MARKER-BASED MAPPING BETWEEN MEDICAL IMAGE AND ROBOT SPACE IN ROBOT-ASSISTED SURGERY

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Abstract  This paper focuses on the problems of matching a virtual and a real environments by means of hardware and software tools. The real space is represented by a patient’s bone where a set of cuts by means of robot system is to be made. The virtual space is a 3D model of the bone reconstructed from a set of CT slices. Robot system is then not only to machine bones but also to perform the fundamental step of registration between the two spaces. An external force sensor is used to adjust robot stiffness in order to perform the tactile searching necessary for the registration. A simple but reliable software algorithm is used to control the robot for matching between medical image and robot space in robot-assisted surgery. The results show the system proposed is precise enough for application, and tests been made also clarify the way to improve it.

Key words  Mapping; Virtual image space; Real robot space; Robot-assisted surgery

I. Introduction

Since 1995 the research group at Robotics Research Institute of Beijing University of Aero. & Astro. have started a project of Computer and Robot-Assisted Surgery supported by the fund of Education Ministry, aimed at assisting the surgeon during an intervention of surgery[1]. The final goal of the robot is to locate the symptom point of disease within patient’s body and to perform a set of very accurate operations on brain, spine or orthopaedics, when those operations are preplanned not on radiograms as surgeons usually do, but on a model of the patient reconstructed on a graphic workstation.

How to obtain a model of the patient is still an open question but well assessed techniques make use of a set of CT slices, taken from the patient before the intervention. The model is reconstructed by piling up slices, making the needed alignment, and interpolating between slices where needed.

we need an instrument able to link the virtual space, represented by the model and the CT reference system, and real space (Fig.1), where the robot acts. Of course, to compute the final transformation between the two spaces, we need some additional information[2]. In this way markers act as a reference system fixed on the bone and can be reached both in the virtual environment (during planning) and in the real one (during surgery). In this paper, we present in details the mapping approach based on marker technique and experiments.
II. Mapping Approach

1. Transformation

The matching between the cutting frame in virtual image space \(\{C\}_V\) and the cutting frame in real robot space \(\{C\}_R\) is represented by the following equation:

\[
{^C}_P_R = T \cdot {^C}_P_V
\]  

(1)

where \(T\) is the unknown transformation matrix. Eq.(1) represents a mapping one point \(C_P_V\) in the cutting frame of virtual image space to one point \(C_P_R\) in the cutting place frame of robot space.

To make possible to solve the above equation we can assume there is a intermediate frame in both the virtual and the real environments. We refer to them as marker frames \(\{M\}_V\) and \(\{M\}_R\). If the following equation:

\[
\{M\}_V = \{M\}_R
\]

is satisfied, the matching transformation can be realized in Eq.(1). In virtual space, we have

\[
W_P_V = W_M^T V \cdot M_P_V
\]  

(2)

\[
W_P_V = W_C^T V \cdot C_P_V
\]  

(3)

where \(W_M^T V\) is a transformation with respect to the intermediate marker frame, \(W_C^T V\) is given by the graphic workstation as a result of the planning phase. In real space, we have

\[
W_P_R = W_M^T R \cdot M_P_R
\]  

(4)

\[
W_P_R = W_C^T R \cdot C_P_R
\]  

(5)

where \(W_M^T R\) is a transformation with respect to the intermediate marker reference in the real space and \(W_C^T R\) is made by the VAL instruction frame. Hence, from Eq.(5) and Eq.(4), we can get

\[
{^C}_P_R = (W_C^T R)^{-1} \cdot W_P_R = (W_C^T R)^{-1} \cdot W_M^T R \cdot M_P_R
\]

Because of coincidence of the marker reference frames in virtual and real space, we can rewrite:

\[
{^C}_P_R = (W_C^T R)^{-1} \cdot W_M^T R \cdot (W_M^T V)^{-1} \cdot W_C^T V \cdot C_P_V
\]  

(6)