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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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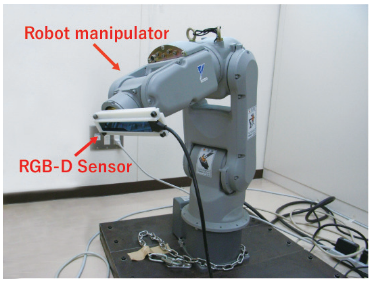

Fig. 1 Manipulator Equipped with an RGB-D Camera

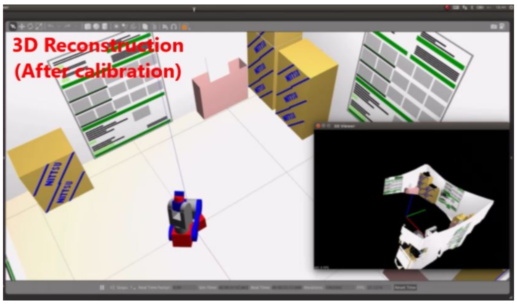

Fig. 2 SKCLAM in Virtual Environment

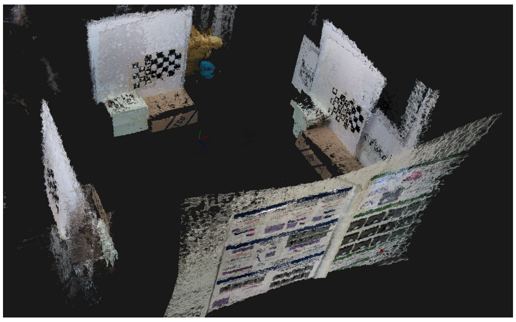

Fig. 3 Example of an Obtained 3D Map

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. 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. 4).

Assisting Online Robot Programming We are developing a support system for online robot programming using an optical see-through AR device that can overlay useful information on a real robot such as its movable area (Fig. 5). The system also supports the above robot programming with manual volume sweeping [4]. Another support system for online robot programming is also developed. In this system, it is possible to group and move existing teaching points, and generate robot motions that connect the points. This is useful for adaptation to product specification changes in robotic assembly [5].

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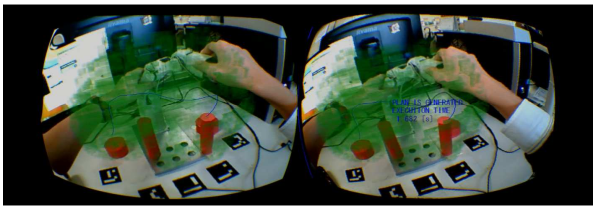

Fig. 4 AR Display of Swept Volume and Planned Path

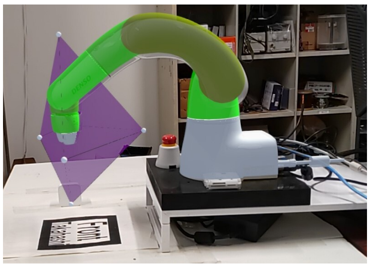

Fig. 5 AR Display of Movable Area with Fixed Gripper Pose

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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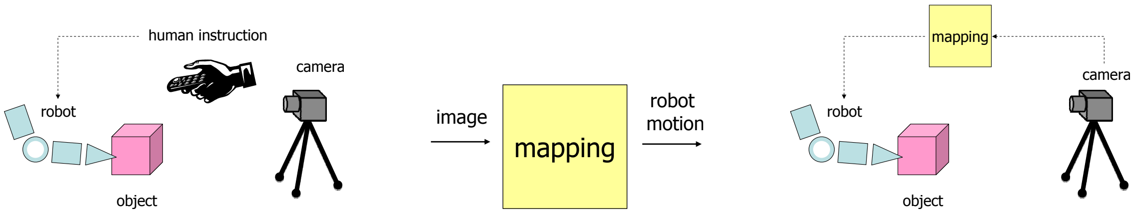

(a) human teaching (b) image-to-motion mapping (c) view-based playback

Fig. 6 Outline of View-Based Teaching/Playback

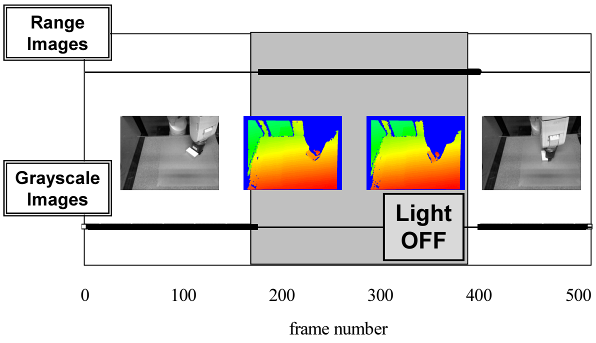

Fig. 7 Switching between Grayscale and Range Images for View-Based Teaching/Playback

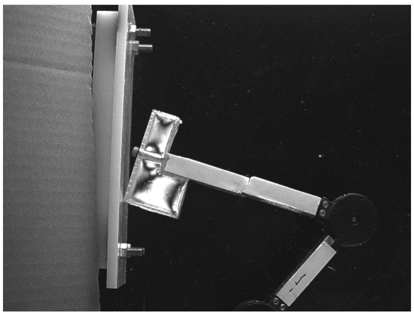

Fig. 8 View-based Teaching/Playback with Photoelasticity

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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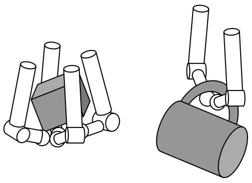

Fig. 9 3D Multifingered Caging

Fig. 10 Caging of a Sphere

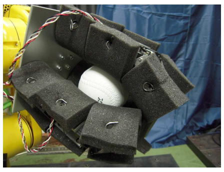

Fig. 11 Caging-based Grasping by a Multifingered Hand

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. A planning algorithm for in-hand caging manipulation was developed [1][2]. We are also studying various forms of in-hand caging manipulation [3] including versatile part feeders [4] (Fig. 13).

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) [5]. It does not require force control, and can deal with a variety of objects by using appropriate end-effectors.

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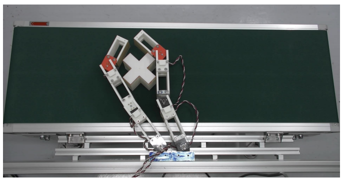
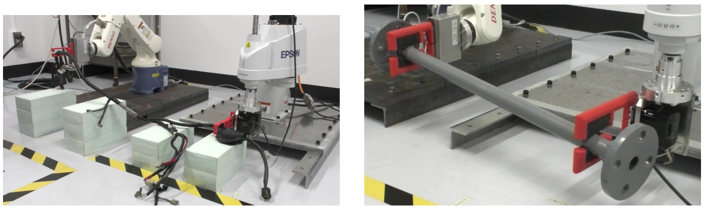


Fig. 13 A Versatile Part Feeder with In-Hand Caging Manipulation



(a) wire harness

(b) long pipe

Fig. 14 Dual-arm Cooperative Manipulation with Caging

Photoelastic Force Distribution Sensing and Its Applications

Photoelasticity enables us to conduct pixelwise stress analysis by using a photoelastic body, a polarized light source and a polarization camera. The distribution of contact forces at the photoelastic body can also be estimated. We developed a robot finger equipped with a photoelastic fingertip (Fig. 15), which can perform online contact force distribution sensing and contact force control [1]. We also developed a robot hand with photoelastic links (Fig. 16) with force sensing ability [2].

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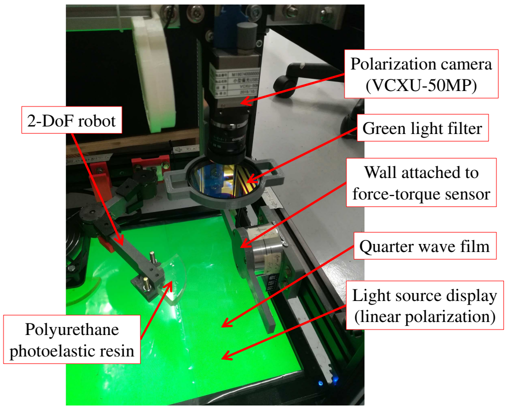

Fig. 15 A robot finger with photoelastic fingertip

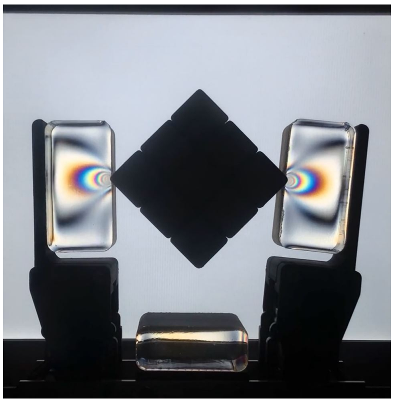

Fig. 16 A robot hand composed of photoelastic bodies

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. 17) [1]. Additionally we are developing an impacting-based method to detect unknown objects for picking (Fig. 18) [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]. 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. 19).

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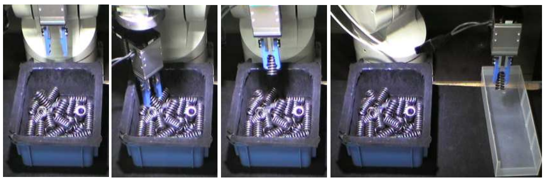

Fig. 17 Bin-Picking of Coil Springs

Fig. 18 Impacting-based Picking

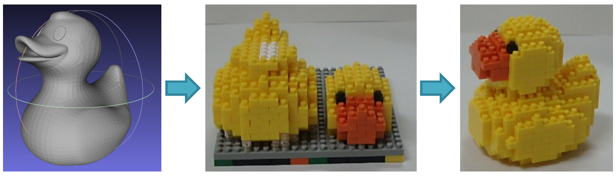

Fig. 19 3D Block Printing

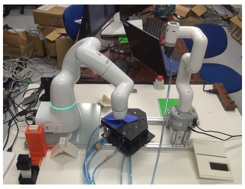

Fig. 20 A Robot System to Fold a Paper Crane

Intelligent Heavy Equipment Systems

Automation and intellitization of heavy machinery is immensely demanded for higher efficiency and safety. We study traffic control of dump truck fleets in mines (Fig. 21) to improve productivity. A combinatorial optimization method is developed for the order of passing intersections and tested on a simulator (Fig. 22) [1][2].

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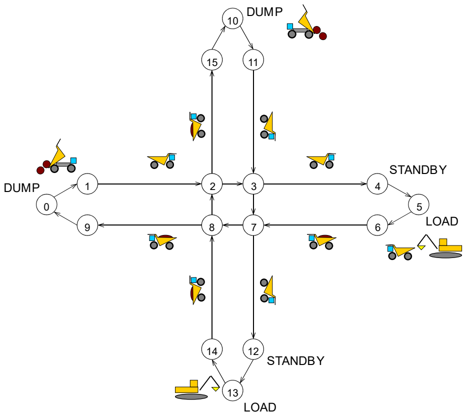
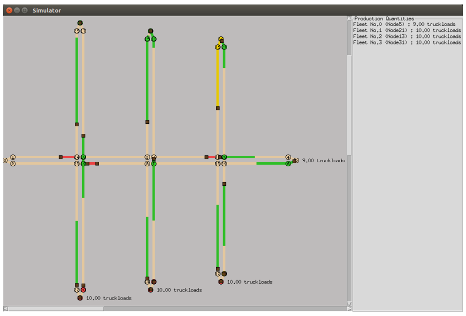


Fig. 21 Dump Truck Fleets in a Mine



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Production Quantities
Fleet No.0 (Node5) : 9.00 truckloads
Fleet No.1 (Node21) : 10.00 truckloads
Fleet No.2 (Node13) : 10.00 truckloads
Fleet No.3 (Node31) : 10.00 truckloads
```

Fig. 22 A Simulator of Dump Truck Fleets

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 Living Activity Modeling Research Team, AIST.

Modeling and Measurement of Human Hands We are developing a method for generating computational models of human hands that have links and skins to represent their motion using motion capture. The applications of the digital hand models include modeling range of motion with subjective discomfort in human hands [1]. We also study a simple grasp measurement device (Fig. 23) [2].

Grasp Measurement and Synthesis Digital hands can be used to synthesize grasps for supporting ergonomic product design (Fig. 24) [3]. Grasps by hands of patients with carpal tunnel syndrome and elderly people can be simulated (Fig. 25) [4].

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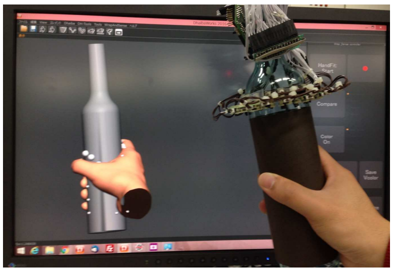

Fig. 23 “Wrap & Sense”

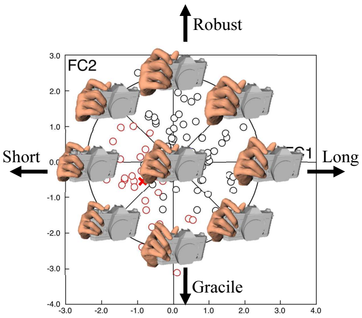

Fig. 24 Grasp Synthesis for Various Hands

Fig. 25 A Synthesized Grasp of a Universal Design Knife by An Elderly Hand

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. 26).

We are also developing a support system for human origami folding [4][5]. It is composed of an origami simulator for design and display of origami folding processes (Fig. 27) and a cutting plotter for adding crease pattern automatically. The system can be used in childhood education and elderly care.

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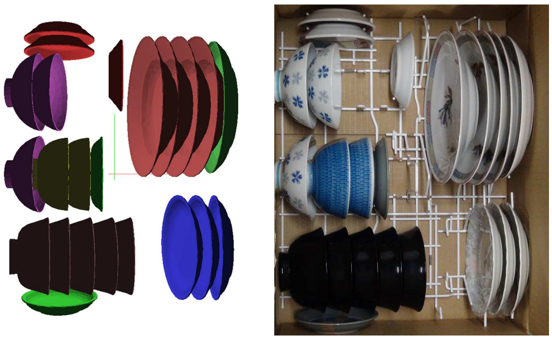

(a) Calculated Result (b) Loaded Dishes

Fig. 26 Optimized Dish Loading

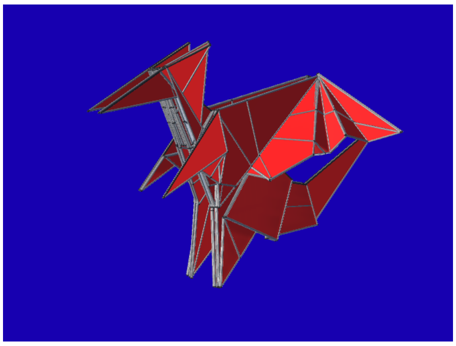

Fig. 27 Origami Simulator