



## Maeda Lab: 2021–2022

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## SLAM-Integrated Kinematic Calibration (SKCLAM)

SLAM (Simultaneous Localization and Mapping) techniques can be applied to industrial manipulators for 3D mapping around them and calibration of their kinematic parameters. We call this “SKCLAM” (Simultaneous Kinematic Calibration, Localization and Mapping). Using an RGB-D camera attached to the end-effector of a manipulator (Fig. 1), we demonstrated successful SKCLAM in a virtual environment (Fig. 2) and a real environment (Fig. 3) [1][2]. We are also studying SKCLAM with spherical cameras [3] and stereo cameras [4].

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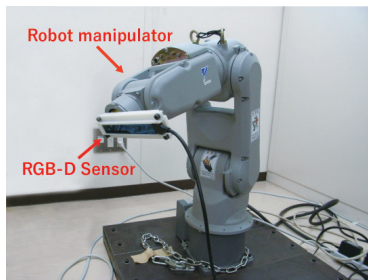


Fig. 1 Manipulator Equipped with an RGB-D Camera

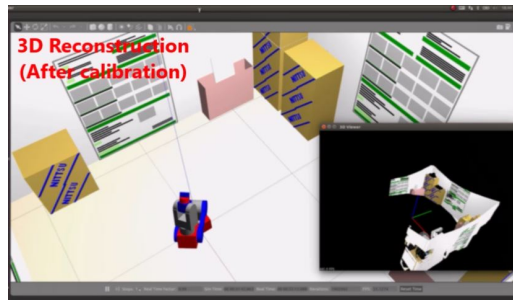


Fig. 2 SKCLAM in Virtual Environment

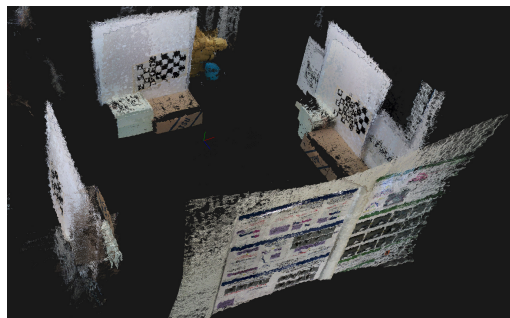


Fig. 3 Example of an Obtained 3D Map

## Robot Teaching

Teaching is indispensable for current industrial robots to execute tasks. Human operators have to teach motions in detail to robots by, for example, conventional teaching/playback. However, robot teaching is complicated and time-consuming for novice operators and the cost for training them is often unaffordable in small-sized companies. Thus we are studying easy robot programming methods toward the dissemination of robot utilization.

**Robot programming with manual volume sweeping** We developed a robot programming method for part handling [1][2]. In this method, a human operator makes a robot manipulator sweep a volume by its bodies (Fig. 4). The swept volume stands for (a part of) the manipulator's free space, because the manipulator has passed through the volume without collisions. Next, the obtained swept volume is used by a motion planner to generate a well-optimized path of the manipulator automatically. The swept volume can be displayed with Augmented Reality (AR) so that human operators can easily understand it, which leads to efficient robot programming [3] (Fig. 5).

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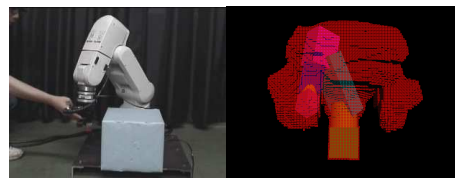
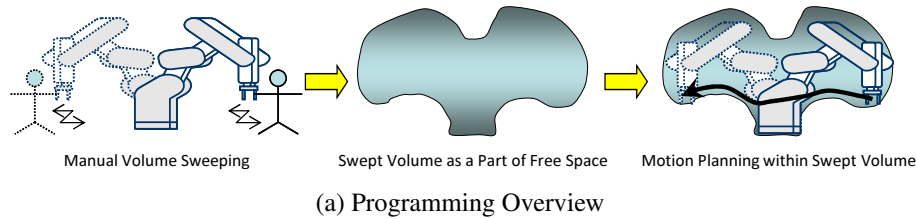
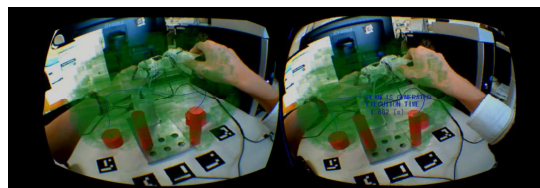


Fig. 4 Robot Programming by Manual Volume Sweeping



## View-Based Teaching/Playback

We developed a teaching/playback method based on camera images for industrial manipulators [1][2]. In this method, robot motions and scene images in human demonstrations are recorded to obtain an image-to-motion mapping, and the mapping is used for playback (Fig. 6). It can achieve more robustness against changes of task conditions than conventional joint-variable-based teaching/playback. Our method adopts end-to-end learning through view-based image processing and therefore neither object models nor camera calibration are necessary. We are improving our view-based teaching/playback by using range images (Fig. 7) and occlusion-aware techniques for more robustness [3]. For application to force-control tasks, visualization of force information based on photoelasticity (Fig. 8) is under investigation [4]. We are also trying to integrate reinforcement learning with the view-based teaching/playback for reduction of human operations for teaching [5].

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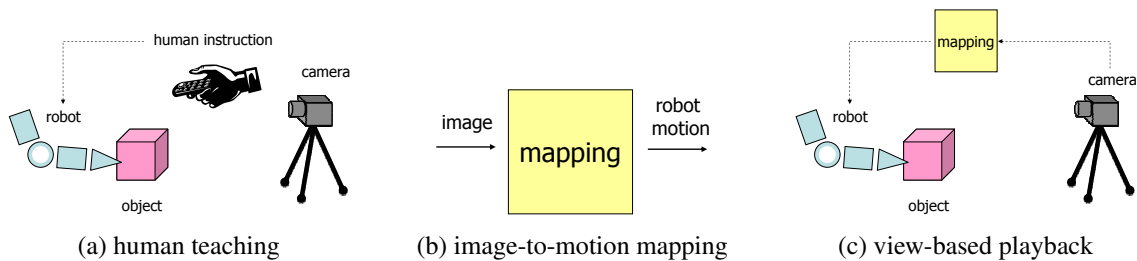


Fig. 6 Outline of View-Based Teaching/Playback

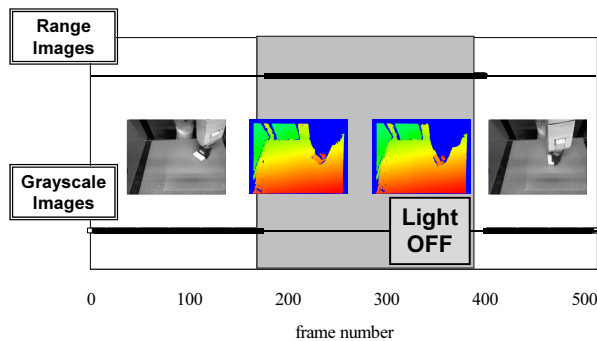


Fig. 7 Switching between Grayscale and Range Images for View-Based Teaching/Playback

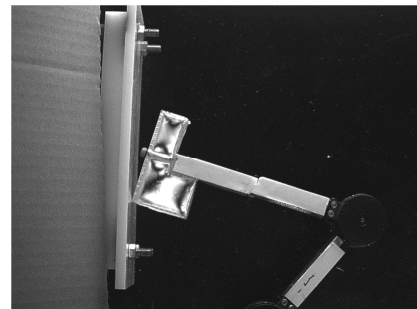


Fig. 8 View-based Teaching/Playback with Photoelasticity

## Caging and Caging-based Grasping

Caging is a method to constrain objects geometrically so that they cannot escape from a “cage” constituted of robot bodies.

**3D multifingered caging** While most of related studies deal with planar caging, we study three-dimensional caging by multifingered robot hands (Fig. 9). Caging does not require force control, and therefore it is well-suited to current robotic devices and contributes to provide a variety of options of robotic manipulation. We are investigating sufficient conditions for 3D multifingered caging and developing an algorithm to plan hand motions for caging based on the conditions [1]. Robot motions generated by the developed planning algorithm were validated on an arm-hand system [2] (Fig. 10).

**Caging-based Grasping** Position-controlled robot hands can capture an object and manipulate it via caging without force sensing or force control. However, the object in caging is movable in the closed region, which is not allowed in some applications. In such cases, grasping is required. We proposed a new simple approach to grasping by position-controlled robot hands: caging-based grasping by robot fingers with rigid parts and outer soft parts. In caging-based grasping, we cage an object with the rigid parts of a robot hand, and construct a complete grasp with the soft parts of the hand. We are studying the formal definition of the caging-based grasping and concrete conditions for caging-based grasping in planar and spatial cases. Based on the derived conditions, we demonstrated planar caging-based grasping by mobile robots and spatial caging-based grasping by a multifingered hand (Fig. 11) [3][4]. We also extend the theory of caging-based grasping so that it can deal with deformable objects (Fig. 12) ([5]).

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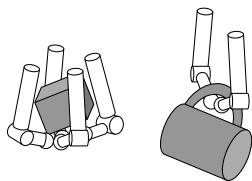


Fig. 9 3D Multifingered Caging



Fig. 10 Caging of a Sphere



Fig. 11 Caging-based Grasping by a Multifingered Hand



Fig. 12 Caging-based Grasping of a Deformable Object

## Caging Manipulation

Caging is a method to make an object inescapable from a closed region geometrically. We study robotic manipulation with caging, or “caging manipulation.”

**In-Hand Caging Manipulation** Pose of objects caged in robot hands can be controlled to some extent by changing hand configurations. We call it “in-hand caging manipulation.” It enables position-controlled robot hands to perform robust in-hand manipulation. In-hand caging manipulation was successfully tested on actual robot hands (Fig. 13). A planning algorithm for in-hand caging manipulation was developed [1][2]. We are also studying various forms of in-hand caging manipulation [3].

**Cooperative Caging Manipulation** The object is not fully constrained in caging. This nature enables cooperative manipulation based on position control without excessive internal forces. We study dual-arm cooperative manipulation of long objects with caging or caging-based grasping (Fig. 14) [4]. It does not require force control, and can deal with a variety of objects by using appropriate end-effectors.

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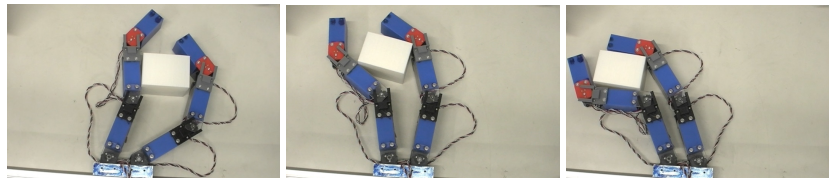
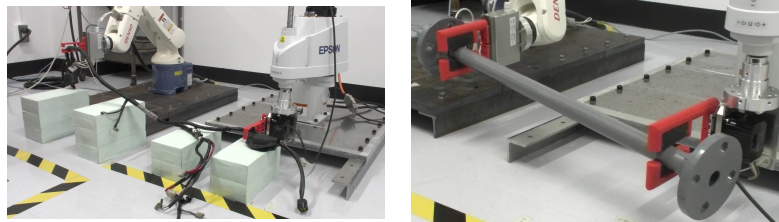


Fig. 13 In-Hand Caging Manipulation



(a) wire harness

(b) long pipe

Fig. 14 Dual-arm Cooperative Manipulation with Caging

## Mechanical Analysis of Robotic Manipulation

Manipulation is one of the most fundamental topics of robotics. We study robotic manipulation toward achievement of human-like dexterity of robots.

Especially we study contact mechanics of graspless manipulation (manipulation without grasping, Fig. 15) and power grasp (grasping with not only fingertips but also other finger surfaces and palm, Fig. 16) [1][2]. Based on the contact mechanics, we analyzed the robustness [3] (Fig. 17) and internal forces of robotic manipulation [4]. We also proposed a method for joint torque optimization for robotic manipulation [5].

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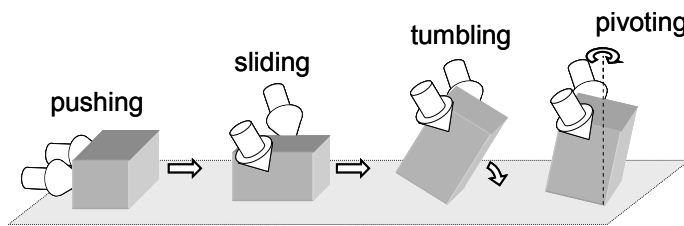


Fig. 15 Graspless Manipulation

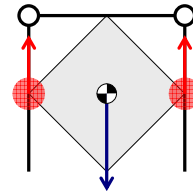


Fig. 16 Mechanical Analysis of Power Grasp

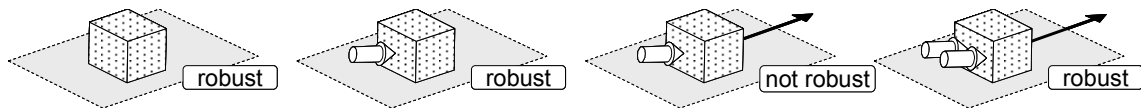


Fig. 17 Robustness of Pushing

## Handling of Various Objects by Robots

Techniques for robotic manipulation of a variety of objects are under investigation.

**Vision-Based Object Picking** Robotic bin-picking is more flexible and versatile than the use of conventional part feeders, and therefore it is effective for low-volume production. Many bin-picking techniques have been proposed, and some of them are in actual use. However, it is difficult to apply these existing techniques to coil springs, due to their shape characteristics. Thus we developed a dedicated method to recognize and localize coil springs in a pile, which enabled robotic bin-picking of coil springs (Fig. 18) [1]. Additionally we are developing an impacting-based method to detect unknown objects for picking (Fig. 19) [2].

**3D Block Printing** We developed a robotic 3D printer: a robot system that can assemble toy brick sculptures from their 3D CAD models [3][4][5]. In this system, a 3D CAD model is automatically converted to a block model consisting of primitive toy blocks. Then an assembly plan of the block model is automatically generated, if feasible. According to the plan, an industrial robot assembles a brick sculpture layer by layer from bottom to top. We demonstrate successful assembly of several brick sculptures (Fig. 20).

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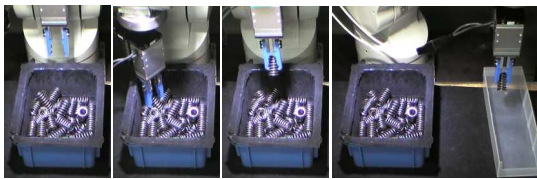


Fig. 18 Bin-Picking of Coil Springs



Fig. 19 Impacting-based Picking



Fig. 20 3D Block Printing

## Modeling and Measurement of Human Hands and Their Dexterity

The theory of robotic manipulation can be applied to analysis of human hands and their dexterity. Understanding of human dexterity is very important to implement high dexterity on robots. We are conducting some studies on modeling of human hands and skills jointly with Digital Human Research Team, AIST.

**Digital Hands** We are developing a method for generating models of human hands that have links and skins (Fig. 21) to represent their motion using motion capture [1]. The applications of the hand models include modeling range of motion with subjective discomfort in human hands [2].

**Grasp Measurement and Synthesis** Digital hands can be used to synthesize grasps for supporting ergonomic product design (Fig. 22) [3]. We also study a simple grasp measurement device (Fig. 23) [4] and grasp synthesis for ROM-limited hands [5].

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Fig. 21 Model of a Human Hand

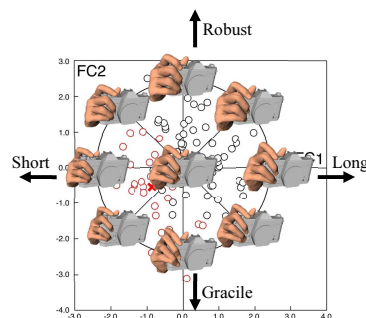


Fig. 22 Grasp Synthesis for Various Hands

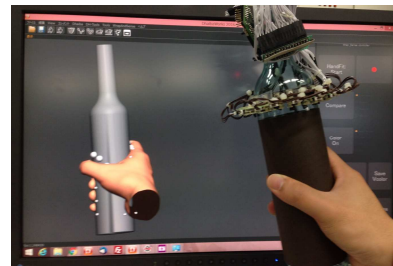


Fig. 23 “Wrap & Sense”

## Application of Robot Technology to Human Activity Support

Robot technology should be applied to various fields to support human activities. For example, home appliances would be robotized more and more to help our daily life intelligently and effectively. We have a proposal on smart dishwashers: our proposed system can support users' dishwasher loading [1][2][3]. This system can recognize dishes from a picture of a dining table after a meal. Then the system calculates the optimal placement of the recognized dishes in the dishwasher and presents the result to users as 3D graphics (Fig. 24).

We are also developing a support system for human origami folding [4]. It is composed of an origami simulator for design and display of origami folding processes (Fig. 25) and a cutting plotter for adding crease pattern automatically. The system can be used in childhood education and elderly care.

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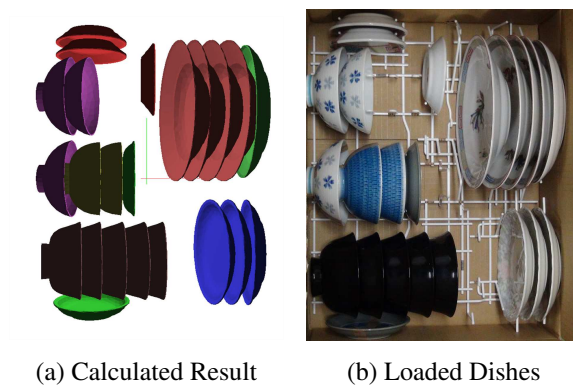


Fig. 24 Optimized Dish Loading

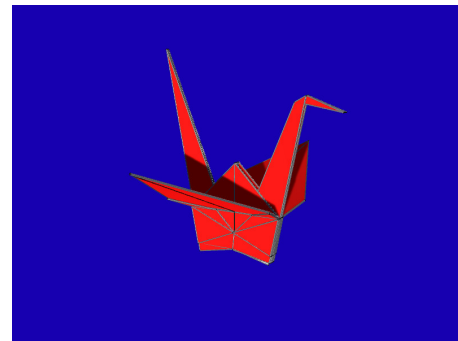


Fig. 25 Origami Simulator