Creature Recognition and Identification by Image Processing Based on Expert System for Control of a Micromanipulator*

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This paper describes an automatic organism recognition and identification method, using image processing based on an expert system for application in a micromanipulator system. Since organisms under a microscope all appear different, are in motion and have time-dependent shapes, the conventional pattern-matching method used for industrial products can hardly be applied. The proposed new method is based on segmentation of the organism images (organism image segmentation method; OISM) and takes advantage of characteristic segment features which are independent of individual size and length. Their complicated shapes are divided into basic shape segments (defined in this paper), such as lines, circles, and ovals. The relations between segments are analyzed and described automatically in the data base of the expert system. Organisms can then be expressed simply in a set of segments their individual differences can be avoided. Tracking the movement of an organism by its image is also shown in this paper. The effectiveness of this method is confirmed by experimental results.

Key Words: Application of Control, Micromanipulation, Expert System, Creature Recognition and Identification, Image Processing, Segmentation Method

1. Introduction

Recently, biotechnology has made startling progress, particularly in the field of gene manipulation. Medicines, cloned organisms and new types of plant seeds created by this technique have already reached the level of practical use⁽¹⁾. It is predictable that in future this technology will be used industrially and hence, its automation will be necessary^{(2)~(4)}.

However, it is difficult to apply the conventional pattern matching method to the automation of such techniques. The reason is that organisms, such as biological cells, being different from industrial products, have individual differences and transform their shape freely. That is, it is impossible to make a unique image pattern of them. An image pattern of the object is essential to the conventional pattern matching method.

In order to solve this problem, this paper proposes

a new image processing and reasoning method, the organism image segmentation method (OISM), to recognize and identify organisms for the application of the micromanipulator system. This newly proposed method is based on the image segmentation method of organisms, consisting of characteristic features independent of the individual length, area and shape. Complicated images of organisms are divided into basic shape segments (defined in this paper), such as lines, circles, and ovals. The length, area and shape of segments are calculated by the expert system automatically, and the connection of segments is also analyzed and described automatically. In this way, organisms are expressed simply in a set of segments. Thus, the method can recognize and identify organisms while avoiding their individual differences and shape transformation resulting from their movement. Details of the image processing and reasoning processes of the OISM are shown in this paper.

Furthermore, the system has two special modes considering some situations that may occur during the process.

The first special mode is the insufficient data supplement mode. In the process of image processing,

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the input images are strongly affected by surrounding conditions; e. g., sometimes the image cannot be obtained completely. The most influential condition is the position and location of lights. In such cases, the insufficient data supplement mode is activated. The mode supplies the insufficient data to the obtained image data.

The second special mode is the tracking mode. Organisms under the microscope are alive, that is, sometimes organism images overlap. In such cases, this tracking mode is activated. This mode tracks the movement of organisms every 1/8 of a second, then distinguishes organisms which are overlapping.

The effectiveness of this method is proved by some experimental results. In the experiments, aqua-microbes and their two-dimensional black and white images are used.

2. Organism Image Segmentation Method

2.1 Outline of the organism image segmentation method

Image segmentation in this paper means that organism images, as defined before, are segmented according to their joints (see Fig. 1).

We made the following three fundamental assumptions to describe organisms by segments of basic shape in order to recognize and identify them.

(1) Organisms may transform their shape, seg-

Fig. 1 Image segmentation

Fig. 2 Even if the organism changes its structure, length, area and basic shape remain unchanged

ment length, segment area and basic shapes (defined below) remain unchanged (see Fig. 2).

(2) The same species of organism has the same set of basic shape segments (defined below) (see Fig. 3).

(3) Between two organisms of the same species, corresponding proportions of segment length and segment area are almost the same (see Fig. 4).

These assumptions would also seem to be reasonable in the biological field⁽⁵⁾.

2.2 Definition of basic shape

We defined "basic shape" as follows (see Fig. 5):

These basic shapes are expressed by distances between points on the centerline and points on the outline (see Fig. 6). The points are extracted from the center line in every two pixels.

Therefore, a segment of an organism can always be expressed with unique data even if the organism changes shape (see Fig. 7).

Fig. 3 For organisms of the same species the set of segments is similar

Fig. 4 For the same specimen, the proportion of length and area of the segments among individuals are almost the same

2.3 Calculation of segment length

The segment length is calculated by adding the distances of dots on the centerline according to Eq. (1) (see Fig. 8).

$$L = \sum \Delta l_n \quad (1)$$

2.4 Calculation of segment area

The segment area is calculated by adding infinite area (S_n)s (see Eq (3), Fig. 9). In Fig. 9, (Δl_n) is the distance between dots on the center line and (ΔW_n) is the width of the segments.

(1) rope shape

(2) stick shape

(3) oval shape

Fig. 5 Examples of basic shape

Fig. 6 Expression of basic shape

$$\begin{aligned} \Delta l_{n-1} &\approx \Delta l'_{n-1} \\ \Delta l_n &\approx \Delta l'_n \\ \Delta l_{n+1} &\approx \Delta l'_{n+1} \end{aligned}$$

Fig. 7 Influence of organism movement to basic shape data

(ΔW_n) is the line from the center line to the outline that is vertical to the center line.

$$\Delta S_n = \Delta W_n \cdot \Delta l_n \quad (2)$$

$$\begin{aligned} S &= \sum \Delta S_n \\ &= \sum \Delta W_n \cdot \Delta l_n \end{aligned} \quad (3)$$

3. Expert System for Organism Recognition and Identification

3.1 Outline of the expert system

The whole system is operated by an expert system written in Prolog using Fortran subroutines for numerical calculations. The system structure consisting of three main parts is shown in Fig. 10.

(1) The first part is the image processing part. Images of organisms on the 'X-Y stage' are input from the CCD camera to the image processing computer and, after analysis, are sent to the host computer.

(2) The second part is the data analysis and calculation part, where the data sent to the host

Fig. 8 Calculation of segment length

Fig. 9 Calculation of segment area

Fig. 10 The system structure

computer are analyzed further. Segment length and segment area are calculated and the connection of segments is analyzed.

(3) The third part is the recognition and identification part. In this part, processed image data is matched with the data base to recognize and identify the organism.

Should matching fail, the system activates the "insufficient data supplement mode" or the "tracking mode" (described later).

3.2 Data base

The data base consists of frame units describing the organisms (see Fig. 11), structured as follows: name of organism, orderly relationship of segments, segment area, length of segment, segment structure, segment shape.

4. Details of Organism Recognition and Identification

4.1 Details of organism recognition and identification processes

This chapter describes the details of whole processes for recognition and identification from the obtained image to the output result using a flow chart shown in Fig. 12 and picture image examples shown in Fig. 13.

The numbers in Fig. 13 correspond to the following explanation numbers. These picture images are from the following tracking mode experiment.

4.1.1 Processes in the image processing part

(1.1) Obtaining a picture image

From the CCD camera on the microscope, seven picture images of organisms are read into the image processing computer every 1/6 second.

(1.2) Setting of window

An operator sets a window around the object organism with a graphics tablet to reduce the image size and thereby the processing time.

(1.3) Extraction of object organism

The image processor reduces the noise in the image and extracts the object organism.

Fig. 11 Structure of the data base

(1.4) Obtain centerlines

(1.5) Extraction of characteristic points

(1.6) Segmentation of object organism

Based on the centerlines and characteristic points, the expert system segments the organism image and then gives every segment a number.

(1.7) Extraction of outline of object organism image

4.1.2 Processes in the data analysis and calculation part

(2.1) Splitting of centerline into dots

To decrease the amount of data and therefore increase processing speed the centerlines are split into dots (one dot in every 3 pixels).

(2.2) Calculation of segment width

The width of every segment is computed as the distance of dots on the outline of the organism (see Fig. 8).

(2.3) Calculation of segment length and segment area See sections 2.3 and 2.4.

4.1.3 Processes in the recognition and identification part

(3.1) Comparison of the segment length

In the following explanations, we take an example object organism X shown in Fig. 14 for better understanding.

Fig. 12 Flow chart for recognition and identification

Fig. 13 Example picture images

Fig. 14 Example object organism

From the orderly relationship of segments,
 $S1=S2$
 $S1<S3 \rightarrow S3>S1=S2$
 $S2<S3$ (4)

the expert system creates the orderly relationship of segment length as follows:

$[>, =, _, _, _, _, _, _, _]$

(3.2) Selection of candidate organisms from data base The expert system selects a candidate organism (organism Y) (see Fig. 15).

In organism Y , the orderly relationship of segments is,

$S'1>S'2$

$S'1>S'3 \rightarrow S'>S'2=S'3$

(5)

$S'2=S'3$

then the orderly relationship of Y becomes:

$[>, =, _, _, _, _, _, _, _]$

which is the same relation with the object organism. In this way, the expert system selects Y as a candi-

date.

(3.3) Renumbering of segment number

The expert system rennumbers the segment numbers of organism X corresponding to Eq. (5).

$$\begin{aligned} S1 &\rightarrow S''3 \\ \text{(Every segment of } X) \quad S2 &\rightarrow S''2 \\ S3 &\rightarrow S''1 \end{aligned}$$

Numbering of segments in (1.6) is done from the left upper corner down to the bottom right corner of the image. But data-matching is done between segments of the same numbering; for example, if the object organism image is obtained upside down, much time is needed for data-matching. To reduce this time, we renumber the segments as shown above, which is equivalent to adjusting the direction from which the organism is viewed. In this way, segment numbers of the object organism and the organism in the data base become the same, and data-matching is very simple.

(3.4) Scale adjustment

We assume that the same species of organism has nearly the same proportion of segment length and segment area among individuals. Further, we assume that the basic segment shape is equal and that a proportional value exists between corresponding segments (see section 2.1).

In this way, the expert system can compute the proportional value between the longest segment of object (S of object X) and candidate organism (S of candidate Y). Regarding this proportional value, every segment is adjusted in size.

(3.5) Matching the segment length

The expert system compares the segment length of object X and candidate Y . Matching is successfully completed if the matching error is within 5% (see Fig. 16).

In the case shown in Fig. 16, the orderly relation of the segments of alpha is equal to that of X , but clearly X and alpha are different, because matching of segments 2 and 3 fails. In this case the expert system deletes alpha from the list of candidates.

(3.6) Matching the segment area

Fig. 15 Candidate organism

The expert system matches corresponding segment areas of X and Y . Again if the matching error stays within 5%, the expert system decides that matching is completed (see Fig. 17).

In the case of beta the orderly relation of the segments is the same, but since area matching for the segments 2 and 3 fails, beta is deleted from the list of candidates.

(3.7) Matching the basic shape of the segments

The expert system matches corresponding segment shapes of X and Y . Both organisms are considered to be the same if the matching error stays within 5%. Even though organism gamma in Fig. 18 matches for orderly length relation and area, it cannot be matched for shape, and therefore gamma is deleted from the list of candidates.

(3.8) Output of the result

If the matching of all three criteria is successful, expert system decides that X equals Y and the result is shown on the CRT display: "The organism is (name of the candidate organism)".

(3.9) In case of recognition and identification failure

If recognition and identification have failed, one of the following three procedures is followed depending on the type of error.

(1) Should no candidate of the data base match in step 3.2, the "insufficient data supplement mode" is activated.

(2) Should matching also fail in the data supple-

Fig. 16 Matching the segment length

Fig. 17 Matching the segment area

ment mode, the "tracking mode" is activated.

(3) Should these two additional modes both fail, the expert system cannot identify the object organism. The resulting message on the CRT is: "Failure of recognition and identification".

4.2 Supplementing insufficient data

In the process of image processing, the input picture images are strongly affected by the surrounding conditions, e.g. sometimes the image cannot be read completely.

The most influential condition is the position and location of lights. However, the expert system, by supplementing data is able to obtain the right result, even for variant light conditions.

In this case, data is supplemented to make the incomplete image sufficient for recognition and identification. Figure 19 shows an example of data supplementation.

In the following, we explain how the expert system supplements data to the insufficient image of organism (P) (see Fig. 19).

At first the system pays attention to the longest segment of the P and computes its length, area and basic shape. After this, a candidate organism Q , which has matching segment data for the longest segment is selected.

Then the expert system tries to match the other segments of P and Q . In the case that most segments of P match Q , the expert system decides P and Q to be the same and supplements the insufficient data of P with data from Q .

4.3 Tracking mode

To recognize and identify images of organisms which are crossed-over (see Fig. 20), the expert system tracks their movement.

For # 1 in Fig. 20, the expert system cannot distinguish whether the two organisms are 'aoc' and 'bod' or 'aod' and 'boc'. When the expert system obtains image # 2 after image # 1 and tracks the edge dots, the correct result can be obtained as:

$$\overline{ao} + \overline{od} = \overline{a'o'} + \overline{o'd'} \quad (8)$$

Fig. 18 Matching the basic shape of the segments

$$\overline{bo} + \overline{oc} = \overline{b'o'} + \overline{o'c'} \quad (9)$$

which means that

$$aod, boc \quad (10)$$

are the organism in image # 1.

However, if the organism does not move in this time period, the tracking mode does not work properly. The sampling time can be changed to suit organism movement speed.

5. Experimental Results

To confirm the effectiveness of the method proposed in this paper, we did experiments using the equipment shown in Fig. 21.

5.1 Recognition experiment

The expert system obtains the image of organisms and then recognizes their species. In this experiment, six species of object organisms were used (see Fig. 22): 1. Cyclops, 2. Diaptomus, 3. Nitzschia fonticola, 4. Cedogonium varians, 5. Paramecium caudatum, 6. Halla parthenopeia.

These six organisms can be found easily in ponds or rivers. Except for Halla parthenopeia (# 6), they are recognizable using a microscope only.

In Fig. 23, the actual Cyclops (# 1) image obtained from a CCD camera is shown as an example. The experimental result (see Table 1) shows that this method works effectively.

Fig. 19 Example of supplementing insufficient data

CROSS

Fig. 20 Tracking mode

5.2 Identification experiment

The expert system obtains images of the same organisms at different times and then recognizes which organism in the former image corresponds to which organism in the latter image. Experiments were

Fig. 21 Experiment equipment

Fig. 22 Cyclops

INPUT IMAGE

PROCESSED IMAGE

Fig. 23 Identification experiment

done with *Halla parthenopeia* (#6): object and sample images are shown in Fig. 24.

Some organisms were placed on shale to obtain the first image and then, after movement, the second image. The expert system re-cognizes which organism in the first image corresponds to which organism in the second image.

The experiment was done with 3.4 and 5 organisms and repeated 20 times. In the case of 3 organisms the identification success rate was 90%, but with increasing number of organisms the success rate decreased. However, the expert system can recognize and identify organisms even in cases where humans cannot.

5.3 Insufficient data supplement experiment

In this experiment, incomplete data was entered into the expert system to verify the effectiveness of the insufficient data supplement mode. We used *Cyclops* (#1) and *Diaptomus* (#2) as the organisms in the experiment.

Table 1 Results of the Recognition Experiment

	Success (times)	Percentage (%)
1	13	65
2	14	70
3	19	95
4	16	80
5	17	85
6	17	85

(20 Repetitions)

Fig. 24 Tracking mode experiment

After 20 runs, the success rate was 70% for Cyclops (#1) and 60% for Diaptomus (#2).

From the result, we consider that the success rate of the expert system does not in this case reach that of humans. This is because humans have macroconstructive judgment ability, which expert systems do not have.

5.4 Tracking mode experiment

In this experiment using *Halla parthenopeia* (#6), the effectiveness of the tracking mode was confirmed for the following cases (see Fig. 25):

- (1) two *Halla parthenopeias* in body contact,
- (2) two overlapping *Halla parthenopeias*.

After 20 trials, the successrate was 70%. The expert system tracking ability differs considerably from that of humans, who can obtain a nearly 100% successrate.

We believe that this is because humans obtain much more information than the expert system: for example, with use of lightintensity the picture image becomes 3-dimensional. In this tracking mode, the expert system obtains two-dimensional black and white images, so it is difficult to extract much information from the image.

This is the biggest difference between humans and the expert system. We consider this to be the reason for the 30% difference in successrates.

5.5 Summary

From the experimental results, the expert system, proposed in this paper, was shown to function better than human beings in the identification studies. Moreover, this system was shown to be quite proficient in the recognition experiment, making it applicable for automation.

However, there is much improvement needed in the insufficient data supplement mode and tracking mode to make the performance of the expert system comparable to that of a human.

6. Conclusions

In this paper, we proposed a new method for organism recognition and identification that is different from the conventional pattern matching method. The effectiveness of the method was confirmed by experiments.

We consider this method to be useful for organisms which have basic shapes, and it can be applied for automation purposes. However, the method cannot be applied to organisms which do not have a definite shape, e.g., the ameba. This remains a problem to be solved.

In this study, only two-dimensional black and white images were used; further study using 3-dimensional color images is being carried out.

References

- (1) Fukuda, T., Tanie, K., Mitsuoka, T., A New Method of Master- Slave Type of Teleoperation for a Micro-Manipulator System, Proc., IEEE Micro Robots and Teleoperators Workshop, (1987), 87TH0204-8/87/0000/0024.
- (2) Fukuda, T., Yaegashi, N., Three Dimensional Recognition of Coloured Objects by Active Controller and Expert System, Proc., IECON'87, (1987), p. 1187.
- (3) Fukuda, T., Hosokai, H., Tanie, K., Mitsuoka, T., Control of Micro-Manipulator by Using Image Processing, (in Japanese), Prepr. of 5th RSJ. Symp., (1987), p. 603.
- (4) Fukuda, T., A Study on Motion Control of Robotic Arm by Using Dynamic Picture Processing in Track of Moving Object, (in Japanese), Prepr. of SICE'86, (1986), p. 695.
- (5) Imahori, K., Yamagiwa, T., Yamada, T., Handbook for Creature Observation and Experiment (in Japanese), (1987), p. 281, Asakura Publ. Co. Ltd.