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Using the KUKA LBR iiwa Robot as Haptic Device for Virtual Reality Training of Hip Replacement Surgery

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***Abstract*—We propose to use an industrial redundant manipulator (KUKA LBR iiwa robot) as a haptic device to provide high force feedback for an orthopedic surgeon while performing the reaming of the acetabula in a virtual environment. Real experiments have been performed to validate the virtual reality training framework. The results show that the system resulted to be intuitive and reliable from the users experience.**

***Keywords*-medical robotics; force feedback; virtual reality; training.**

I. INTRODUCTION

Surgical manipulative skills are traditionally trained by observing an expert surgeon on operation, by practicing on livestock and human cadavers. Since almost 25 years virtual reality technologies have been proposed to offer an alternative approach to surgical training. However, all haptic virtual reality-training systems have been concentrated on minimally invasive surgical procedures (e.g. laparoscopic surgery) where the involved feedback forces are of small scale (less than 40N) [1]. Virtual reality systems require haptic devices to enhance the user experience through realistic force feedback. In this context, commercial haptic devices in surgical training might be used: Sigma.7 and Omega.7 from Force Dimensions[1], PHANTOM Desktop and PHANTOM Omni from 3D Systems[2]. Their role in virtual reality training systems for medical applications is discussed in [2]. In orthopaedic surgery, virtual training applications are limited to arthroscopy. A review of virtual reality based training simulators for orthopaedic surgery is illustrated in [3]. One of the most recent simulator in this area is HIPS [4], a virtual reality systems for training the reaming of an acetabula during hip joint replacement surgery. During the *acetabular reaming* task the hip socket is enlarged and cleared of cartilage tissue in order to facilitate the fitting of a prosthetic hip socket. During reaming interaction forces up to 180 N between the instrument and the surgeon occur. Hence, in order to be effective, the training system should provide force feedback of this magnitude. The problem is that the majority of indicated commercial haptic devices are limited to a maximum force of 20 N [2]. Therefore, this task would require a custom solution. In this paper we propose to use an industrial lightweight robot (KUKA LBR iiwa[3]) as haptic device for hip joint replacement surgery training. The haptic feedback has been implemented through the Jacobian matrix. The physical robot and the virtual simulator are tested by two human operators at the Virtual Reality Center for Production Engineering Lab of the TU Chemnitz. A picture of the proposed framework is shown in Fig. 1.

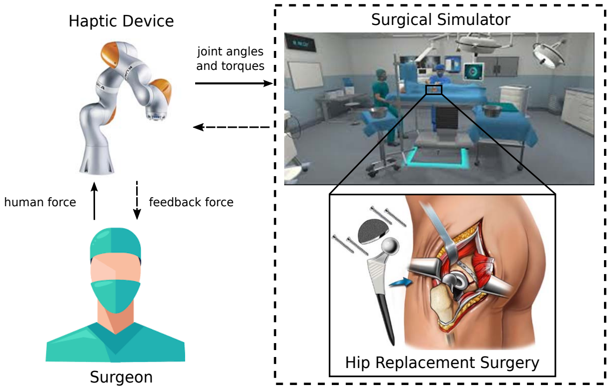

Figure 1. The proposed framework of virtual training for robotic surgery.

II. FRAMEWORK

A. Description

The system is based on the concept of cartesian force-allowance, which mirrors the users input force up to a maximum force given by the current situation into the virtual reality scene. To do that, the geometric Jacobian of the robot was derived to compute the feedback forces for the operator starting from the measured joint torques.

B. Jacobian–based force computation

We can use two different approaches to compute the cartesian forces: 1) using of a force sensor mounted in the end–

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[1] `http://www.forcedimension.com/`
[2] `https://www.3dsystems.com/`
[3] `http://www.kuka.com/`

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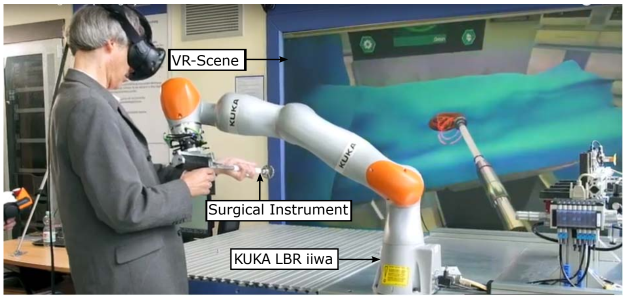

Figure 2. The experimental setup comprising the KUKA LBR iiwa robot as haptic device and the virtual reality hip prosthesis implantation simulator, as remote environment.

effector; 2) using a model–based approach by computing the robot Jacobian. In the first case, the robot's force feedback is equal to the external force applied by the human operator; for this reason the output will be independent from the robot posture. In the second case, the force feedback depends of the robot posture (through the Jacobian matrix) and the joint torques. In our case, where the real robot moves a tool inside the virtual reality environment, it is necessary to link the robot posture with the tool position during the operation; in this way we get a force feedback during the movement of the robot and during the impacts of the tool with the virtual patient. The geometric Jacobian J relates the joint torques τ to the end–effector forces f of the manipulator as $\tau = J^T f$. The geometric Jacobian for the KUKA LBR iiwa is a 6×7 matrix; therefore, the last equation can be inverted as $f = (J^T)^+ \tau$ where $J^+ = (JJ^T)^{-1} J$ indicates the pseudo–inverse matrix. The pseudo–inversion tends to have stability problems in the neighbourhoods of singularities. At a singularity, the Jacobian matrix no longer has full row rank. For this reason, in the aforementioned conditions, a Singular Value Decomposition model is used.

III. EXPERIMENTS

A. Experimental setup

Fig. 2 illustrates the experimental setup. HIPS was developed using Unity3d[4] and is displayed with a HTC VIVE[5] head mounted display. The connection between the master and slave side is guaranteed by a connection library [5].

B. Task and Subjects

The experimental task of *acetabular reaming* consists of reaming the cartilage from the acetabulum using a custom surgical instrument. The operator pushes the surgical reamer against the acetabula until all the desired amount of cartilage has been removed. The experiments involved 2 male volunteers aging 23 and 40. These subjects had a healthy and robust constitution, they were right hand dominant and they did not have any deficiency in the ability of visual and haptic perception. Each participant made 3 trials of the task.

C. Results and discussion

The framework was validated from the user experience perspective of the two human operators. The average task execution time of all the trials is 97 seconds, and it reduces by 12% from the first to the third trial, as the humans become trained. Furthermore, the human operators were asked to give a score between 1 and 10 about the user experience regarding the smoothness (average 7.5) and the intuitiveness (average 8.5) of the framework.

IV. CONCLUSIONS AND FUTURE WORKS

This work can be interpreted as an initial activity in the direction of further studies on using the KUKA LBR iiwa as haptic device in the virtual training of the hip replacement surgery. Indeed, a series of more structured experiments have been planed by the authors to better validate the method. We will conduct a user study involving a statistically significant population of subjects (surgeons) for the evaluation of the system, using a software platform for decision making (i.e. ELIGERE platform [6] as in [7]).

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[4] `https://unity3d.com/`

[5] `https://www.vive.com/`