The 2009 IEEE/RSJ International Conference on
Intelligent Robots and Systems
October 11-15, 2009 St. Louis, USA

Automated Initial Setup Method for Two-Fingered Micro Hand System

Izumi Hatta, Kenichi Ohara, Tatsuo Arai, Yasushi Mae and Tomohito Takubo

Abstract— **A two-fingered micro hand has been available for use for years and allows dexterous manipulation of a single cell: grabbing, positioning, rotating and releasing. The end-effector of this micro hand consists of two glass needles; however, the glass tips must be finely adjusted and the micro hand must be calibrated prior to use. Because these initial procedures require highly skilled human operators and a great deal of time, a fine adjustment module (FAM) has been developed for assisting with the fine adjustment work and was successfully shown to make the initial setup easier. However, problems with the calibration process and with the dependence on a user of the FAM control are still present. One means of improving the system for users is to automate the initial setup. The detection of the glass tips in a wide range of Z directions from a microscopic image having a small depth of focus requires robust calibration and must be possible using an automated FAM control. From this perspective, the tip position detection algorithm using the evaluation function, Image Quality Measurement (IQM), is proposed in this paper. Based on this algorithm, the automated initial setup method is explained and its effectiveness is experimentally evaluated.**

I. INTRODUCTION

In biological fields, technology able to operate at micrometer levels is essential for manipulating cells and tissues. To satisfy this need, we have developed a two-fingered micro hand, adopting parallel mechanisms and piezoelectric devices as actuators, which resembles the use of chopsticks. This system has six degrees of freedom (DOF) for motion and highly accurate positioning of each finger, both of which allow for dexterous manipulation of a single cell at the micrometer level, such as grabbing, positioning, rotation and releasing[1].

Many studies have been conducted on this micro hand system. Tanikawa proposed a mechanism that arranges the module in parallel to achieve the movement similar to chopsticks[2]. There is a 1-DOF arc-shaped hinge, and a translational joint can be attained by the combination of two or more arc-shaped hinges. Moreover, 4-DOF link mechanics were accomplished using 2 translational joints and 2 rotational joints, and the 3-DOF micro finger was completed by arranging the three link mechanics in a parallel structure[3]. Obtaining the parameters of link length of a parallel link, the hinge shape, and the size of the plate using an optimization technique to maximize the workspace of the micro hand has been suggested[4]. Moreover, the expansion mechanisms that can be made by punching a steel sheet to reduce the cost of manufacturing of the micro hand have been developed[5]. Because operations conducted by the micro hand are executed under a microscope using a shallow depth of focus, a function to focus on the micro hand tip and the object being held is important. The auto focus method using edge detection[6], and using the change in the color generated by the chroma aberration[7] has been proposed. Moreover, template matching has been used to obtain the position of glass tips and the held object in the focused image. The contour of objects having complex shapes or that change shape often is detected using the dynamic contour model, SNAKES[8]. A function to hold an object using an automated operation has been achieved using the position of the micro hand tip and an object[9]. The three dimensional shape of a protein crystal was reconstructed to determine the point where the micro hand touched the surface of the object being held, and if auto manipulation succeeded[10], and it has been reported that the success of auto manipulation was improved by completing the calibration between the coordinate system of both the camera and the micro hand[11]. From the necessity of sensing a manipulation force, a force sensor was developed and tested during actual manipulation[**?**].

Studies using the micro hand are mainly focused on micro hand mechanisms, image processing, auto manipulation and sensing. However, before using the micro hand, the glass tips must be finely adjusted and the micro hand must be calibrated. Because these initial procedures require highly skilled human operators and a great deal of time, a fine adjustment module (FAM) has been developed for assisting with the fine adjustment work and was successfully shown to make the initial setup easier[12]. However, problems with the calibration process and with the dependence on a user of the FAM control are still present. One means of improving the system for users is to automate the initial setup. More specifically, an automated FAM control must be developed with robust calibration.

II. SYSTEM CONFIGURATION

The configuration of the cell analysis system using a two-fingered micro hand is shown in Fig. 1 (Fig. 2). The micro hand has two 3-DOF modules to drive two fingers adopting a parallel mechanism, which has the merits of high speed, high accuracy and high rigidity, in addition to its simple configuration. The joint of the micro hand consists of a thin plate, hole-punched and bent, enabling the development of a small, inexpensive mechanism with beneficial characteristics. Three piezoelectric actuators (NEC TOKIN, AE0203D16) are arranged on the base-plate and another three on the middle plate. Their extensional direction is vertical to the plate. Each finger has a 1-mm diameter glass needle sharpened at the end. Each module is controlled by a PC (Pentium 4,

Department of Systems Innovation, Graduate School of Engineering Science, Osaka University 1-3 Machikaneyama, Toyonaka, Osaka 560-8531, Japan k-oohara@arai-lab.sys.es.osaka-u.ac.jp

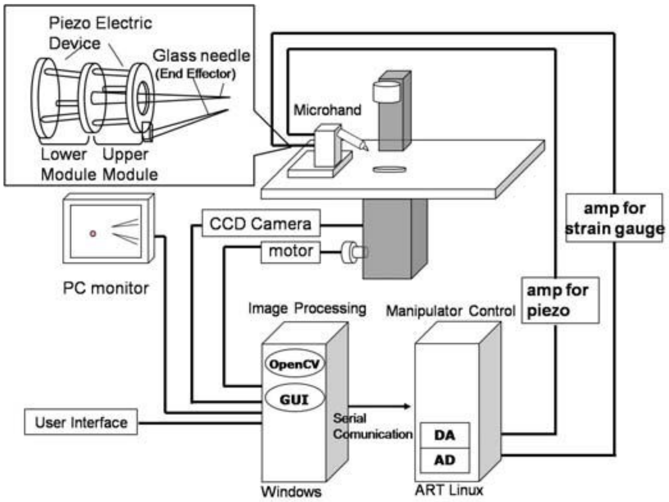

Fig. 1. System configuration

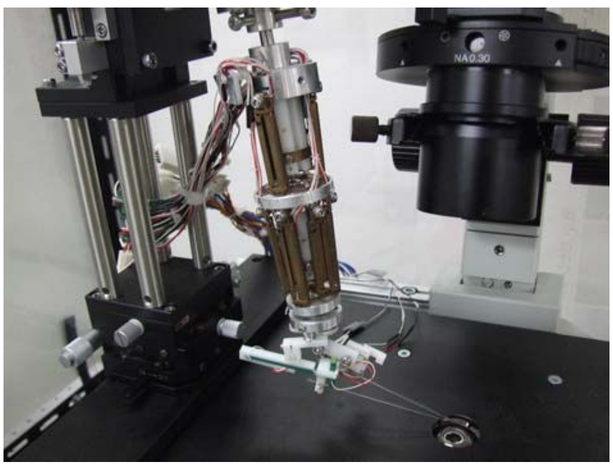

Fig. 2. Two-fingered micro hand

2.53 GHz, 512 MB RAM) through a D/A board (Interface, PCI-3346A) and drive amp (MATSUSADA, HJPZ-0.15Px3). The displacements are measured by strain gauge attached on the piezoelectric devices and sent to the PC through an A/D board (Interface, PCI-3133) for PI control to reduce the influence of hysteresis with piezoelectric devices. The micro hand and object are put on the optical microscope stage and the image of the end-effector tips are captured using the CCD camera (Point Gray Research, Flea) and displayed on the PC monitor. A motor is attached to the microscope and raises or lowers the objective lens for focusing. The microhand system is basically controlled by tele-operation using an input device (e.g., joystick, PHANTOM omni device, or GUI).

III. AUTOMATION OF INITIAL SETUP

A. Initial setup

In this paper, the "initial setup" is defined as the process including the following steps:

1) Fine adjustment of the glass tips.
2) Micro hand calibration

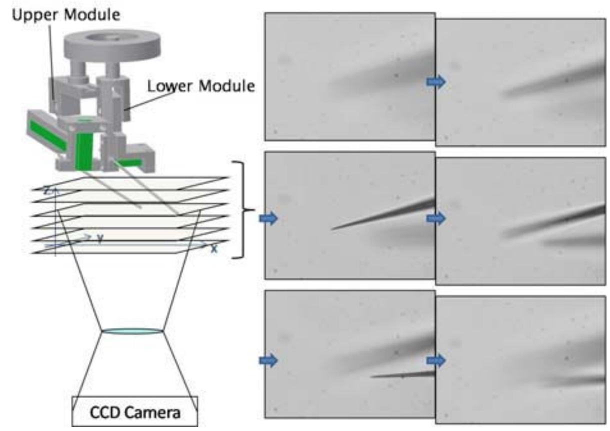

Fig. 3. The situation before FAM

Before operating the micro hand system, the glass needles must be brought closer together manually (fine adjustment process). However, this operation requires high manual dexterity, so a fine adjustment module that enables micrometer movements in three different directions has been developed[12]. A user roughly aligns the glass tips, and then, while looking at the microscopic image, the fine adjustment module is used to bring the tips closer together. Even though this module reduces the burden associated with fine adjustments, it still requires human operation.

On the other hand, calibration of the micro hand includes obtaining the relationship between the displacement of the actuators and the displacement of the position of the glass tips. In this case, the Jacobian matrix is obtained by the least squared method using data sets of piezoelectric displacement and tip position.

B. Analysis of current adjustment work

The micro hand end-effector being roughly aligned by a human operator is shown in Fig. 3. The two glass tips are at different heights and positions, and the images are on different focal planes. In order to automate the adjustment using the FAM, it is necessary to measure the positions of the glass tips. However, because the focal plane of one glass tip is in focus and the other is not, it is difficult to establish these positions. It can be assumed that the distance between two glass tips in the Z direction is 100-200 [um] because a human operator is able to align the glass tips within the workspace of the FAM, but the position of the two tips in three dimensions is necessary. At the same time, position detection is also important in the calibration process of the micro hand. Because the auto focusing method proposed by Kato et al.[7] works only within a narrow range, approximately 4 [um], the position detection easily fails when the glass needle rapidly moves in the depth direction. To improve position detection, a method to stably track positions through a large range is required. Therefore, a technique to detect the position of the glass tip through large variations in the Z direction is necessary for automating the initial setup.

C. All-in-Focus Image generation algorithm

The Micro VR Camera System, developed by Ohba et al.[13], adopted the All-in-Focus Image generation algorithm. This system can obtain All-in-Focus images by capturing microscopic images in different focal planes and then processing the data based on the evaluation function, Image Quality Measurement (IQM), shown in Eq. (1).

$$IQM = \frac{1}{D}\sum_{x=x_i}^{x_f}\sum_{y=y_i}^{x_f}\left\{\sum_{p=-Lc}^{Lc}\sum_{q=-Lr}^{Lr}\left|I(x,y)-I(x+p,y+q)\right|\right\} \quad (1)$$

The IQM value describes the condition of focus in each area. This area is represented as 5 by 5 pixels in the case of our system. The procedure for making All-in-Focus images is as follows:

1) Raising and lowering the objective of the microscope to acquire images in different focal planes.
2) Calculating the IQM value of each pixel in each image.
3) Setting the calculated IQM as the maximum value of each pixel for all focused images.

In this system, the depth information of the viewable area is obtained using the All-In-Focus image based on the Depth From Focus theory[14]. The resolution and the range in the depth direction can be decided according to the demanded accuracy. Therefore, this system is effective for the initial setup.

D. Tip position detection algorithm using All-in-Focus Image generation algorithm

The problem of recognizing the focal plane of a tip from the microscopic image during the automated fine adjustment process and the calibration process can be resolved by applying the All-in-Focus Image generation algorithm. More specifically, the total IQM values in a partial area are compared between acquired images, and images that have the maximum value representing the focal plane of the area. The procedure (Fig. 4) is described as follows:

1) The objective lens is raised and lowered, and images in different focal plane are acquired.
2) X and Y coordinates of the glass tip are detected.
3) The partial images that center on the X and Y coordinates of the point are extracted from the image row.
4) The IQM value of each pixel is calculated in each partial image and the total value, representing the total additional value of IQM on partial image, is calculated.
5) The partial image having the maximum total value is judged to be the suitable in-focus position, or, simply, the Z coordinates.

This method can acquire the focal plane at arbitrary (X,Y) coordinate positions, because the acquired number of images and the distance between each image can be arbitrarily selected. From this perspective, this algorithm is suitable for automatically detecting a wide range of tip positions during the initial setup.

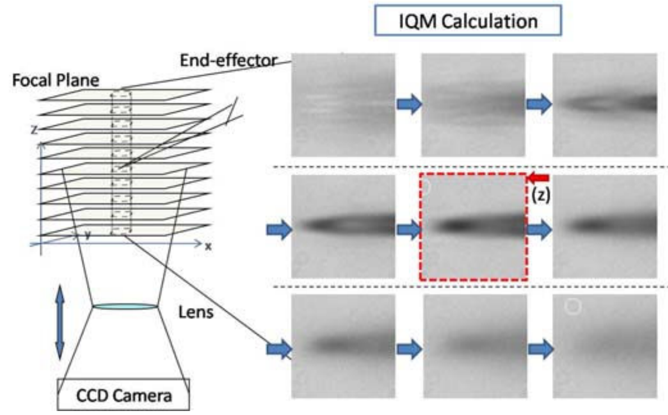

Fig. 4. Algorithm of focus plane detection

IV. AUTOMATION OF FINE ADJUSTMENT MODULE CONTROL

A. Tip position detection by All-in-Focus image

The detection of tip position is indispensable in achieving automatic control of fine adjustment. To make the task simple, the following assumptions are made regarding the automation technique:

1) Each glass tip is set to avoid crossing or contacting one another.
2) The glass tips are located at the left-hand side of an image.
3) The location of the Upper glass tip is determined, followed by the Lower glass tip.

The tips of two end-effectors are detected by the following algorithms (Fig. 5) under these preconditions:

1) Generation of All-in-Focus image by capturing images in different focal planes.
2) Binarization, Erosion, and Dilation of image data to remove noise.
3) Completion of labeling to obtain the silhouette of the two glass needles.
4) Determination of the tip position (X,Y)from the left end in each silhouette by condition (2).
5) Application of the tip position detection algorithm, Z coordinates are requested.

B. Workspace measurement

To judge the possibility of automatic fine adjustment using the FAM, the workspace must be measured. Because the directions of the movement of the FAM are not orthogonal, the direction and distance (workspace) of the movement have to be measured using the world coordinate system. Therefore, the workspace of the FAM refers to the range of movement when a voltage, 0-150 V (maximum voltage), is applied to the piezoelectric device. Here, the case of PZT2 is explained as an example. The upper glass finger moves when voltage is applied to PZT2 (Fig. 6). The Lower glass must be deleted from the image in order to acquire the tip position of the Upper glass, as both the Upper glass and the Lower glass

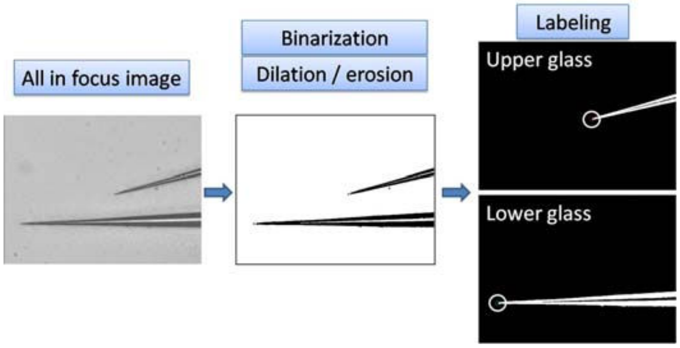

Fig. 5. The Algorithm of finger edge detection

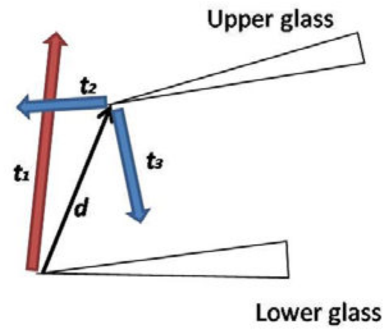

Fig. 7. vector

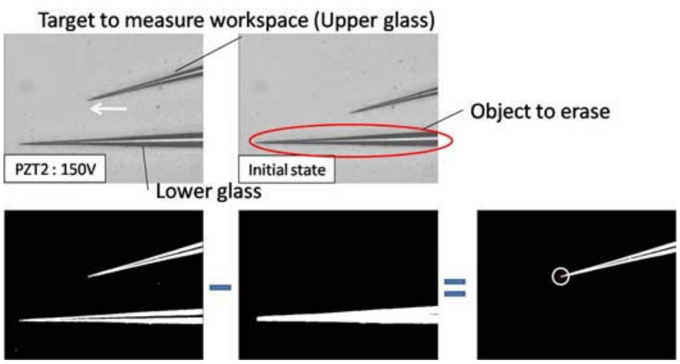

Fig. 6. Measuring workspace of PZT2

are detected in the labeling of the All-in-Focus images. The silhouette of the Lower glass is removed from the image of the initial state, using a background subtraction method, and the labeled image of only the Upper glass is obtained.

C. Method of judging the possibility of automated Fine Adjustment Module control

If the workspace of the FAM and the distance between tips are acquired, it can be determined if the tips are brought closer together using the FAM from a currently known position. The vector between the tips of the Lower glass and the Upper glass is defined as d, and the vector of FAM for each workspace is defined as t_1, t_2, t_3, respectively. The relation among these vectors is expressed by Eq. (2)

$$\vec{d} = \alpha\ \vec{t_1} - \beta\ \vec{t_2} - \gamma\ \vec{t_3} \tag{2}$$

and the coefficients $\alpha, \beta, and \gamma$ are determined uniquely(Fig. 7. If these coefficients fulfill the condition (3),

$$\begin{array}{c} 0 \leqq \alpha \leqq 1 \\ -\frac{1}{2} \leqq \beta \leqq \frac{1}{2} \\ -\frac{1}{2} \leqq \gamma \leqq \frac{1}{2} \end{array} \tag{3}$$

applying a voltage value corresponding to the ratio of coefficients makes the distance between the tips zero.

D. Procedure of automation

The process of automated fine adjustment is as follows (Fig. 8):

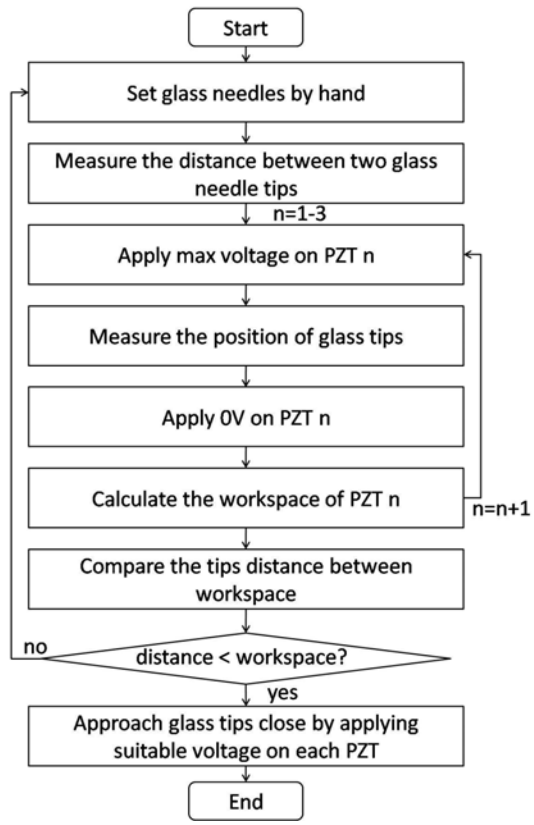

Fig. 8. The flowchart of automated fine adjustment

1) Detecting the positions of the two glass tips that are roughly aligned by hand in the camera image; the distance between both tips is calculated (Fig. 9(a)).
2) Measuring each workspace by applying 0-150 V (maximum voltage) to each piezoelectric device (Fig. 9(b)-(d)).
3) Judging whether the glass tips are brought closer together.
4) Applying the appropriate voltage to adjust the glass tips, if fine adjustment is possible based on the result of step (3). If fine adjustment is not possible, the system encourages the user to retry.

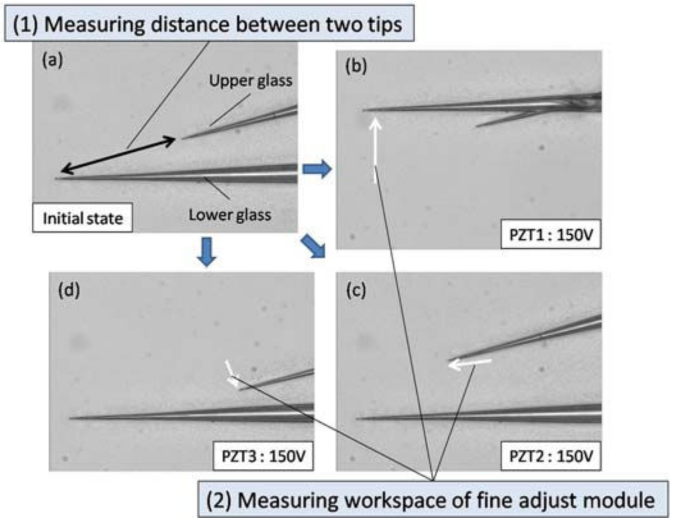

Fig. 9. The tip movements by FAM

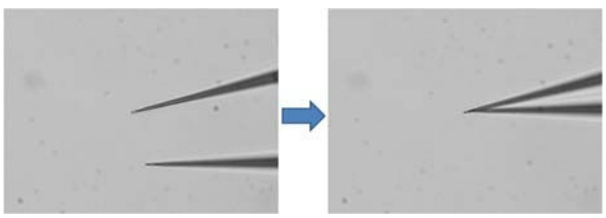

Fig. 10. The result of automation FAM experiment

E. Experiments and consideration

Four experiments of automated fine adjustment using the FAM were conducted. An example of the results is shown in Fig. 10. The mean distances between the tips after automated fine adjustment were 9.067, 6.975, and 13 (m in the X, Y, and Z axis, respectively, and the tips were brought sufficiently close together. However, errors related to the workspace may introduce errors into the distance measurements. This algorithm is very flexible though, and additional fine adjustment is possible by changing a magnitude of the objective lens or the distance between each image plane.

V. Improvement of Tip Position Detection Algorithm in Calibration

The calibration requires the displacement of a tip in each module, respectively, when an arbitrary voltage is applied to the piezoelectric element. When the voltage is applied, the movement of the glass needle being measured may be disrupted by the second glass needle that is not being measured if they are close together, and the relationship between the voltage and the amount of displacement of the tip cannot be accurately determined. So, prior to the calibration, the glass needle not being measured is moved out of the image using the FAM.

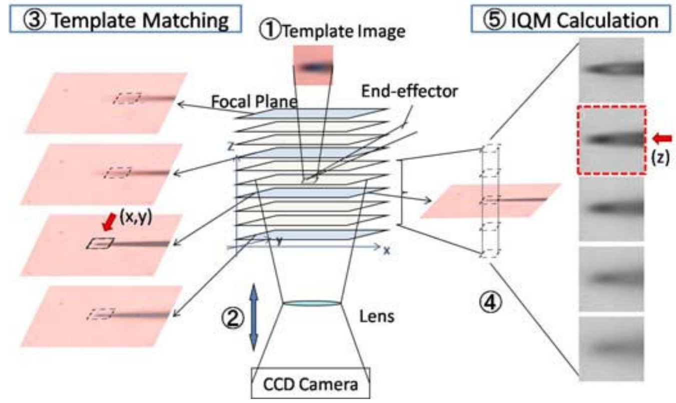

Fig. 11. End-effector detection algorithm

A. The tip position detection method using template matching

This section describes the tip position detection method in the calibration process (Fig. 11).

1) A template image of the glass tip is acquired prior to calibration.
2) Images at different focal planes are acquired.
3) The template matching method is applied to each image, and (X,Y) coordinates of the glass tip are decided from the image that gives the maximum correlation value; the Z coordinates are assumed to be temporary Z.
4) The partial images that center on (X,Y) are extracted from the images on different focal planes.
5) Z coordinates are determined using the position detection algorithm on the partial images.

The auto calibration procedure using this algorithm is as follows:

1) An arbitrary voltage is applied to each piezoelectric actuator.
2) The position of the glass tip is detected and recorded along with the voltage data.
3) Returning to step (1), the algorithm is repeated as necessary, depending on the sampling data.

B. Experiments and consideration

The motor installed on the microscope moved the objective from (40 to 40 um in increments of 1 um, and 80 images at different focus planes were acquired. The number of sampling points was 25.

A theoretical glass tip position is calculated from the displacement of the piezoelectric device and the Jacobian matrix obtained from the calibration (re-projection). A graph, comparing these values to actual measurements, is shown in Fig. 12. Next, the micro hand was moved relative to the instruction value obtained using the Jacobian matrix. The relationship between the instruction value and the actual glass tips is shown in Fig. 13. Mean error and standard deviation are shown in Table I. The mean error of the re-projection results is approximately 3 (m, suggesting this

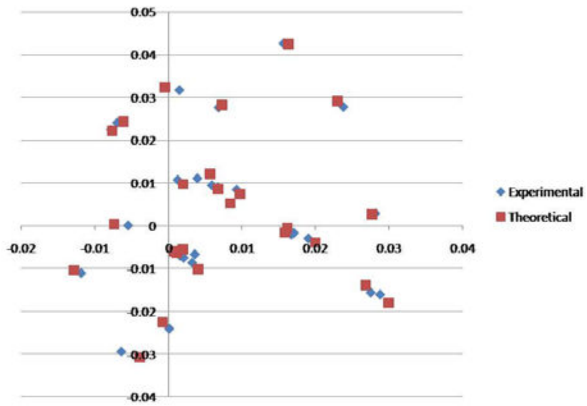

Fig. 12. Relation between theoretical value and actual value

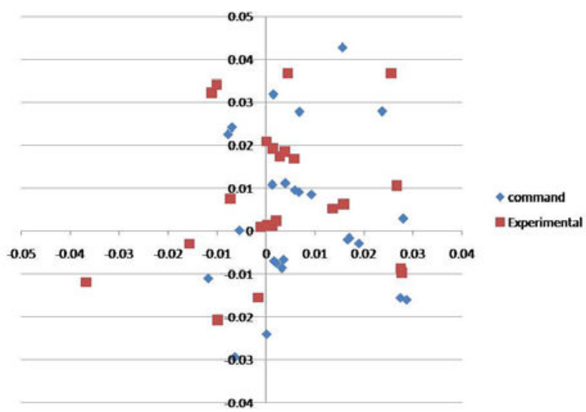

Fig. 13. Relation between command value and actual value

method has good accuracy. However, the error between the instruction value and the actual tip position is larger than the re-projection result, which may result from small movements of the glass needles. The glass needles are fixed using the screw and ball joint of the FAM, but not completely, so the position of glass needles may be altered by impacts to or vibrations of the micro hand. From this perspective, the design of the FAM must be improved. The hysteresis of the piezoelectric device is another possible cause of the resulting error.

TABLE I

AVERAGE OF ERROR

	Average	Standard Deviation
re-projection [μm]	3.04	1.99
instruction [μm]	15.78	10.49

VI. CONCLUSION

This paper describes an automated initial setup process to reduce the burden of this procedure on users. To achieve this, a tip position detection algorithm using the evaluation function, Image Quality Measurement, was proposed. Automated initial setup experiments showed the effectiveness of this method. Currently, however, the accuracy of the calibration result is not precise, and to improve this, future studies will modify the design of the Fine Adjustment Module.

VII. ACKNOWLEDGMENTS

This work was supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) under Grant-in-Aid for Scientific Research on Priority Areas (Project No. 17076010).

REFERENCES

[1] Kenji Inoue, Tatsuo Arai, Tamio Tanikawa, Kohtaro Ohba: “Dexterous Micromanipulation Supporting Cell and Tissue Engineering”, Proceedings of the 2005 International Symposium on Micro-NanoMechatronics and Human Science, pp.197-202, 2005.

[2] T.Tanikawa and T.Arai, “Development of a micro-manipulation system having a two-fingered micro hand”, IEEE Trans. Robotics and Automation, Vol. 15, No. 1, pp. 152–162, 1999.

[3] T.Tanikawa and T.Arai, N.Koyachi “Development of Small-sized 3DOF Finger Module in Micro Hand for Micro Manipulation”, Proceedings of the 1999 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS’99), Vol.2, pp. 876–881, 1999.

[4] Ahmed. A. Ramadan, K. Inoue, T. Arai, and T. Takubo: “Chopstick-like Two-fingered micromanipulator hybrid hand”, 2008 International Symposium on Flexible Automation (ISFA2008), pp. JL021, 2008.

[5] Tamio Tanikawa, Motohide Ukiana, Kazuhiro Morita, Yoshihiko Koseki, Kotaro Ohoba, Kazuhiro Fujii, Tastuo Arai: “Design of 3DOF Parallel Mechanism with Thin Plate for Micro Finger Module in Micro Manipulation”, Proceedings of IEEE/RSJ International Conference on Intelligent Robotics and Systems, pp. 1778–1783, 2002.

[6] Yousuke KATOH,Tatuo ARAI,Kenji INOUE,Yasushi MAE,Tamio TANIKAWA: “Auto Focusing and Tracking for Micro Manipulation”, Mecatoronics’01 5th France-Japanese Congress, pp. 349–354, 2001.

[7] Y. Kato, T. Arai, K. Inoue, Y. Mae, and T. Tanikawa: “Vision System for Micro Manipulation”, Journal of Robotics and Mechatronics, Vol.14, No.2, pp.203–209, 2002.

[8] Tatsuo ARAI, Akihiro SUZUKI, Yasushi MAE, Kenji INOUE, Masahito TAYA and Tamio TANIKAWA: “Automated micro handling system for micro-scale objects”, Proceedings of the 2004 Japan-USA Symposium of Flexible Automation, JL030, 2004.

[9] Akihiro SUZUKI,Tatsuo ARAI,Yasushi MAE,Kenji INOUE,Tamio TANIKAWA, “Automated Micro Handling”, Proceedings of the 2003 IEEE International Symposium on Computational Intelligence in Robotics and Automation CIRA2002 Japan, TP-3-I-2, 2003.

[10] K. Ohara, K. Ohba, T.Tanikawa, M.Hiraki, S.Wakatsuki, M.Mizukawa, “Hands Free Micro Operation for Protein Crystal Analysis”, Proceedings of 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems, 2004.

[11] Kenichi Ohara, Kohtaro Ohba, Tamio Tanikawa, Masahiko Hiraki, Soichi Wakatsuki, Makoto Mizukawa, and Kazuo Tanie, “Automated micro manipulation system with protein crystal”, Proceedings of 2004 International Symposium on Micro-NanoMechatronics and Human Science, pp.301–306, 2004.

[12] Tamio Tanikawa, Masashi Kawai, Noriho Koyachi, Tatsuo Arai, Takayuki Ide, Shinji Kaneko, Ryo Ohta, Takeshi Hirose, “Force Control System for Autonomous Micro Manipulation”, Journal of Robotics and Mechatronics, No. 14, Vol. 3, pp. 212–220, 2002.

[13] Izumi Hatta, Kenichi Ohara, Tatsuo Arai, Yasushi Mae, Tomohito Takubo, and Kenji Inoue, “Cell Analysis System Using Two-fingered Micro Hand -Fine Adjustment Mechanism for End-effector-”, 19th IEEE International Symposium on Micro-NanoMechatronics and Human Science in 2008 (MHS 2008), 2008.

[14] Kohtaro Ohba, Jesus Carlos Pedraza Ortega, Kazuo Tanie, Masataka Tsuji and Shigeru Yamada, “Microscopic vision system with all-in-focus and depth images”, Machine Vision and Applications, Vol.15, pp. 55–62, 2003.

[15] Murali Subbarao and Jenn-kwei Tyan, “Selecting the optimal focus measure for autofocusing and depth-from-focus”, IEEE Trans. Pattern Analysis and Machine Intelligence, Vol. 20, pp. 864–870, 1998.