Teleoperation of surgical robot using force feedback

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***Abstract*—Haptic feedback is a form of transferring information to the user via the sense of touch, usually through some sort of input device the user gives commands with. This makes it ideal for teleoperating tasks requiring precision in applied force, robotic surgery being a prime example. Currently, haptic feedback in teleoperation is subject to numerous constraints on time delay and accuracy. Nonetheless, results show that implementing this type of feedback in teleoperated robotic surgery gives vastly better results. In this paper we propose a new method of teleoperating the DaVinci surgical robot using haptic feedback. The method involves using a state-of-the-art haptic device to control a surgical tool serving as the robots end-effector. Since the dynamics of the surgical tool are strongly non-linear, estimation techniques are used to calculate reaction forces on the device. Changes are made to existing communication protocols in order to reduce time delay, which is an important factor. The various constraints and challenges are adressed individually in each section.**

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I. Introduction

Over the last couple of decades the use of robots for minimally invasive surgeries has increased. This is mainly due to it's precision and the reduction in tissue damage [1]. Robot used in these surgical procedures have an attached end-effector that is used as a surgical tool. One such tool is the Endowrist. The main advantage of the Endowrist lies in it's construction, as it is made to be manipulated in a similar manner to a human wrist.

Currently the only feedback operators get is visual, using live video transmissions of the surgery. The problem with the operator having exclusively visual feedback lies in the fact that he has to guess how much force is applied to skin and organs in every single manoeuvre made. It has been shown experimentally that haptic feedback has a considerably positive effect on the reduction in surgical error [2].

The purpose of haptic feedback is to apply force that resist the operators movement in such a way that it reperesents some information about the environment or situation. In theory, this should mage teleoperated surgical procedures a lot more realistic to the operator and thus reduce accidents.

The haptic feedback could be done as direct force feedback calculated from the resistance on the actuators but as the tool is highly non-linear the transparency of the controller will become less transparent. It would be possible to solve this problem by implementing a sensor to the end effector to measure the force but due to the demand of high hygiene the tools have to be sterilized at temperatures over a 100° C which could damage the sensor(s). Furthermore it is stated by law that each surgical tool has to be discarded after a few times in use. This means that the cost of the tool has to stay as low as possible and therefore make the idea of implementing an expensive sensor not ideal.

Therefore the force feedback has to be estimated through the actuators which gives a high demand for the feedback controller as it has to be as precise as possible to feedback the correct force to the operator. Another important subject is the transparency of the feedback as the operator should have the feeling of doing the operation by hand and not remote. This puts a demand on the speed of the feedback loop as the faster the loop runs the more smooth the force feedback to the operator will feel. This will set demands on communication frequency since we need to keep time delay to a minimum.

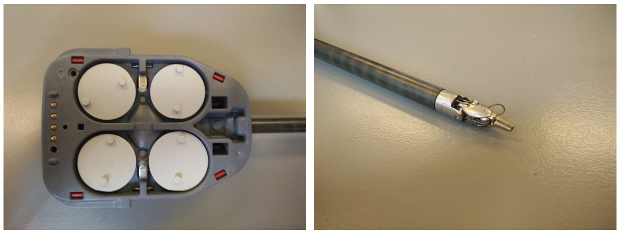
In the section II we will take an overview of our proposed control system as a whole, briefly presenting each of the components and their interaction. Section III will cover methods used to create a dynamic model of the Endowrist and proposed methods of translating the estimated force to actual force fed back to the operator. Section IV contains descriptions of various problems pertaining the requirement of transparency and explanations of methods used to address them. Finally, we present (the expected) experimental results in section V and and draw a short conclusion in section VI.

II. System overview

In out proposed system, the surgeon uses the Geomagic Touch joystick to control an Endowrist tool on one of the arms of the DaVinci surgical robot. It is important for the operator to have a feeling of resistance the tool is experiencing in order to adjust the position and grip strength and thus prevent damage to the patients tissue. To achieve this, we use the Geomagics haptic feedback feature in order to project the reaction forces acting on the Endowrist to the operator. The communication between system components is done through the Robot Operating System (ROS).

A. Endowrist

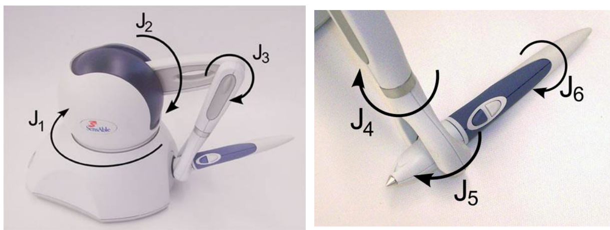
An Endowrist, see 1a is a surgical tool which can be manipulated as a human wrist. It is used in surgical procedures such as Laparoscopic surgeries, better known as minimally invasive surgery (MIS), where small incisions in the human body is made under the surgery. Because the incision cuts are



(a) Actuator plates, which can alternate the end effector position

(b) End effector of the Endowrist

Fig. 1: The Endowrist and it's end-effector



(a) Overview of the Phantom omni's first three joints.

(b) Overview of the Phantom omni's last three joint

Fig. 2: Overview of all the Phantom omni's joints [3]

small, blood lose under the surgery and the risk of infection is reduced. This has a positive effect on the recovery time for the patient.

As mentioned the Endowrist has the ability to be manipulated as a human wrist and thereby has four DOF, see 1b. This enables the movement of roll, pitch, yaw and an open closing mechanism that acts as the thumb and index finger of a hand.

The end-effector is manipulated by the four wheels seen on 1a. Wheel one and three define the movement of the yaw and the closing mechanism. Wheel two and four moves the pitch and roll. The Endowrist is cable driven, which enables the opportunity of making the Endowrist small but it also makes the system nonlinear as the force acting at one end is not directly transmitted to the other end due to friction.

B. Geomagic touch

The geomagic touch is a haptic feedback device, which has the ability to manipulate its joints in such a way that the user feels resistance when moving the pin in a certain direction or way. The geomagic touch described in this section is the model Phantom omni and can be seen on 2.

As mentioned the Phantom omni has the ability to generate resistance for the user. In other words, when moved in a specific direction it can create a counter force in respect to a certain position. On 2, it can be seen that the omni has six DOF, where only the first three can be actuated, see 2a. This means that the device only has the ability to generate force feedback with three DOF, in this case roll, pitch and yaw.

The connection to the omni can either be made directly through a ethernet cable or through ethernet cable to a usb converter into a computer. For programming the omni an API is included, which enables the connection to the omni. The Geomagic Touch has a lot of features which can be programmed through the language C++, e.g force rendering or drawing graphics.

C. ROS

The ROS is an open source software development tool for implementing robotics software. It provides the opportunity of hardware abstraction, low level device control, implementation of commonly used functionalities, messages between different processes and package management.It provide tools and libraries which utilize the the opportunity of communicating between disturbed computers, obtaining, writing and running codes.

ROS has three different levels of concepts [4]

- **The file system level**
  Handles the main unit for a ROS system which is packages. A package may include data sets, ROS dependent libraries, configure files etc. to define a ROS process. In ROS a process is denoted as a node.
- **The computation graph level**
  Handles the communication of the peer to peer network of the system in which data is processed. Through the computation graph level, the different nodes can communicate with each other by messages. When a node is sending data it is said to be publishing a topic. The different nodes can then subscribe to this topic to get the information that is published.
- **The Community level**
  ROS has a huge community which contain distribution of software installations, repositories and documentation of ROS. It also has a question and answer section with ROS related topics. This community makes the process of learning the system considerably easier.

D. Overview

As mentioned before , a fully featured DaVinci robot has 7 degrees of freedom on the Endowrist instrument. Since the robot has 4 arms, there are 4 instruments. Although our setup controls only 4 motors, in funcionality it is equivalent to one DaVinci arm.

As mentioned before, the sbRio board controls the test setup and as such represents the onboard computer on the DaVinci robot. In order to perform higher level functions such as force feedback control, it is necessary to remotely handle data and send high-level commands. This is handled by an

Fig. 3: Full view of the mechanical test setup

external computer system that is connected to the Phantom omni device.

The sbRio board communicates with the computer using UDP communication protocols, while the Geomagic Touch does so using TCP/IP. The computer also performs force estimation using a dynamical model of the test setup (or Endowrist, more precisely), this is vital for force feedback. In order to connect software components responsible for communicating with hardware and the ones responsible for the control algorithm and estimation. For this purpose we use the Robot Operating System (ROS), which uses a network architecture to share data between components via data streams.

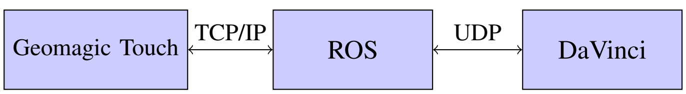


Fig. 4: Block diagram representing the system.

III. Force estimation

In order to have a representation of the reaction force on the Endowrist, we must resort to estimation. Because of the reasons mentioned in section II, we cannot measure it directly using sensors and thus have to rely on mathematical models as functions of torque measurements.

The main challenge we face in making a model lies in the fact that the pulley system on the Endowrist is non-linear, and thus it's full dynamics cannot be modeled in a simple manner. Regardless, a physical model for grip force can be derived [5], which serves as a good starting point for parameter estimation.

IV. Communication

V. Results

VI. Conclusion

The conclusion goes here.

Acknowledgment

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