Development of a Monitoring System for Tele-Surgery

Gil Whoan Chu, Jae Hean Kim, Do Hyoun Kim, and Myung Jin Chung

Dept. of Electrical Engineering, KAIST, Taejon, 305-701 KOREA
chgh@cheonji.kaist.ac.kr mjc@ee.kaist.ac.kr

ABSTRACT
To obtain a natural view of the operation room and autonomous image selection and transformation during tele-surgical operation, we propose a tele-monitoring system which is composed of two types of camera systems. One is an active camera system controlled by surgeon’s gesture and gaze direction to obtain natural view image. Another is a fixed camera system that is composed of multiple cameras and autonomously selects and transfers optimal images by comparing the image usability. From the cooperative operation of these two camera systems, surgeon is able to monitor remotely located patient and the operating room easily and efficiently.

1. INTRODUCTION
In tele-surgery operation, it is very important to transfer visual information of a patient and an operating room to a surgeon and assistants. During the operation, a surgeon requires various views and continuous observations of a patient, surgical tools, and manipulators. It is difficult to obtain continuous observation of the patient because surgical tools and slave manipulators may disturb camera view during the operation. Therefore, the position and orientation of cameras located in the operating room should be modified according to the surgeon’s requests. For a natural view selection and continuous observation of a patient and an operating room during the surgical operation, we develop a tele-monitoring system that is composed of two types of camera systems. One is an active camera system that controls the position and orientation of a camera according to the intention of the surgeon based on the inference method. The position and orientation of a camera to obtain natural view is inferred from a surgeon’s gesture. The other is a fixed camera system that guarantees continuous observation of the patient during the operation. In this case, multiple cameras are arranged within an operating room. Among the images from multiple cameras, an optimal image is automatically selected and transferred to the surgeon by comparing their usability. From the cooperative observation of the active camera system and fixed camera system, the surgeon is able to obtain a natural view and continuous visual information of a patient and an operating room conveniently and efficiently.

2. FIXED CAMERA SYSTEM
A monitoring system with fixed camera has no ability to modify the position and orientation of a camera according to the change of surrounding objects or the environment. To overcome this disadvantage, multiple cameras are attached within the operation room and these cameras are monitoring the environment and a patient in different directions. However, every image obtained from multiple cameras is not always helpful to the operator. Some times, visual information of a patient could not be obtained due to the hindrance of surrounding objects. Moreover, when there is a limitation of communication capacity between local operation room and a surgeon in tele-surgery system, it is hard to transfer all of images obtained from multiple cameras to the surgeon. Therefore, it needs to calculate the usefulness of images, usability, and transfer the most useful image to the surgeon.

To define and calculate the usefulness of images, and to transfer the most useful one among multiple images to the operator, we consider two constraints: visibility and boundary distance. To obtain visual information of a patient, a camera should be able to ‘see’ the patient without
Fig. 1: Fixed camera system

Fig. 2: Experimental Environments

hindrance of any other objects. If a camera is located within visibility region, it guarantees that whole part of the patient could be observed. The boundary distance constraint means that the camera should be located as far away from boundaries of the visibility region as possible. Because, the closer is the distance between camera and boundaries of the visibility region, the higher is the probability for camera to be out of the visibility region and violates the visibility constraint. And, if we locate a camera more perpendicular to the face of the target object, we can easily obtain visual information of the target object. From these considerations, we define the usability of images as follows.

\[
M(\theta, \phi) = KV(\theta, \phi) \cdot f_1(\theta, \phi) \cdot f_2(\theta)
\]

where

\[
f_1(\theta, \phi) = W_1 \sum_{\theta_b, \phi_b \in S_c} \sqrt{|\theta - \theta_b|^2 + |\phi - \phi_b|^2}
\]

\[
f_2(\theta) = W_2 \cos(\theta)
\]

\[K, W_1, W_2 : \text{weights}\]

Here, \(V(\theta, \phi)\), \(f_1(\theta, \phi)\), and \(f_2(\theta)\) represents visibility constraint, boundary distance constraint, and the perpendicularity of a camera to the face of a target object, respectively. \(V(\theta, \phi)\) is 1 when \((\theta, \phi)\) is within the visibility region, while \(V(\theta, \phi)\) is 0 when \((\theta, \phi)\) is not within the visibility region. The higher the value of \(M(\theta, \phi)\) is, the more information of the target object could be included in the image.

In order to verify the proposed fixed camera monitoring system, we have carried out some simulations and experiments. The workspace is composed of a manipulator (RV-M2, Mitsubishi) and some equipments for peg-in-hole task. The locations of four cameras are at \((\theta = 0^\circ, \phi = 0^\circ)\), \((\theta = 45^\circ, \phi = 0^\circ)\), \((\theta = 45^\circ, \phi = -45^\circ)\), and \((\theta = 45^\circ, \phi = -90^\circ)\) respectively. In this case, the quadrangle located at the center of workspace is a target object. Fig. 3 shows the change of usability value of these four cameras during the motion of manipulator. And, a sequence of selected images according to the usability values during the operation is shown in Fig. 4.
3. Active camera system

During surgical operation, a surgeon needs to see the patient in different directions if he/she wants. To obtain an adequate image of the patient, it needs to modify the position and orientation of a camera. In active camera system, we control the position and orientation of camera according to the surgeon’s motion and gaze direction. For example, if the surgeon moves his/her head forward to the monitor, camera moves to the target object and gets a magnified image of it. If the surgeon moves his/her head to a side direction, camera also moves to a side direction and gets side view of the target object. To control camera configuration from the motion of the surgeon reduces the burden and allows the surgeon to concentrate on the surgical operation.

![Diagram of Active Camera System](image)

To find the motion and gaze direction of a surgeon, magnetic sensor (The Flock of Birds, Ascension Technology) is attached to the head of a surgeon. From this sensor, we can obtain the position and orientation of surgeon’s head with 6-dof. The resolution of position and orientation of this sensor is 0.02 inch and 0.1 degree, respectively. Fig. 6-(a) is a magnetic sensor system to find head position, and Fig. 6-(b) is a result of sensor output when the user looks at each intersection of lines. As table 1, the position error is less than 4mm. Through RS-232C, motion information of the surgeon’s head is transferred to the controller of manipulator at which camera is attached. Therefore, the position and orientation of a camera is modified according to the motion of surgeon’s head. Fig. 7 shows the active camera system controlled by the head motion of a user.

![Table 1: Position errors and variances of magnetic sensor](image)

<table>
<thead>
<tr>
<th></th>
<th>min error</th>
<th>max error</th>
<th>mean</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>0.01</td>
<td>0.69</td>
<td>2.52</td>
<td>1.93</td>
</tr>
<tr>
<td>v</td>
<td>0.02</td>
<td>0.80</td>
<td>3.72</td>
<td>2.70</td>
</tr>
</tbody>
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(a) Detection of head position  (b) Position data
Fig. 6: Detection of head position with magnetic sensor

(a) forward  (b) backward
(c) right  (d) left
(e) up  (f) down
(g) roll  (h) pitch
Fig. 7: Control of active camera system from the motion of user
4. CONCLUSIONS

For natural view selection and cooperative observation of a patient and the environment during tele-surgical operation, we proposed a tele-monitoring system which consists of two types of camera structures. To acquire a natural view of a patient or the environment, active camera system is controlled by the gesture of a surgeon. For continuous acquirement of visual information and automatic selection of optimal images from multiple cameras, the usability based on visibility constraint and boundary distance constraint is proposed. Cooperative operation of these two camera systems allows a surgeon to monitor a patient and the environment of remotely located operational room easily and efficiently during surgical operation.

REFERENCES


