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Robotic Assembly System Guided by Multiple Vision and Laser Sensors for Large Scale Components

Peng Wang, Zhengke Qin, Zhao Xiong, Jinyan Lu, De Xu, Xiaodong Yuan and Changchun Liu

Abstract—**The assembly of large scale components are still challenging tasks due to the heavy weights of the objects, and the requirements of high precision and high efficiency. Therefore, the design of robotic assembly system for large scale components, and the studies on the corresponding methods and strategies are still very important and very urgent.**

In this paper, we design a new robotic assembly system for large scale components guided by two vision sensors and three 1-D laser sensors. Novel high precision localization and alignment methods are proposed to automatically localize the components and search the best three-dimensional position and orientation between the object and the installation location. Experimental results show that the system can well complete the assembly task for large scale components automatically, including automatic detection and localization, automatic grasping, automatic guidance, and automatically insertion, with high precision and high efficiency.

I. INTRODUCTION

Robotic assembly is one of the most important tasks in industrial areas, and numerous systems have been designed for different operations, such as peg-hole assembly [1], and flat panel parts assembly [2], and their accuracy and effectiveness has been proved under many challenging industrial environments. However, the autonomous assembly tasks guided by different kind of sensors, such as vision sensors, laser sensors and ultrasonic sensors, are still have many open challenging problems, especially for some specific tasks.

Vision has become one of the popular sensors for robotic assembly due to its low cost and effective performance. It can extract useful information, such as position and pose, without contacting the parts or other things in the environment. S. Kwon *et al*. [3] proposed a visual alignment system with a vision system to recognize the alignment marks, and proposed an observer-based coarse-to-fine control strategy for the display visual alignment systems. S. Natsagdorj *et al*. [4] proposed a vision-based assembly and inspection system with two cameras mounted on the robot arm and positioned laterally respectively, to capture top-view images and to provide the corresponding side view. B. Zhang *et al*. [5] designed a vision-guided robotic assembly system with uncelebrated camera, and the system was based on camera space manipulation method, which is relied on a local calibration method to achieve the high accuracy alignment for the final assembly. H. Song *et al*. [6] used camera to estimate the poses of pegs and holes of complex-shaped parts, and the robot grasped the peg and placed it in the initial position for assembly.

In many industrial environments, due to the feature of assembly task, such as the scale of the parts, the distance between sensors and the target, vision sensors usually works together with other sensors to obtain good performance. Laser sensors are good complementary with vision sensors under some conditions. Z. Liu *et al*. [7] proposed a laser tracker based robotic assembly system for the assembly of large scale peg-hole type parts, and a laser interferometry guidance methodology was designed to calibrate the geometrical characteristics of parts, and to eliminate the uncertainty caused by the flexible grippers. Y. Kim et al. [8] designed a measurement system with three laser range sensors and one vision sensor, to directly measure the full 6-DOF motions between the laser sensor unit and the target screen unit.

The assembly of large scale components, such as large scale optical-mechanical modules used in large laser driver device [9], large - diameter panels used in construction industry [10], are still challenging tasks, especially for robot automatic assembly. The main difficulties include two aspects. First, the large components must be transferred from a large range of distance to, and the sensors should be able to work both in long range and close range. Second, due to the high accuracy and efficiency requirements, multiple sensors should be used to work together, and with their complementary information, the robot will be guided precisely to finish the assembly task.

In this paper, we design a new robotic assembly system for large scale components guided by two vision sensors and three 1-D laser sensors. Novel high precision localization and alignment methods are proposed to automatically localize the components and search the best three-dimensional position and orientation between the object and the installation location. Experimental results show that the system can well finish the assembly task for large scale components automatically, including automatic detection and localization, automatic grasping, automatic guidance, and automatically insertion, with high precision and high efficiency.

The paper is organized as follows. Section II describes the robotic assembly system, and Section III gives the details of the localization and alignment method and strategy based vision sensors and 1-D laser sensors. The qualitative and quantitative experimental results are given in Section IV, and conclusion is presented in Section V.

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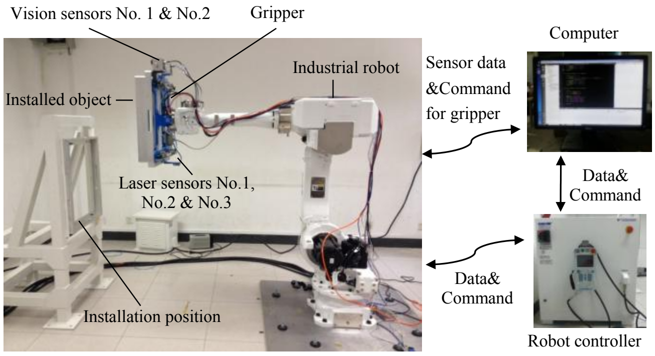


Fig. 1. The proposed robotic assembly system

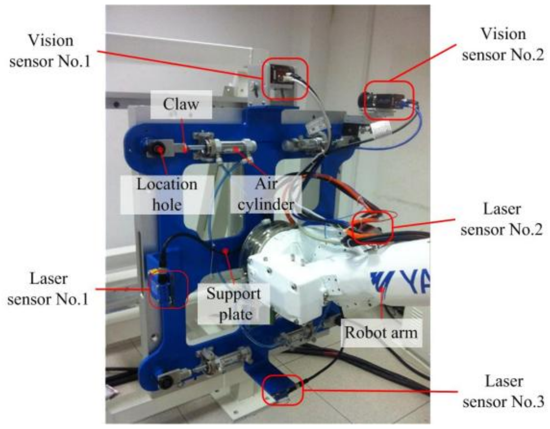


Fig. 2. The gripper and sensors mounted on it

II. Robotic Assembly System

As shown in Fig.1, the designed robotic assembly system consists of four subsystems, *i.e.,* the industrial robot, the sensors, the gripper, and the computer with software. The data of the vision and laser sensors are collected to the computer, and then they are processed by the proposed detection and localization algorithm module. Based on the obtained 3-D localization information of the installed object and installation position, the proposed alignment and planning strategy module automatically calculates and sends the command to the industrial robot and also the gripper. The industrial robot moves according to the command made by the computer, and the gripper also performs the catching or releasing action accordingly. The processes are carried out iteratively until the whole task is completed. The detailed process and strategy will be given in Section III.

Due to the large sale of the components, the sensor should work both in long range and close range, and the final measurement accuracy should meet the assembly precision requirements. The designed gripper and the layout of sensors are shown in Fig. 2, and two vision sensors and three 1-D laser sensors are used and mounted on the gripper.

The vision sensor No.1 (upper part of gripper, the center position) is used for the detection and localization of the installed object and the installation location in long range, and the sensor usually can observe the entire object. When the robot end-effector approaches to object for grasping or assembly, the vision sensor No.1 can only observe local information of object, and using the limited information, it’s difficult to detect and localize the object accurately in the three-dimensional space. Therefore, the vision sensor No.2 (upper part of gripper, the right/left side) and three 1-D laser sensors are introduced, and by taking the advantage of their complementarity, the system can obtain higher localization and alignment accuracy.

The gripper is composed by one support plate used for load bearing and the carrier of other devices, and other devices such as four claws, four air cylinders, and four location holes, used to catch or release the large scale components.

III. Automatic Assembly Guided by Multiple Vision and Laser Sensors

A. The Automatic Guidance and Assembly Strategy

The key processes of robotic assembly for large scale components include the grasping and the transferring, the guidance, the alignment and insertion. The system detects and localizes the object using the vision sensor No.1 initially and then automatically grasps and holds up the object using the gripper shown in Fig. 2.

1) Automatic Guidance: As shown in Fig. 3, after the grasping step, the object is transferred to the approximate location, where the system can observe the installation position. Then based on the data from the vision sensor No. 1, the proposed detection and localization algorithm module calculates the 3-D position and attitude of the installation location. Based on the localization information feedback to robot, the robot control and planning module guides the robot end effector approaching to the installation location.

2) Automatic alignment and insertion: When the object is close to the target location enough, the process shifts to alignment step. In this stage, vision sensor No.2 and three laser sensors work together to accurately measure the values in X, Y, θ_z and Z, θ_x, θ_y directions respectively, where X direction and Y direction are parallel to the plane of the gripper and the installation location, θ_x, θ_y and θ_z denote the angles rotating around X, Y and Z respectively. Based on the position and attitude information feedback to robot, the robot control and planning module constantly adjusts the robot end effector to align and approach to the installation location. When the object contacts with the installation location, the automatic insertion step starts, and the assembly is completed when the values of three laser sensors satisfy the default requirements.

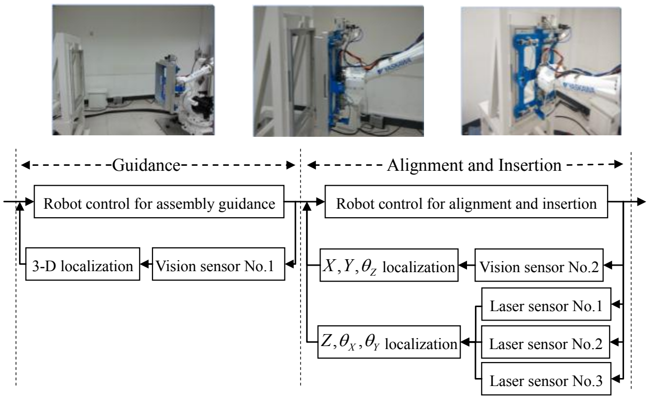


Fig. 3. The process of automatic guidance, alignment and insertion

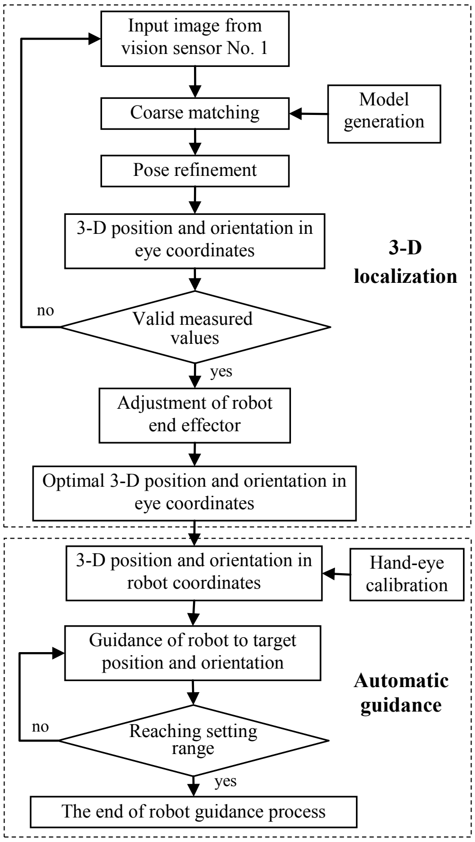


Fig. 4. Process of 3-D localization and robot guidance with vision sensor No.1

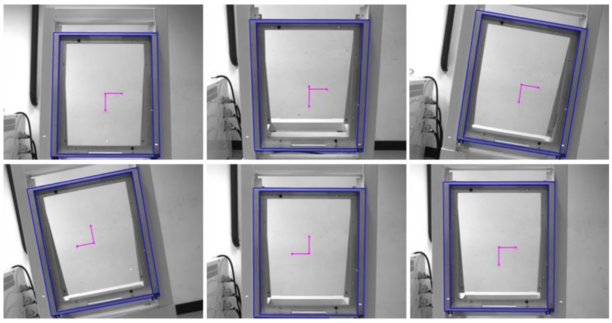


Fig. 5. Detection and 3-D localization results with different relative position and pose

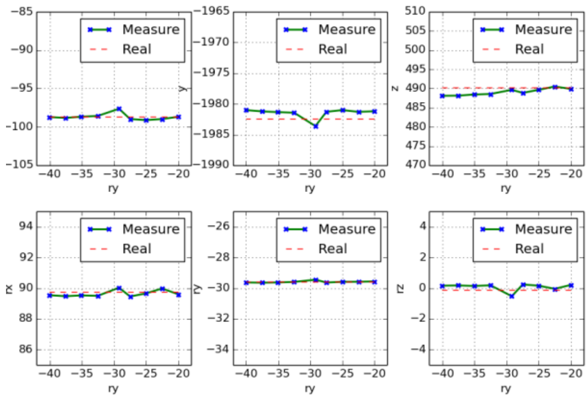


Fig. 6. The fluctuation of localization results in X, Y, Z, θ_x, θ_y, θ_z when the end effector rotates around Y axis (ry denotes the angle rotating around Y axis, and the measurement unit is degree; the measurement units of vertical axis are mm for X, Y, Z, and degree for θ_x, θ_y, θ_z).

B. 3-D Localization and Robot Guidance with Vision Sensor

The Automatic localization and guidance process is shown in Fig. 4. When the object is crawled and transferred to the approximate location, vision sensor No.1 is used to observe the installation location. Based on the data from vision sensor No.1, a novel 3-D localization based robot guidance method is proposed.

In 3-D localization step, we propose a new CAD model based 3-D localization algorithm, which is illuminated by M. Ulrich *et al.* [11]. As shown in Fig. 4, an off-line model generation is used to get the 2-D projections library from 3-D model. For each input image, the 3-D position and orientation of observed target is calculated through coarse matching and pose refinement based on the library. In the localization and guidance stage, once localization result is obtained, the robot directly moves to the corresponding location without additional localization. In other words, the robot is guided by only one localization result. Therefore, the localization accuracy is very important to the guidance result. To improve the localization accuracy, we proposed a new localization strategy with robot end effector adjustment, *i.e.*, "vision localization - robot adjustment", because that the localization accuracy is usually relying on the relative pose between the sensor and the observed object. For each localization result, we first evaluate its uncertainty, and then adjust the robot end effector to reduce the uncertainty. The above "vision localization-robot adjustment" process carries out iteratively until the localization gets satisfactory evaluation result.

The obtained optimal 3-D position and orientation in eye coordinate system is transferred to robot coordinate system based on the hand-eye calibration result obtained off-line. And then the robot end effector is guided to the target location until the relative distance between the end effector and the installation

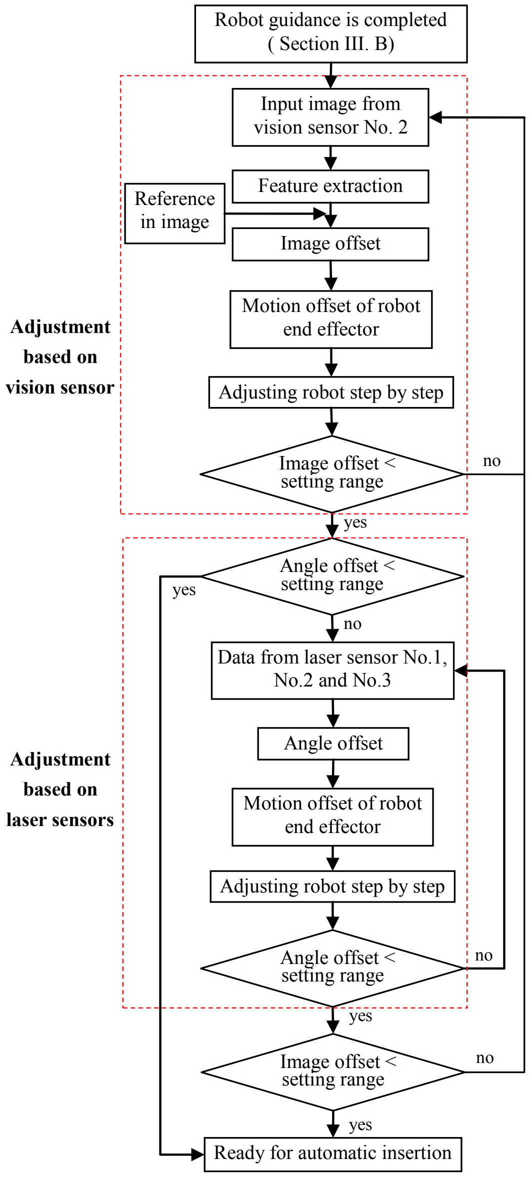


Fig. 7. Process of precise alignment with vision and three 1-D laser sensors

location reaches the setting range, and the relative distance is measured by the three 1-D laser sensors.

Some detection and 3-D localization results are given in Fig. 5. In order to test the robustness of the proposed method, we also do plenty of experiments in which the robot end effector changes the position and orientation around the optimal observed location in small range. Fig. 6 shows the experimental results of localization in X, Y, Z, θ_x, θ_y, θ_z when the end effector rotates around Y axis, which is with bigger influence on the result than other axis. In Fig. 6, lateral axis denotes the variations of the rotation around Y axis, and vertical axis denotes the fluctuation of localization results in X, Y, Z, θ_x, θ_y, θ_z respectively. The algorithm is with high accuracy and robustness, and can meet the requirement of automatic guidance.

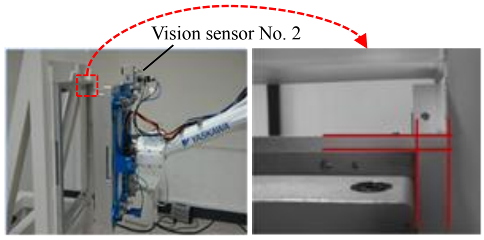


Fig. 8. Illustration of Image features used for alignment with vision sensor

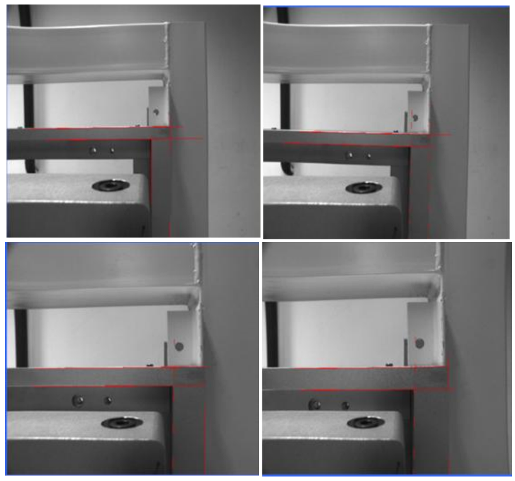


Fig. 9. Image features extracted for alignment

C. Precise Alignment with Vision and Three 1-D Laser Sensors

After the above automatic guidance step is completed, the relative distance between the end effector and the installation location is with a small value, and it's difficult to localize the object accurately using vision sensor No. 1. Therefore, the vision sensor No.2 (upper part of gripper, the right/left side) and three 1-D laser sensors starts to work together, and the assembly process shifts to precise alignment.

The precise alignment process is shown in Fig. 7. The alignment is implemented based on information from vision sensor No.2 and three laser sensors iteratively. In the step of adjustment based on vision sensor, the four lines and their intersection points in the top right corner of the installation location are used, and the reference position and orientation of image features are obtained offline. The illustration of image features used for alignment is shown as Fig. 8, and the feature extraction results are shown in Fig. 9.

1) Adjustment based on vision sensor No.2: For each input image, we can calculate the image offset, and then transfer it into the motion offset of robot end effector. PI control strategy is used to adjust the robot end effector to reduce the position and orientation error step by step until the image offset is smaller than the setting range. In this step, vision sensor No.2 is used to measure the offset in X, Y, θ_z directions, and the robot end effector is adjusted accordingly.

2) Adjustment based on three laser sensors: Once the image offset meets the requirements, it means that X, Y, θ_z directions are well-adjusted. Based on the measured values by three laser sensors, we can calculate the relative parameter Z, θ_x, θ_y between the robot end effector and installation location, and the angle offset $\Delta\theta_x$, $\Delta\theta_y$ can be transferred into the motion offset of robot end effector. Then the robot end effector is adjusted step by step until the angle offset is smaller than the setting range. In this step, leaser sensors are used to measure the offset in Z, θ_x, θ_y directions, and the robot end effector is adjusted accordingly.

Because X, Y, θ_z and Z, θ_x, θ_y are usually coupling with each other, after the finish of adjustment based three laser sensors, the image offset is measured and adjusted once again. Above process is implemented repeatedly until the alignment is completed in all directions.

D. Insertion Guidance with Multi-peg-in-hole

Once the precise alignment is completed, the remaining thing is the insertion of the object to the installation location. There are two guide pegs with chamfer in the installation location, and two guide holes in the object correspondingly. The insertion process is automatically implemented guiding by the guide pegs and guide holes until the distance value is less than a small threshold, and the relative distance between the object and the installation location is measured by the three laser sensors.

IV. Experimental Results

A. System Configuration

The industrial robot is with load capacity 50 kg, 6 degrees of freedom, repeated accuracy of positioning 0.07 mm, maximum radius of action 2046 mm. Vision sensors No. 1 and No. 2 are with the resolution 1620*1220 pixels, and they are equipped with 8mm and 5mm lens respectively. Three Distance Laser Sensors with measurement range 80 mm - 300 mm, resolution 0.1%, are used as laser sensor No. 1, No. 2 and No. 3.

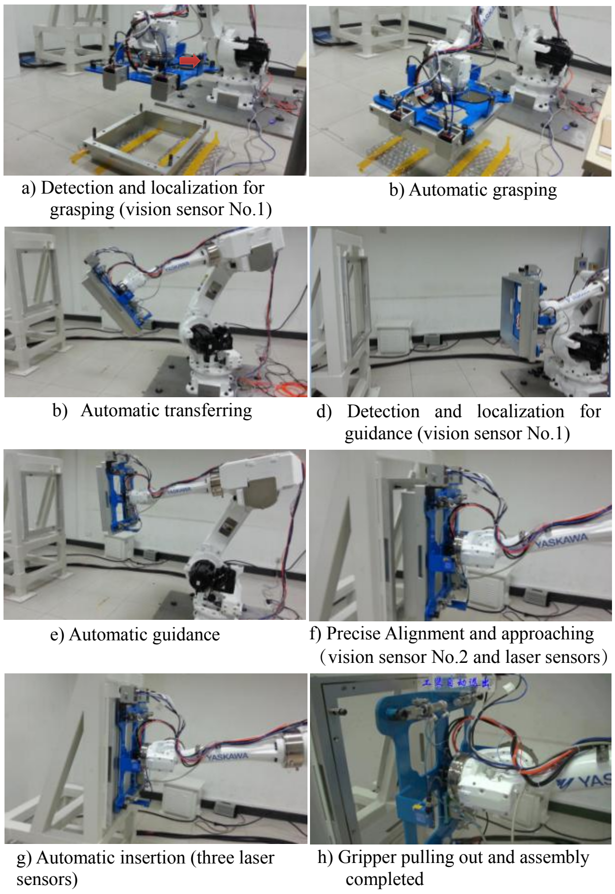
The large sale component for assembly in experiments is with the scale of 555 mm*665 mm, and the guide pegs and guide holes are with the radius of 3.8 mm and 4.0 mm respectively.

B. Qualitative and Quantitative results

The software interface of the robotic assembly system is shown in Fig. 10, including the original data of vision sensors, localization results of vision sensors, data of laser sensors, the current state and expected state of robot, robot servo on/off, gripper control, assembly process operation, disassembly operation, state of system and operation, device status indicator, and assembly step indicator.

The automatic assembly processes and qualitative results of the proposed system are shown in Fig. 11, including detection and localization for grasping, automatic grasping, automatic transferring, detection and localization for guidance, automatic guidance, precise alignment and approaching, automatic insertion, gripper pulling out and assembly completed. In automatic insertion step, the precise alignment

Fig. 10. The software interface of the robotic assembly system



a) Detection and localization for grasping (vision sensor No.1)

b) Automatic grasping

b) Automatic transferring

d) Detection and localization for guidance (vision sensor No.1)

e) Automatic guidance

f) Precise Alignment and approaching (vision sensor No.2 and laser sensors)

g) Automatic insertion (three laser sensors)

h) Gripper pulling out and assembly completed

Fig. 11. The automatic assembly processes of the proposed system

reduces the difficulty of inserting the guide pegs into guide holes.

The quantitative experimental results of the final alignment are shown in Fig. 12. The fluctuations of precision in X, Y, Z, θ_x, θ_y, and θ_z are ±0.45 mm, ±0.4 mm, ±0.35 mm, $\pm 0.1^{\circ}$, $\pm 0.1^{\circ}$ and $\pm 0.1^{\circ}$ respectively. The precision of alignment can meet the requirement of insertion with Multi-peg-in-hole. The final assembly precision is ±0.2 mm, and this is guaranteed by the guide pegs and guide holes which are with the radius of 3.8 mm and 4.0 mm respectively. The final installation process is

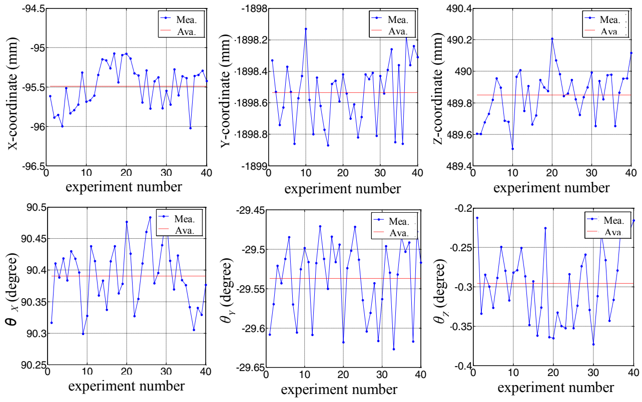


Fig. 12. The precision of alignment in multiple experiments. "Mea." denotes the measurement result, and "Ava." denotes the average result.

guided by guide pegs and guide holes, and the assembly accuracy is improved. Due to the existing of chamfer in the guide peg, although the final alignment precision is lower than the final assembly precision, the guide pegs can be inserted into the guide holes successfully. Experimental results demonstrate that there is some assembly force during insertion process. In the future works, we will add a six-axis force sensor to this system, and develop a vision-laser-force sensors guided robot assembly system for large scale components.

V. CONCLUSION

We designed a new robotic assembly system for large scale components guided by two vision sensors and three 1-D laser sensors. To automatically localize the components and search the best three-dimensional position and orientation between the object and the installation location, novel high precision localization and alignment methods are proposed. Experimental results show that the system can well finish the assembly task for large scale components automatically, including automatic detection and localization, automatic grasping, automatic guidance, and automatically insertion, with high precision and high efficiency.

The future works include the integration of force sensor and the study of corresponding method and strategy.

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