Automated Handling of Construction Components Based on Parts and Packets Unification

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ABSTRACT: This paper proposes a method of pose (position and orientation) fitting of construction components in a construction site for automated handling based on the relation between components (parts) and their information (packets). Robots can acquire the required information of the component via the environment-attached storages, such as RFID devices. When an ID reader identifies an ID device, it should take some pose in its communication range. This fact may bring the idea of estimating the pose of a component that carries the device. In this idea, only single device identification cannot fix the pose of the component. We define the conditions of the ID reader and ID devices for the pose fitting, and propose a fitting method with at least two different identifications where two devices are not attached to the same plane or parallel planes of the component. Several examples of pose fitting show the feasibility of our idea.

KEYWORDS: Automated Handling, Pose Fitting, ID devices, Radio Frequency Identification

1. INTRODUCTION

The recent advancement of information and communication technologies has brought feasibility of efficient construction automation. Robot arms or automatic machines have been developed in order to apply to a construction task [1][2]. These robot arms need information acquisition systems to achieve tasks in construction sites.

We have proposed the construction automation system using based on the relation between construction components in the construction site (parts) and their information (packets) [3]. Robots or workers obtain task information for achieving tasks via components in the workspace. And the parts are strongly related to the parts information. Therefore the robot can obtain the required data for achieving tasks easily [4][5][6][7]. The acquired information via the environment-attached storages improves the sensing ability of the robot.

A robot requires current pose information of component when it achieves automated handling. Since the current pose of component will be changed in the process of construction, it is not easy to store it in the packet or the database. The pose should be measured or estimated in any way to achieve handling.

In this paper, we propose a method of pose (position and orientation) fitting of a construction component using multiple ID devices [5][8]. The basic idea is to estimate a component pose in the reference coordinate frame based on the movement of the ID reader and a series of ID device poses in the component frame. When the ID reader accesses a device, its pose information can be obtained in the component frame. However, a single device cannot define the component pose uniquely. If the robot obtains a set of device poses attached on the component, the component pose can be defined perfectly in the reference frame. These devices should be attached carefully on the component sides.

In the followings, we will define the geometrical relation between an ID device and the reader. Then, we will show that the pose of the component can be estimated using the pose data of at least two ID devices attached.

2. SYSTEM CONFIGURATION BASED ON PARTS AND PACKETS UNIFICATION

We have proposed the idea of "parts and packets unification", where we use an ID device attached to each component to define the relation of construction components with their information. The actual component data, including component attributes, relation among components, and so on, are stored in the database. The database of components and task plan are managed comprehensively and consistently. Robots or workers can obtain task information via construction components (i.e. parts) at a construction site. And the

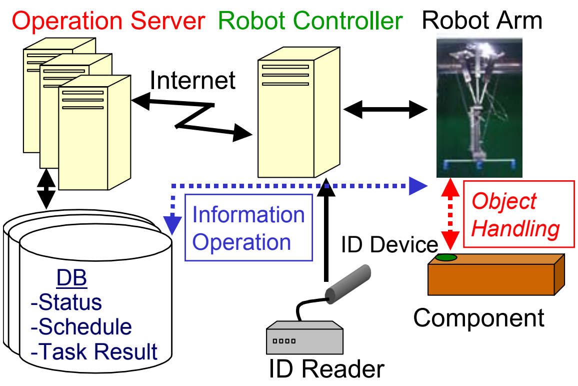

Figure 1. Relation between components and their information under the parts and packets unification

parts are strongly related to the accompanied component data (i.e. packets).

Figure 1. shows a relation between construction robots, components, and their information. A robot can acquire required information for the task and about the component via ID attached and it can accomplish the task by operating the component. First, the robot acquires an ID from the actual ID device attached to the component. The robot sends the acquired ID and the task results to the operation server while achieving the task. The operation server creates required information for achieving the task using the ID and sends the required information to the robot. Then, the operation server updates the component data according to the task results. There are several methods to acquire an ID in this system, for example, RFID device, bar code. The communication between the robots and the server may be a private network or the Internet.

When an RFID device is applied, a geometrical relation of device and its reader can be defined in the access. This idea leads to the pose fitting of component.

3. POSE FITTING USING ID READER

3.1. Acquisition of ID attached to the component using ID reader

Figure 2. shows a method of obtaining an ID using the ID reader. An ID device is attached on the surface of a construction component. The ID reader is mounted on the robot hand, and the position and orientation of the ID reader is estimated based on the kinematics parameters of the robot.

As shown in Fig. 2, the robot can detect the ID, when the device comes within the communcation area of the ID reader. There are several problems in using ID devices:

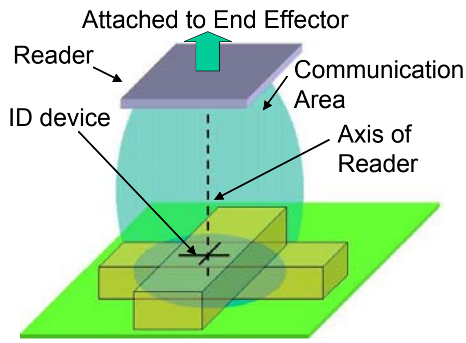

Figure 2. Communication area of ID reader

- It is difficult to obtain the pose of the component that the ID device is attached.
- The robot cannot obtain the distance between the ID reader and the component by detecting the ID device.

3.2. Fitting of component pose

A component pose will be fit by reading multiple ID devices attached to the component. We propose a method of fitting a component pose in the reference frame. The idea is to use the movement data of the reader and the device pose in the component frame read by the ID reader. In this method, the robot can make the plan of the ID reader to read the other ID devices for pose fitting of the component from the obtained ID of the ID device attached to the component.

There are some assumptions in our fitting method. Several ID devices are attached to the surface of a component, and the poses of the ID devices in the component frame are registered in the operation server as component data in advance. When the ID reader detects a device, there is only one device within the communication area of the ID reader.

Figure 3 shows our proposed idea. First, the robot searches an ID device attached to the component by moving the reader. When the robot detects a first device and obtains its ID, the robot sends the ID and the robot pose to the operation server. The server searches the device pose data represented in its component frame. The server tries to find a near ID device on the component, and sends the coordinates of the next ID device to the robot for its motion planning. Then, the robot will search the next ID device.

When the robot obtains the next ID, the robot again sends the ID and the robot pose to the server. The server estimates the origin of the component frame with respect to the reference frame, that is, the pose of the component. Once the robot obtains

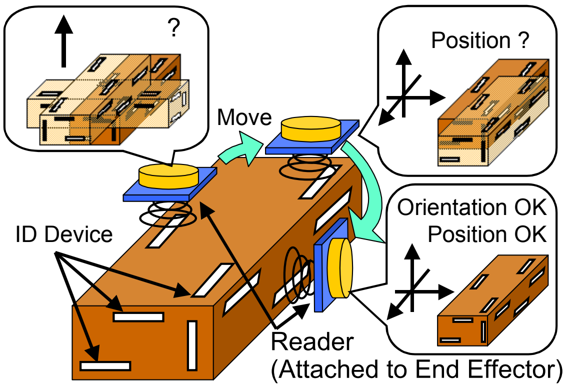

Figure 3. Estimation of component pose using ID devices

the component pose, the robot can handle it perfectly.

In the fitting process, the correct pose of the ID reader can be obtained, since it is calculated using the robot kinematics. A series of the device poses in the component frame can be obtained by matching the IDs and the component data in the operation server. Therefore the robot can estimate the pose of the component using an ID reader without any sensors.

4. POSE FITTING ALGORITHM

In this section, we discuss an algorithm of pose fitting of component using ID devices. First, we define the geometrical relation of the ID reader and ID device when the reader detects the device. Next, we show the pose of the component in the reference frame using the relation. Last, we discuss the property the fitting result because of the relation of the pose of ID devices used for the pose fitting of the component.

4.1. Model of ID reader

In order to fit a pose of the component by reading the attached ID devices, we define a model of ID reader. The properties of the reader are the followings.

- There is a communication area along the axis of the reader. It is shown as a dotted line in Fig.4. The actual communication area can be modeled by a 3-D volume.
- The reader can obtain an ID of the device if the device exists within the communication area and the device is directed to the reader surface.
- There is only one ID device within the communication area of the reader.

Figure 4 shows a relation of an ID reader and an ID device in the reference frame. Σ^O indicates the reference frame, Σ^R indicates the coordinate frame of the ID reader, Σ^C indicates the coordinate frame of the component, and Σ^T indicates the co

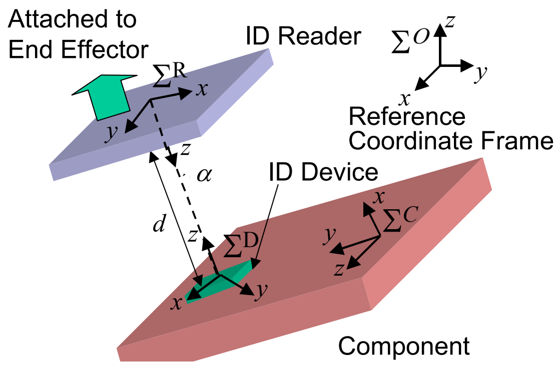

Figure 4: Relation of ID reader and ID device

ordinate frame of the ID device. d indicates a distance between the reader and the device, and α indicates a rotation angle about z-axis of the reader frame.

Generally, the distance cannot be obtained by just reading the device. We will define a geometrical relation model between a reader and a device based on the properties of the reader. To make the model easier, we assume some additional conditions that the device exists on the axis of the reader, and the orientation of the device is directed to the reader surface. Therefore we define the conditions that the reader detects the devices as follows:

(1) The position where the reader can detect the device is on z-axis of the reader frame.
(2) The distance that the reader can detect the device is initially unknown and $d>0$ is assumed.
(3) The rotation angle α is initially unknown.
(4) The direction of z-axis of the device frame is to the opposite direction of the z-axis of the reader frame.

From the condition (1) and (2), we can define the position of the device using the homogeneous transformation matrix of the ID reader with respect to the reference frame ${}^O T_R$ and the matrix of the ID device with respect to the reference frame ${}^O T_D$ as follows:

$$ {}^O T_R \begin{bmatrix} 0 \\ 0 \\ d \\ 1 \end{bmatrix} = {}^O T_D \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} . \qquad (1) $$

And from the condition (3) and (4), we obtain the relation of the orientation between the reader and the device using vector $\mathbf{a}^R$ and $\mathbf{a}^D$. ${}^O R_R$ is a rotation matrix of the reader with respect to the reference frame and vector $\mathbf{a}^R$ is its third column. ${}^O R_D$ is a rotation matrix of the device with respect to the reference frame and vector $\mathbf{a}^D$ is its third column. The relation is shown as follows:

$$ \mathbf{a}^R = -\mathbf{a}^D . \qquad (2) $$

We can obtain the relation between the reader and the attached device for the pose fitting of the component.

4.2. Pose of attached device

We discuss the relation between the ID reader and the ID device attached to the component. $\mathbf{p}_{R,D1}$ represents the position of the reader with respect to the reference frame where the reader detects device D1. From Fig. 4, the position of D1 is described by using equation (1) as follows:

$$ {}^{O}T_R \begin{bmatrix} 0 \\ 0 \\ d_{D1} \\ 1 \end{bmatrix} = {}^{O}T_C \begin{bmatrix} x^C{}_{D1} \\ y^C{}_{D1} \\ z^C{}_{D1} \\ 1 \end{bmatrix} \tag{3}$$

where $\mathbf{p}^C{}_{D1} = \left[x^C{}_{D1}, y^C{}_{D1}, z^C{}_{D1}\right]^T$ is the position of D1 with respect to the component frame. And ${}^{O}T_C$ is the homogeneous transformation matrix of the component frame with respect to the reference frame.

The relation of the orientation between the reader and the device is expressed by the equation (2). The relation of the orientation between the reader and the attached device is described as follows:

$$ {}^{O}R_R \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} + {}^{O}R_C {}^{C}R_{D1} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = 0 \tag{4}$$

where ${}^{O}R_C$ is the orientation matrix of the component with respect to the reference frame, and ${}^{C}R_{D1}$ is the orientation matrix the device with respect to the component frame. From the equation (4), we obtain

$$ {}^{R}R_O {}^{O}R_C {}^{C}R_{D1} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = I_3 \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix} \tag{5}$$

where I_3 is a unit matrix. Here we define the following matrix.

$$ {}^{R}R_O {}^{O}R_C {}^{C}R_{D1} = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix}.$$

From equation (5), the element of the third column is $\begin{bmatrix} 0 & 0 & -1 \end{bmatrix}^T$. Since the matrix is orthogonal, it is described as follows.

$$ {}^{R}R_O {}^{O}R_C {}^{C}R_{D1} = \begin{bmatrix} c_{11} & c_{12} & 0 \\ c_{21} & c_{22} & 0 \\ 0 & 0 & -1 \end{bmatrix}. \tag{6}$$

By considering that α is a rotation around z axis, the equation can be rewritten as follows.

$$ \begin{aligned} {}^{R}R_O {}^{O}R_C {}^{C}R_{D1} &= \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} C\alpha & -S\alpha & 0 \\ S\alpha & C\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \\ &= \mathbf{R}_{x,\pi} \mathbf{R}_{z,\alpha} \end{aligned} \tag{7}$$

where $C\alpha = \cos\alpha, S\alpha = \sin\alpha$, and $\mathbf{R}_{x,\pi}$ indicates the rotation of π about x-axis. Here α is still arbitrary. Therefore we can obtain a rotation matrix of the component

$$ {}^{O}R_C = {}^{O}R_R \mathbf{R}_{x,\pi} \mathbf{R}_{z,\alpha} {}^{D1}R_C . \tag{8}$$

We will discuss the property of the component pose when the reader detects the attached device. The homogeneous transformation matrix of the component frame with respect to the reference frame ${}^{O}T_o$ is expressed using equation (8) as follows:

$$ {}^{O}T_C = \begin{bmatrix} {}^{O}R_R \mathbf{R}_{x,\pi} \mathbf{R}_{z,\alpha} {}^{D1}R_C & \mathbf{p} \\ 0 \;\; 0 \;\; 0 & 1 \end{bmatrix} \tag{9}$$

where $\mathbf{p} = [x, y, z]^T$ is the position of the component with respect to the reference frame. The position of the attached device is expressed using equation (3) as follows:

$$ {}^{R}T_O {}^{O}T_C \begin{bmatrix} x^C{}_{D1} \\ y^C{}_{D1} \\ z^C{}_{D1} \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ d_{D1} \\ 1 \end{bmatrix}. \tag{10}$$

Now, we define the position of the component with respect to the reader frame.

$$ \mathbf{p}^R = \begin{bmatrix} x^R & y^R & z^R \end{bmatrix}^T = {}^{R}R_O\left(-\mathbf{p}_{R,D1} + \mathbf{p}\right). \tag{11}$$

The position of the attached device can be obtained using equation (10).

$$ \begin{bmatrix} x^R \\ y^R \\ z^R \end{bmatrix} = -\mathbf{R}_{x,\pi} \mathbf{R}_{z,\alpha} {}^{D1}R_C \begin{bmatrix} x^C{}_{D1} \\ y^C{}_{D1} \\ z^C{}_{D1} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ d_{D1} \end{bmatrix}. \tag{12}$$

Since ${}^{D1}R_C$ is given, from equation (8), x^R and y^R are described by sine and cosine function with the same coefficients respectively. Therefore the origin of the component frame is on a circle in the x-y plane at given z^R.

When the reader detects the attached device, the origin of the component frame with respect to the reference frame, that is, the position of the component is on the surface of a cylinder whose center is on the axis of the reader. The orientation of the component is not defined and has one degree of rotational freedom.

4.3. Fitting 3-D pose of the component using two ID devices

We will discuss a method of fitting 3-D pose of the component using two ID devices. We define that the reader position is $\mathbf{p}_{R,D1}$ when the reader detects device D1, and that the rotation matrix of the reader is ${}^{O}R^{(D1)}{}_{R}$.

The pose relation between the reader and the component is obtained by detecting two attached devices D1 and D2. First, we consider the pose relation using one device pose by detecting D1. We define two homogeneous transformation matrices, the reader pose (${}^{O}T^{(D1)}{}_{R}$) and the component (${}^{O}T^{(D1)}{}_{C}$), with respect to the reference frame. These matrices are shown as follows:

$$
\begin{aligned}
{}^{O}T^{(D1)}{}_{R} &= \begin{bmatrix} {}^{O}R^{(D1)}{}_{R} & \mathbf{p}_{R,D1} \\ 0\ \ 0\ \ 0 & 1 \end{bmatrix} \\
{}^{O}T^{(D1)}{}_{C} &= \begin{bmatrix} {}^{O}R^{(D1)}{}_{C} & \mathbf{p} \\ 0\ \ 0\ \ 0 & 1 \end{bmatrix}
\end{aligned}
\tag{13}
$$

where ${}^{O}R^{(D1)}{}_{C}$ indicates a rotation matrix of the component using a rotation matrix of device D1 with respect to the component frame (see equation (8)). From equation (3), the position of the component can be obtained as follows:

$$
\mathbf{p} = \mathbf{p}_{R,D1} - {}^{O}R^{(D1)}{}_{C}\mathbf{p}^{C}{}_{D1} + {}^{O}R^{(D1)}{}_{R}\begin{bmatrix} 0 \\ 0 \\ d_{D1} \end{bmatrix}. \tag{14}
$$

It is also described by using the pose of device D2.

$$
\mathbf{p} = \mathbf{p}_{R,D2} - {}^{O}R^{(D2)}{}_{C}\mathbf{p}^{C}{}_{D2} + {}^{O}R^{(D2)}{}_{R}\begin{bmatrix} 0 \\ 0 \\ d_{D2} \end{bmatrix}. \tag{15}
$$

The orientation of the component, that is, the rotation matrix, is fixed while the reader detects two devices. From equation (14) and (15), we obtain

$$
\begin{aligned}
&\mathbf{p}_{R,D1} - \mathbf{p}_{R,D2} + {}^{O}R_{C}\left(\mathbf{p}^{C}{}_{D2} - \mathbf{p}^{C}{}_{D1}\right) \\
&+ {}^{O}R^{(D1)}{}_{R}\begin{bmatrix} 0 \\ 0 \\ d_{D1} \end{bmatrix} - {}^{O}R^{(D2)}{}_{R}\begin{bmatrix} 0 \\ 0 \\ d_{D2} \end{bmatrix} = 0
\end{aligned}
\tag{16}
$$

where the rotation matrix of the component with respect to the reference frame ${}^{O}R_{C}$ is

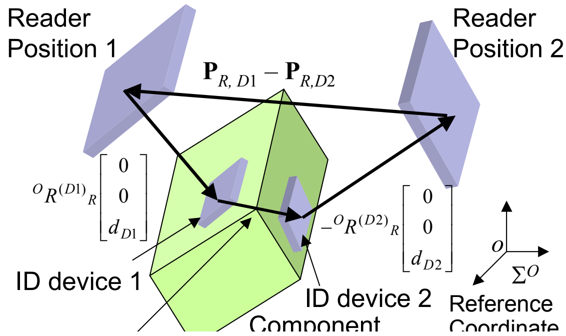

Figure 5. Relation of ID reader and ID devices attached to an component

$$
{}^{O}R_{C} = {}^{O}R^{(D1)}{}_{R}\mathbf{R}_{x,\pi}\mathbf{R}_{z,\alpha_{D1}}{}^{T}R^{(D1)}{}_{C} \tag{17}
$$

and α_{D1} is the rotation angle of device D1 about the reader axis. From equation (16), we obtain three equations for α_{D1}, d_{D1}, and d_{D2}. By replacing α_{D1}, d_{D1}, and d_{D2} by the solution of equation (16) in equation (14) and (17), we obtain the pose of the component. Figure 5 shows the relation of the reader and two attached. Equation (16) is expressed based on this relation. From Fig. 5, the pose of the component is obtained based on the relative position between two attached devices and the relative position between two reader positions with respect to the reference frame.

Now, we suppose that the vectors of the third column of matrix ${}^{O}R^{(D1)}{}_{R}$ and ${}^{O}R^{(D2)}{}_{R}$ are the same, that is, the reader detects two devices having the same direction. Since these devices are attached to the component, they should be on the parallel planes of the component. In this case, we define relative distance $d = d_{D1} - d_{D2}$, then d is obtained by equation (16). But d_{D1} and d_{D2} cannot be determined directly. The rotation matrix of the component with respect to the reference frame can be obtained. Therefore another condition is required in order to define the pose of the component when two devices attached on the parallel planes of the component. For example, the component is on a known plane.

We have tried experiments of 2-D pose fitting when the component is fixed on a floor of the room using our method. The pose of the component is fitted by two device detections. Sometimes the pose fitting errors have been observed. It is considered that these errors are mainly due to the modeling error of the reader and that the error may be reduced by carefully selecting the attached points of the devices.

5. CONCLUSIONS

This paper proposed a method of pose fitting of construction component using multiple attached ID devices in order to achieve automated handling in construction. We introduced the geometrical relation model of a reader and a device to fit the pose of the component. We showed that the 3-D pose of component could be fitted using at least two ID devices attached to the component. The orientation of the component is fitted but the position of the component is not estimated if the reader detects multiple ID devices attached on the parallel planes of the component.

When the reader detects one ID device, the position of the component is on the cylinder whose center is on the reader axis. The orientation of the component is not defined and has one degree of rotational freedom. This result shows a pose of second ID device can be estimated based on the pose fitting of the first device. It is useful to plan a search motion of the reader in order to detect the second ID device.

There is a communication area along the axis of the reader. The communication area can be expressed by a 3-D volume. The reader axis is not always in the same direction of a device and this may cause the estimation error of the pose fitting. This estimation error has not been discussed in this paper and remains to be a future work.

This time we assumed a pose of a device with respect to the component frame. Then it is required to measure the pose of device when the ID device is registered to the database in the actual application. Since a device is attached to a component directly, a simplified model of the device is required.

In the future works, we will propose the modeling of ID device with the consideration of the communication area, the pose fitting of the component, the estimation of the modeling error, the automated handling of the real component, and so on.

6. ACKNOWLEDGMENT

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