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Human Abdomen Recognition Using Camera and Force Sensor in Medical Robot System for Automatic Ultrasound Scan

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Abstract—**Physicians use ultrasound scans to obtain real-time images of internal organs, because such scans are safe and inexpensive. However, people in remote areas face difficulties to be scanned due to aging society and physician's shortage. Hence, it is important to develop an autonomous robotic system to perform remote ultrasound scans. Previously, we developed a robotic system for automatic ultrasound scan focusing on human's liver. In order to make it a completely autonomous system, we present in this paper a way to autonomously localize the epigastric region as the starting position for the automatic ultrasound scan. An image processing algorithm marks the umbilicus and mammary papillae on a digital photograph of the patient's abdomen. Then, we made estimation for the location of the epigastric region using the distances between these landmarks. A supporting algorithm distinguishes rib position from epigastrium using the relationship between force and displacement. We implemented these algorithms with the automatic scanning system into an apparatus: a Mitsubishi Electric's MELFA RV-1 six axis manipulator. Tests on 14 healthy male subjects showed the apparatus located the epigastric region with a success rate of 94%. The results suggest that image recognition was effective in localizing a human body part.**

I. Introduction

Images of internal organs and tissues are obtained through ultrasound scan devices because such devices send out high-frequency sound waves and record the reflected waves' pattern. Compared to other methods such as computed tomography (CT), and magnetic resonance imaging (MRI), ultrasound scan is inexpensive, safe from radiation, noninvasive, and produces real time images. However, aging society and physician's shortage at the remote areas caused difficulties for those people to be diagnosed by such scans. Thus, it is significant to develop a robot system that performs autonomous ultrasound scan to compensate the human factor in remote areas.

Recently, there are many researches that implement robot technology and image processing in ultrasound scan. For example, A. Vilchis's team [1] developed a robot used for remote controlled ultrasound scan. C. Delgorge et al. [2] developed a mobile ultrasound scanner using a light weight robot to perform tele-operated scan. Probe's motion mechanism and its application for tele-echography were researched by K. Masuda's team [3]. The construction for remote ultrasound diagnosis technology was published by N. Koizumi team [4]. W. H. Zhu and P. Abolmaesumi continued the study and developed a remote ultrasound diagnosis system. The study includes image, force and motion control and image-guided control for remote diagnosis system [5][6]. The hardware development for remote ultrasound diagnosis system was presented in F. Pierrot [7], Y. Sadamitsu [8] and R. Nakadate [9] [10] papers.

However, none of them stated about the development of an autonomous robot system that mimics physician's actions in ultrasound scanning process. We had previously developed a robot system for performing ultrasound scan by mimicking a physician's procedures. This robot also able to maintain the contact between scan probe and human body by keeping the amount of force applied. Liver was chosen as the target area since it is the biggest organ in the abdominal section and located near the surface of the body which makes it comparatively easier to be identified compared to other organs. However, in the previous scan system, probe's position for starting the autonomous scan must be set up manually by physician according to the human's position on the bed.

For this purpose in this paper, we present a system that autonomously recognizes the epigastric region as probe's initial position for starting the ultrasound scan. (Fig. 1) The system for epigastric region recognition includes image processing of human body to identify the position of umbilicus and mammary papillae. Using the information, we develop an equation to estimate the location for epigastric region. Besides, we also developed a system to distinct the epigastrium and ribs using the relationship of feedback force and displacement.

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Figure 1: Autonomous scanning robot system consist of a robot attached with a camera and a force sensor, an ultrasound diagnosis device and a control PC

II. SYSTEM DESIGN AND IMPLEMENTATION

A. System Requirement

Ultrasound scans on liver starts by placing the ultrasound probe on the epigastric region. There are no bones there, which helps physician to easily obtain an image of the liver.

Since the epigastrium itself cannot be defined by any visual features, it is presumed that doctors use other landmarks on human body to estimate its position. The landmarks used are umbilicus and mammary papillae. By using the distance relationship of both landmarks, the position of epigastric region was estimated. Ultrasound probe attached to manipulator moved to the estimated position. Next, using the force sensor, the robot confirmed whether the position has any bone or not. If there was bone, the probe moved towards the position with no bone that is estimated as epigastric region.

B. Image Processing

In order to identify the position of umbilicus and mammary papillae from human body surface, an ordinary web camera was used. The camera was set at a fixed point facing the bed which can obtain the whole abdominal image.

The algorithm for identifying the position of landmarks from image was designed as follows;

1. Separation of human's part from the background.
2. Distinction of human abdomen.
3. Recognition of navel and papilla's position.

Figure 2: Sample images used in pre-test to optimize the parameters in the image processing algorithm. The samples differ in term of bed's color, body sizes and clothes' color

The algorithm was pretested using six sample images shown in Fig. 2 that differ in background and clothes' colors, as well as body types.

First, for separation of human's part from the background, a still image of the bed was taken used as background image (Fig. 3a). Then image of human laying on the bed ready for ultrasound scan was taken (Fig. 3b). Background subtraction was done between the bed image and human image. After that using the hue information from Hue, Saturation and Value (HSV) color model of the subtraction image, parts containing only human skin color were extracted. It was done by deciding the threshold values for separating hue higher and lower than human skin hue range to separate skin from clothes and background. The decision was done through trial and error process along the pretest period. From the pretest results, we know that darker background color resulted in cleaner separation of skin part.

For distinction of human abdomen, a technique called labeling was used. Image containing skin parts was in bi-level mode which made the skin areas were in white and the background part was in black. All of the skin areas were measured and section containing the biggest area was extracted. This step was used to extract the human abdomen since head and arms were also extracted by the previous step (Fig. 3c). In addition, the labeling technique enabled noise cancelling.

Finally, for recognition of umbilicus and mammary papillae's position, the image was firstly converted from 'RGB' image to monochrome image. Next, using a technique published by Otsu [11], bi-level image was automatically produced (Fig 3d). The bi-level image shows the navel and papilla in black section and other abdomen area in white.

Besides, a step of image expansion and contraction was applied to the bi-level image. It is a step of increasing a target color level by comparing the target area and its surround. This was done to clear any noises from a group of hair or moles that is 8mm in diameters.

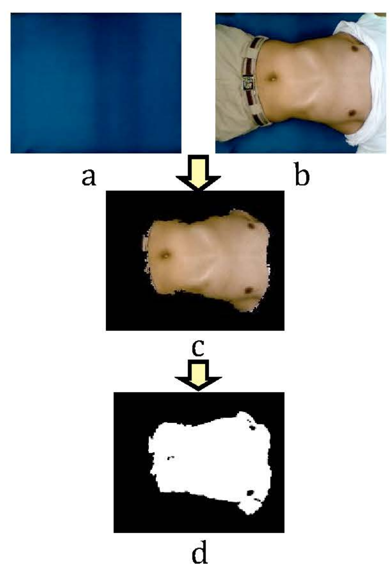


Figure 3: Steps for Image Processing. a) bed image or called background image, b) patient lying on the bed image, c) extracted abdomen image, d) bi-level image of extracted abdomen with umbilicus and mammary papillae

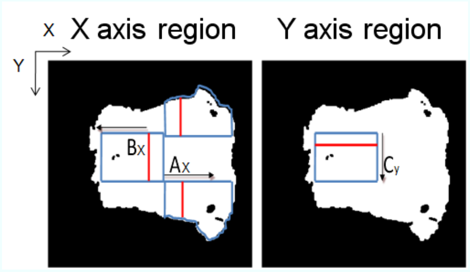


Figure 4: Search Area for Umbilicus and Mammary Papillae

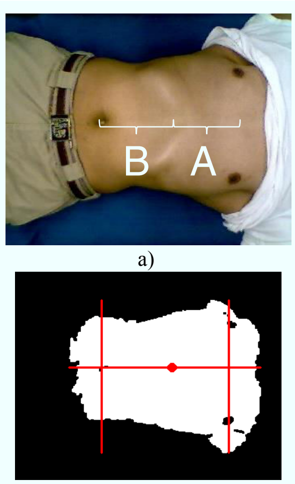
In order to localize the position of the umbilicus and mammary papillae, firstly, the horizontal axis was defined as x-axis and the vertical axis as y-axis in the image. From the human structure point of view, head to toe is x-axis and right to left is y-axis. Then, the brightness value: I(x,y) white = 255 and black = 0 of each pixel was averaged for every line along the x-axis. Next, a center line was drawn on the abdominal area to divide it into two sections horizontally (Fig 4). For umbilicus recognition, starting from this line heading downward (x value declining), the smallest sum of brightness value's position was determined. The search for mammary papillae used the same method but the searching area was between this line and upward (x value increasing).

$$A_x = \frac{\sum_{y=a}^{b} I(x,y) + \sum_{y=c}^{d} I(x,y)}{(b-a)+(d-c)} \tag{1}$$

$$B_x = \frac{\sum_{y}^{c} I(x,y)}{(c-b)} \tag{2}$$

$$b-a = d-c = \frac{d-a}{3} \tag{3}$$

By using the information gained so far, which are the position and the distance of umbilicus and mammary papillae, the position of epigastric region was estimated. The relationship between the position of umbilicus and mammary papillae was previously researched on eight healthy male subjects. The subject number deemed to be suitable because



a)

b)

Figure 5: a) shows the relationship between A and B. b) shows the result of the estimated position where red dot refers to the center point of epigastric region

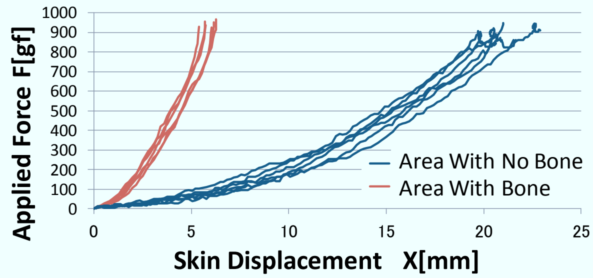


Figure 6: Result of Reaction Force with its Displacement

the result was used as estimation. As a result, the relationship for distance between epigastrium and mammary papillae A, and distance between epigastrium and umbilicus B, could be shown in (4) (Fig. 5a).

$$\frac{A}{B} = 0.83 \pm 0.06 \tag{4}$$

Using this relationship, position of epigastric region was estimated as shown in Fig. 5b. By converting the coordinate system of the image to the manipulator base, ultrasound probe guided to the epigastric region.

C. Force Feedback Response

Even though ultrasound probe is guided to the estimated position, there was no guarantee that the position is the epigastric region. Thus an algorithm was developed to double check that the position is correct where no bone at the position. A six axes force sensor fixed to the end effector of the manipulator to be used in the algorithm.

In order to determine whether force sensor able to differentiate the surface that contains bones under it or not, a preliminary experiment was conducted on 11 healthy male subjects. Probe was applied with force between 100gf to 1000gf towards the abdominal areas that contain bones under the skin and area with none and applied force and displacement of the skin was recorded. A sample of the recorded data is shown in Fig. 6

As results, it was known that when the applied force was above 200gf, a distinctive different between both areas' displacement was seen. However, it was also known from the experiment that human felt pain when the force exerted was above 1000gf. In addition, when deciding the threshold value

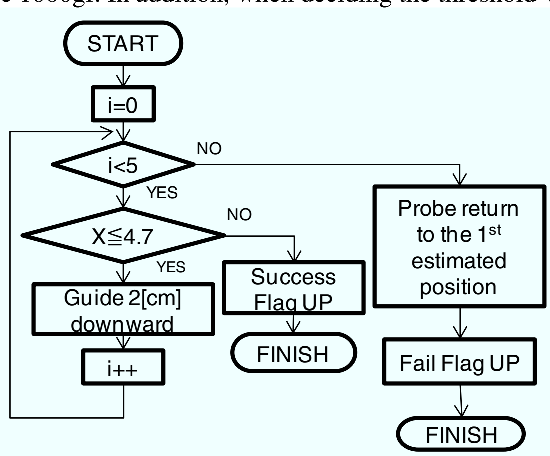


Figure 7: Flow Chart for Probe Guidance towards No Bone Region

for differentiating the area with bone or none, the range for the force must be higher than 500gf. Thus, it was decided that the force range used to differentiate the area is between 200gf to 500gf where displacement below threshold value was set up as area with bone.

When the algorithm resulted in the area with bone, an escape algorithm was designed to guide the probe towards the area with no bone. In most of the case, probe would be guided towards the sternum. Therefore, the probe was guided toward the umbilicus position. The flow chart of the algorithm is shown in Fig. 8.

III. CLINICAL EXPERIMENT AND RESULTS

A clinical experiment was conducted to test the validity of the designed and implemented algorithm on 14 healthy male subjects aged 22.5±2, with BMI 24±6. The validity test was divided into two parts, each for one algorithm.

1. Success Rate of Camera Image Processing

Subject lay on the bed and with a push of a button the system started. The image of the subject was taken and processed to estimate the epigastric region. For each subject, the test was done 10 times.

As a result, the success rate was 130/140 (94%). The algorithm failed for one subject. The success case and fail case for the image processing are shown in Fig. 8.

2. Success Rate of Force Feedback Algorithm

The subjects that were successful with the Part 1, continued to lie on the bed and the probe was guided towards the estimated position. When the probe reached the position, force feedback control was activated to maintain the contact between probe and human body. After that, bone existence was tested and position with no bone under the skin was searched. As result, the success rate was 130/130(100%).

3. Success Rate of Whole System

In whole, the success rate of the whole algorithm was 94%.

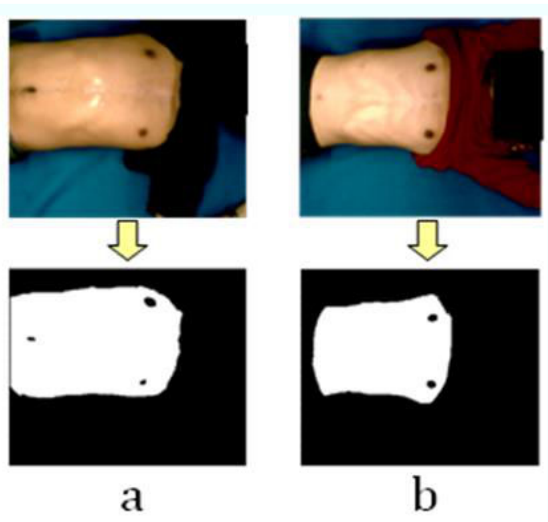


Figure 8: Sample Images of the Subjects. a) show the success sample where both umbilicus and mammary papillae were extracted from the original image. b) shows the fail sample where only mammary papillae was extracted

IV. DISCUSSION AND CONCLUSION

Based on the results of Part 1, it can be concluded that the recognition algorithm for the epigastric region was successfully implemented and tested on male subjects. However, the failed sample was caused by failure in bi-level image processing. The brightness level for umbilicus and its surround could not be separated since there was no significance difference between the levels. Force feedback algorithm works as a safety net to recover the failure case of the image processing algorithm.

Overall, from the experimental result, it can be concluded that the algorithm designed to identify the starting position for liver ultrasound scans has shown its validity to be used in the autonomous robot system. For future works, the algorithm will be tested on female and subjects with a wide variance of age and skin colors.

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