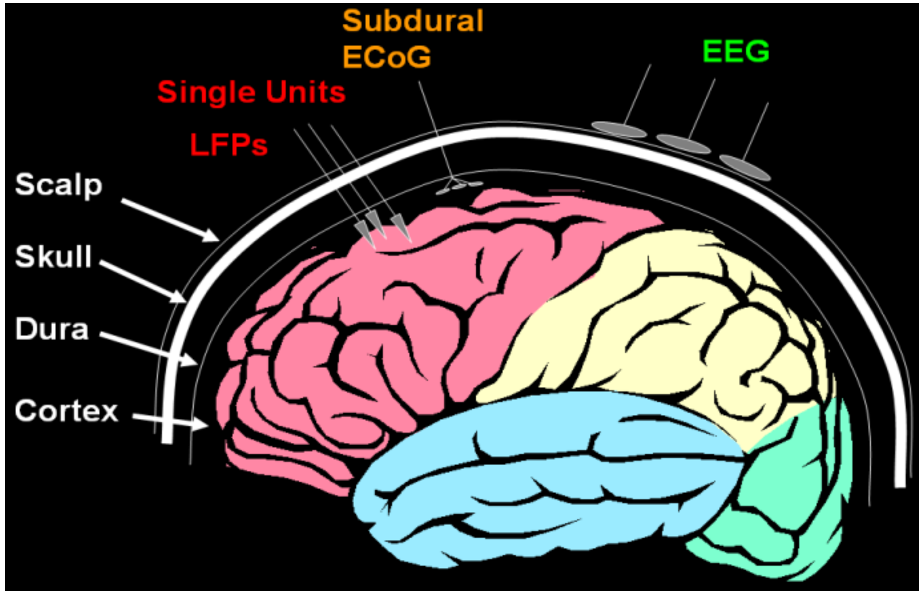
Feedback:
Visual, vocal
, Tactile

commands





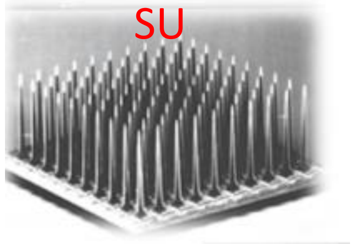
SU: Single-unit recording
ECoG: Electrocorticography
EEG: Electroencephalography



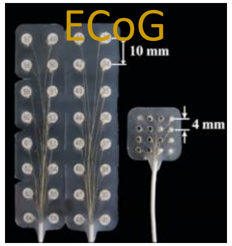
Invasion
Precision
Frequency

low

SU

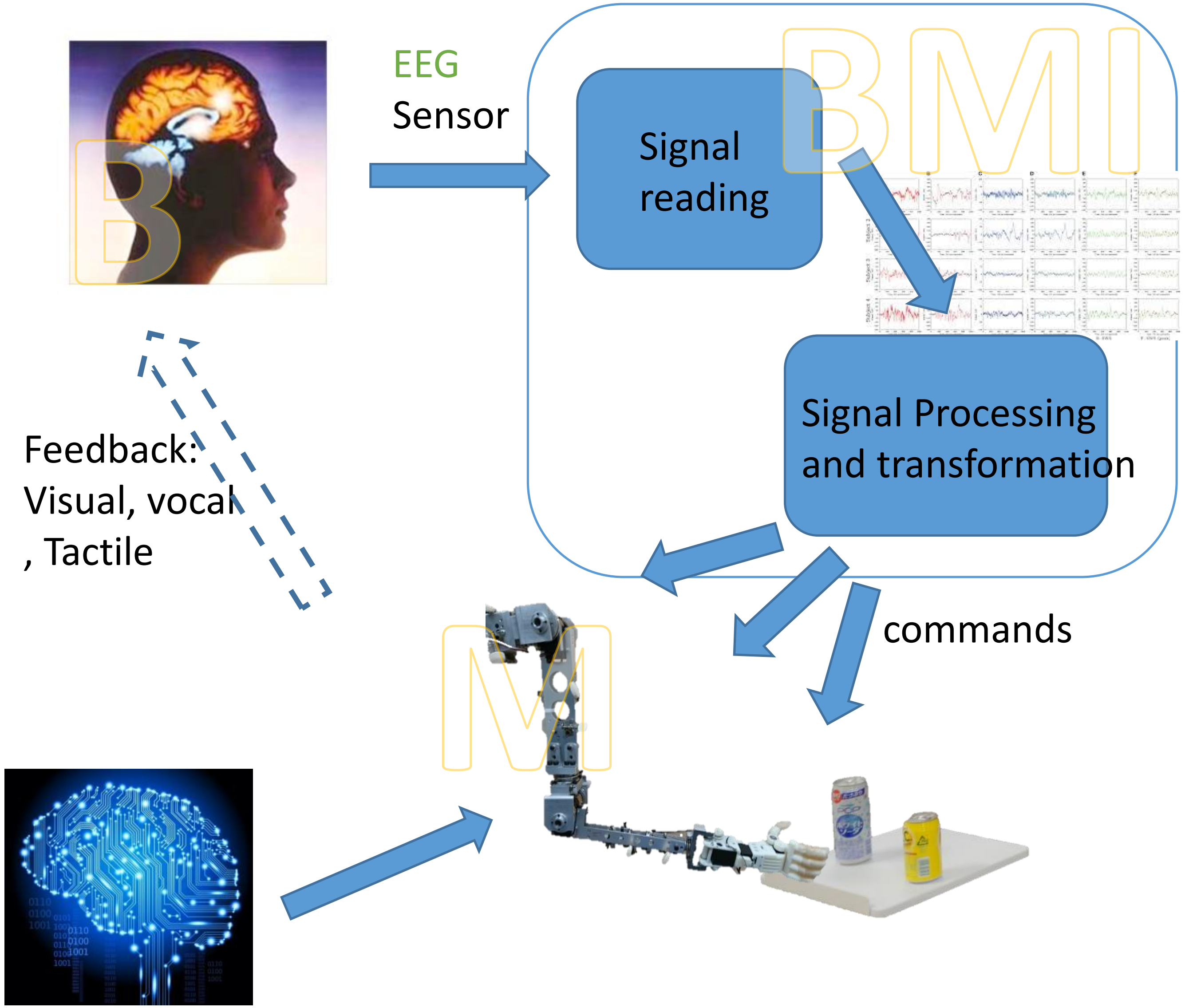


ECoG



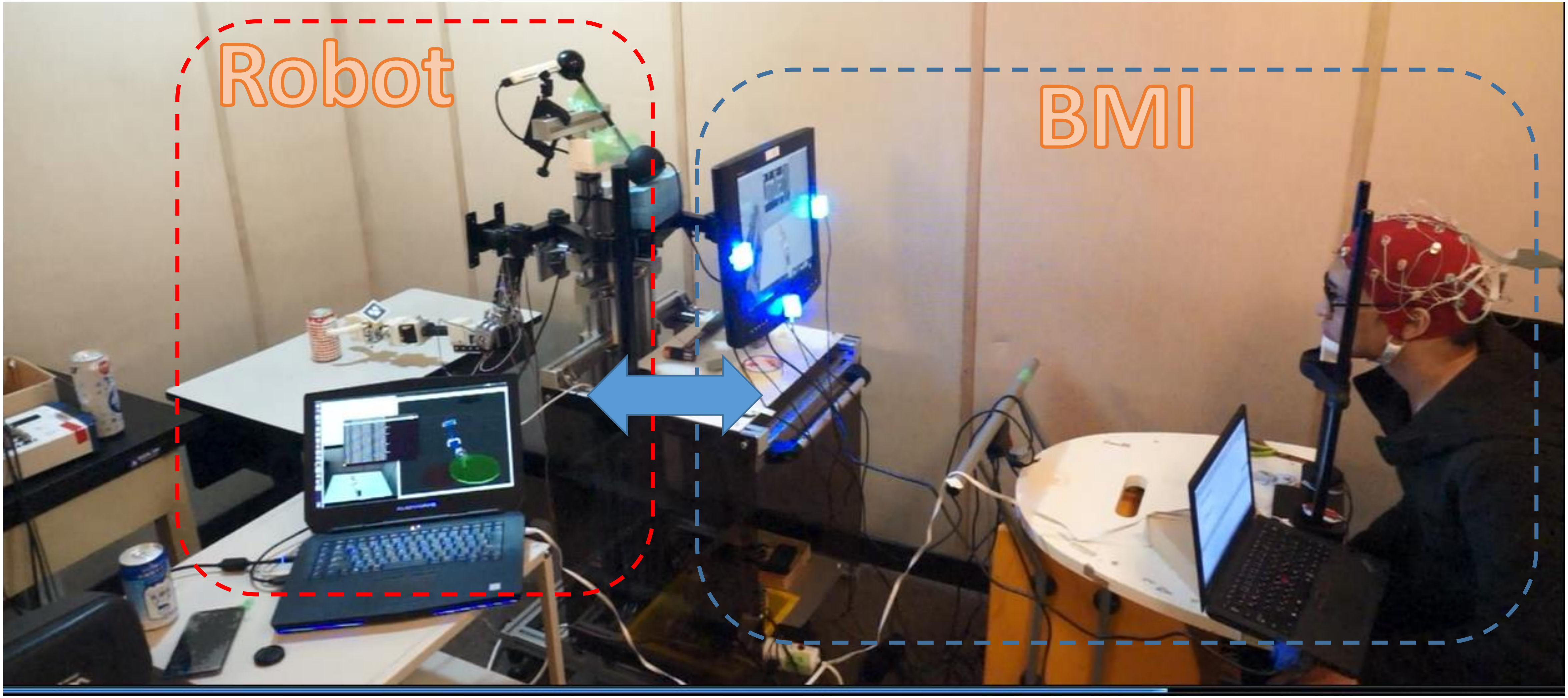
EEG

Project objective

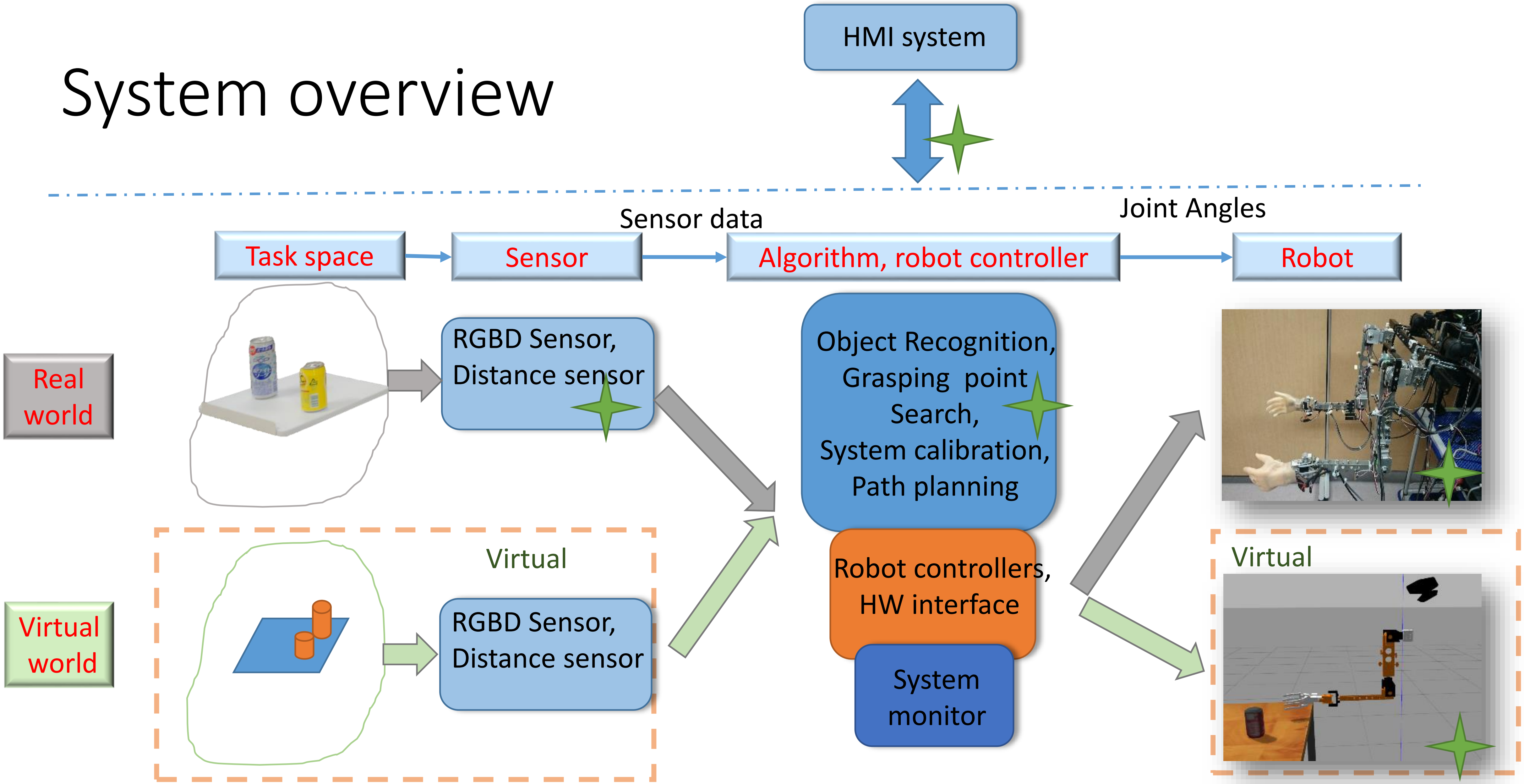


- Using EEG sensor and develop brain signal classification algorithm
- Develop a light but powerful robot arm
- Add some Automatic functions to assistant the patents
- Main task is grasping the objects on the table

System overview



System overview

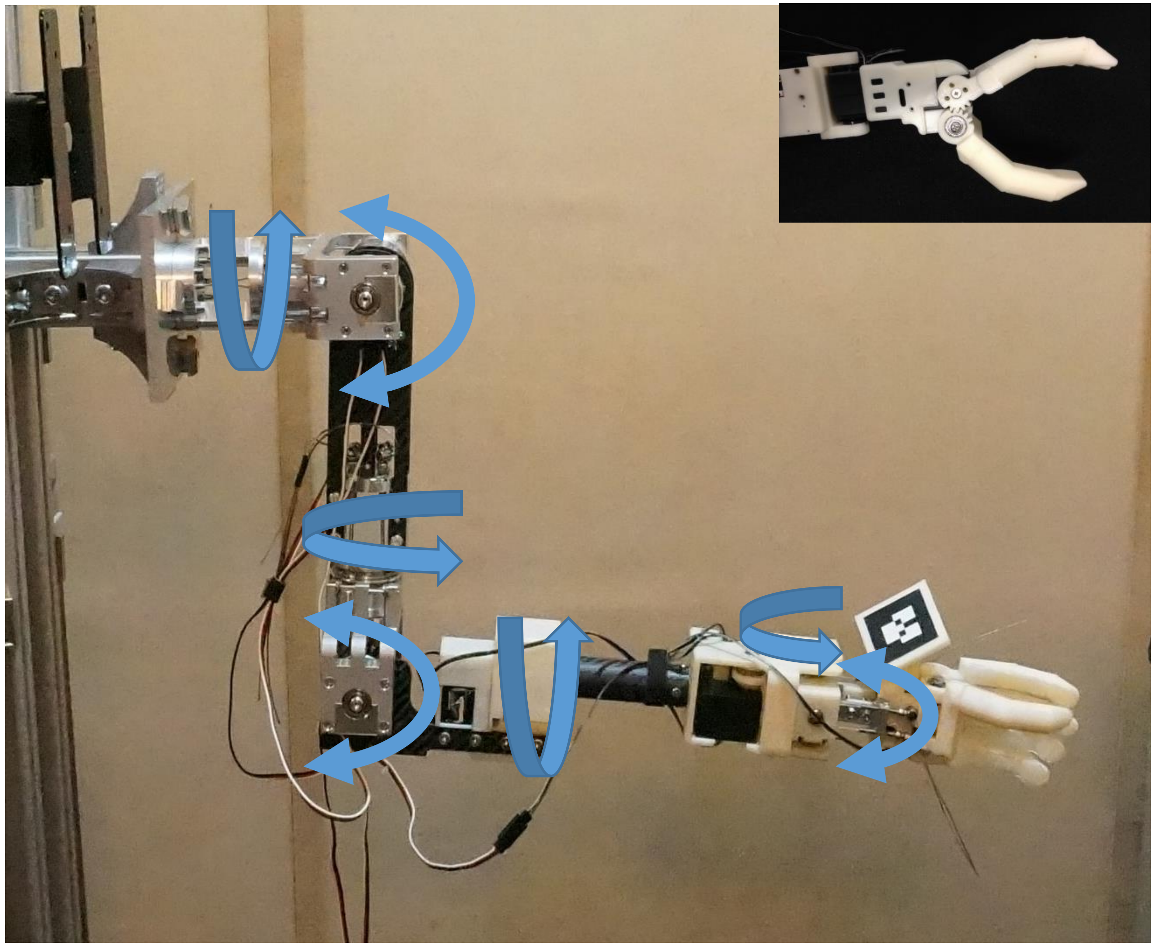


BMI robot arm

- Basic System
  - Hardware design
  - Vision sensor
  - System calibration
  - Simulated robot
  - Base robot control function
- Machine vision based automatic grasping
- Control sharing with BMI system

Hardware design

既存の超軽量ロボットアームとの比較



項目	本研究	MICO²+KG-2
制御軸数	7	6
最大リーチ[m]	0.8	0.7
本体質量[kg]	2.6	5.2
可搬質量[kg]	1.0	0.8
ハンド動作自由度	1（握り･開き）	1（握り･開き）
最大速度[m/s]	2（円接線）	0.2（直線）

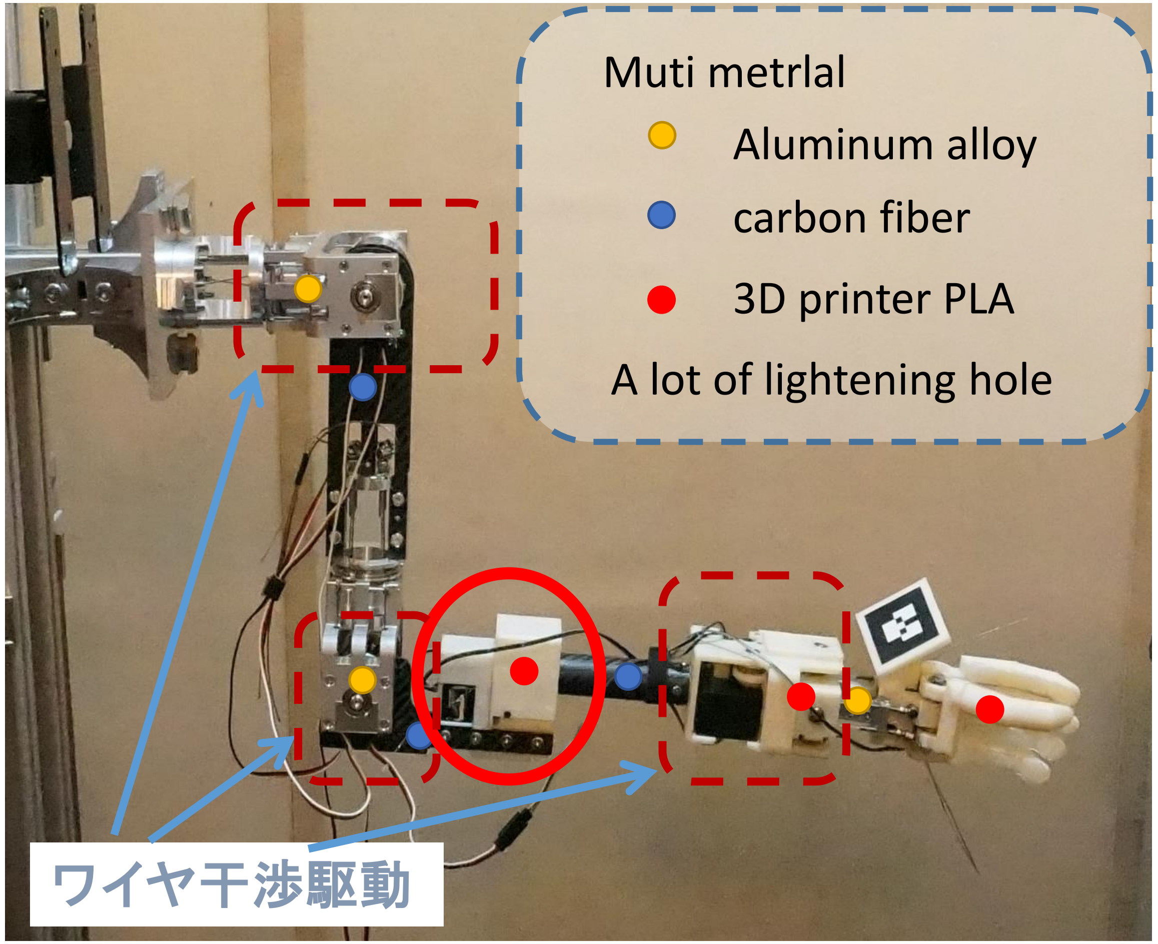
本研究のアームはMICO²+KG-2と比較して，

出力/重量比が**2.5倍**

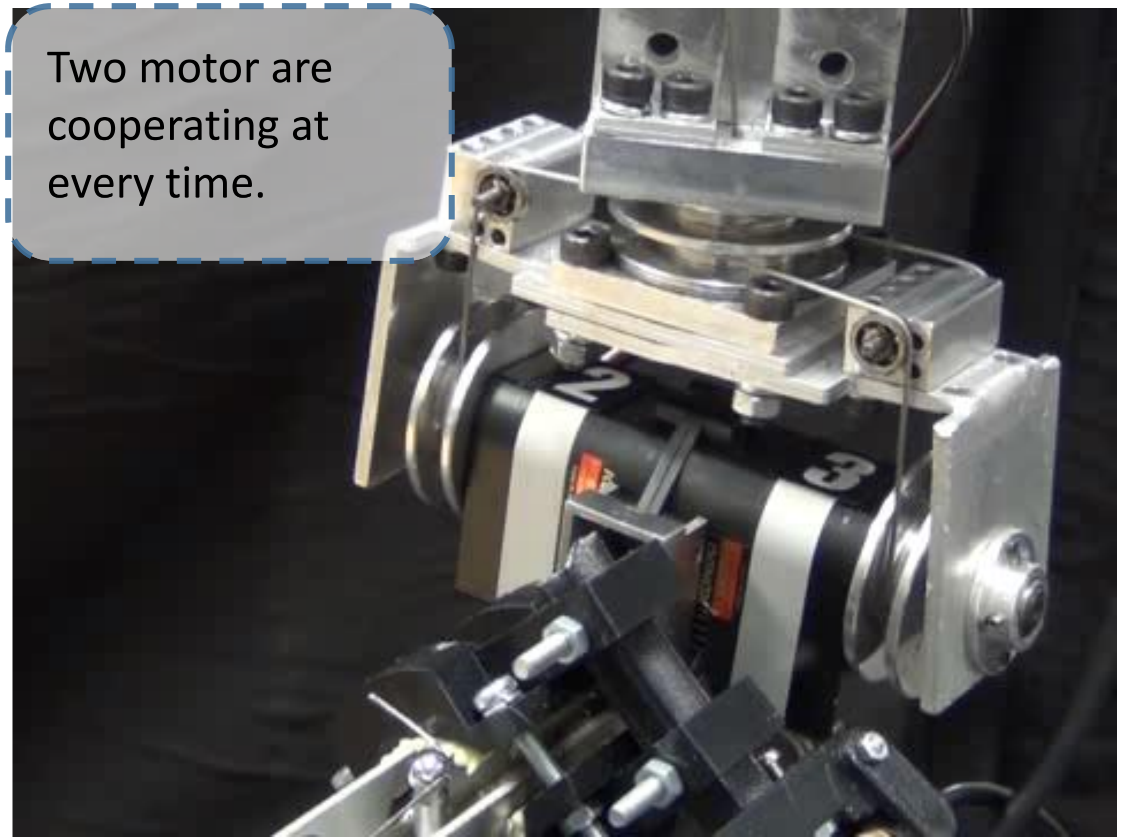
自由度数/重量比が**2.3倍**

ヒトの関節に対応した自由度を有する

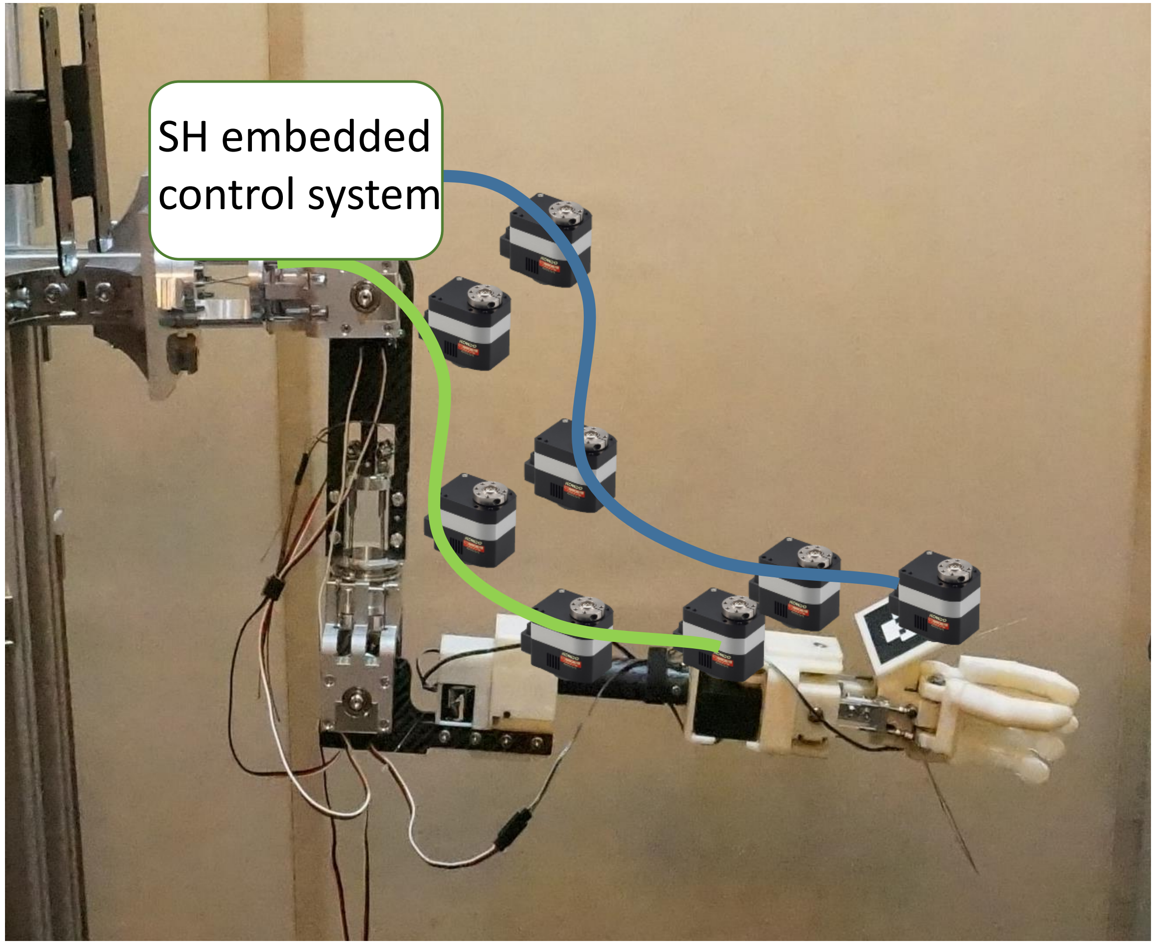
Lightweight and powerful



Coupled Tendon-Driven(ワイヤ干渉駆動)
特願2016-109120



Parallel control of the motors



最大トルク:67.0kg・cm
●最高スピード:0.22s/60°

●寸法:51×32×39.5mm(突起部除く)
●重量:103g(サーボホーン含む)
●最大動作角度:270°
●最大消費電流:6.1A
●ギヤ種類:特殊アルミギヤ
＋ステンレスギヤ
●ケース材質:アルミ(トップ、ミドル)
ガラス入り樹脂(ボトム)
●ギヤ比:362.88:1
●電源電圧:HV仕様(9V〜12V)

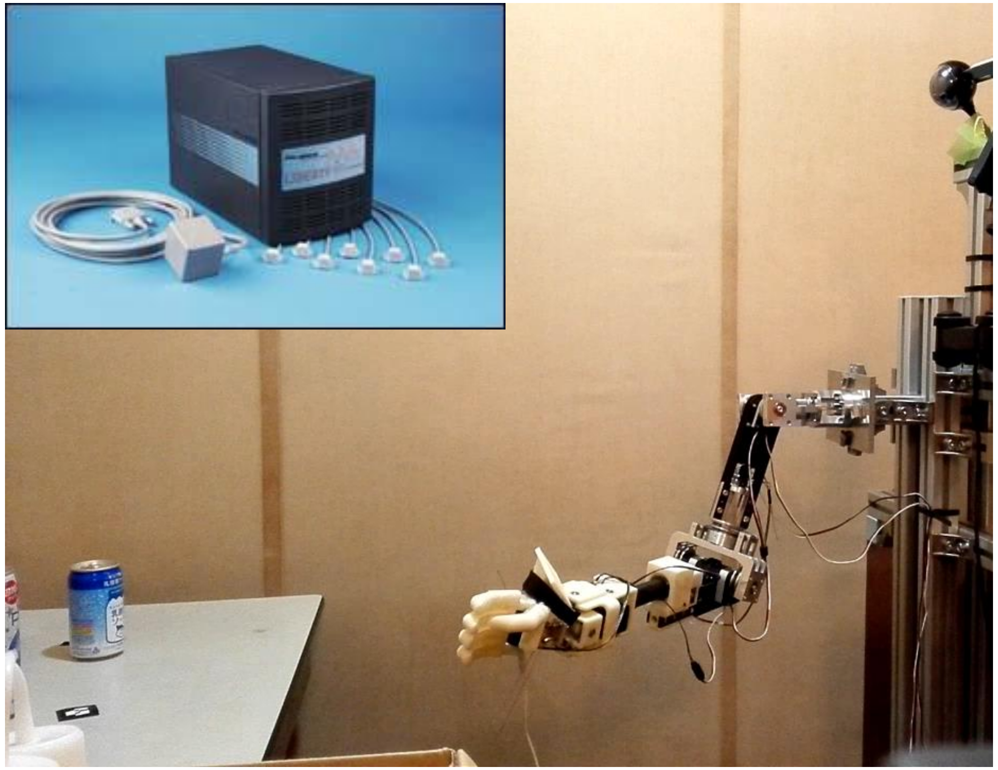
●通信規格:ICS3.5(シリアル/PWM選択式)
●通信速度:115200/625000/1250000bps
●初期設定:ID0/BR115200
●信号レベル:TTL

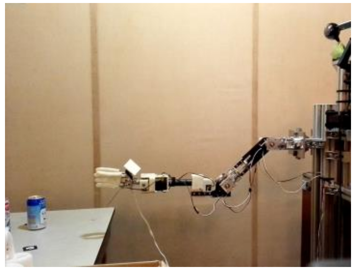
Repeat accuracy testing

Test Pose → Random Pose

5 measures for one Pose

- 3 Poses are tested

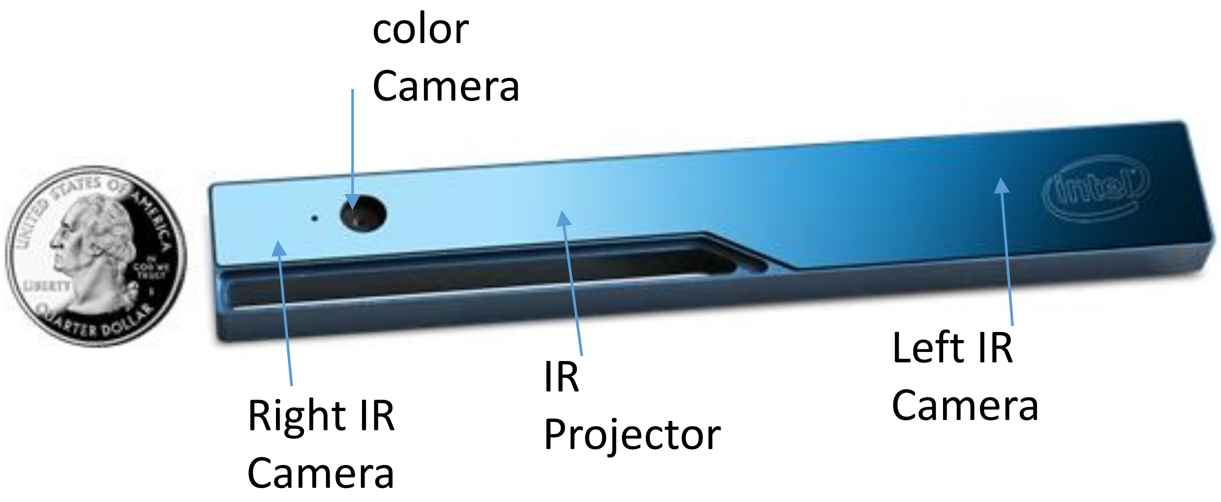




		Average (mm)	Max absolute error (mm)
Pose1	X	20. 72833	0. 16544
	Y	47. 34129	0. 426108
	z	3. 725552	0. 126973
Pose2	X	37. 14884	0. 100315
	Y	53. 16144	0. 136713
	z	−3. 60846	0. 200365
Pose3	X	25. 38503	0. 184033
	Y	22. 46846	0. 512729
	z	−2. 37699	0. 176066

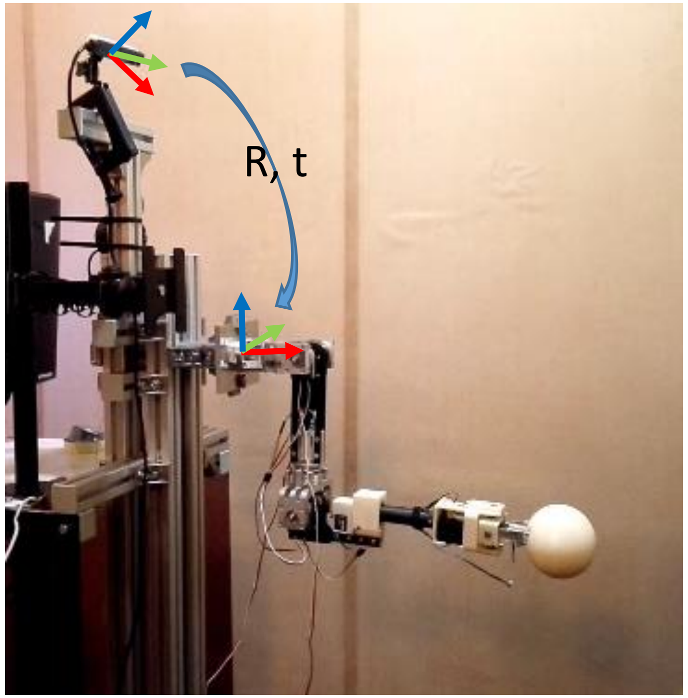
Vision sensor system

- RGB-D sensor can simultaneously capture the
  - RGB —— color information
  - D —— Depth information

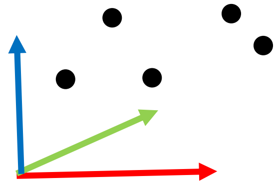


One frame of sensor data

Vision System calibration

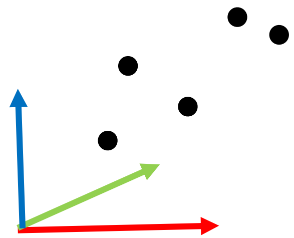


$$\boldsymbol{q}_i = \boldsymbol{R} \cdot \boldsymbol{p}_i + \boldsymbol{t}$$



camera

$$\{\boldsymbol{p}_i\}, i = 1, 2, \ldots N$$



robot

$$\{\boldsymbol{q}_i\}, i = 1, 2, \ldots N$$

$$\arg\min \sum_{i=1}^{N} \left\| \boldsymbol{q}_i - (\boldsymbol{R} \cdot \boldsymbol{p}_i + \boldsymbol{t}) \right\|^2$$

$$\boldsymbol{p} = \frac{1}{N} \cdot \sum_{i=1}^{N} \boldsymbol{p}_i \qquad \boldsymbol{p}_i' = \boldsymbol{p}_i - \boldsymbol{p}$$

$$\boldsymbol{q} = \frac{1}{N} \cdot \sum_{i=1}^{N} \boldsymbol{q}_i \qquad \boldsymbol{q}_i' = \boldsymbol{q}_i - \boldsymbol{q}$$

$$\arg\min \sum_{i=1}^{N} \left\| \boldsymbol{q}_i - \boldsymbol{R} \cdot \boldsymbol{p}_i \right\|^2$$

$$\boldsymbol{H} = \sum_{i=1}^{N} \boldsymbol{q}_i' \cdot \boldsymbol{p}_i'^{\mathrm{T}}$$

SVD Decomposition

$$\boldsymbol{H} = \boldsymbol{U} \cdot \boldsymbol{S} \cdot \boldsymbol{V}^{\mathrm{T}}$$

$$\boldsymbol{R} = \boldsymbol{V} \cdot \boldsymbol{U}^{\mathrm{T}}$$

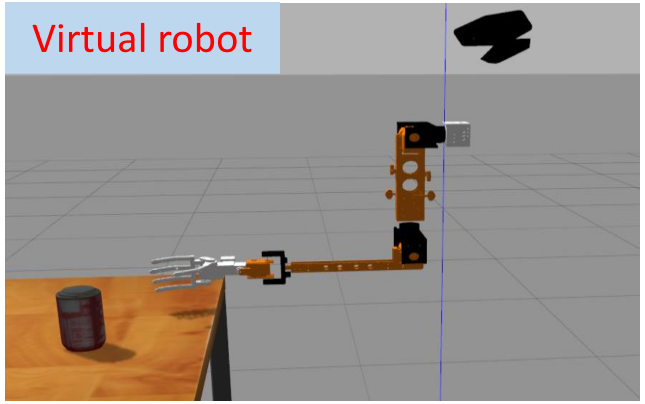
$$\boldsymbol{t} = \boldsymbol{q} - \boldsymbol{R} \cdot \boldsymbol{p}$$

$$\mathrm{err} = \frac{\sum \left\| \boldsymbol{R} \cdot \boldsymbol{p}_i + \boldsymbol{t} - \boldsymbol{q}_i \right\|}{\mathrm{n}} = 0.021\mathrm{m}$$

Simulate robot

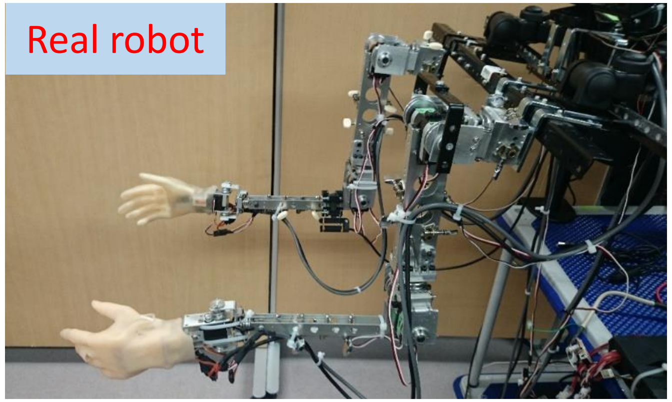
- Gazebo is integrated in ROS

Virtual robot

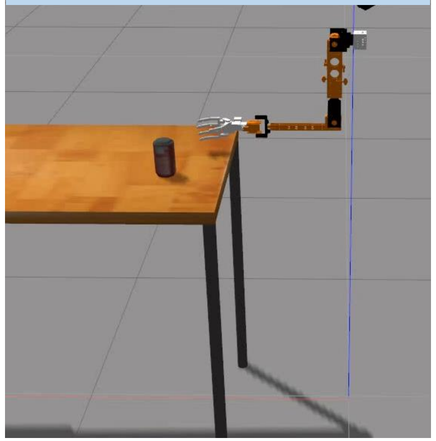


≈ Physical properties
≈ Task space information
≈ Sensor information
= Control interface

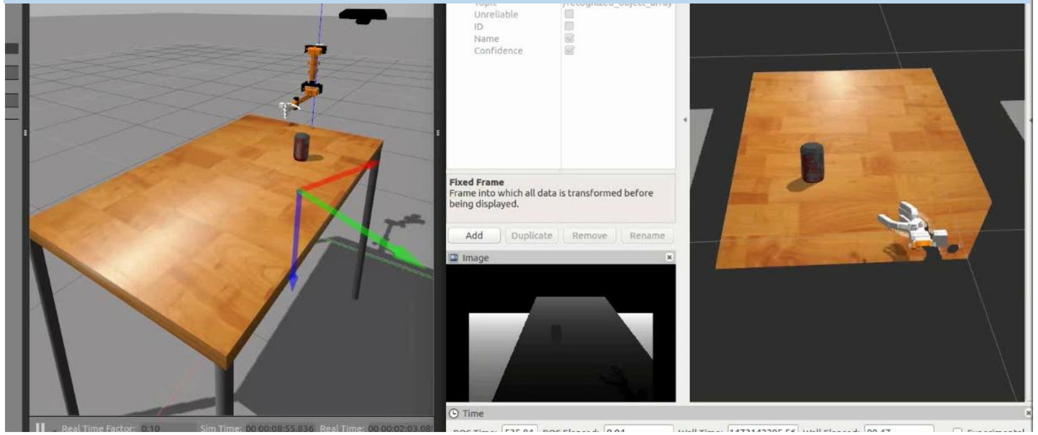
Real robot



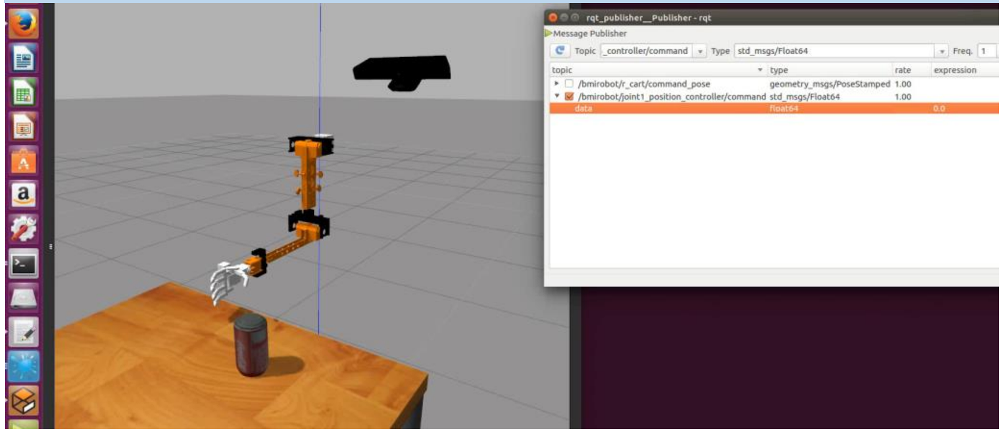
Physical simulation



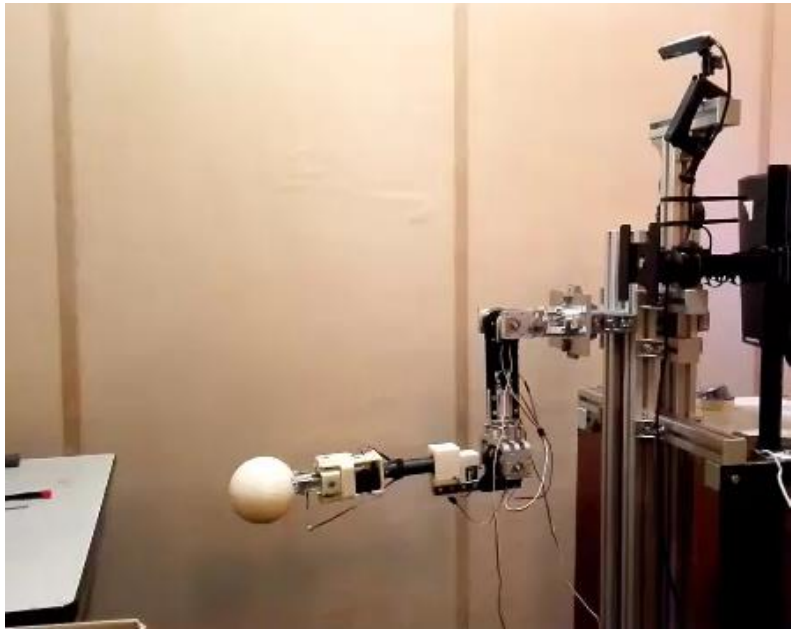
Sensor data



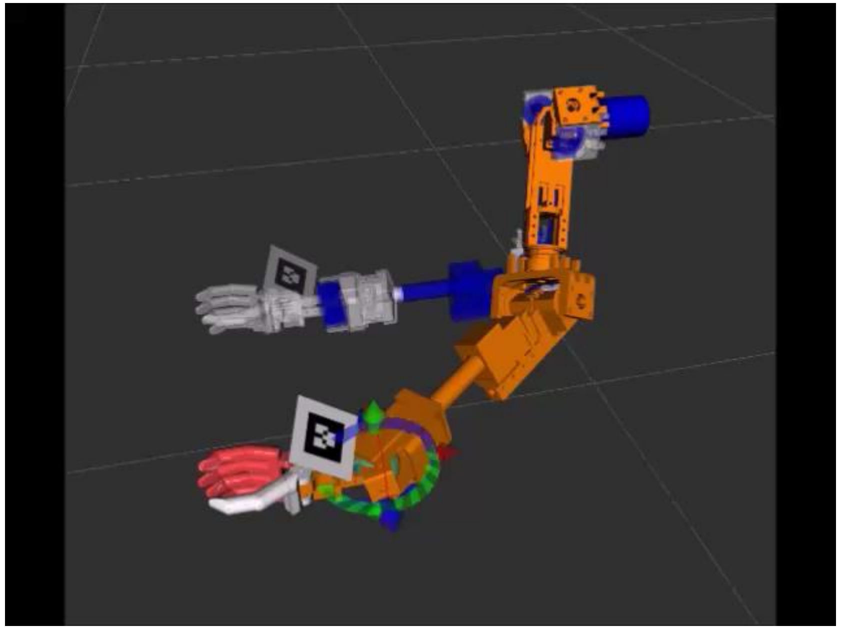
Robot Control



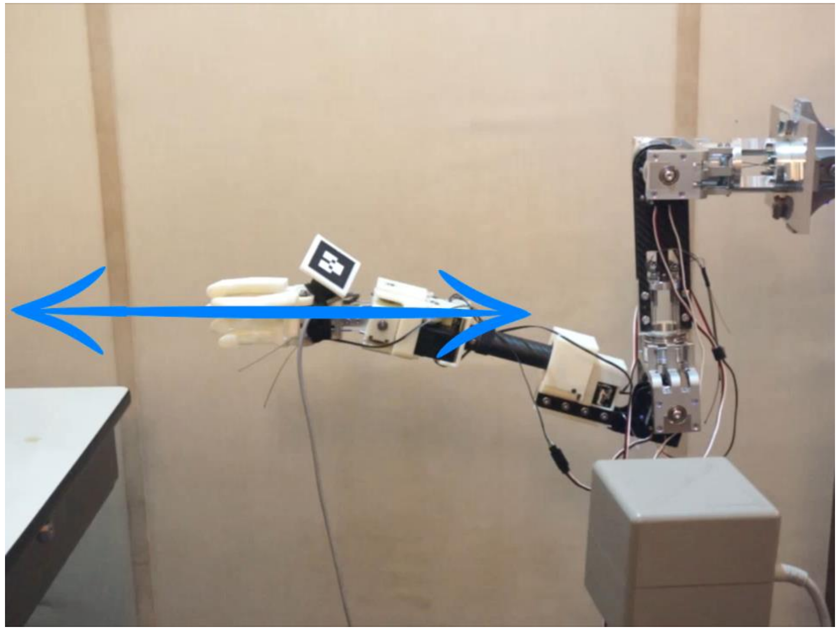
Basic Control functions



Joint Control



Trajectory Control



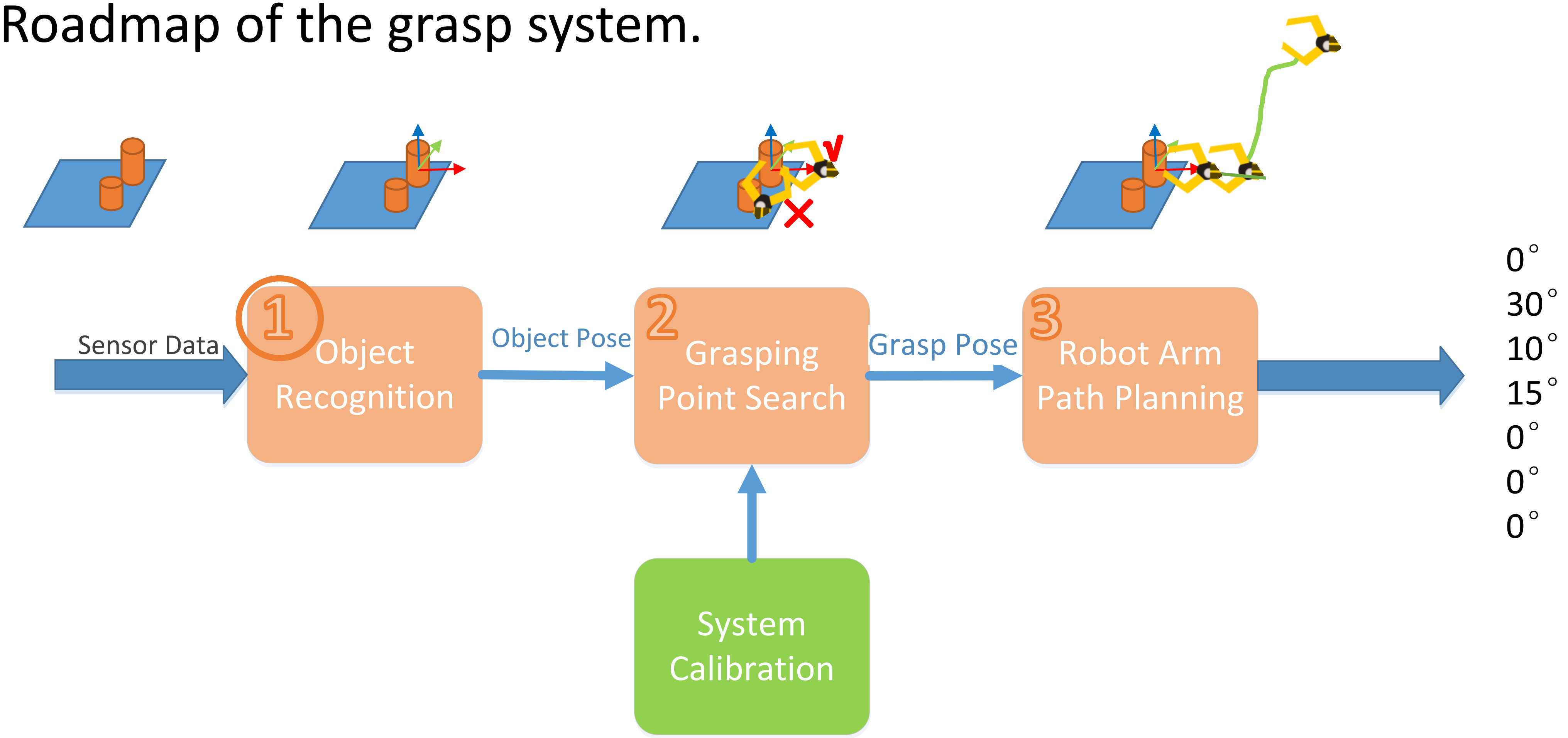
Cartesian Control

BMI robot arm

- Basic System
- Machine vision based automatic grasping
  - Object recognition
  - Grasping point determining
  - Arm path planning
  - Demonstrating
- Control sharing with BMI system

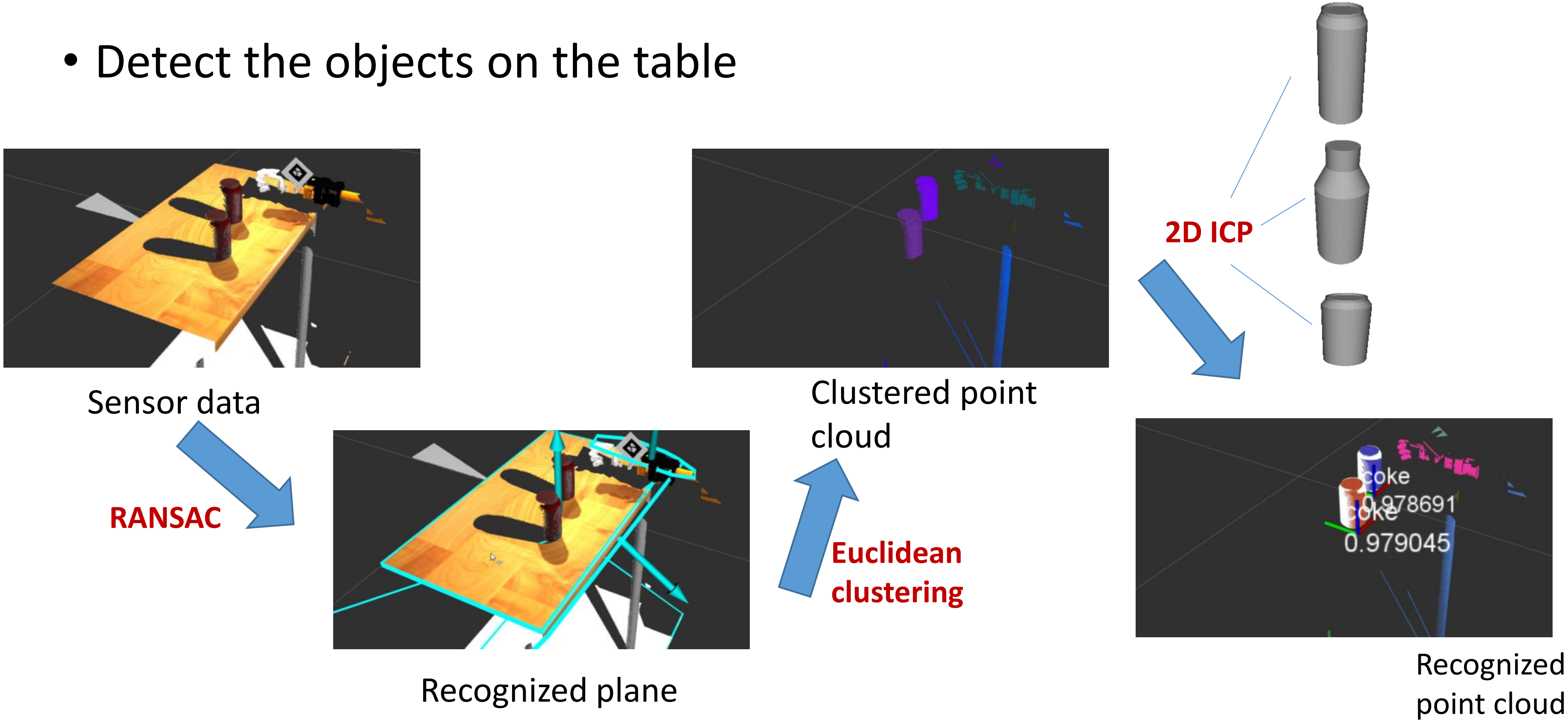
Machine vision based automatic grasping

- Roadmap of the grasp system.

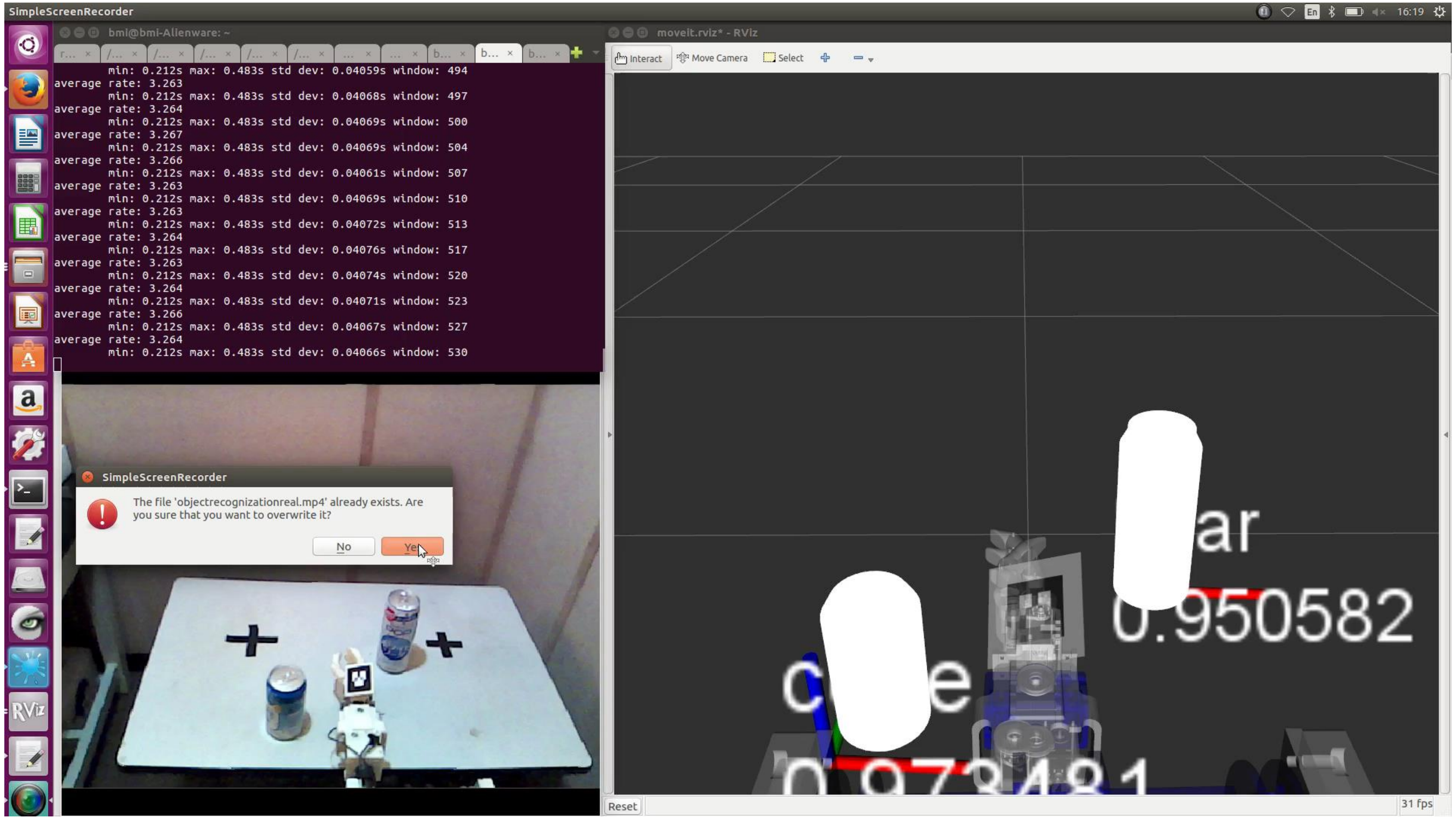


Object recognition

- Detect the objects on the table



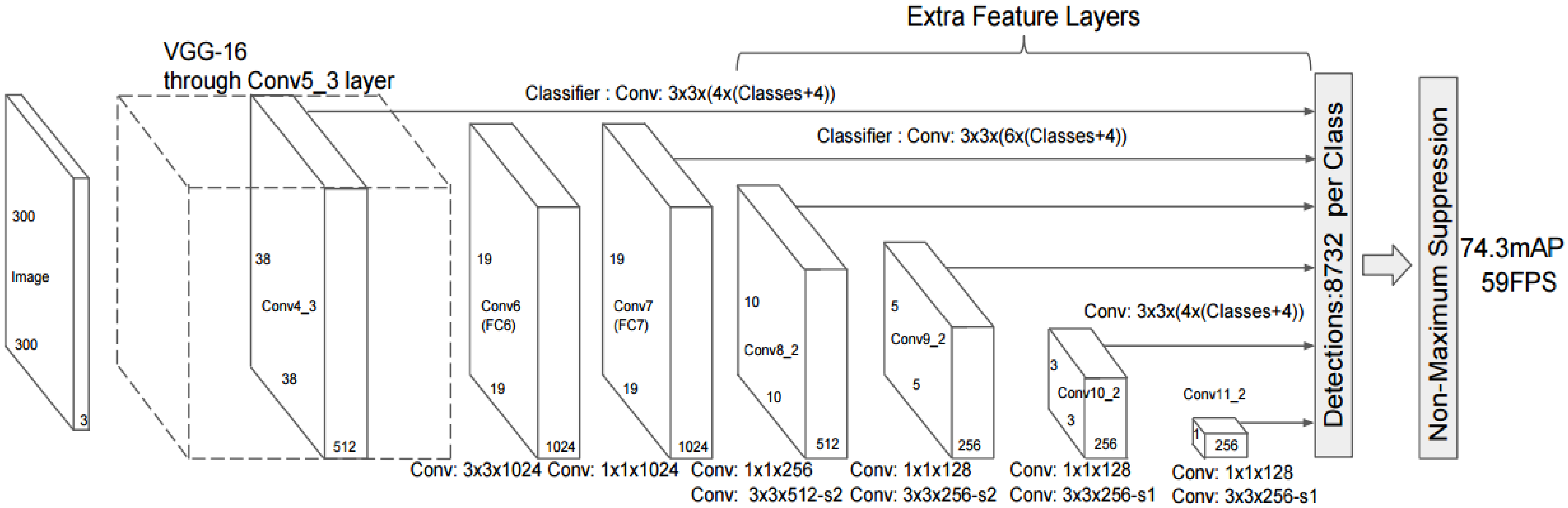
Recognition result



- Run at 3.5Hz
- The object most be a Rotational symmetry with Z axis
- The Z axis most Perpendicular to the table plane
- Not use the color information

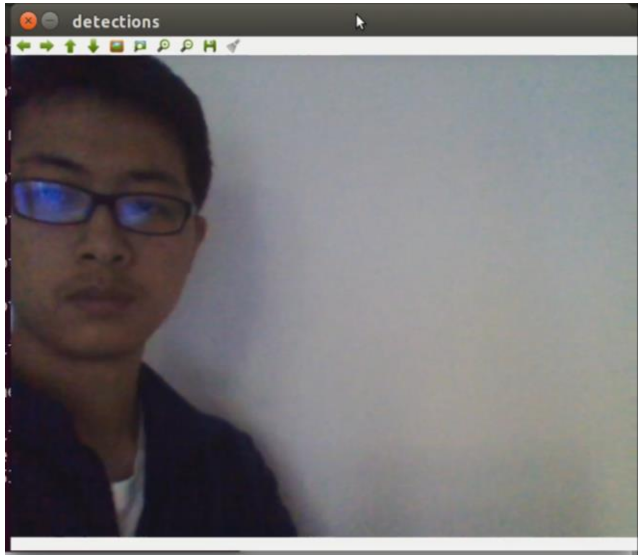
Using CNN for object recognition

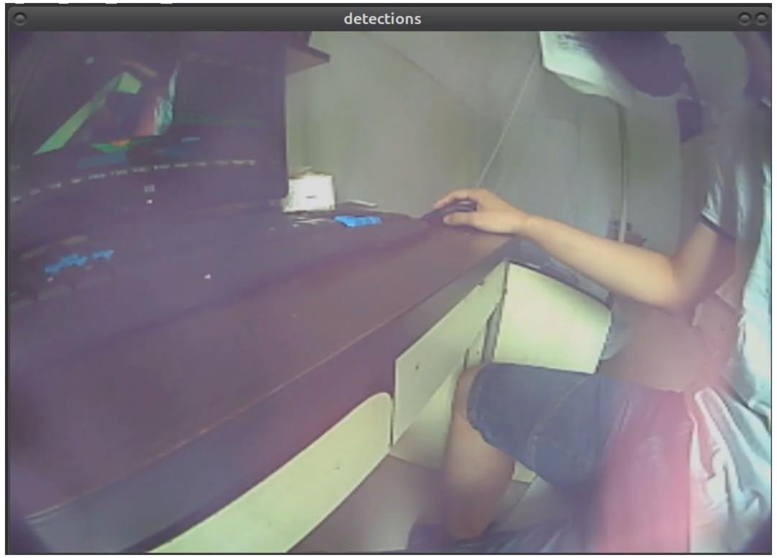
SSD: Single Shot MultiBox Detector (Wei Liu etc.， 2016)



- Robust to background and Motion blur
- Running at real-time

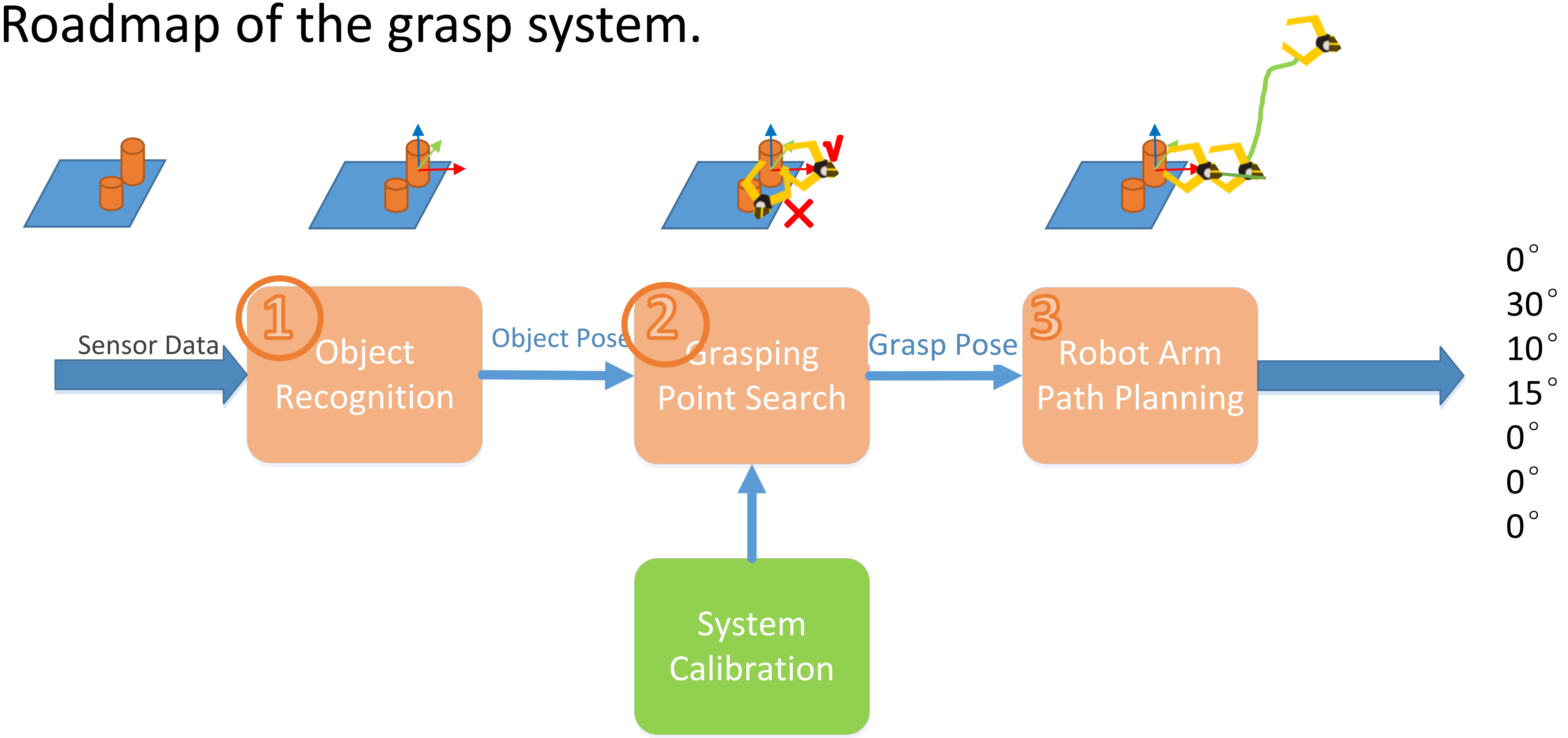
200 images for training





Machine vision based automatic grasping

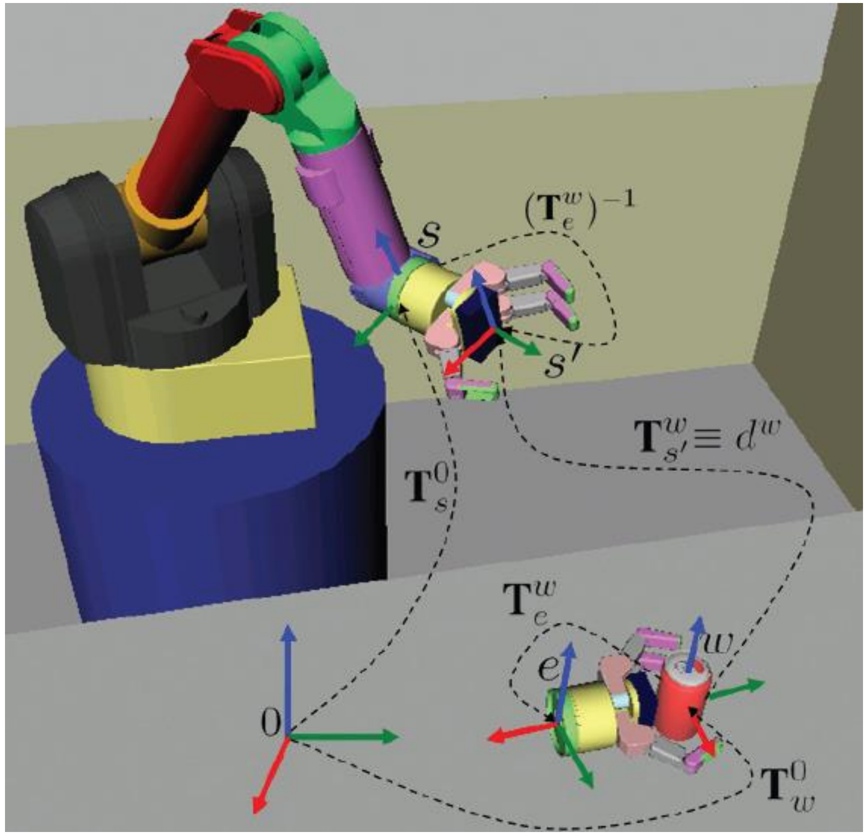
- Roadmap of the grasp system.



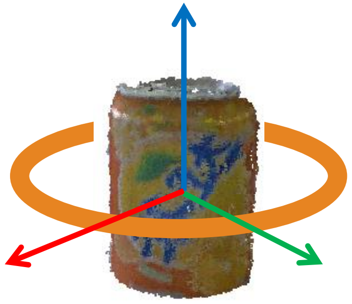
Task Space Region(TSR)(Berenson 2011)

- Continuous graspable area.

$$ {}^{o}_{e}\boldsymbol{T} = \begin{bmatrix} {}^{o}_{e}\boldsymbol{R} & {}^{o}_{e}\boldsymbol{t} \\ \mathbf{0} & 1 \end{bmatrix} \Rightarrow \begin{bmatrix} x \\ y \\ z \\ \theta_x \\ \theta_y \\ \theta_z \end{bmatrix} $$



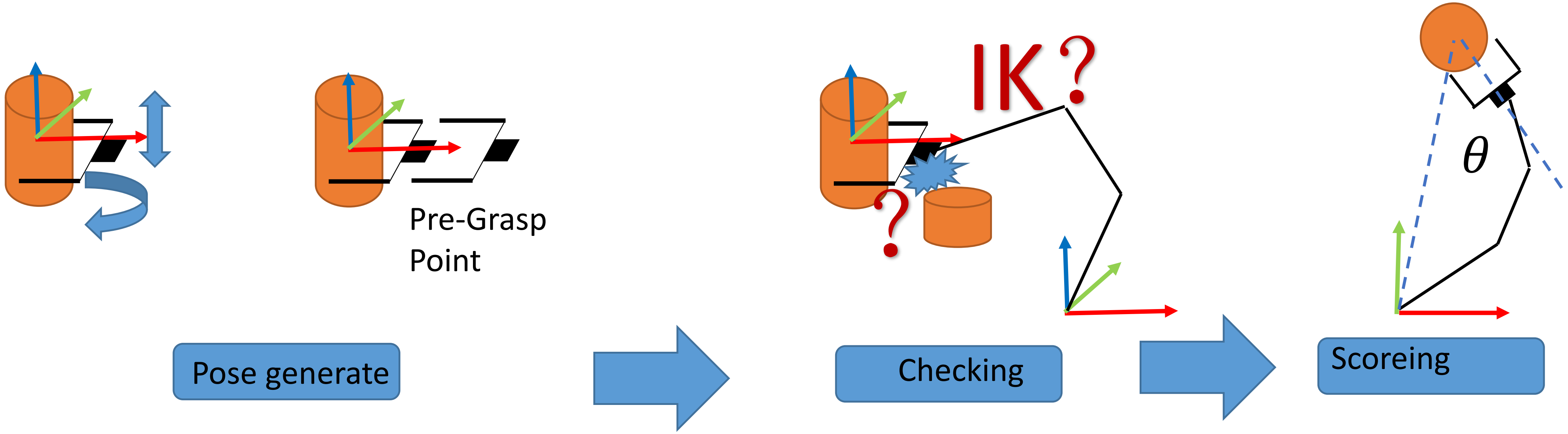
$$ {}^{o}\boldsymbol{B} = \begin{bmatrix} x_{\min} & x_{\max} \\ y_{\min} & y_{max} \\ z_{\min} & z_{\max} \\ \theta_{x\min} & \theta_{x\max} \\ \theta_{y\min} & \theta_{y\max} \\ \theta_{z\min} & \theta_{z\max} \end{bmatrix} \qquad {}^{o}\boldsymbol{B} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ -\pi & \pi \end{bmatrix} $$



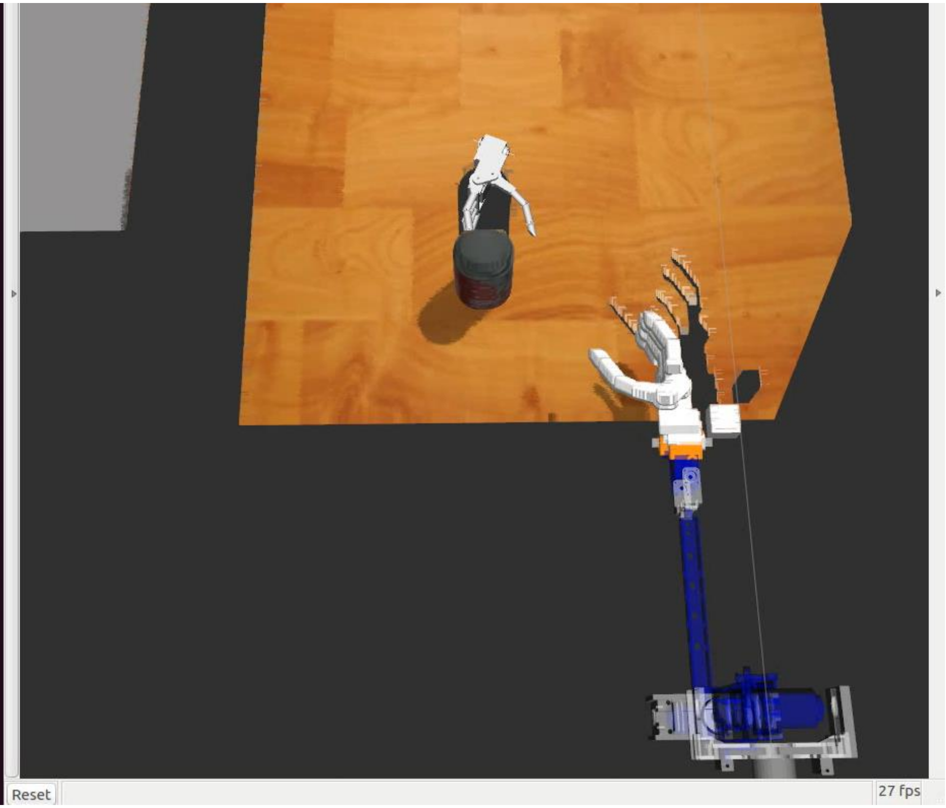
Grasping point searching

- We use searching method to find the grasp point
  - Generate a lot possible grasp poses of the grasper.
  - Check those pose include the pre-grasp pose with Inverse Kinematic, collision etc.
  - Compute a score for every possible grasp pose.

$$\text{Score} = \begin{cases} 2 * cos\theta, & if\ \theta > 0 \\ cos\theta\quad , & if\ \theta < 0 \end{cases}$$



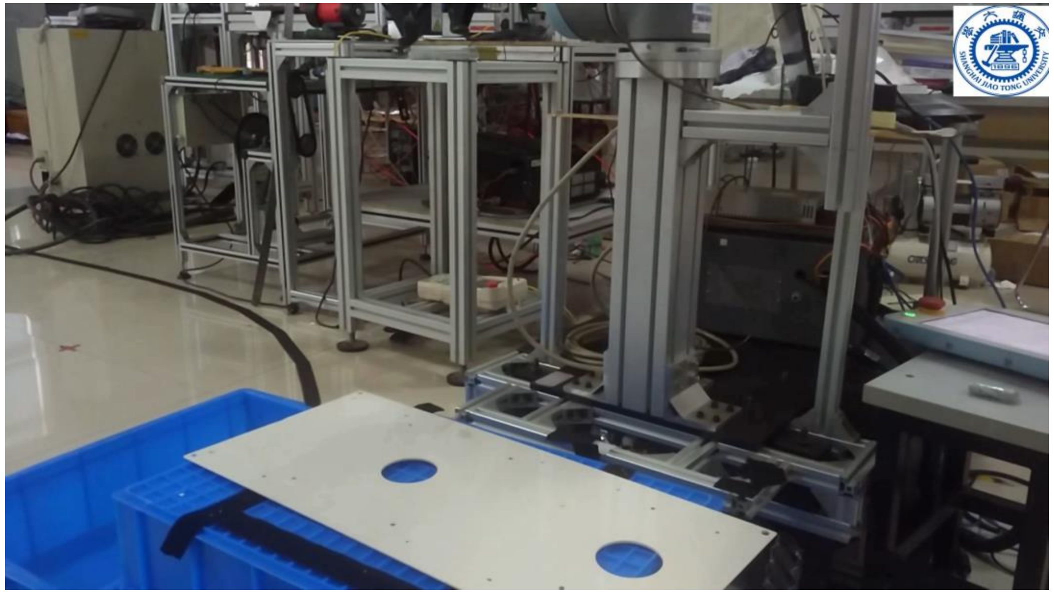
Grasping point searching

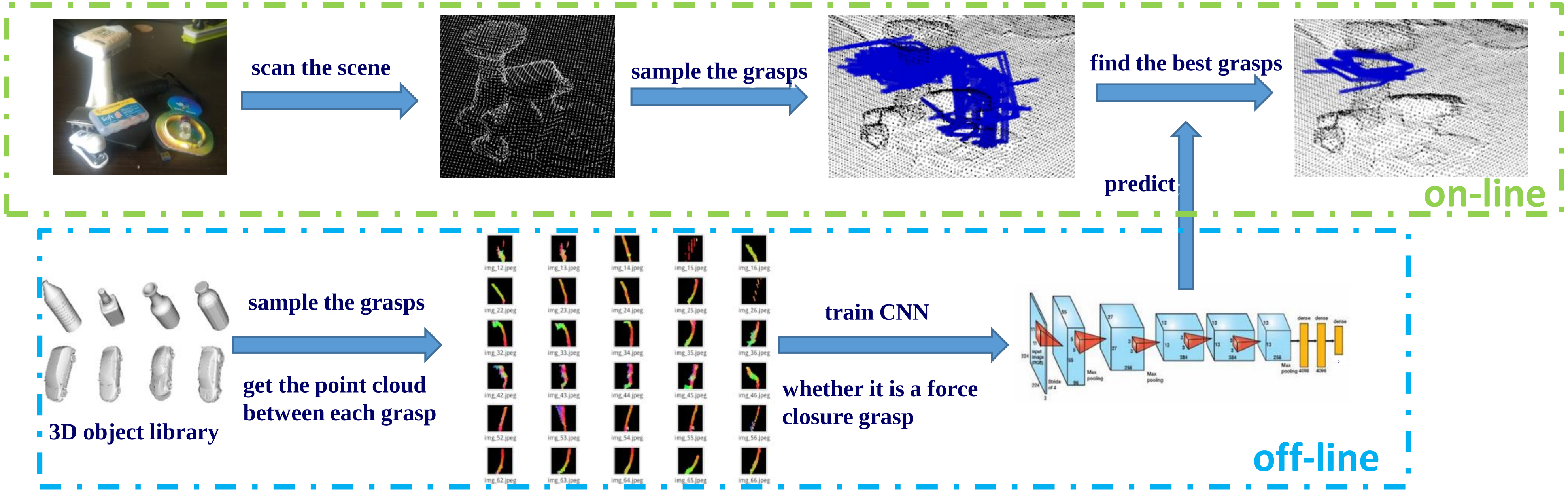


- This method is stable
- By using parallel computing the search speed is acceptable
- Not work well for objects with complex shape

Deep learning based grasping point computing

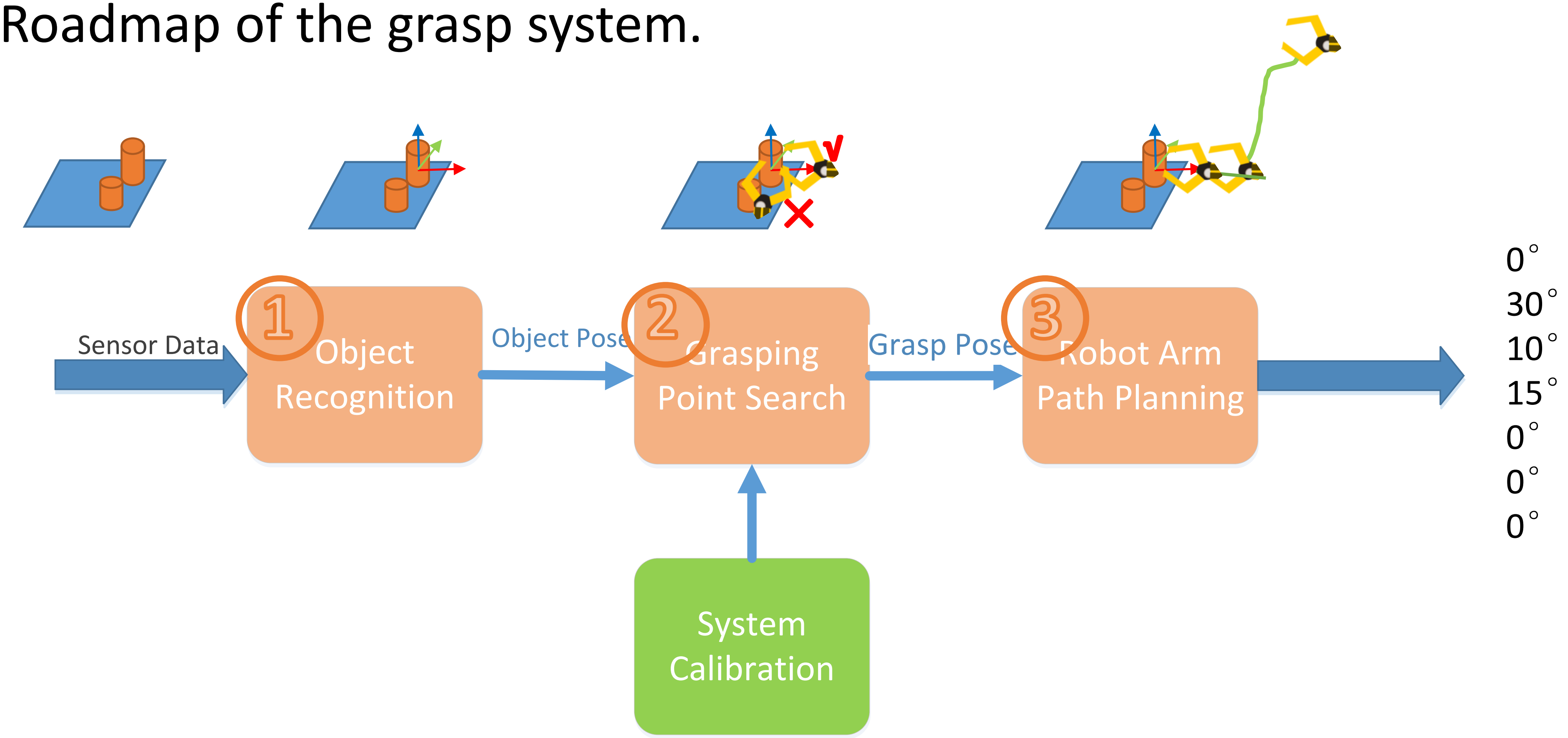
- features：
  - 1.For different objects in high clutter grasping
  - 2.No human demonstration, No human labeling
  - 3.Suitable for different size of gripper. No retraining
  - 4.Better for known objects; Suitable for unknown objects.
  - 5.Can be combined with object detection





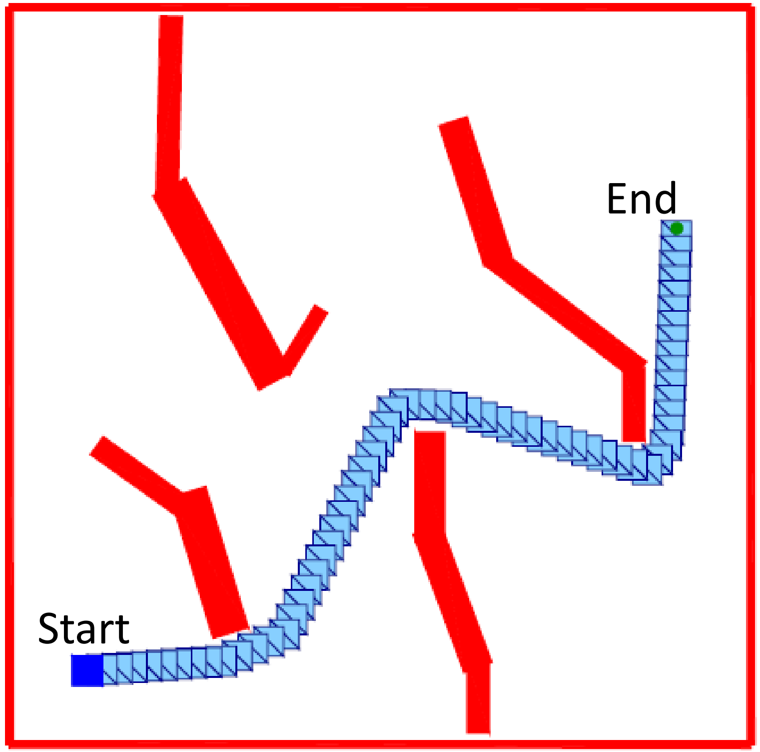
Machine vision based automatic grasping

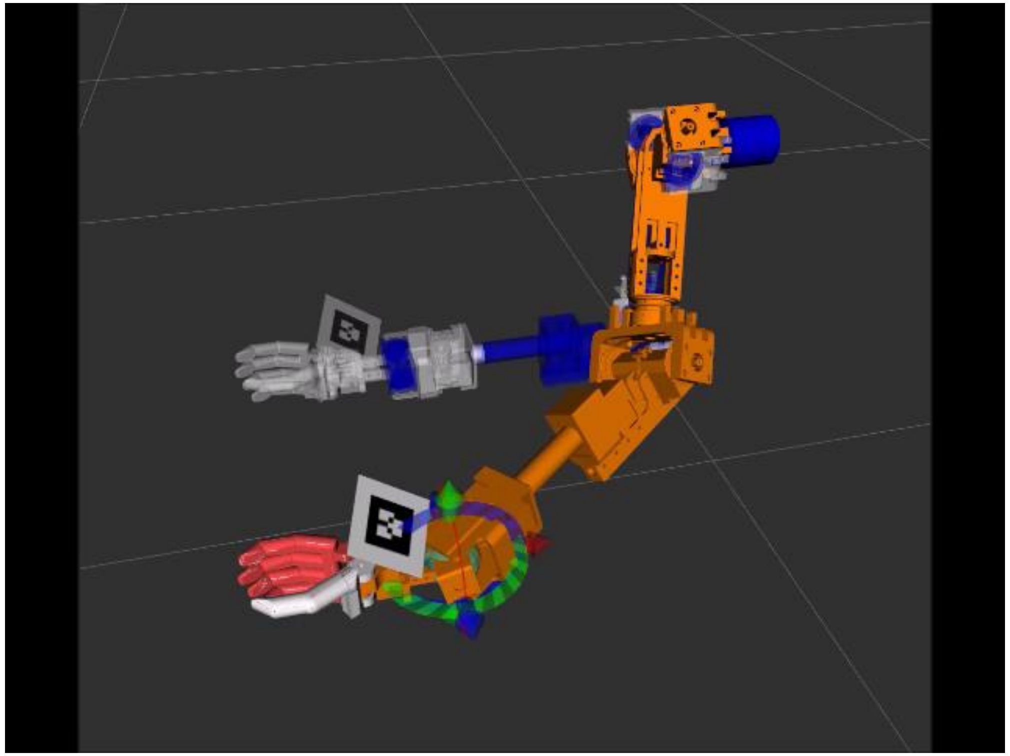
- Roadmap of the grasp system.



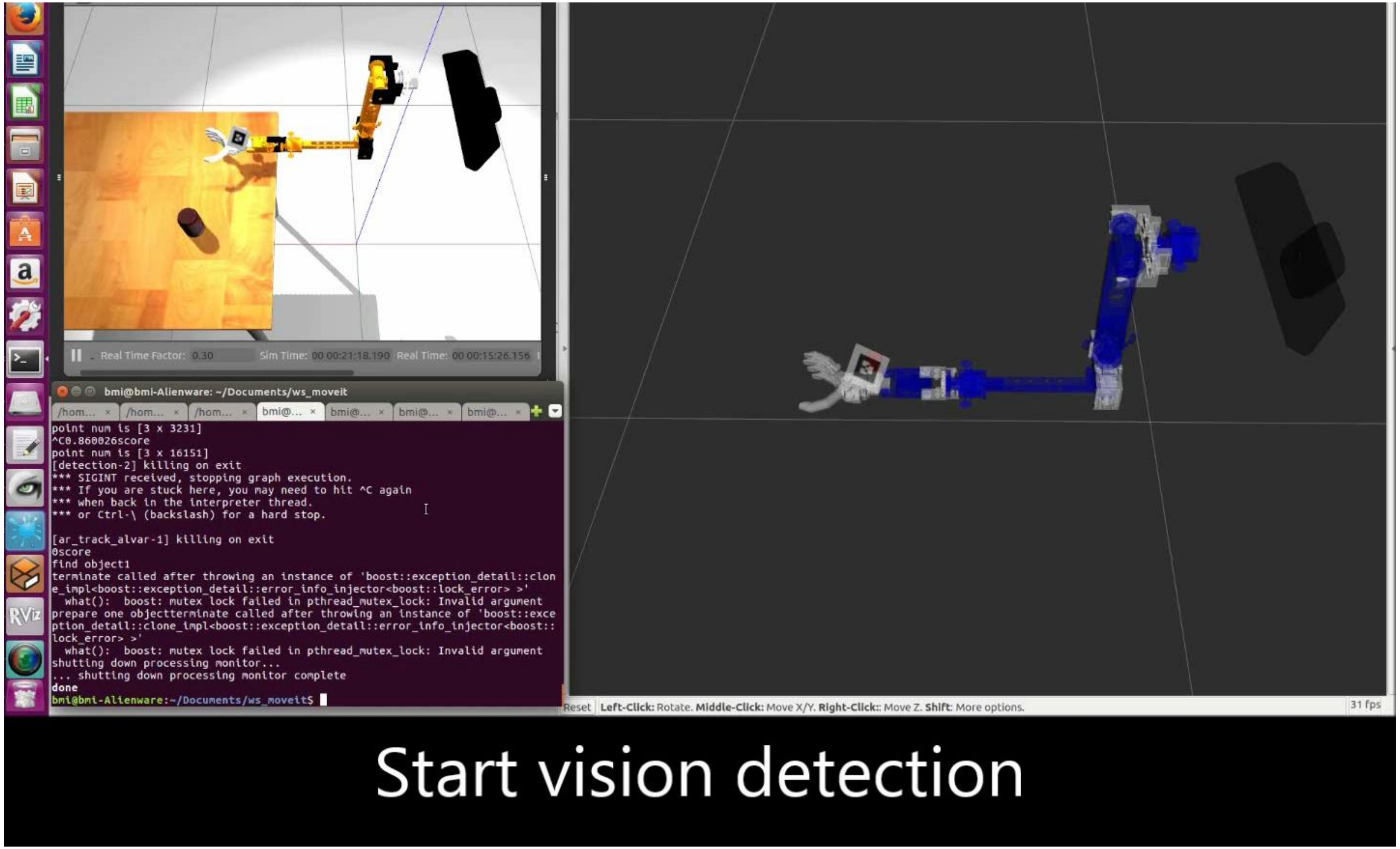
Robot arm path planning

Using a RRT (rapidly exploring random tree) method to find a Collision-free path.





Simulation experiment



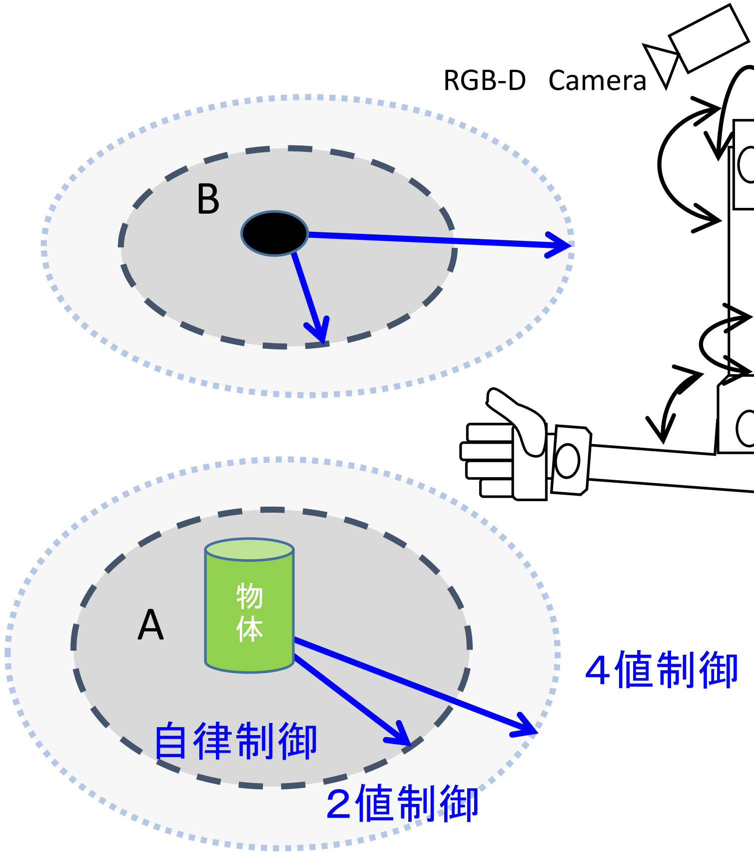
Real robot experiment

BMI robot arm

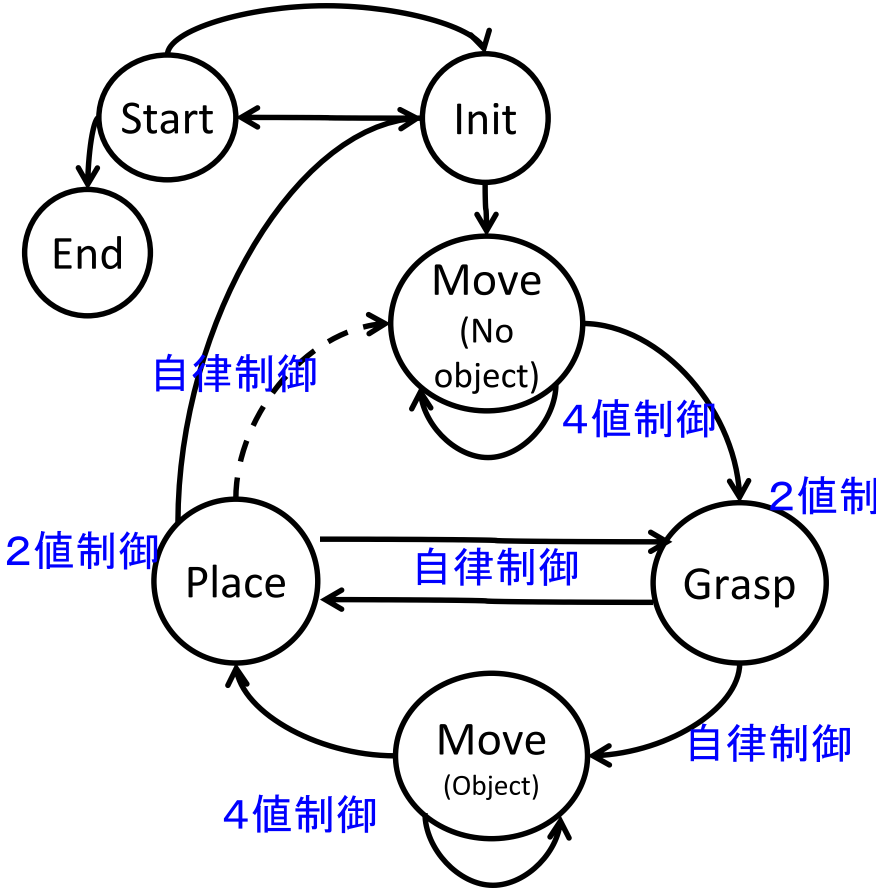
- Basic System
- Machine vision based automatic grasping
- Control sharing with BMI system
  - Strategy
  - Experiment

Sharing control with BMI system

- Using state switching such that either the BMI user or the robotic system had control during specific phases
- A Finite state machine system is used.



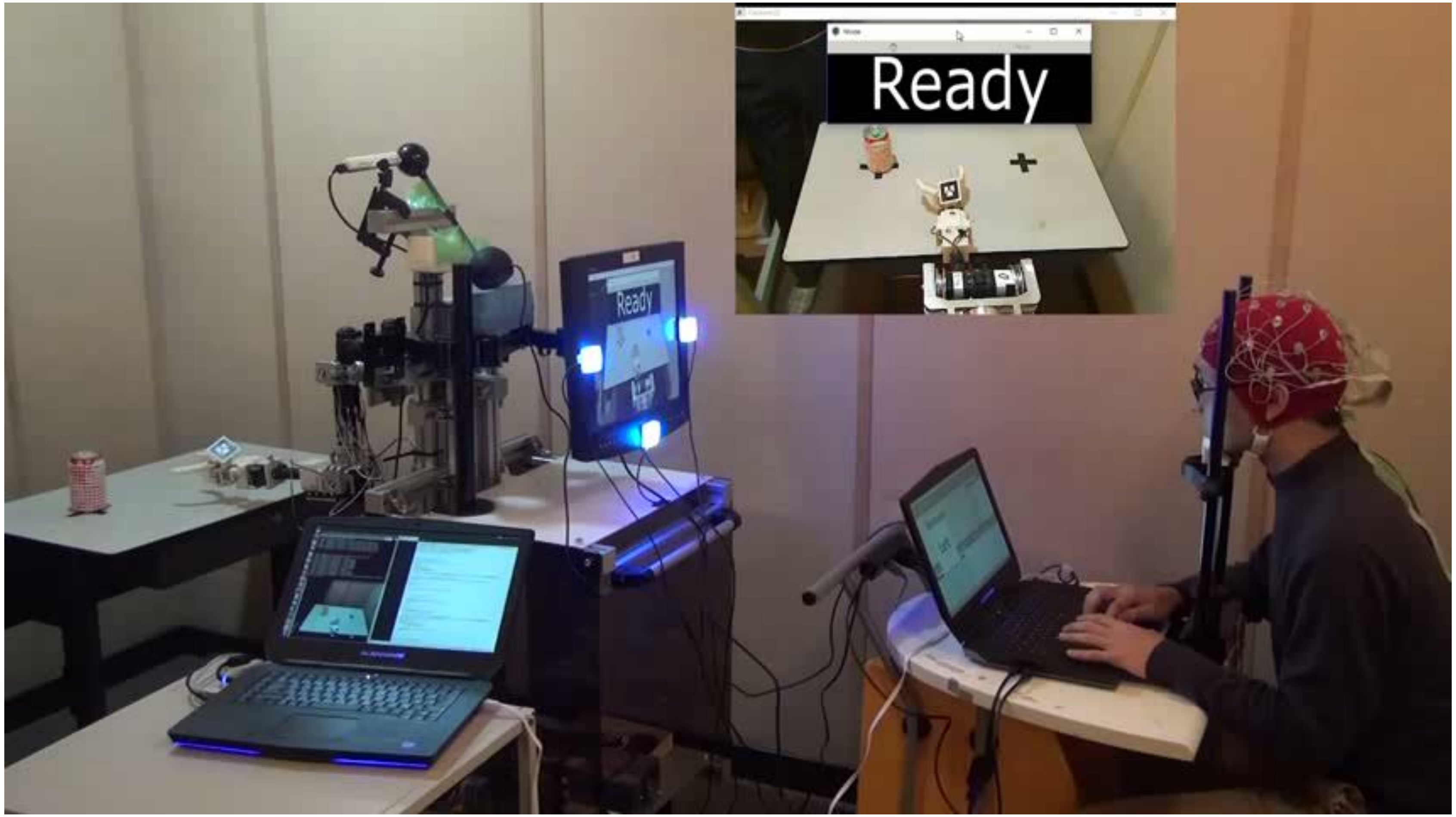
BMI：
Robot control
自律制御:
物体認識, 障害物回避, 経路・軌道計画,
把持姿勢探索, 物体の把持・保持・放す



Finite state machine

BMI grasping experiment

- SSVEP is used for BMI system
- 10 tests are all successful and the average grasping time is 1 mins



conclusion

- A light but powerful robot arm is designed. The robot arm has a similar DOF configuration and work space with human. The repeat precision is high.
- A vision based automatic grasping system is developed, which has good stability for special grasping task. More intelligent function is under developing.
- A Finite State Machine system is used to communication with the BMI.
- The robot control software is based on ROS.

Thank you for your attention!