Human-Robot Collaborative Catching with High-speed Vision System and Deep Learning

Master 1st, Department of Mechanical Engineering, the University of Tokyo

Yuki Kawawaki

Yamakawa Laboratory, The University of Tokyo
High-speed Flexible Robotics
http://www.hfr.iis.u-tokyo.ac.jp

Agenda

- Introduction of our laboratory
- My research
  1. Background
  2. Related Work
  3. Problem&Purpose
  4. Progress
  5. Summary

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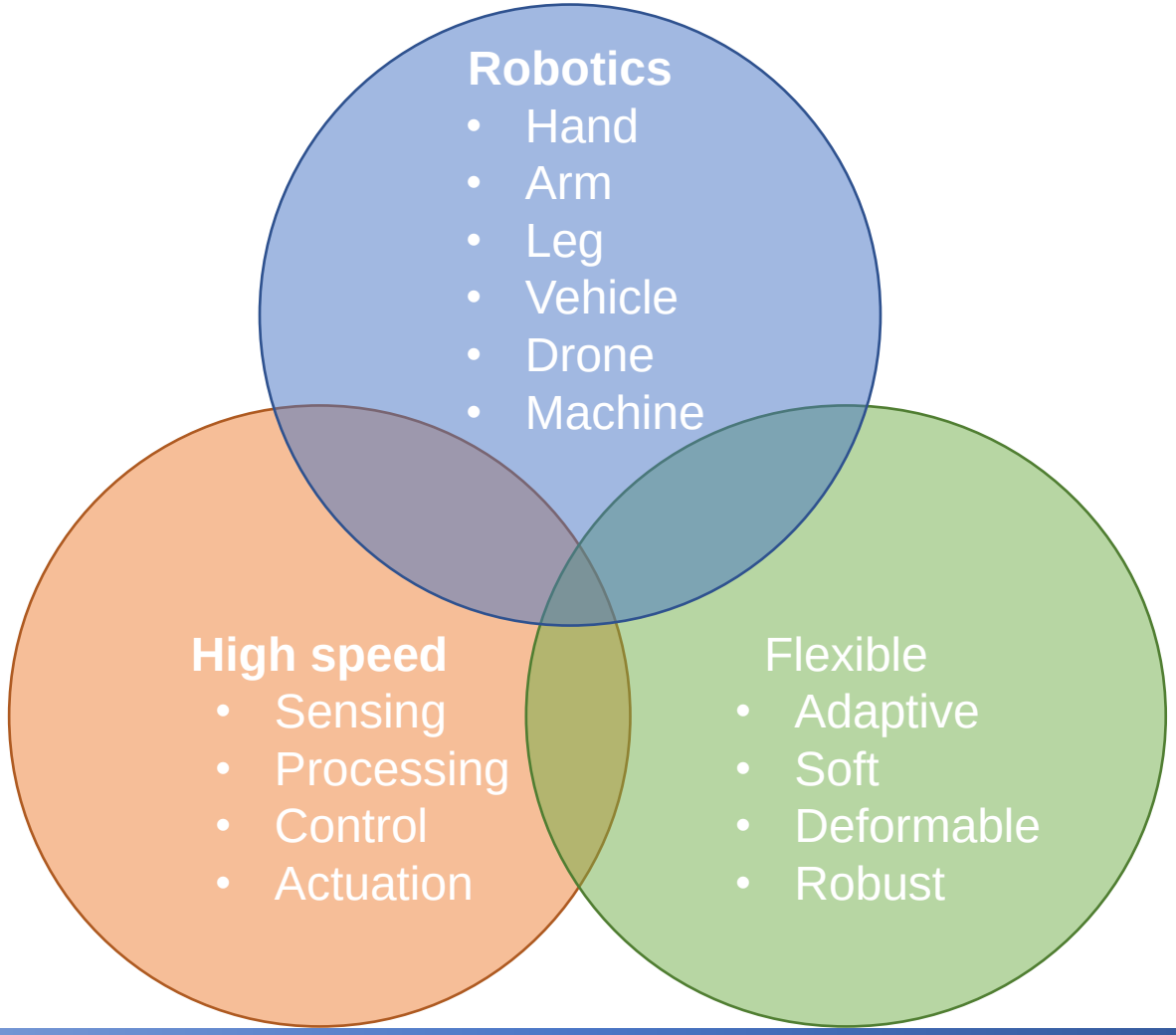
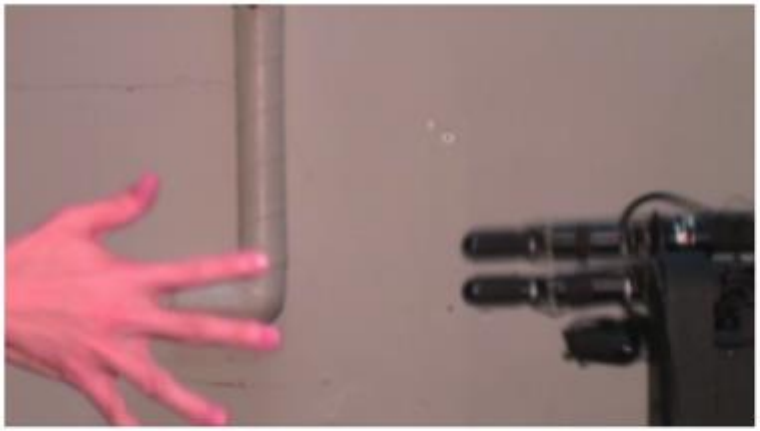
High-speed Flexible Robotics

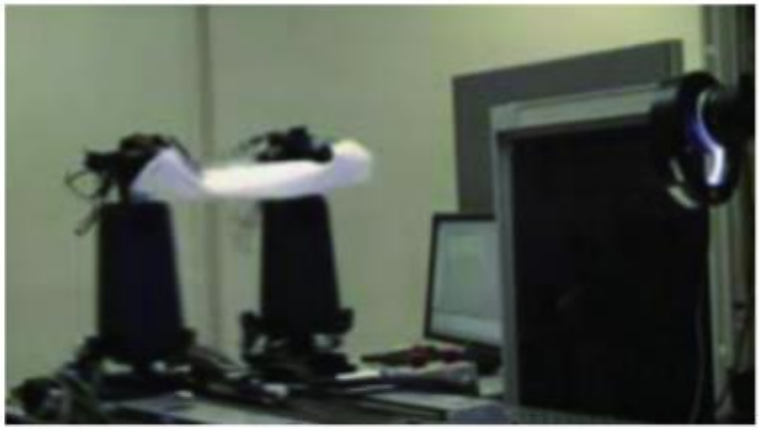
Intelligent system , Autonomous system



Research Topic

Robots and Solutions with High-speed and Flexible Technologies



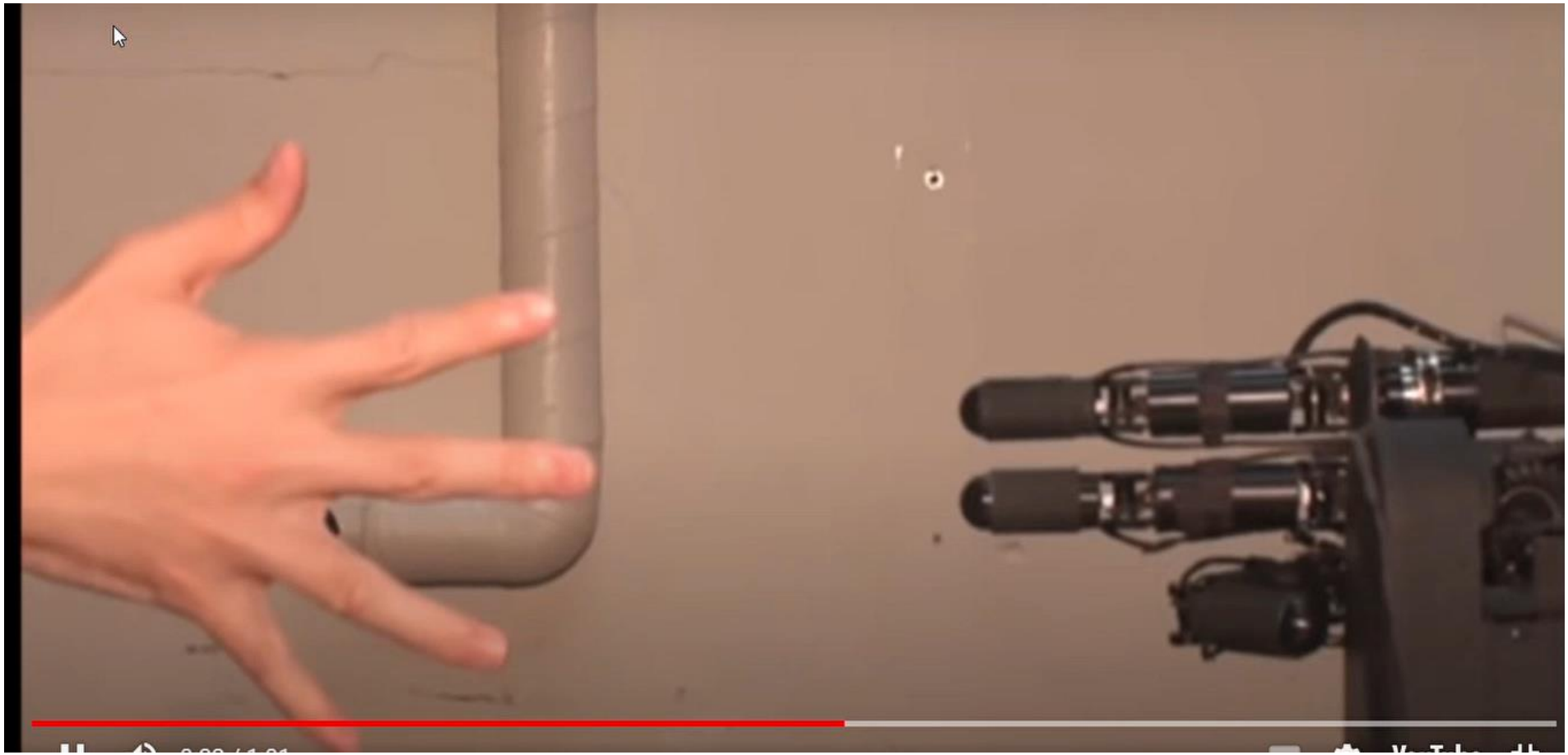


Yamakawa Laboratory
The University of Tokyo

High-speed robot system
Flexible ojbect manipulation
Human-robot interaction

Rock-Scissors-Papers

Win 100% in Rock-Scissors-Papers



http://www.hfr.iis.u-tokyo.ac.jp/research/index-j.html

Ball Catching

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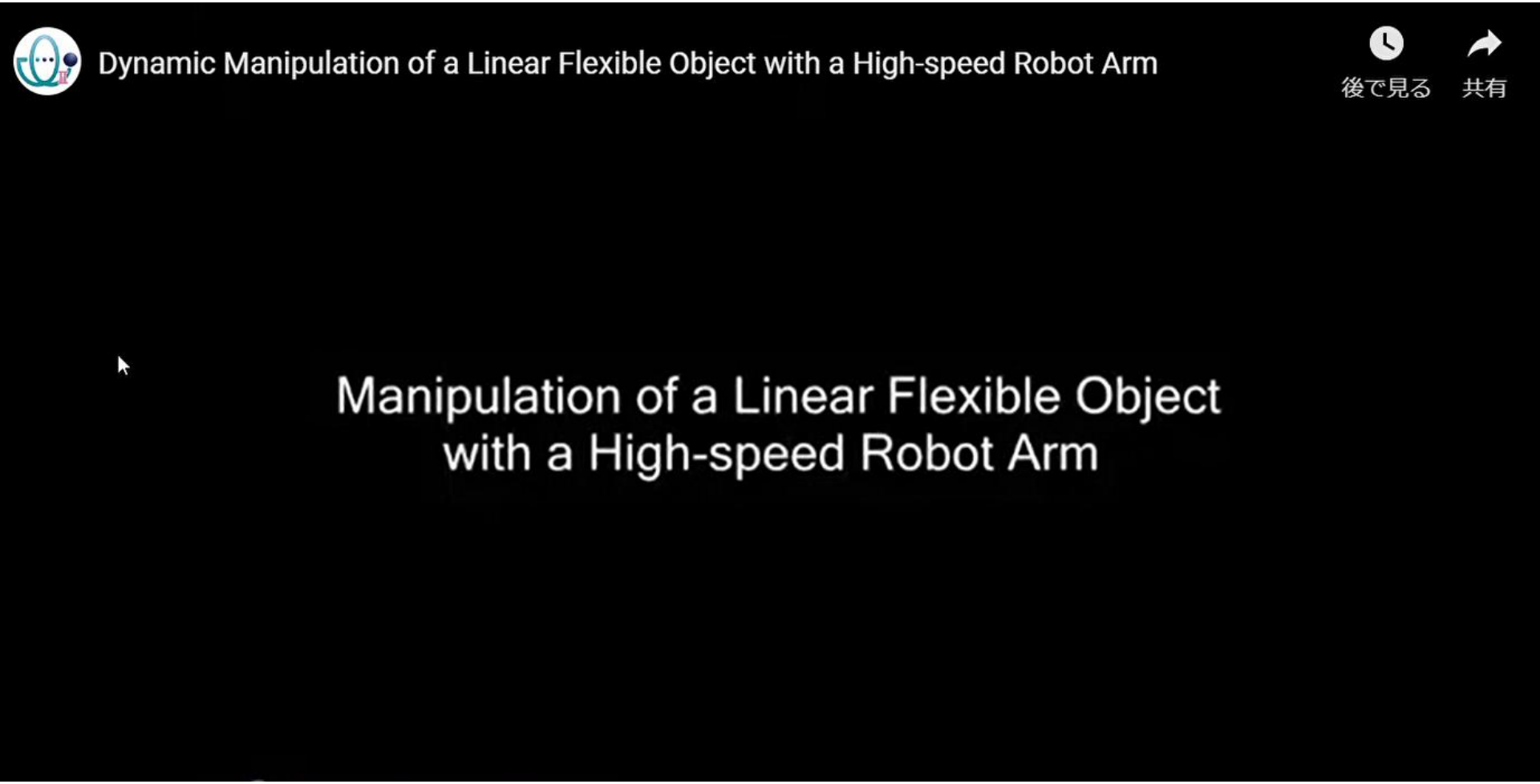
High-speed Knotting with Robot Arm



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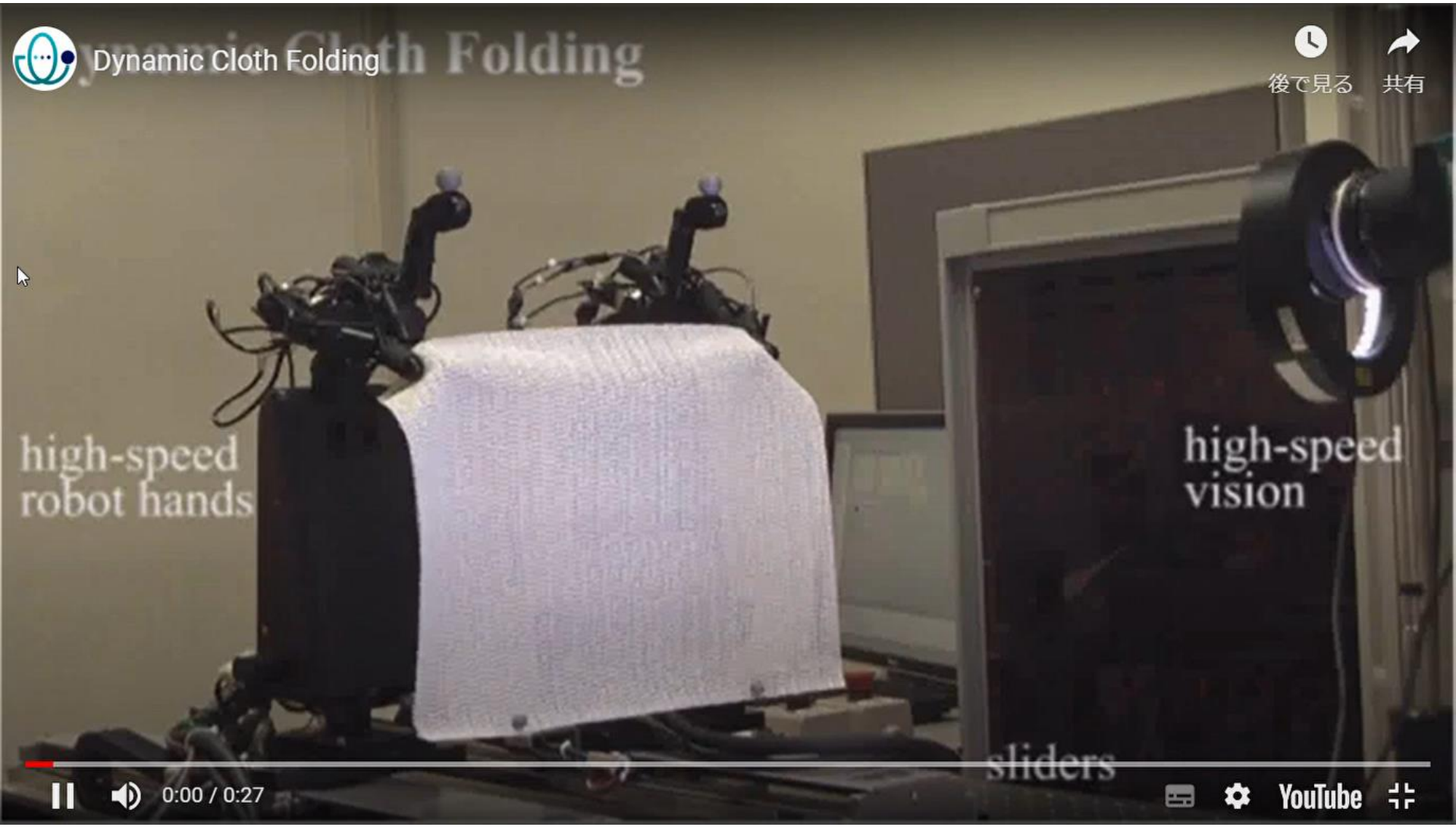
Folding a Towel with Robot Hand



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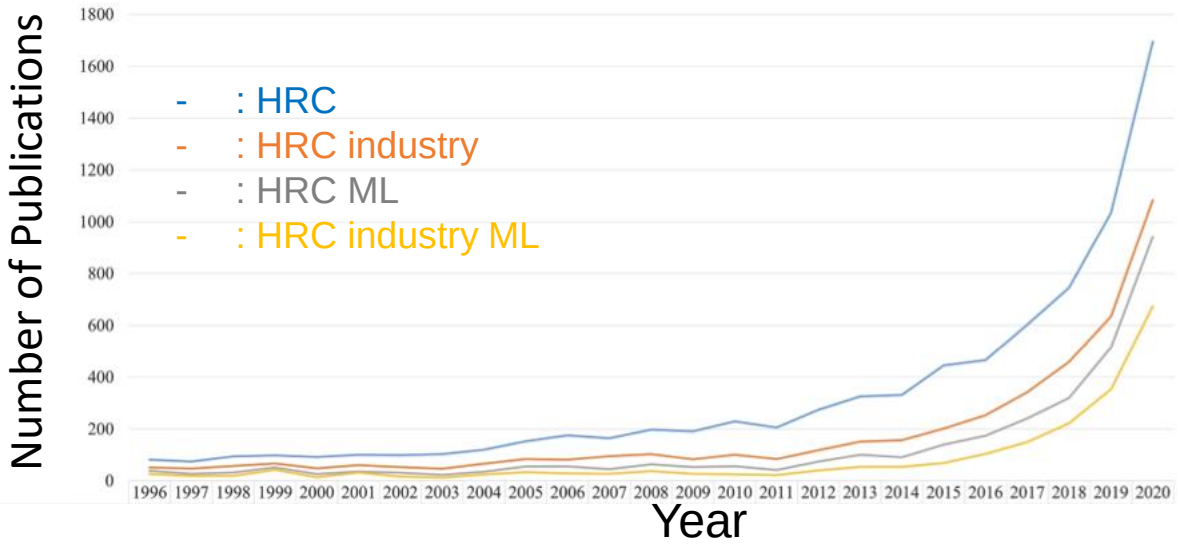
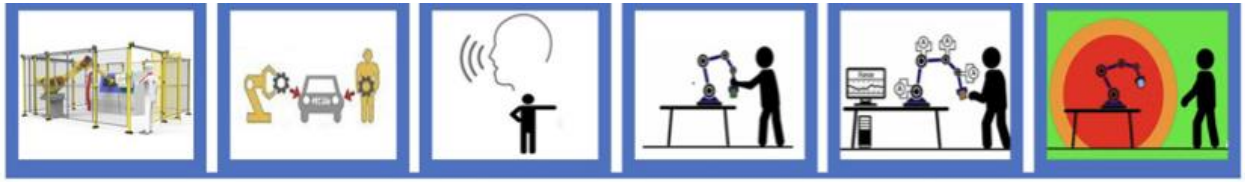
Background

Increase of Co-operating Robots

Number of HRC-relevant publications between 1996-2020



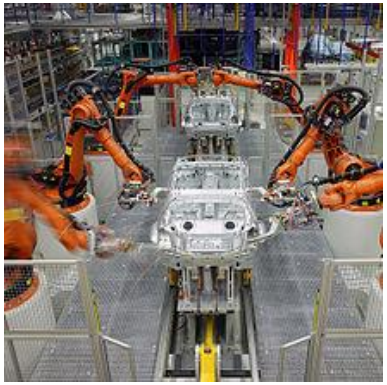
Human-Robot Collaboration (HRC)



Fully Programed → Co-existence → Co-operation → Collaboration

Conventional Robot

Manufacturing Robot(KUKA)



Collaborative Robot

URe Robot (UR)

More and more robots are working with human closely
→A Real-time Collaborative Robot moving smoothly according to human motion

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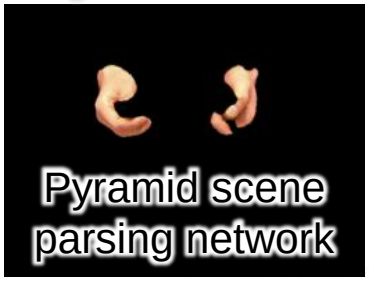
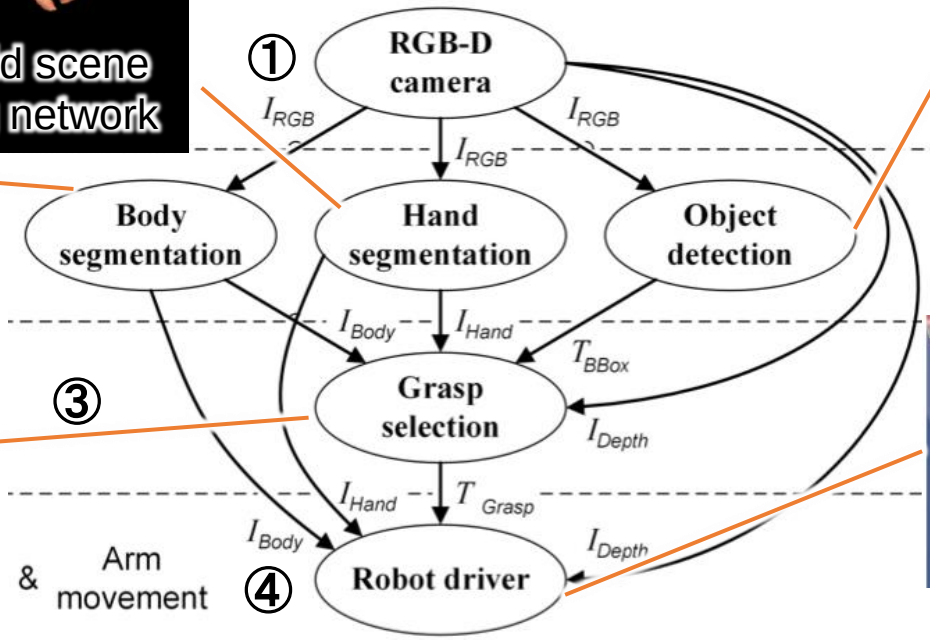
Related Work – Receiving tools from Human

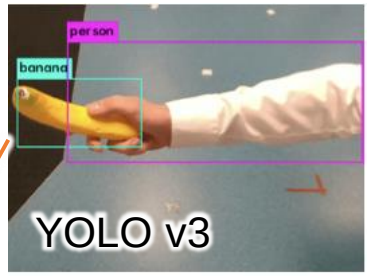
P.Rosenberger et.al, “Object-Independent Human-to-Robot Handovers using Real Time Robotic Vision”(2021)

For safety

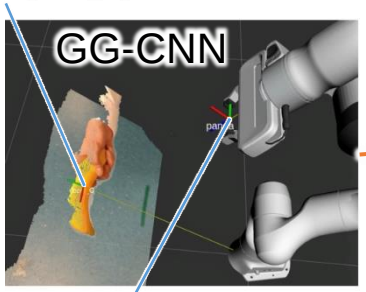


System Overview





Grasping point



Robot position&orientation

- Success rate：**81.9%**
- Processing Time(1~3)：**0.196 sec (5.1 Hz)**

○ : **No need of special environment settings like markers or lightning conditions**

△ : **Processing time is slow → difficult to work smoothly with human**

Related Work – Peg-in-Hole Task

Y.Yamakawa et.al, “Development of a Real-Time Human-Robot Collaborative System Based on 1kHz Visual Feedback Control and Its Application to a Peg-in-Hole Task”(2021)

High-speed Vision Camera

1000 fps

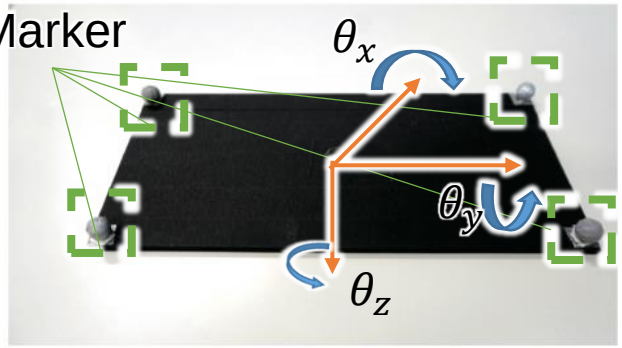
Estimate Position&Orientation

1000 Hz

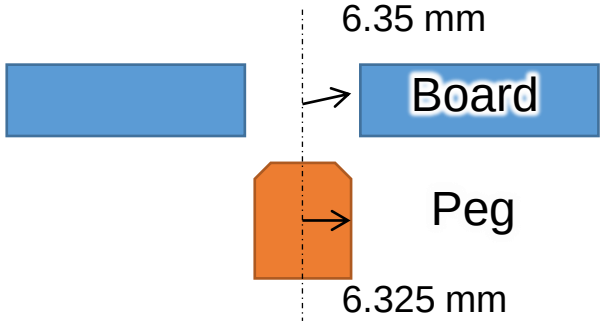
Control Robotic Hand

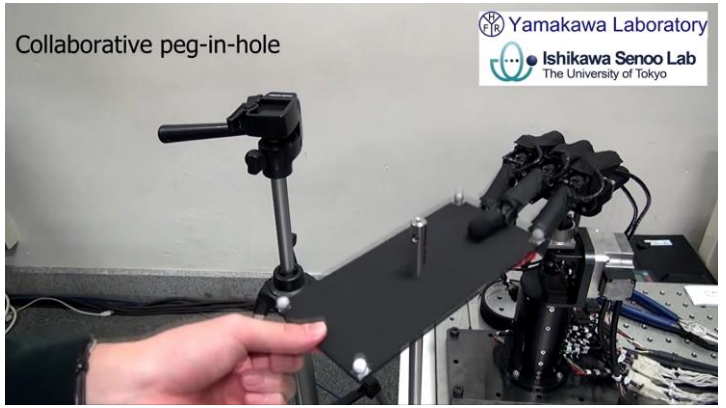
1000 Hz

Marker Tracking



Parallel Control of Board





https://youtu.be/xB9-vEiZwKY

○ : ・ **High Accuracy**: θ_x ~ **0.1 rad** ・ **Real-time Collaboration System(1000 Hz)**

△ : ・**Necessity of Environment Settings like markers and Lightning Conditions**

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Problem & Purpose

Problem:

- ✓ No HRC (Human-Robot Collaboration) System working in a normal environment with low-latency

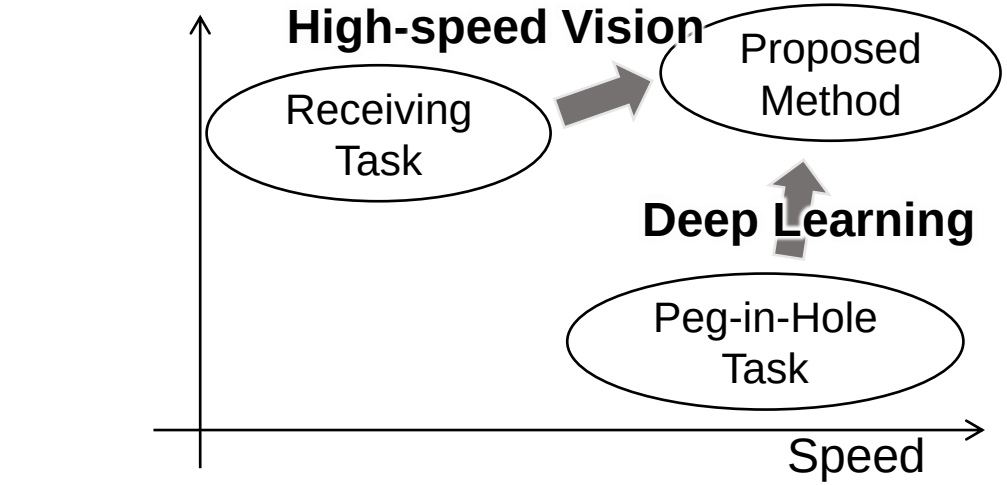
Purpose:

- ✓ No Environment Settings like markers or lightning conditions
- ✓ Working smoothly with low latency even if humans change their motion abruptly

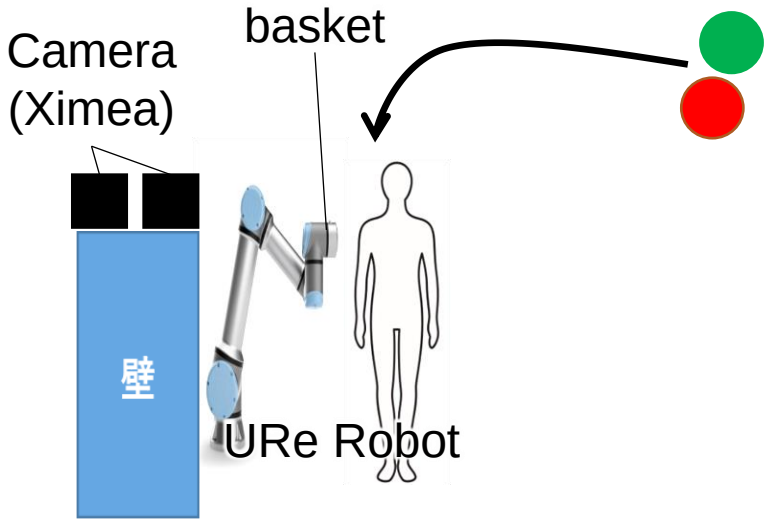
Dynamic Object & Real-time Task

Human and Robot catch 2 balls separately

Concept



System Overview



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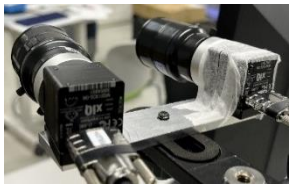
System Overview

1000 fps
High-speed Camera (Ximea)

Stereo Matching



30 Hz
Object Detection (YOLO)

1000 Hz
Object Tracking

x_{b1}, x_{b2}, x_h

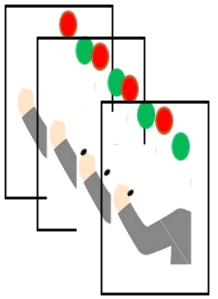
$||x_b - x_h||$

キャッチング

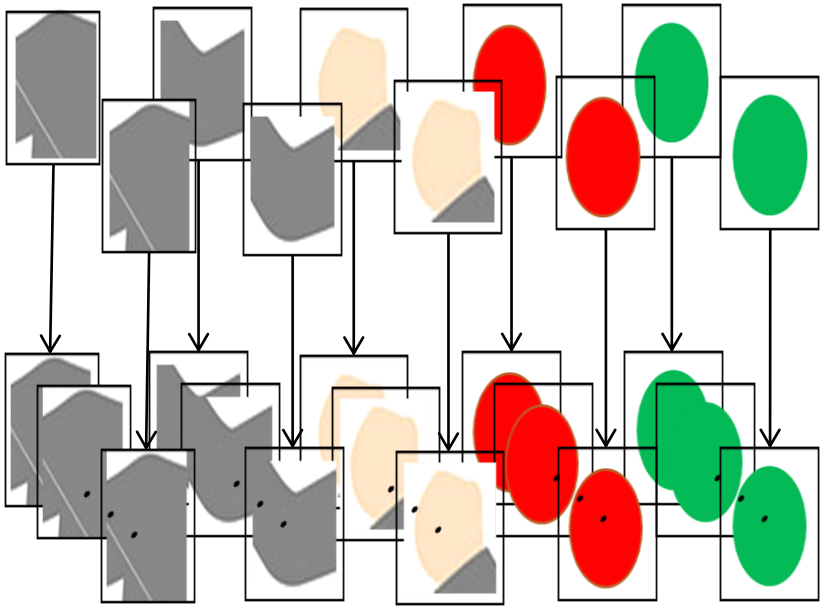
x_h, x_e, x_B

Define Safety Zone

3D Position
x_{b1}:Ball 1,x_{b2}:Ball 2
x_h:Handx_e:Elobow
x_B:Body

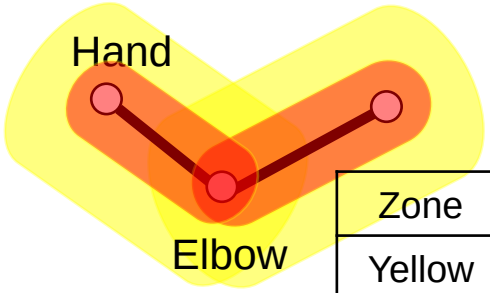


Body Elbow Hand Ball1 Ball2



If $||x_{b1} - x_h|| < ||x_{b2} - x_h||$:
Human: ball1,Robot : ball2
If $||x_{b1} - x_h|| > ||x_{b2} - x_h||$:
Human: ball2,Robot : ball1

Safety Zone around arm



Zone	Velocity
Yellow	½
Red	~ 0

Object Detection – YOLO

Object Detection with YOLOv7

Class : Ball, Hand, Elbow, Body

Average accuracy: **0.81**

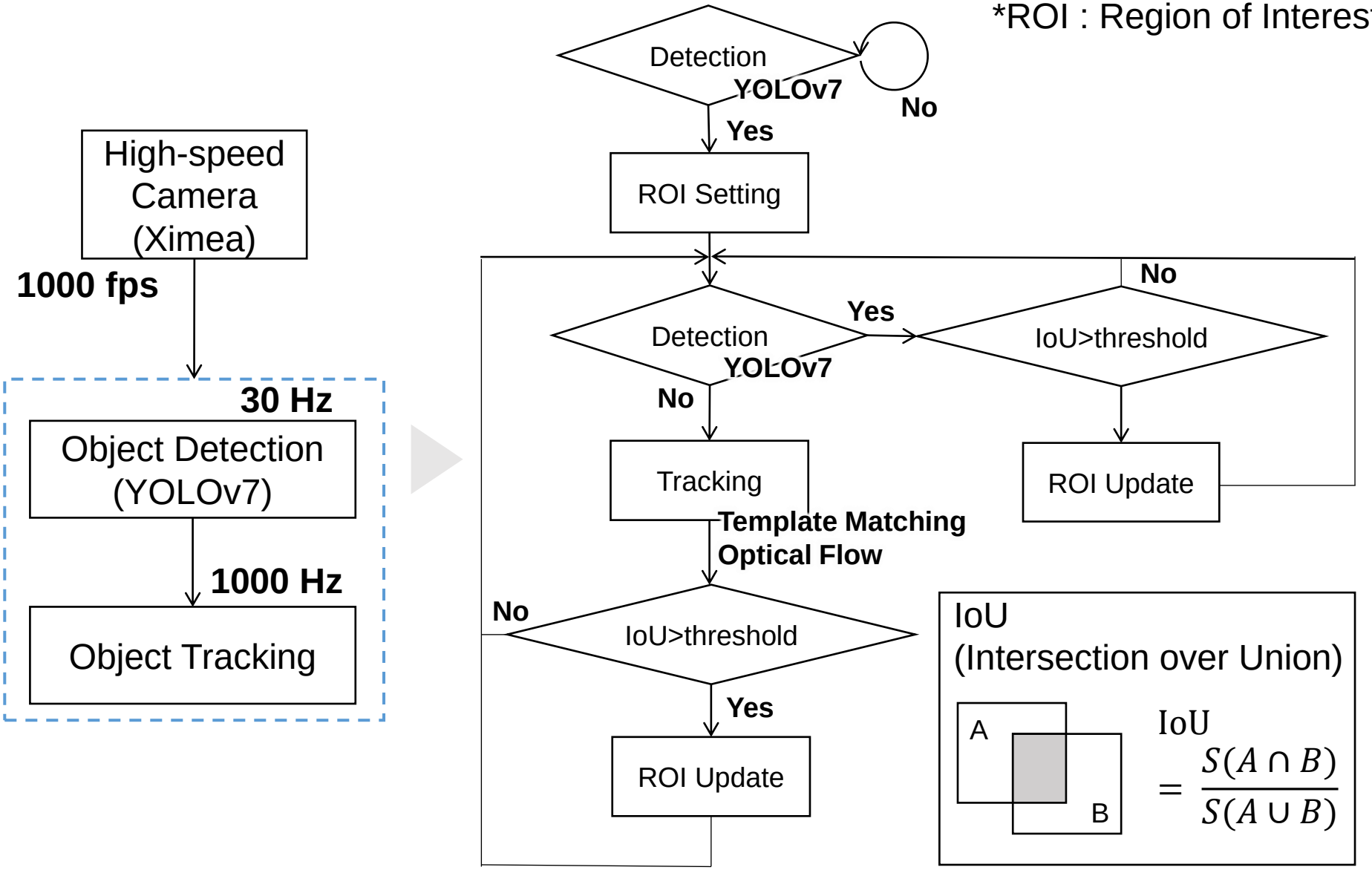
Prediction \ Label	Ball	Hand	Elbow	Body
Ball	0.80			
Hand	0.07	0.71		
Elbow			0.73	
Body				1.00
Back-ground	0.13	0.29	0.27	

- Ball, Hand and Elbow are wrongly classified as background
- Contours are likely to be vague → Can't detect objects

✓ Introduce Edge filter

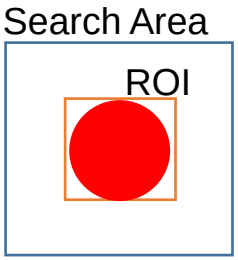
Object Tracking – System Overview

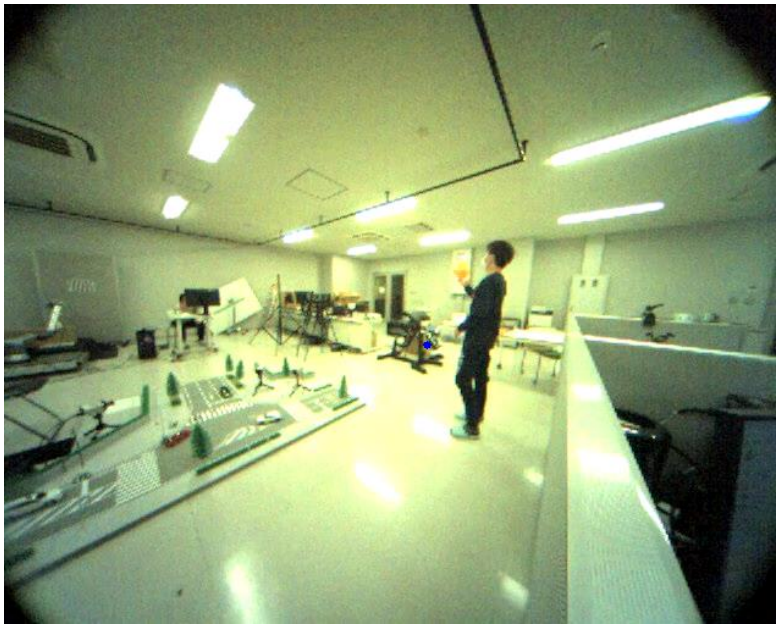
*ROI : Region of Interest

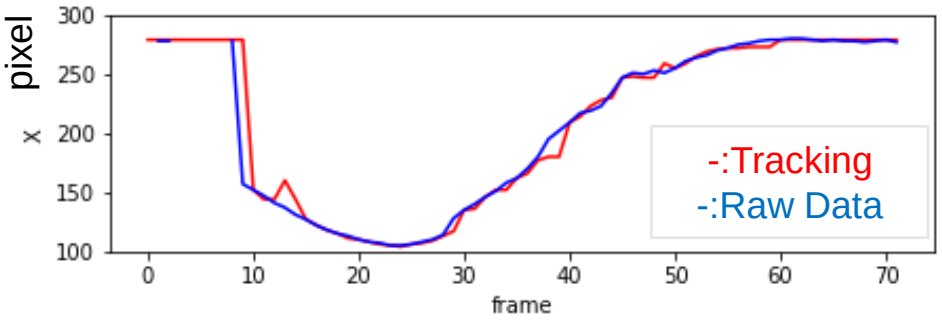


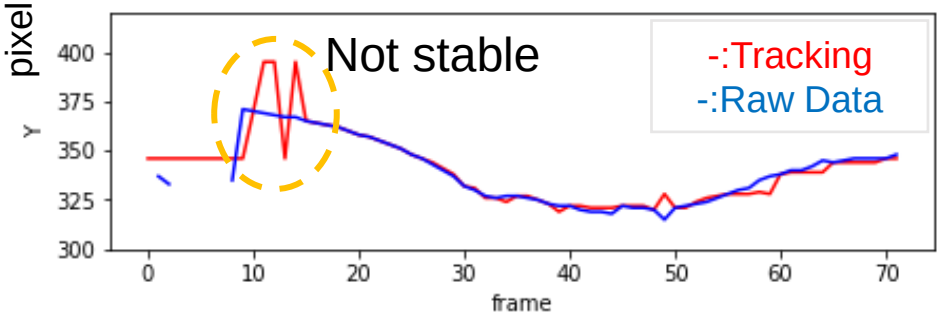
Tracking of Ball – Template Matching

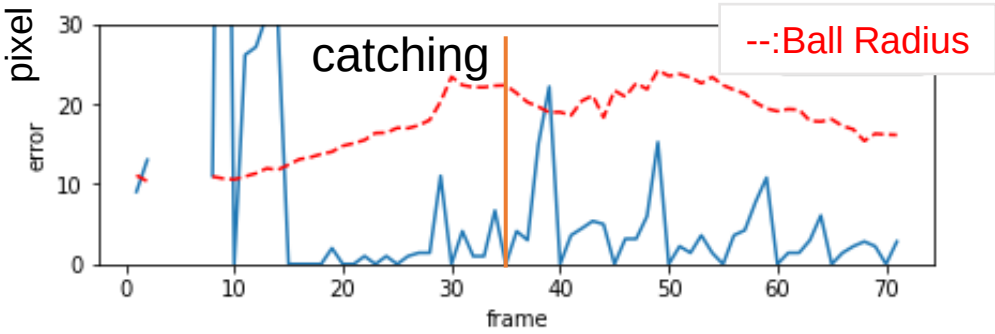
- ROI Update every 5 frames with YOLO
- Template:
  ROI from YOLO detection
- Search Area:
  Around ROI











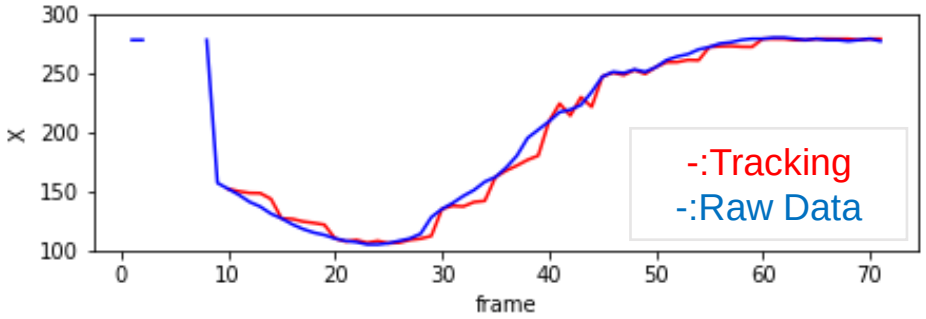
- MSE(Mean Squared Error) : 8.0 pixel (3.4 pixel if first outliers are excluded)
- Tracking is not stable when ball passes around poles on the ceiling

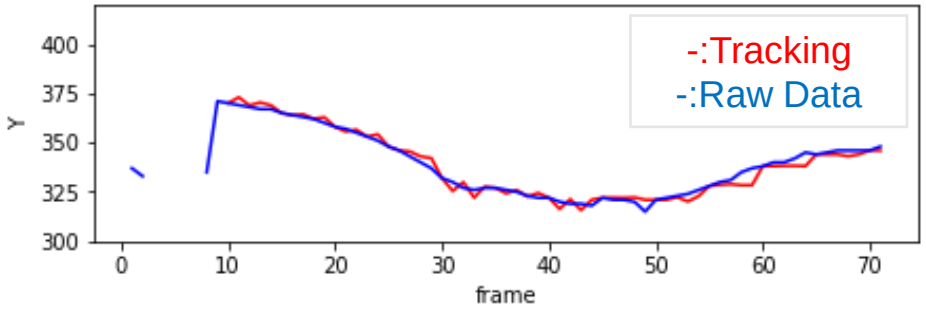
→ Sensitive to the change of surrounding environment

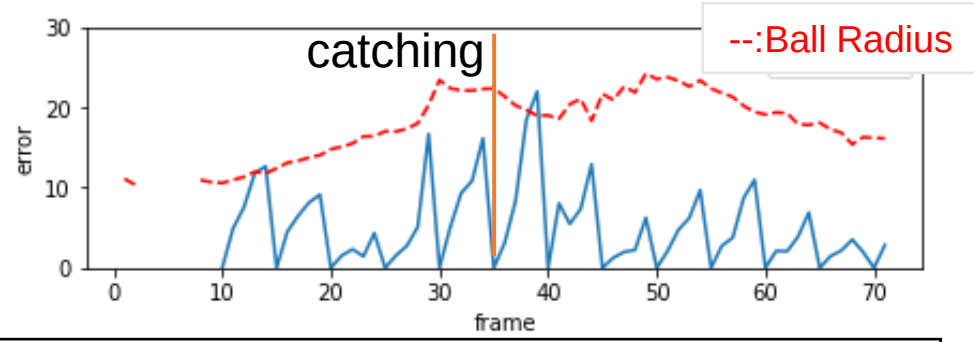
Tracking of Ball – Optical Flow

- ROI Update every 5 frames with YOLO
- Feature points:
  Shi-Tomashi method
- Search Area:
  ROI

Search Area







MSE(Mean Squared Error) : 5.1 pixel
The faster the motion, the worse accuracy → not problem in high-speed vision
Sensitive to the change of lightning condition → Edged filter will be effective

Object Tracking

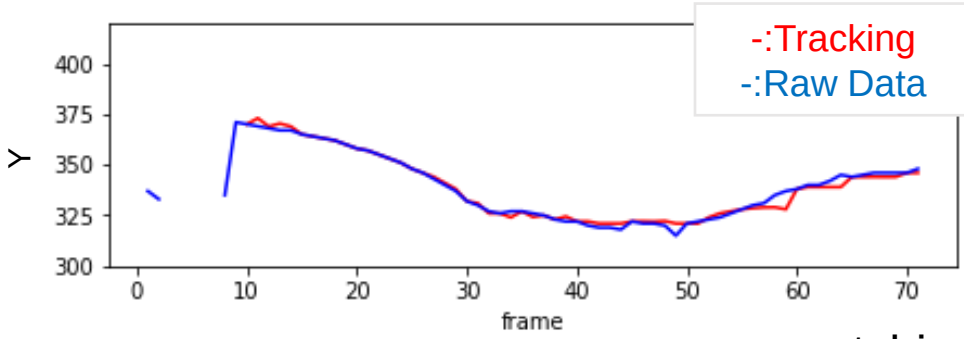
Method	Merit	Demerit	Solution
Template Matching	• Accurate when there is no occlusion	• Sensitive to the change of the surroundings • Necessary larger search area	• Edge Filter • Combine simple prediction $x_{t+1} = x_t + v_t \cdot \Delta t$ → Narrow search area
Optical Flow	• Only small area is necessary	• Sensitive to the lightning change • Error becomes larger as time passes	• Edge Filter

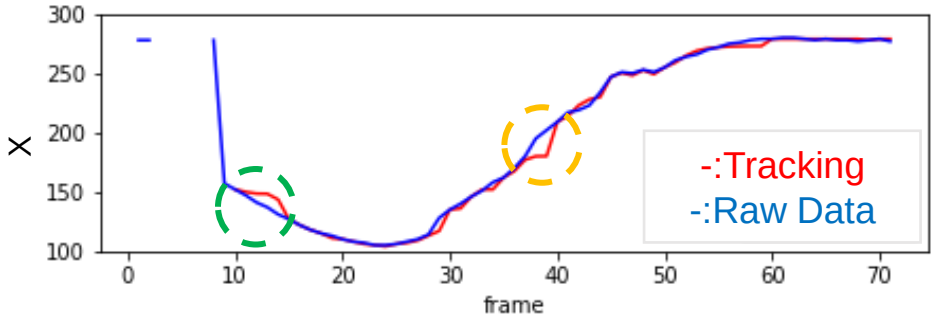
- Detection : YOLO
- Parallel Tracking : Template Matching and Optical Flow

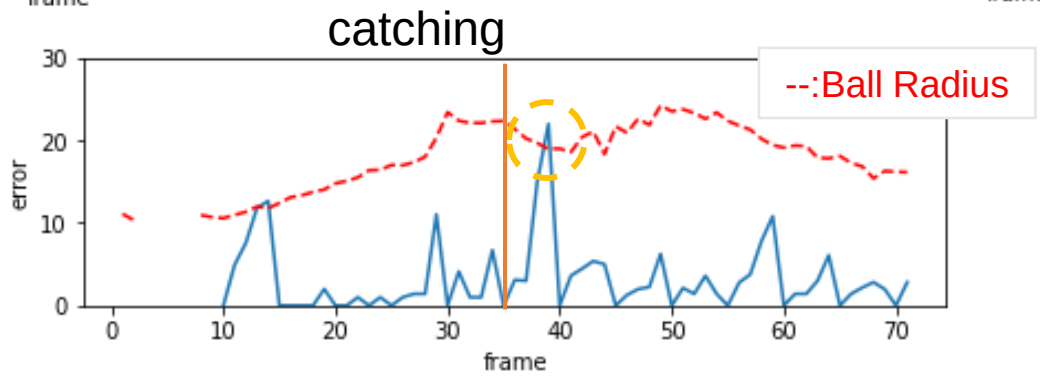
→ High-speed and Robust Tracking System

Tracking of Ball– Optical Flow + Template Matching

- ROI Update every 5 frames with YOLO
- Tracking:
  Optical Flow + Template Matching







MSE(Mean Squared Error) : **3.2 pixel**
(Template Matching : **8.1 pixel**, Optical Flow: **5.1 pixel)**
Error in Y axis is large after catching→ Edged filter will be necessary

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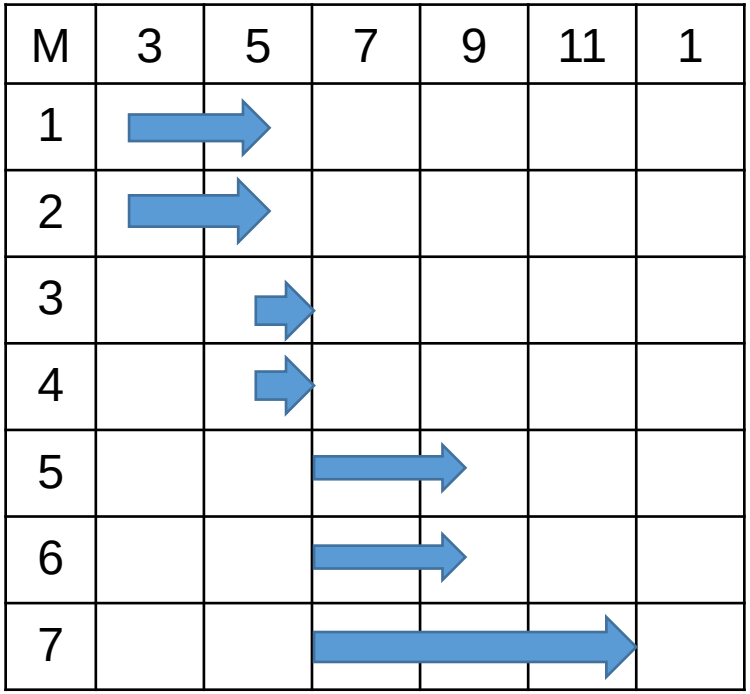
Summary & Future Plan

Summary

- Detection with YOLOv7
  - Accuracy : 81 %
- Tracking System combining YOLO detection and Tracking system
  - Template Matching : MSE= 8.1 pixel
  - Optical Flow : MSE = 5.1 pixel
  - Mix = 3.2 pixel

Future Plan

- Vision System
  1. 3D Reconstruction by Stereo Matching
  2. Real-time Multi-object Tracking system with YOLO and Template Matching and Optical Flow
  3. Calculate the distance between balls and hand
  4. Making safety zone
- Control of Robot Arm
  5. Inverse Kinematics and PD control of torque
  6. Speed Control according to the Safety Zone
7. Experiment



Reference

P4

(1)https://ja.wikipedia.org/wiki/産業用ロボット

(2)https://wiredworkers.io/cobot-arm

(3) Inkulu, A.K, Bahubalendrumi, M.V.A.R, Dara, A and K, S.(2022) “Challenges and opportunities in human robot collaboration context of Industry 4.0 – a state of the art review”, Industrial Robot, Vol. 49 No.2, pp.226-239. https://doi.org/10.1108/IR-04-2021-0077

(4) Debasmita, M., et.al, "A Survey of Robot Learning Strategies for Human-Robot Collaboration in Industrial Settings", Robotics and Computer-Integrated Manufacturing, 2022, Volume73, 102231, ISSN 0736-5845, https://doi.org/10.1016/j.rcim.2021.102231

P6

P. Rosenberger *et al*., "Object-Independent Human-to-Robot Handovers Using Real Time Robotic Vision," in *IEEE Robotics and Automation Letters*, vol. 6, no. 1, pp. 17-23, Jan. 2021, doi: 10.1109/LRA.2020.3026970

P7

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https://youtu.be/xB9-vEiZwKY

P9

- URe : https://iot.aperza.com/2019/09/3789/

Thank you for listening