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A Study on Robot System to Hand Surgical Instrument to a Surgeon in a Surgery
(1st Report, Development of Surgical Instrument Recognition System)

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The nurse supporting robot system to prepare and hand surgical instruments to a surgeon is proposed to reduce work of nurses in a surgical operation. In this paper, the surgical instrument recognition system (SIRS) is developed to hand the surgical instruments to a surgeon by the robot. The characteristics of the instruments are area of the instruments, ratio of minimum center-contour distance to maximum one and its outline contour, are recognized by using the image processing. Kinds of the instruments are distinguished by these characteristics.

1. INTRODUCTION

There is not enough of the total number of the nurses in Japan(1). Moreover, experience and knowledge for many years are demanded for the nurses, and they have been obliged to support for a long time in surgical operations. The robot system plays an important role to reduce work of the nurses, so that we proposed the robot system to prepare and manage surgical instruments in the surgical operations. Therefore, development of the surgical instrument recognition system (SIRS) is indispensable for the nurse robot system.

In this paper, the direct-helping nurse supporting robot system (DNRS) is presented after the mention of the work of the nurses in a surgical room. We proposed the SIRS to recognize surgical instruments using the image processing. The instruments are classified into some groups by its structure and using purpose to improve the recognition speed. The instruments are distinguished by area of the instruments, ratio of minimum center-contour distance to maximum one and its outline contour.

2. DIRECT-HELPING NURSE ROBOT SYSTEM

2.1 Work of the direct-helping nurse

The team of the surgical operation is constituted by surgeons, anesthetists, direct-helping

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nurses, indirect-helping nurses, medical engineers, and so on[1,2]. The work of the direct-helping nurses is assistance of the operating and preparation of the instruments with an aseptic condition keeping. Main roles of the nurses in the operation are (a) handing the instruments to surgeons, (b) preparing and managing of the instruments and medical supplies, and (c) keeping the aseptic condition. The instruments are used over and over, so that the nurses wipe and disinfect thoroughly the instruments which blood adhered to. And, it is important for the nurses to predict instruments demanded with understanding circumstances of the operation.

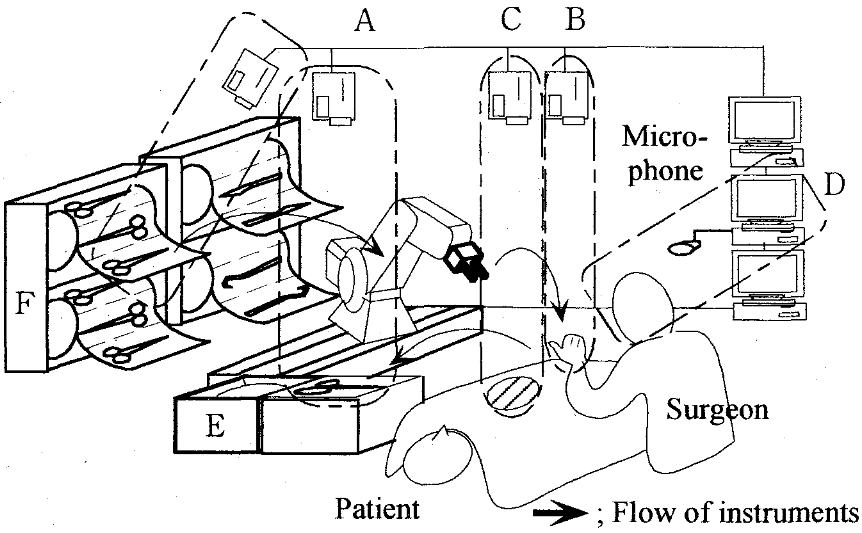


Fig 1. Direct-helping nurse supporting robot system (DNRS)

2.2 Configuration of Direct-helping Nurse Robot System

The work of the direct-helping nurses is various, so that we propose DNRS consisted of plural system such as figure 1. For example, we are developing the systems as follows; (a) the surgical instrument recognition system to distinguish the required instruments by the image processing, (b) the surgical instrument handing robot system to supply surgeon's hand with the instruments, (c) the surgical instrument predicting system to estimate a number and kind of the required instrument by grasping circumstances of the operation, (d) the voice indication recognition system to recognize instrument's name directed by a surgeon, (e) the surgical instrument disinfection system for reuse the instruments used, (f) the surgical instrument supply system to select the required instrument from many instruments regulated, and so on.

3. SURGICAL INSTRUMENT RECOGNITION SYSTEM

3.1 Configuration of SIRS

SIRS has two main functions, such as to recognize the instrument by the image processing and to improve the processing speed. SIRS is composed of a CCD camera, a microcomputer and a surgical cloth such as figure 2. The instruments are placed on tray as those are not overlapped.

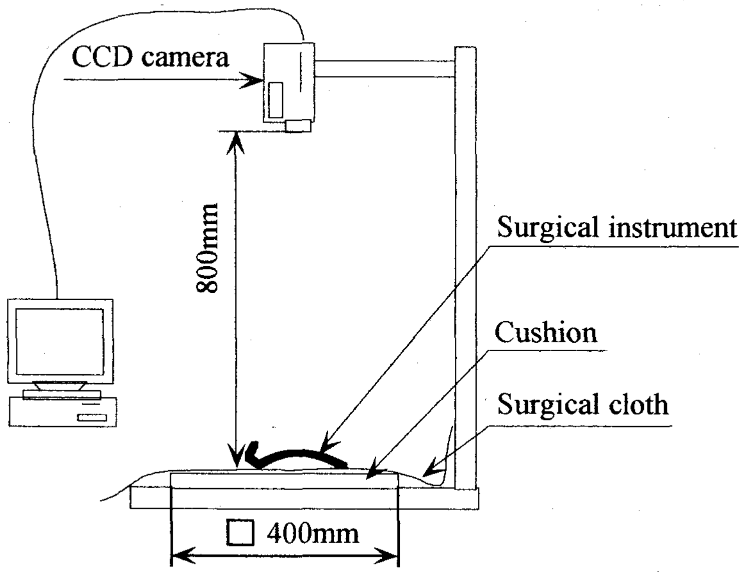


Fig 2. Configuration of SIRS

3.2 Classification of surgical instruments

Kinds and numbers of the instrument used are varied in surgical procedure(3). In this system, the instruments group into the structure type, then into the using purpose in each type.

The structure type of the instruments is classified into three types which are (A_1) moving type with saw-tooth hooks to keep holding condition such as a vascular clamp, (A_2) moving type without the hooks such as a scissors, and (A_3) unmoved type such as a surgical knife. The using purpose is classified into six groups which are (B_1) incision of tissue, (B_2) dissecting of tissue, (B_3) scraping of tissue, (B_4) cutting of tissue or threads, (B_5) holding of tissue or a needle, and (B_6) the others.

3.3 Recognition method

(1) Characteristics of instrument

The instruments are standardized to compare with the instruments limited by the structure type and the using purpose. Features of the instruments recognized by image processing are area of the instruments, contour length (Lq) and center-contour distance (Dq) such as figure 3. The contour length is outline length from start point of chasing to a contour point. The center-contour distance is distance between center gravity of the instrument and a contour point. Characteristics of the instruments to distinguish are the area, the ratio of minimum center-contour distance to maximum one and outline contour. The instrument shape is shown by curve of the coordinate system with the X-axis placing the outline length and the Y-axis placing the center-contour distance.

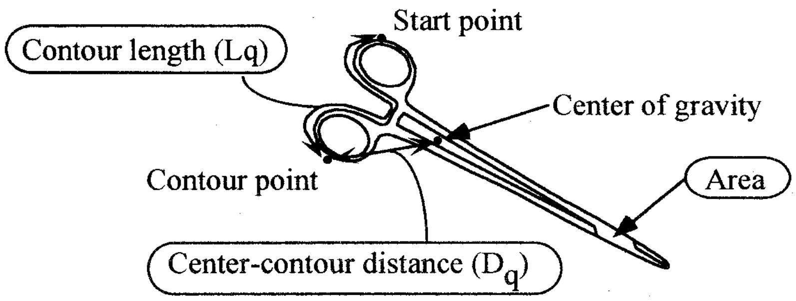


Fig 3. Features of instrument recognized by image processing

(2) Procedure of recognition by image processing

The input image of the instrument taken from the CCD camera is processed by the binalization and then the labeling(4). If several instruments were chosen by the area of the instruments, then the process is continued as follows; the contour coordinate and outline length are obtained by the contour chasing method(4). The center-contour distances of the instruments are calculated between the outline of the instruments and its center(5,6). If one instrument is recognized by the ratio of the center-contour distance, the instrument name is output. If there is not so, the instrument shapes are compared with the instruments database which is data of shape shown the relation between the center-contour distance and the outline length. The output characteristics calculated in SIRS are the instrument name, the center of gravity, the extreme point which is the maximum point of the center-contour distance to grasp the instrument by the robot.

(3) Standard for classification by area of instrument

The instruments are arranged in small order of its area. Let A_i be area of instrument, where i is instrument number. The standard STAj to classify instruments is made an intermediate value of two areas (A_i and A_{i-1}) having a difference more than 1.0 cm^2, expressed as

$$STA_j = \frac{A_i + A_{i-1}}{2} \qquad (A_i - A_{i-1} > 1.0, i = 0, 1, 2, \cdots), \qquad (1)$$

where j is standard number for area classification.

(4) Standard for classification by ratio of minimum D_q to maximum D_q

Let $DMIN_i$ and $DMAX_i$ be minimum center-contour distance and maximum one as instrument number i, respectively. The instruments are classified by ratio of the $DMIN_i$ to the $DMAX_i$ after those are classified by its area. The percentage R_i is calculated by the equation (2).

$$R_i = \frac{DMIN_i}{DMAX_i} \times 100 \qquad (i = 0, 1, 2, \cdots). \qquad (2)$$

The standard STR_k to classify the instruments is set up a mid-value having a difference more than 1% , expressed as

$$STR_k = \frac{R_i + R_{i-1}}{2} \qquad (R_i - R_{i-1} > 1,\ i = 0, 1, 2, \cdots), \qquad (3)$$

where k is standard number for ratio classification.

(5) Method of classification by outline contour of instrument

The instruments which are not able to be classified by the area and the ratio are compared with the registration data by the outline contour. The instrument of different size can not be compared, so that the outline length and the center-contour distance are transformed into integral numbers from 0 to 999 and value from 0 to 1, respectively.

(a) Standardizing of outline contour

Let L_q and RL_q be contour length and real number of contour length from 0 to 999 as contour number q. The RL_q is transformed from the L_q by using the maximum contour length L_n such as the equation (4), where n is last number of contour number.

$$RL_q = (L_q \,/\, L_n) \times 99 \qquad (q=1, 2, \cdots, n). \qquad (4)$$

Then the RL_q is transformed into the center-contour distance DI_b based on the integral contour length b from 0 to 999 by the equation (5). In this equation, the DI_b is calculated by the relation of the center-contour distance D_{q-1} in the RL_{q-1} and the D_q in the RL_q nearest the b. This RL_q is the minimum in real contour lengths more than the b.

$$DI_b = \begin{cases} D_q & (RL_q = b) \\ \dfrac{RL_q D_{q-1} - RL_{q-1} D_q}{RL_q - RL_{q-1}} + \dfrac{D_q - D_{q-1}}{RL_q - RL_{q-1}}\, b & (RL_q > b) \end{cases} \qquad (5)$$

$$(b = 0,1,2, \cdots, 999,\ q = 1, 2, \cdots, n).$$

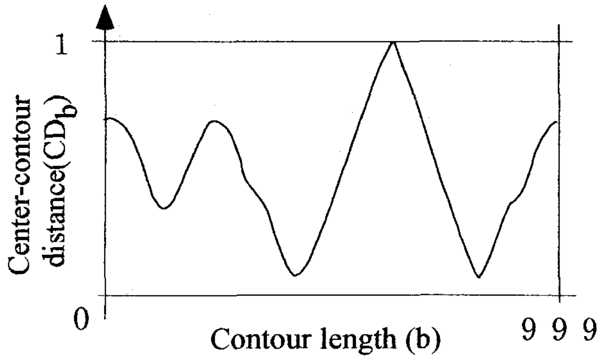


Fig 4. Example of outline contour (needle holder)

The center-contour distance CD_b is transformed into the value from 0 to 1 by using the maximum center-contour distance DIMAX such as the equation (6).

$$CD_b = DI_b \,/\, DIMAX \qquad (b = 0, 1, \cdots, 999). \qquad (6)$$

The example of the outline contour is shown in figure 4. This instrument is a needle holder Hegar-type. The maximum

portion of the curve is expressed a tip of the instrument .
(b) Matching of outline contour and determination
The input image is compared with the instruments database registered beforehand. Even if the same instrument, the contour is different by the start point of the contour chasing, so that the maximum point of the contour is coincided with that of the database before comparison[5]. Let CDS_c and CDR_c be the center-contour distance of the input image and that of the database, the total sum TS of absolute differences between the CDS_c and the CDR_c expressed as

$$TS = \sum_{c=0}^{999} (CDS_c - CDR_c)^2, \quad (7)$$

where c is the integral contour length from 0 to 999 after the maximum point of the contour was coincided. The input image data is determined to the instrument of the minimum TS.

4. APPLICATION

4.1 Classification of surgical instruments

Number of instruments used in a lung thoracotomy was fifty-six kinds[3], for example. These instruments were grouped into eight classes by the structure and the using purpose shown in table 1. It was assumed that the instruments were classed beforehand in these groups.

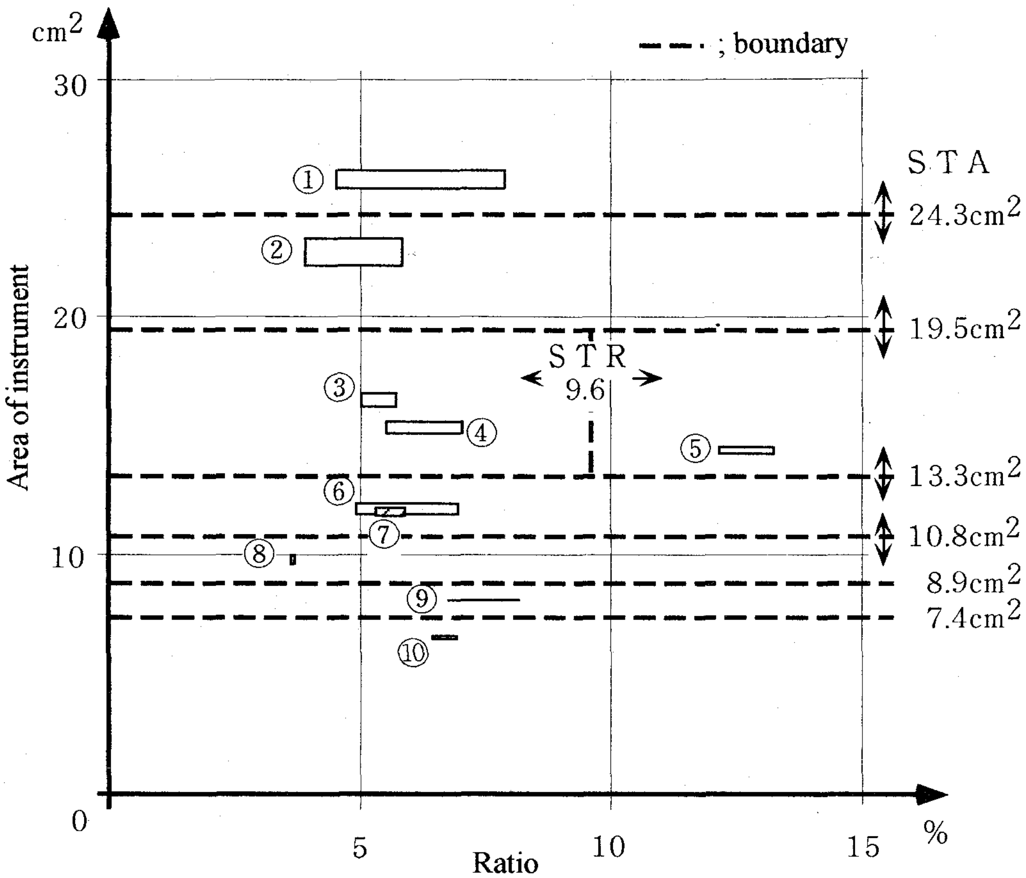
Table 1. Classification by structure and using purpose in a lung thoracotomy

Structure type	Using purpose	Number of instrument
moving type with hooks	holding	21
moving type without hooks	cutting	10
	holding	5
unmoved type	incision	2
	dissecting	5
	scraping	1
	holding	7
	others	5
total		56

4.2 Application of the SIRS

In this study, the recognition ability of SIRS was examined fourteen instruments. Ten instruments were the moving type with the hooks and the holding purpose. These instruments names were as follows; ① Satinsky vascular clamp (26cm), ② peripheral vascular clamp (24cm), ③ needle holder Hegar-type (20cm), ④ needle holder Hegar-type (18cm), ⑤ needle holder Mathieu-type (18cm), ⑥ vascular clamp (17cm), ⑦ curved Kelly's forceps (18cm), ⑧ Kocher's hemostatic forceps straight (15cm), ⑨ needle holder Hegar-type (13cm), ⑩ curved Kelly's forceps (18cm). The others were the moving type without the hooks and the cutting purpose. The ten instruments were classified into eight groups by six standards for the area and one standard for the ratio shown in figure 5. The others four instruments were classified into three groups by one standard for the area and one standard for the ratio shown in figure 6, and these names were as follows; ⑪ curved Metzenbaum scissors (20cm), ⑫ Mayo-type scissors (14cm), ⑬ curved Metzenbaum scissors (14cm), ⑭ straight Metzenbaum scissors (14cm). Three pairs of instruments not classified were the ③ and ④, the ⑥ and ⑦, and the ⑬ and ⑭.

The vascular clamp had seven hooks and was curved wholly. The curved Kelly's forceps had three hooks and was curved on tip. The needle holder Hegar-type had three hooks. Experiment conditions were as follows; shape of instrument with a hook was changed to stop by one step,



① : Satinsky vascular clamp (26cm),
② : peripheral vascular clamp (24cm),
③ : needle holder Hegar-type (20cm),
④ : needle holder Hegar-type (18cm),
⑤ : needle holder Mathieu-type (19cm),
⑥ : vascular clamp (17cm),
⑦ : curved Kelly's forceps (18cm),
⑧ : Kocher's hemostatic forceps straight (14cm),
⑨ : needle holder Hegar-type (13cm),
⑩ : curved Kelly's forceps (13cm)

Fig 5. Result of instrument classification in moving type with hooks and holding purpose (10 instruments)

curving instruments were considered a case turned over. In registration data, hook condition of the vascular clamp was determined to the fifth step, and those of the other were the first step.

SIRS distinguished the almost instruments except the first step and seventh step of hook condition with the vascular clamp, and recognized the center of gravity and the extreme point. The result figure of the needle holder Hegar-type (18cm) was shown in figure 7.

5. CONCLUSION

We proposed the direct-helping nurse robot system (DNRS) to prepare and hand the instruments. The surgical instrument recognition system (SIRS) was distinguished the instruments, and recognized the center of gravity and the extreme point of the instrument.

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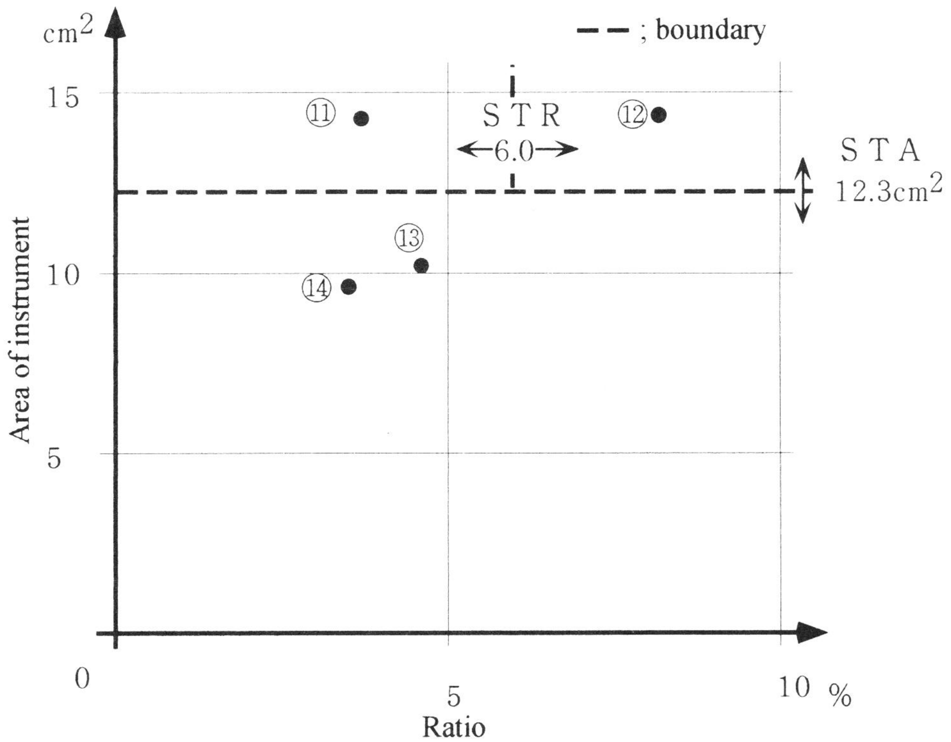

⑪ : curved Metzenbaum scissors (20cm), ⑫ : Mayo-type scissors (14cm), ⑬ : curved Metzenbaum scissors (14cm), ⑭ : straight Metzenbaum scissors (14cm)

Fig 6. Result of instrument classification in moving type without hooks and cutting purpose (4 instruments)

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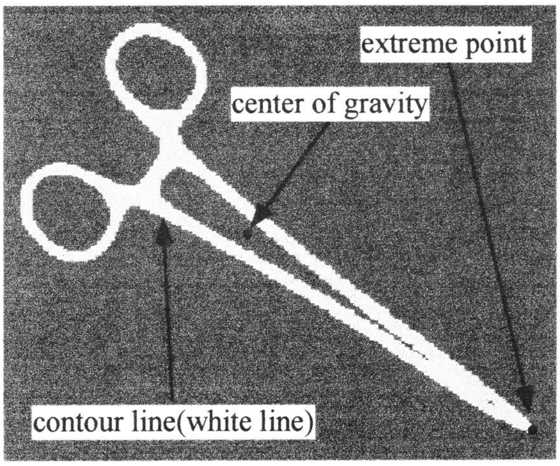

Fig 7. Result of image processing for the needle holder Hegar-type (18cm)