Multiple Magnification Images Based Micropositioning for 3D Micro Assembly

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Abstract

This paper presents micropositioning system using feedback of multiple magnification images from CCD cameras mounted on an optical microscope. In order to guarantee of the accurate micropositioning to micro assembly system, high precise sensors are required. But many kinds of sensors, which are used in macro world, have insufficient resolution and size. The visual data from an optical microscope have vast information, however, the single field-of-view of optical microscope essentially limits the workspace of the micromanipulator and the low depth-of-field makes it difficult to handle micro parts. To overcome these problems and increase precision of micropositioning system, we use multiple magnification images that have same viewpoint.

The use of multiple magnification images reduces the time consuming for handling of micro parts and increases precision of micropositioning. We propose this method for micropositioning system.

1 Introduction

In the past two decades have been developed diverse micro electromechanical devices. The processing techniques for these devices are also equally diverse, and in some cases these methods are not compatible. The needs of high levels of precision and repeatability are required despite the fact that the mechanics of the micro domain have proven to be difficult to model accurately. It is due to the fact that mechanics in the micro domain are substantially different from the macro domain where most manipulation research has been conducted. The governing physics in the micro domain such as Van der Waals forces, electrostatic forces, and surface tension are only approximately known. Therefore accurate estimation and modeling is not possible over entire micro domain. As a result, open loop positioning techniques are not sufficient for the micro domain.

A sensor-based micropositioning system is developed in order to guarantee both high precision and repeatability. Visual data from a CCD camera mounted on an optical microscope have very useful information for micro-manipulation. They also have many applicable image processing algorithms that have been developed and verified their performance in the past. As a matter of fact, in micro domain most systems use CCD camera mounted on an optical microscope because of the inadequacy of sensors which have suitable size and high-resolution [1][4][6]. However, there exist remarkable differences between highly magnified visual data and general macro visual data. These differences offer both merits and demerits to performance of image processing in the micro domain. Highly magnification images under on optical microscope offer plenty of information for handing micro parts. For instance, surfaces that appear smooth at normal magnification were highly textured under a magnification lens system. Smooth boundaries also appear rugged under a magnification lens. Moreover focused and defocused image data offer meaningful information for calculating difference of heights of numbers of objects, etc. Such elaborate and plenty information makes a vision sensor suitable for the micro domain. But sometimes some of data under an optical microscope offer redundant information and that causes difficulty in image processing such as feature extraction, and boundary extraction, etc.

It is natural that the images, which have bigger scale of enlargement, have more precise information. In the same way, using visual data for micromanipulation, the bigger enlargement ratio is more useful for getting precise information about target object. But higher magnification images bring narrower field-of-view and consequently it limits field for object recognition and possible work area. Also slight movement of micro positioner brings large displacement in highly magnified image. So small amount of displacement error causes disappearance of target object in sight.

Many researches have been made to solve the problems mentioned above. Those researches have used object lens at microscope or multiple cameras that have different magnification and different viewpoint. The use of multiple object lenses causes large time consuming and difficulty of manipulation. Moreover, new focusing operation is needed at each time of at exchanging the lenses. And in the use of multiple cameras, the complex image calibration process is needed. So it adds calculation load to vision system and also increases calculation time. Accordingly the reliance of result cannot be guaranteed.

In this paper we present micro vision system for
2 Micropositioning System

Micro position system is composed of three parts. An optical stereomicroscope and three CCD cameras mounted on stereomicroscope is the first part. The second part is micro XYZ stage. And the last part is a high performance PC that has controller for micro XYZ stage and an image processing board. Fig. 1 below shows the system architecture of micropositioning system.

![Fig. 1. Composition of Micropositioning System](image)

The system has optical stereomicroscope (MZ-12.5 of Leica co.) with superior recognition ability for 3D-shaped micro parts, multiple CCD cameras (XC-55 of Sony co.), and a DSP frame grabber (GENESIS of Matrox co.). Obtained visual data from three CCD cameras are fed into the image processing board, and three CCD cameras are synchronized both horizontally and vertically. The optical stereomicroscope has wide range of magnification, high resolution, and long working distance. Also its field-of-view is larger by 8 times at low magnification and 10 times at high magnification than general optical microscope (Mitutoyo FS60 optical microscope was referred), and it could recognize from a few micrometers to several millimeters. Moreover the working distance of MZ-12.5 optical microscope is 97mm while general optical microscope has small working distance around 10mm, which restricts the workspace of micro-manipulator.

The micropositioning XY-stage (M-126.DG of PI co.) is leadscrew-driven translation stage with the travel range of 25mm. Precision crossed roller bearings guarantee straightness of travel of better than 2µm. It uses a compact closed loop DC motor with shaft-mounted high resolution position encoder and a precision gearhead providing 0.1µm minimum incremental motion and designed resolution is 0.005µm. The micropositioning vertical stage (M-501.1DG of PI co.) uses precision-ground re-circulating ball screws with preloaded nuts, which provide low-friction and backlash-free positioning. It has 12.5mm travel range and designed resolution is 0.005µm.

Fig.2 shows software architecture for vision-based micropositioning system. The multi-thread method is used for real time data translation. GUI(Graphic User Interface), image processing and micropositioning stage control threads share their information.

![Fig. 2. Software Architecture](image)

3 Micro Vision System

In this section, we define multiple image space and explain autofocus and recognition algorithms by using multiple magnification images.

3.1 Multiple Image Space Definition

The main characteristic of micro vision system is the system simultaneously offers multiple magnification images that have same viewpoint. They have same cartesian 2D coordination, which are shown Fig.3.

![Fig. 3. Basic Definition of Image Coordination](image)

We define these three image space to $I_1(x, y)$, $I_2(x, y)$
and $I_o(x,y)$. Each x and y denotes that number of pixels in x-axis and number of lines in an image. Also all of them have same resolution of $640 \times 480 \times 8$bits, and they have different enlargement ratios as $I_1:I_2:I_3 = 1:0:1.5:3.0$.

![Fig. 4. New Definition of Image Coordination](image)

As shown in Fig. 4, we redefine the image coordination of Fig. 3 for easy calculation of relationship of multiple input images. After redefining image coordination, we get Eqs (1) and (2).

$$I_1(x,y) = I_2(1.5x, 1.5y)$$

(1)

$$I_1(x,y) = I_3(3x, 3y)$$

(2)

(\text{where,} - 320 < 1.5x < 320 \text{ and } -240 < 1.5y < 240)

Input visual data $I_1, I_2$ and $I_3$ have close relationship and $I_1, I_2$ have more detail information than $I_3$. Therefore, visual data $I_2$ and $I_3$ will be used for accurate micropositioning while visual data $I_1$ will be used for the operations which require the large field-of-view. This selective view offers effective information and incensement of precision to micropositioning system.

### 3.3 Recognition Algorithm

Characteristic points matching and pattern matching methods are widely used for object recognizing algorithm. However, characteristic point matching method needs preprocessing step for characteristic point detection. This preprocessing may cause time delay for computation, so it is improper for real time control. On the other hand, pattern matching method is just the comparison of target image and model image, so pattern matching algorithm becomes fit for object recognizing by the assistance of developed hardware such as high performance DSP, in recent years. Generally, pattern matching is performed by the equation of correlation in the convolution type as below;

$$r = \sum_{i=1}^{N} I_i M_i$$

(4)

where, $r, I_i, M_i$ are the correlation value, the pixel value of target image and the pixel value of model image. The correlation operation can be seen as the form of convolution where the pattern-matching model is analogous to the convolution kernel. In fact, ordinary (un-normalized) correlation is exactly the same as the convolution.

In this case, the area that has maximum correlation value is the most similar area of model image; so we can find the pattern by calculating the coordinates. Unfortunately, with ordinary correlation, the correlation value $r$ increases if the image gets brighter. In fact, the function reaches a maximum when the image is uniformly white, even though at this point it no longer looks like the model. The solution is to use a more complex, normalized version of the correlation function;

$$r = \frac{\sum_{i=1}^{N} I_i M_i - (\sum_{i=1}^{N} I_i)(\sum_{i=1}^{N} M_i)}{\sqrt{[\sum_{i=1}^{N} I_i^2 - (\sum_{i=1}^{N} I_i)^2][\sum_{i=1}^{N} M_i^2 - (\sum_{i=1}^{N} M_i)^2]}}$$

(5)

With this expression, the result is unaffected by linear changes (constant gain and offset) in the image or model pixel values. The result reaches its maximum value of 1 the image matches the model exactly, gives 0 where the model and image are uncorrelated, and is negative where the similarity is less than might be expected by chance. To reduce the calculation time, reliable method of reducing the number of computations is to perform a so-called hierarchical search. Basically, a series of smaller, lower-resolution versions of both the target and the model image are produced, and search begins on a more reduced scale[7]. The search starts at low resolution to find likely-
match candidates quickly. The search process iterates on the higher resolutions than that of the formal one sequentially to refine the positional accuracy and make sure that the matches found at low resolution actually are occurrences of the model. Because the position is already known from the previous level, the correlation function is evaluated only at the very small number of locations. But, if the level were too high, original image would be damaged. So the search algorithm must trade off the reduction in search time against the increased chance of not finding the pattern at very low resolution.

Above pattern matching algorithm is not suitable for object handling. For handling micro objects by micro gripper, additional image processing algorithm for extract gripping points is needed. We use this pattern matching algorithm only for object positioning.

4 Micropositioning

4.1 Control Loop

In the micro domain, accurate estimation and modeling are not possible due to the different mechanics of macro domain. Therefore, accurate estimation and modeling are not possible over entire micro domain. As a result, open loop positioning techniques are not sufficient for the micro domain. Vision is non-contact sensing modality that provides dense information about the environment and enables recognition of objects. However, because of this intensive information, fast closed loop systems could not be realized until recently with the advent of sufficiently powerful microprocessors.

With the advancement in microprocessor’s speed, it becomes possible to incorporate a vision sensor into the closed loop system. Fig. 5 shows closed control loop of micropositioning system.

![Fig. 5. Closed control loop for micropositioning](image)

Position feedback is obtained in the form of visual data from a CCD camera on an optical microscope that is incorporated into closed loop control architecture.

4.2 Micropositioning Strategy

For micromanipulation, two kinds of micropositioning are needed. One is micropositioning of vertical micro stage for autofocusing, and the other is XY-micro stage positioning for handling of micro objects. Highly magnified image is effective for obtaining precise data about micro objects. But lowly magnified image offers large field of view for observing the workspace. We use both data for effective micropositioning and for precise micropositioning. Fig. 6 shows the strategy of micropositioning for moving vertical stage. After concerned region is selected at lowly magnified image space, autofocusing algorithm is executed. After finding the exactly focused position, same operation is executed at the highly magnified image space for finding more precisely focused position.

![Fig. 6. Micropositioning strategy for autofocusing](image)

Fig. 7 shows micropositioning strategy for moving XY-stage. First, system searches the object using lowly magnified image space. It is easier to find than using highly magnified image space. If it succeeds in finding object image processing algorithm calculate its current position and target position, and generate moving trajectory. And move the micro XY-stage using visual feedback data of \( I_1 \). After finishing the operation, the system examines the position of object by using more highly magnified image space \( I_2, I_3 \). If there exist position errors at the highly magnified image space, the system resumes micropositioning by using highly magnified visual feedback data. This strategy is efficient for high precision of micropositioning.

![Fig. 7. Micropositioning strategy](image)

5 Experiments and Results
5.1 User Interface

The user interface is divided into two parts. The first one shows multiple enlargements images and offers information of recognized micro objects to user. The Fig. 8 shows user interface part 1. The lower part on the right side window is for moving micro XY-stage by shifting and clicking the mouse point to the target area.

Fig. 8. User interface 1.

Fig. 9 shows the second user interface. It has camera control module, image processing control module, and stage control module and also have three sub-windows for showing trajectory of recognized objects.

Fig. 9. User interface 2.

5.2 Micro Parts Centering

Fig. 10 shows the experiment of object centering. Object centering is positively needs for micro-manipulation. If the object is out of sight in image region, micro-manipulation is impossible, therefore centered position of a micro object is most effective for micromanipulation. Object recognition is accomplished in whole operation and position information is obtained in real time. For micro object handling, higher magnification image is more effective and has more precise information, but it limits field-of-view. So we use both lowly and highly magnified visual information in micropositioning system. Also the position error exists in different magnification image. So we search and center the micro object roughly by using II image space data. After finished centering operation in II image space, the second and the third centering is executed for more precise micropositioning. Fig. 8 shows the example of micropositioning. The initial position of needle type micro object is (162, 118) in II image space. And target position is (320, 240). And each magnification of $I_1$, $I_2$ and $I_3$ are 100, 150 and 300.

Fig. 10. Centering of micro object

5.3 Autofocusing

Fig. 11 shows the result of calculated focus value using autofocus algorithm that is described in section 3.2. The graph shows that the focus value is larger when the vertical stage is closer to exactly focused position and graph shows symmetrical figure. The 496th position of vertical stage offers exactly focused image. In this experiment, the stage moves 1000 times per 10um to upper direction. And the image has magnifying power of 100.

Fig. 11. Focus value of micro image
background image impacts on the focus value. The difference of exact focusing value between (a) and (b) is because the effective for precise focusing. The difference of exact focusing value. So, for more precise focusing, using highly magnified image is needed. And different exact focusing value. So, for more precise focusing, using highly magnified image is needed. And also the graph shows that using object region is more effective for precise focusing. The difference of exact focus value between (a) and (b) is because the background image impacts on the focus value.

The exactly focused position is different between image space $I_1$ and $I_2$. The exactly focused image is basis for obtaining precise visual data; that is to say, defocused image itself contains the image processing errors.

6 Conclusions

In this paper we illustrate multiple magnification images based micropositioning system and its architecture. The micro images have different characteristics when they are compared with macro images. The micro image offers more precise information about micro object. That vast visual information provides possibility of vision based micropositioning, but certain information is redundant for object recognition in micropositioning system. Also high enlargement ratio of optical microscope limits field of view. We solve these problems using multiple magnification based micro vision system.

Micropositioning operation for micro assembly is divided into two parts. One is micropositioning of vertical micro stage for autofocusing and the other is for X and Y micro stage. For using multiple magnification images effectively, we established the micropositioning strategy and the strategy worked excellently, and as a result, increases precision of micropositioning.

For handlings of micro objects, there are many remaining problems to be solved. More precise object recognition algorithm is needed. Development of image processing algorithm for micro image processing is one of serious problem. The different height and overlapping of micro object and micro gripper is have an influence on vision based micropositioning system and micro-manipulation. For solving these problems we are doing research about developing image-processing algorithms suitable for micromanipulation.

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