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Development of a Vision Integration Framework for Laparoscopic Surgical Robot

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Abstract— **In order to realize intelligent laparoscopic surgical robot, a vision integrated system constitutes one of the fundamental components. The authors have constructed a vision framework in the current version of NCC (National Cancer Center) laparoscopic surgical robot controlled on a real-time OS (RTLinux-Pro, FSMLabs Inc., U.S.A.). Adding vision framework, we have been applying and testing image processing algorithms- edge detection of object for positioning surgical tool, Watersheds for recognizing object. This paper documents the implementation of the framework and preliminary results of the image segmentation using Watersheds algorithm. Finally the real-time processing capability of our vision system is discussed.**

I. Introduction

THE laparoscopic surgery robot of the National Cancer Center has implemented reliable function and motion in basic tasks for robotic surgery.

In addition to this, continuous research on force-feedback control and vision integration toward intelligent visual-servo control of the robot, is underway.

This study is to implement a machine intelligence algorithm with which target object in laparoscope image can be identified and tracked adaptively in accordance with varying position and shape in real-time.

II. Methods

A. System Description

The NCC laparoscopic surgery robot system has a conventional master/slave robot configuration and the control system consists of axis controllers, a host controller, power units and a laparoscopy vision system. Three axis controllers are equipped in each robot arm for the control of 5 axis motors. Each master and slave controller set pair has a dedicated CAN (Controller Area Network) channel for control and monitoring signal communication. A commercialized laparoscopy vision system is incorporated in the system with the image digitized in the host controller for display and further processing. The robot control was implemented as a simple axis-to-axis direct link method utilizing the unique symmetry in the kinematic design of the master/slave manipulator structure.

B. Software configuration

The laparoscope images were captured by a frame-grabber (RTV-24, AdLink Technologies Inc, U.S.A.) and Video4linux application programming interface [1].

The graphical user interface for viewing the captured and processed images was based on Qt/X11 (Trolltech Inc, Norway), and the rendering was implemented in OpenGL. Two threads were run in parallel. One thread handled the capture of the images from the laparoscope camera and the other the rendering process and the user interface. Fig. 1. shows brief structure of the software.

The captured images were in RGB color data of 640 x 480 resolution and refreshed at 33 Hz.

Fig. 2. Shows first version of vision integrated user interface software of NCC laparoscopic surgical robot.

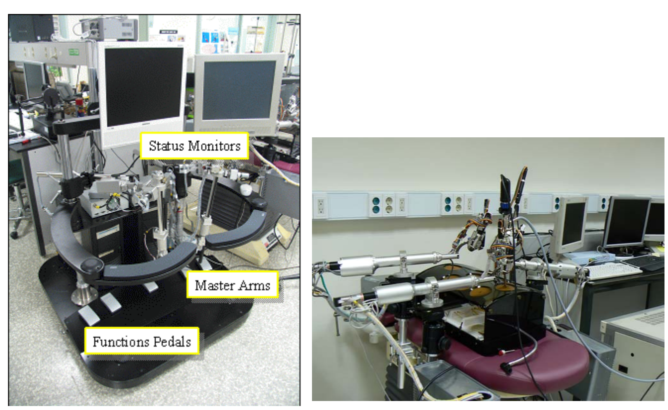

Fig. 1. The NCC laparoscopic surgery robot system: (left) master console, (right) slave arms

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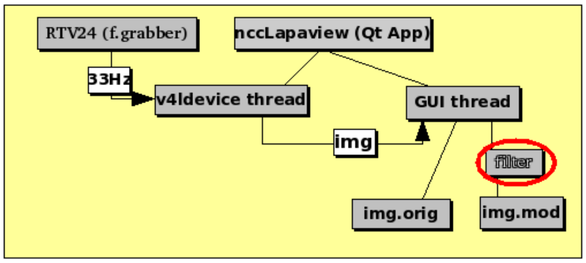

(a)

(b)

Fig. 2. (a) Software configuration (b) screenshot of the developed software

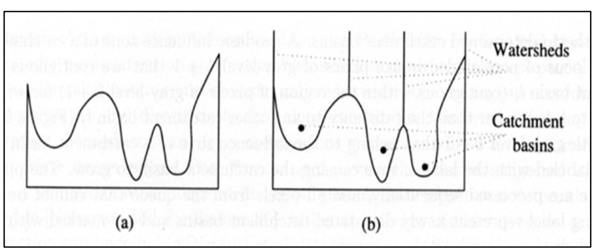

Fig. 3. (a) Gray scale of digital image (b) catchment basin & watershed

C. Objects detection

In order to accomplish useful functions, the first thing to be done is detecting objects from sequential laparoscopic images accurately. Therefore segmentation algorithms should satisfy accuracy and speed enough to refresh images in real-time.

We considered edge-based algorithms first. Edge-based segment algorithms aim at providing the borders of image segments. When the boundaries are determined properly, they are formed by closed curves and the interior of such a curve then sought of a segment. Most techniques based on edge use a differentiation filter in order to approximate the first order image gradient or the image Laplacian. Then, candidate edges are extracted by thresholding the gradient or Laplacian magnitude [3].

However, the raw edge representation of an image obtained by edge-based segmentation is usually far from ideal edge because the obtained edges are usually disconnected, sometimes multiple or excessively thick, and many of the detected edges don't correspond to segment borders, but rather to spurious rims due to noise [5]. Our sequential laparoscopic images, which usually have unclear and/or noisy borders might not be well segmented by edge-based algorithms due to these practical deficiencies.

The algorithm applied to detect our target object in the image was Watersheds algorithm [2]. That is a kind of region-based segmentation. In the algorithm, each pixel in the image is regarded as a point in a virtual terrain with height proportional to the gray scale value of the pixel, and the edges of objects are constructed from the perimeter of the part of each object that is above a virtual water level.

Fig. 3. shows the conceptual definition of the watershed algorithm.

There are two typical approaches to achieve watersheds on digital space. One is immersion-based watershed algorithm based on an immersion process analogy, in which the flooding of the water in the picture is efficiently simulated using a queue of pixels.[2]

The other is toboggan("steepest slope line" in [2])-based algorithm. This approach is called "tobogganing" because of its similarity to riding a sled downhill to the bottom of a basin. Pixels that slide into the same local minimum could be efficiently grouped together by assigning them a unique label and those pixels form a catchment basin and a boundary of them is watershed.

Conceptually, the immersion approach can be viewed as an approach that starts from low altitude to high altitude, and the toboggan approach an approach that starts from high altitude to low altitude [4].

Our approach is immersion-based watershed segmentation because the accuracy-the most important element of the surgical robot-of this algorithm is superior to that of the existing implementations. The fact that its adaptation to any kind of digital grid and its generalization to n-dimensional images are straightforward could be regarded as a key segmentation algorithm to our future 3D laparoscopic facilities [3].

Our procedure of image processing represented in Fig. 4. After taking raw image data from capture board, we made them in grayscale for future manipulation and reduced noise by applying a simple noise filter-average of neighborhood-performed respectively. Then, computing watersheds starts from gradient values of output of pre-steps.

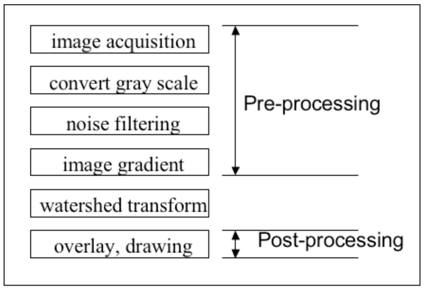

Fig. 4. Procedure of overall image processing

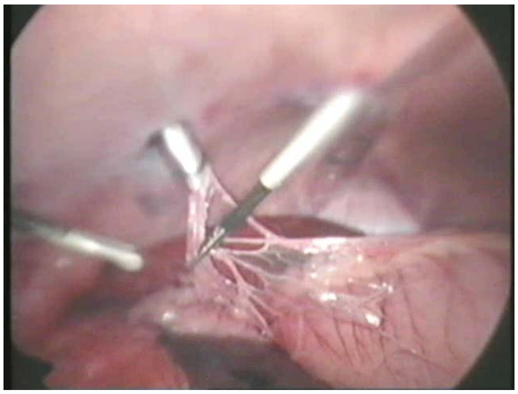
Fig. 5. Captured image of laparoscopic robot surgery

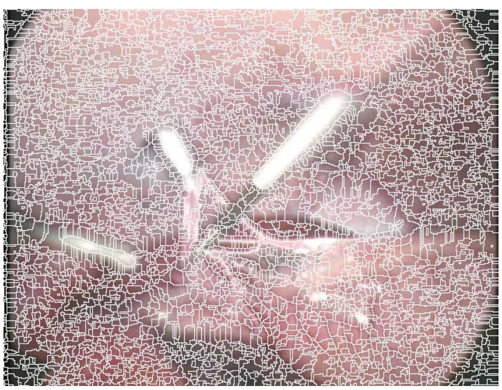
Fig. 6. Result of the watershed transform of 640x480 image


Fig. 7. Result of the watershed transform of 256x192 image

Table 1. Elapsed time of operation on laparoscopic image (AMD 3500+, 2GB Memory)

Size	Pre-processing	Watershed
640x480	26 ms	88 ms
521x391	17 ms	58 ms
256x192	4 ms	12 ms

Figs. 5-7 shows preliminary results of the image segmentation using the watersheds algorithm in a laparoscopic image from an animal experiment evaluating our laparoscopic surgery robot.

III. Results and Discussion

The preliminary result of the image segmentation using the watersheds algorithm did not show remarkable result in separation of objects in the laparoscope image. (Table 1)

This shows a lot of local minimum and the necessity of post processing such as region merging that unites a group of segmented regions into meaningful object. Considering the requirement of region-merging processing time, the appropriate image size for the real-time operation is 256x192.

IV. Conclusion

The objective of the study is to construct proper hardware and software to our surgical robot and to find appropriate algorithm with which target objects in the laparoscopic image can be segmented in real-time. To achieve object detection, we chose the immersion-based watershed algorithm but current status of its performance isn't satisfied with real-time operation. The modified toboggan-based algorithm proposed by Yung [4] might be good complement because they showed performance of their approach is faster than immersion-based watershed algorithm proposed by Vincent [2].

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