Improved Three-dimensional Image Processing Technology for Remote Handling Auxiliary System

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1. Introduction

Remote handling devices are used in the radioactive environment of nuclear power plants since humans cannot enter the work environment to perform handling operations. Fuji Electric has developed a remote handling auxiliary system based on shape recognition technology to identify the location and orientation of a handling object (target) virtually. The operator adjusts a virtual screen to the desired viewing direction so that a handling device such as a manipulator can be operated with ease. This paper presents an overview of the remote handling auxiliary system and describes details of its development.

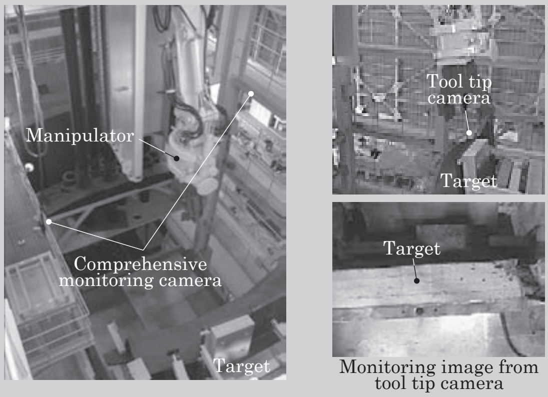
2. Development Background

With fuel handling equipment, which are typical conventional remote handling devices, the nuclear fuel to be handled was placed at a precise location and orientation, and accurate and sophisticated remote controlled movement in a harsh environment was required. Most operations, however, such as moving a certain distance along a predetermined trajectory, stopping, and then performing a separate operation were planned in advance.

However, in recent years there has been an increase in the use of targets which have a non-distinct profile. In such cases, an articulated manipulator is operated manually. When dismantling a nuclear power reactor during decommissioning and when performing remote operations within a cell, an articulated manipulator and camera are placed in the work environment, and the operator implements manual operations while viewing the camera video in an operation room. Figure 1 is an example of a nuclear power reactor remote dismantling test device. Using this device, in a remote operation test (Fig. 2) in which a manipulator picks up a target from the floor, the effect that changing the number of cameras had on work efficiency (work time) was investigated. With video images from a camera, depth is difficult to sense, and in some cases, the target may be obstructed by an object in the forefront, making it impossible to obtain an adequate image. If the number of cameras is increased to compensate for such a problem, the work efficiency improves. On the other hand, performing the time consuming task of adjusting a large number of images and visually comparing the results increases the burden on the operator, and as a result, work efficiency may decrease. Additionally, the cameras cannot always be installed at the best locations for all scenes.

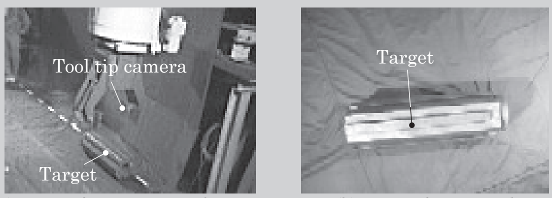
Marks or guides placed nearby the target are often used as references for operation. Figure 3 shows an example wherein, in order to insert the tip of a tool into the hole in a target, a laser pointer attached to the tool shines a laser spot onto the target, and the operator

Fig.1 Examples of camera images of dismantling work



Monitoring image from tool tip camera

Fig.2 Examples of monitoring image



(a) Image from a comprehensive monitoring camera

(b) Image from a tool tip camera

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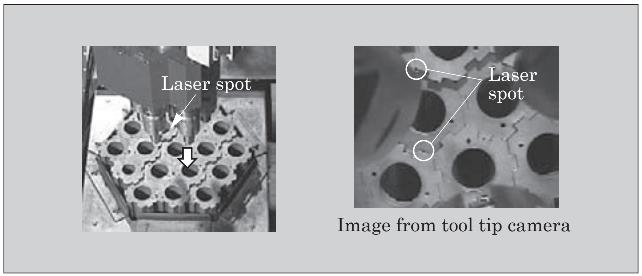
Fig.3 Example of alignment according to positioning mark



positions the tool while watching the camera image. However, the presence of adjacent objects other than the target will cause the operating environment to become more challenging and as a result, more camera images will be needed. The determination of which cameras to use from among the available cameras, how to best adjust the image (orientation and angle) to facilitate the operation, and how to use positioning marks depends upon the experience of the operator. Therefore the skill level of an operator affects the work efficiency and the quality of the work.

For this reason, a system capable of providing uniform quality of work, regardless of the skill level of the operator, is desired.

3. Concept of the Remote Handling Auxiliary System

The concept of a remote handling auxiliary system developed under these circumstances is shown in Fig. 4.

This remote handling auxiliary system displays the location and orientation of the target on an operation screen during remote operation, and provides the necessary images and distance information for manual operation of the manipulator. The operation screen displays the actual image from the camera and also displays a monitoring image, which is a virtual representation of the operating environment (scene). The scene is obtained as point-cloud data by using a distance sensor installed in the work environment to scan an area that includes the target. Based on this point-cloud data, the relevant objects are expressed as multiple layers of computer graphic (CG) images, and exhibit the following characteristics.

(a) The scene is expressed by a point-cloud containing three-dimensional data (having spatial three-dimensional coordinates).
(b) The contour of the target and outline of the manipulator are displayed in the scene.
(c) The line of sight along which the scene is viewed may be moved freely.
(d) The distance between two arbitrary points, such as between the manipulator tip and the target, can be obtained by pointing on the monitoring screen.

The operator observes both the actual image from

Fig.4 Remote handling auxiliary system

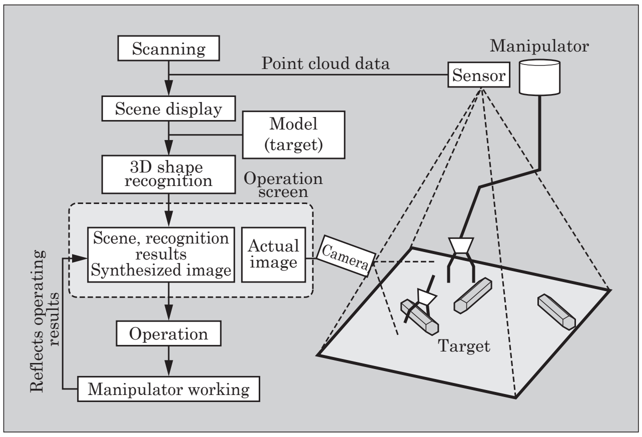
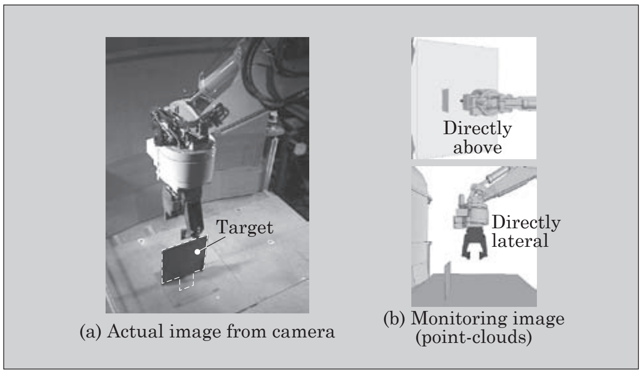


Fig.5 Operation screen (image)



the onsite camera and the above-described monitoring image while performing the appropriate operation. Figure 5 shows an image of the operation screen. The operation screen shown in Fig. 5(a) is the actual image from the camera. Figure 5(b) is a virtual image generated by the system.

Even in cases where only a portion of the target has been captured by the sensor, the application of three-dimensional shape recognition technology to the outline of the visible portion of the target provides the capability to view a virtual CG-synthesized display of the entire image, and this is the greatest benefit of using a virtual image. Additionally, this virtual image also synthesizes a display of the manipulator outline, so that the image may be changed freely to show the desired line of sight. By observing the virtual image, the operator gains a sense of gazing around the positional relationship between the target and manipulator. In Fig. 5, the actual image is from a camera fixed in a specific direction and a sense of distance is difficult to grasp. When viewed in combination with the virtual images viewed from directly above and lateral perspectives, a sense of horizontal and vertical distance is easier to grasp. If combined with distance display on the screen, the scene in Fig. 5 will provide the operator with an understanding of how and by what distance to move the manipulator.

When the manipulator is moved, the virtual manipulator shown in the virtual image will also move in the same manner in real time. When the manipulator is being moved, the desired task can be accomplished while monitoring the status of the virtual image.

This remote handling auxiliary system is provided with dictionaries containing multiple point cloud target shape models that are compared with the target chosen to be handled and the scanned scene (point cloud data). The primary objective of this system is to realize the capability to identify the location and orientation of a target, even when only a portion of the target is visible. The system was developed by focusing on three-dimensional shape recognition technology.

4. Three-dimensional Shape Recognition Technology and the Remote Handling Auxiliary System

Computer-aided visual recognition technology is required for the automation of tasks involved in recognition and judgment making by humans. We are still learning about the processes by which humans recognize and make judgments, and general-purpose recognition algorithms are still being researched. The application of a recognition algorithm often involves the use of custom recognition algorithms developed for each of the specific tasks to be automated.

The technology to automate visual recognition and judgment using an image from a camera or other two-dimensional image is spreading to industrial inspection and recognition devices and to biometric recognition devices. These devices, however, assume an environment having a fixed observing point for viewing the object and therefore have difficulty in providing sufficient support for an environment in which multiple observing points are required, such as for remote operation by a manipulator.

Three-dimensional recognition technology is effective in solving the aforementioned types of problems. The processing of data in three dimensions involves dramatically more data than does two-dimensional data processing, but high-speed processing has become possible through the rapid development of computer technology. Moreover, three-dimensional measurement technology is also being widely utilized and the cost of distance sensors is decreasing for both laser and stereo vision methods. Under such conditions, research into three-dimensional recognition technology is being accelerated, but at present, there is still no established technique.

When observing a three-dimensional object in two dimensions, the resulting image is treated as a two-dimensional image from a certain observing point, and for the same object, this image will differ if the observing point changes. Humans are able to comprehend the shape of an object empirically, and can recognize an object even when the image is from a different observing point. A computer, however, does not possess empirical knowledge, and thus in order to achieve the same recognition results, must either retain two-dimensional data from all observing points and apply a two-dimensional recognition algorithm, or apply a three-dimensional recognition algorithm that does not depend on the observing point. The former has the advantage of allowing existing technology to be utilized, but has difficulty in providing a sense of perspective such as when the size of the object changes according to its proximity.

The development of the remote handling auxiliary system involved the following two research topics.

(a) A scene including the arbitrary location and arbitrary orientation of the assumed object (model) is measured by a distance sensor as point cloud data, and three-dimensional shape recognition technology is used to recognize the type and orientation of the model.

(b) Construction of an auxiliary system that enables easy remote operation of a manipulator when a non-expert operates a screen displaying a CG image showing the recognition results, and then verifies the image from a convenient observing point.

4.1 Three-dimension shape recognition principles, application and evaluation results

In case there exists a large quantity of data of the object to be recognized, as in the case of an image, for example, rather than processes that data directly, the recognition algorithm typically converts the data to a low-loss quantity of a reduced dimensionality (known as the characteristic quantity) and then processes the data. In order to realize recognition that does not depend on the observing point, the orientation of the object, and the distance to the object, a characteristic quantity that does not depend on the observing point, orientation or distance must be used. Three-dimensional recognition was implemented with this system using a characteristic quantity having the following properties.

(a) Low dependency on perspective and orientation of the object

(b) Low dependency on distance from observing point

(c) Low susceptibility to influence from other objects positioned nearby

This assumes the case where the object is partially blocked by an obstructing object in its vicinity and only a part of the object can be measured (partial absence).

The principles for recognition using this characteristic quantity are described below. Firstly, a point-cloud of the object to be recognized (the model) is prepared in advance, and a characteristic quantity is computed at each sampling point spaced apart at regular intervals. Each characteristic quantity is mapped to the three-dimensional coordinates of a point on the model. A dictionary that combines three types of data, i.e., characteristic quantity, model type and three-dimensional coordinates of the corresponding point, is prepared in advance.

Next, during the recognition processing, the point-clouds of a scene that includes the object to be recognized is measured and then the characteristic quantity is computed for an arbitrary sampled point. Using a pattern recognition technique, this characteristic quantity is compared to characteristic quantities in the dictionary, and a similar characteristic quantity is selected. As a result, the point sampled from the scene is mapped, via the characteristic quantity, to three-dimensional coordinates of the model type and in the model. Based on multiple mapping relationships obtained thusly, the type, location and orientation of the model in the scene are obtained.

By applying the above principles, the following elemental technologies were developed and applied.

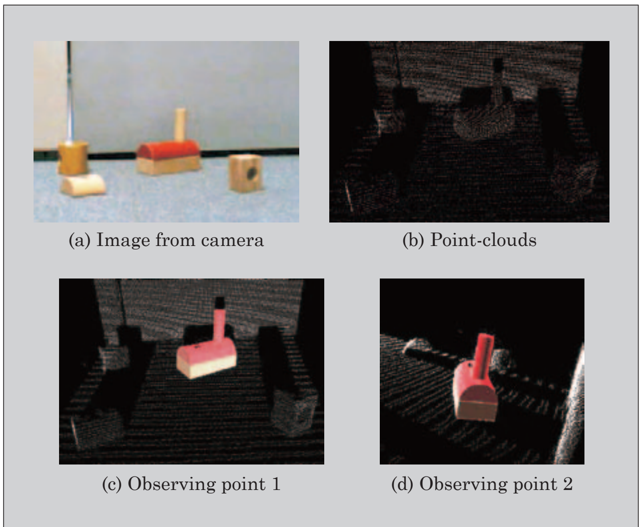
(a) Algorithm for extracting a specified object from a combination of multiple objects (segmentation)

(b) Algorithm for recognizing a rotating object (columnar, etc.), for which recognition had been difficult according to the principles of three-dimensional recognition

(c) Algorithm (typically an application of the ICP method) for matching the dictionary data with the measured data using an iterative approach with the above-mentioned recognition results as initial values

The results of evaluations performed using the recently developed three-dimensional recognition algorithm are described below. The example of recognition results in Fig. 6 shows (a) an image from a camera, (b) measurement data of point-clouds from a three-dimensional distance sensor, (c) a virtual image as viewed from a different observing point and displayed as a CG model of the recognition results, and (d) a virtual image from an observing point approaching the object.

Fig.6 Examples of camera image, point-clouds and recognition results



Good recognition performance was achieved in cases where the three-dimensional characteristics (at parts having unevenness or other characteristics) were measured or where three surfaces of a solid body could be measured. However, the recognition was difficult in cases where three-dimensional characteristics could not be measured (from directly lateral to or from directly above, etc.), since the measurement data did not contain three-dimensional characteristics. As a solution, the three-dimensional characteristics must be re-measured from an observation point at which the three-dimensional characteristics can be measured. For approximately 10 types of objects prepared for evaluation-use, the recognition results were nearly always correct when the three-dimensional characteristics could be measured.

4.2 Remote handling auxiliary system

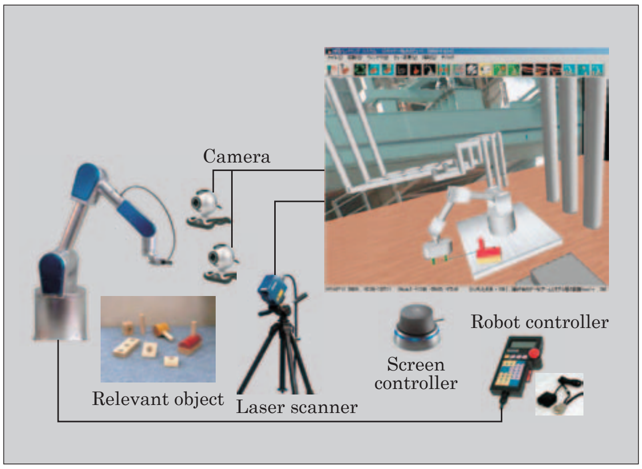
A remote handling auxiliary system that incorporates results from three-dimensional shape recognition is described below.

Figure 7 shows the system which is configured from a control PC, a three-dimensional mouse for screen control, a laser scanner, a robot, a robot control terminal, and a camera for image recognition. The object, having been measured by the laser scanner, is recognized by the PC and the results are expressed as a CG image, and the manipulator, expressed as a CG image, and the measured point-clouds are displayed. The operator uses the three-dimensional mouse to change the observing point to one that is easy to view, displays the screen from that easy-to-view observing point, and then uses the robot control terminal to operate the robot. The coordinate systems for the robot and laser scanner are calibrated beforehand using a calibration tool that has been developed.

Recognizing the shape of the model and then expressing the results as a CG image has the following two advantages.

(a) The contour of the entire target surface can be

Fig.7 System configuration



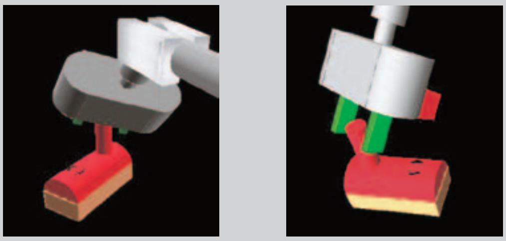
displayed. By moving to an arbitrary observing point with a simple mouse operation, the image from an observing point from which observation is not actually possible or the image of a region that has not been measured can be displayed to provide visually accurate information. The remote handling auxiliary system is particularly effective in the case of utilizing an observing point located at the hand at the tip of the arm.

(b) Specifying certain arbitrary points in the measurement data and the recognition results enables the distance between the observing point and object to be calculated, and is effective in obtaining information that provides a sense of perspective.

While the manipulator is moving, information from each axis (encoder values) is acquired in real-time so that the CG image of the manipulator can move with the same movements as the actual manipulator.

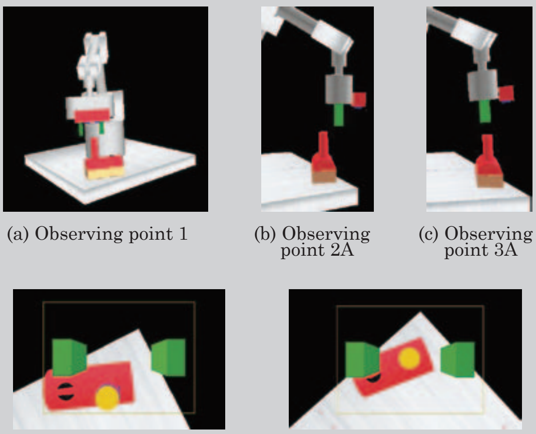
Thus, as is shown in Fig. 8, the point-clouds of measurement data, the CG representation of the recognized model and the CG representation of the manipulator are superimposed to create a display of augmented reality. In Fig. 8(a), the object is obscured by the hand part and cannot be seen, but in Fig. 8(b), the observing point has been changed so that the object status can be confirmed.

Fig.8 CG representation of manipulator and model



(a) Observing point 1 (b) Observing point 2

Fig.9 Example of handling by moving the observing point



(a) Observing point 1 (b) Observing point 2A (c) Observing point 3A

(d) Observing point 2B (e) Observing point 3B

An example of auxiliary handling by moving the observing point is described below. Figure 9(a) is an image from an observing point in the direction of the measuring instrument, and whether the manipulator has been moved to a location where it can grip the object is unclear in the figure. Performing a mouse operation to move the observing point of the image enables a determination to be made as to whether an object lies in a location that cannot be gripped as shown in Figs. 9(b) and (d), or whether it lies in a state in which the object can be gripped as shown in Figs. 9(c) and (e).

As described above, with this system, the object to be gripped is expressed as a CG image based on the results of three-dimensional shape recognition. Side surfaces that cannot be actually viewed can be displayed and the CG representation of the manipulator enables observation from an arbitrary observing point. Moreover, multiple observing points can be specified and multiple observation images can be displayed continuously. As a result, the object can be verified from a direction in which a sense of distance is easy to grasp, the object can be viewed from an observing point that avoids other obstructing objects, and this system can provide suitable assistance for handling operations by an operator having a non-expert level of skill.

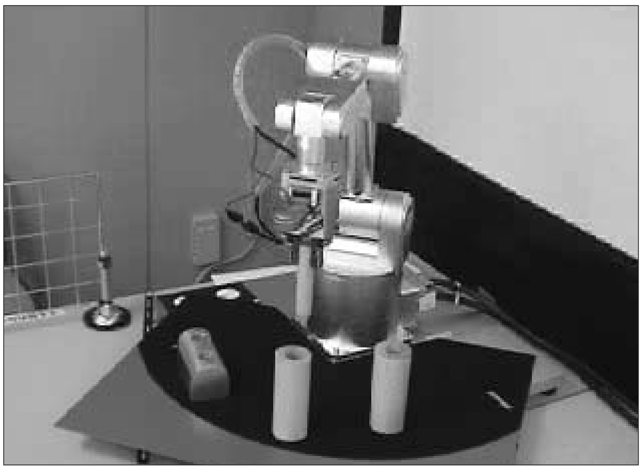
The following functions were developed to assist the remote handling by an operator.

(a) Image from an observing point at the hand: An image in which the observing point is the hand location is useful when performing an operation of gripping the object with the hand. (Fig. 9(d) and 9(e)).

(b) Automatic observing point change: A manual operation can be performed to display an image from an observing point clearly showing the relationship between the hand and the object to be gripped, but a clearly visible observing point can also be computed automatically and the image displayed.

(c) Environment creation function: Three-dimen-

Fig.10 Tabletop robot manipulation system



sional information in the vicinity of the hand is acquired as needed, via a stereo camera mounted on top of the hand, and combined with three-dimensional information acquired by the laser scanner to create three-dimensional information of the peripheral environment. Thus, collisions between the manipulator and obstructions can be avoided.

As a prototype system that combines these elemental technologies, Fuji Electric developed a tabletop robot manipulation system that automatically recognizes an object placed at an arbitrary location and performs automated tasks. (See Fig. 10.)

4.3 Issues to be resolved for practical application

The following issues must be resolved for practical application.

(a) Improvement of three-dimensional recognition function: Elemental technologies that boost the recognition percentage and increase recognition accuracy are at the research and experimentation stages. Improvement in the recognition percentage, recognition accuracy and recognition speed is needed before this function can be incorporated into practical applications.

(b) Recognition of metal objects: The three-dimensional measurement of metal objects presents a difficult challenge. Improved mechanisms for measurement of metal objects or techniques for recognizing the shape without measurement must be explored.

(c) Non-rigid, flexible objects: Rope, cables and the like are non-rigid, flexible objects that can also change their shape. Laser scanners or other similar measuring instruments that require time to perform their measurements are not well suited for capturing the movement of these types of objects. For tracking such movement closely, stereo vision imaging that is capable of high-speed measurement must be explored.

(d) Radiation tolerant cameras: Laser scanners cannot be used in a radioactive environment. Stereo vision that uses multiple radiation tolerant cameras is thought to be well suited for obtaining three-dimensional information in a radioactive environment.

5. Postscript

Development for the remote handling auxiliary system has focused mainly on shape recognition technology, and the original objective of achieving the capability to identify a target from within a scene has been achieved. In the future, Fuji Electric plans to develop a simple and easy-to-use human-machine interface that assumes a more practical work environment. Moreover, this system was developed as a manually operated auxiliary system, but it could also conceivably be applied as an automated location measurement function that targets the arbitrary location and orientation of objects to be handled, and can be developed in the future as a combined system that also includes automated operation.

The use of remote handling devices is not limited to the nuclear power field. Applications involving the handling of dangerous substances and the use of a crane to handle large and heavy objects are tasks requiring skill for remote operation and candidates for application of a remote handling auxiliary system. The application of this system not only increases efficiency, but also enables such tasks to be performed by operators who may not be highly skilled, and this is believed to be a significant advantage. Use of the remote handling auxiliary system in fields other than nuclear power is anticipated.