Software / Hardware Integration for MRI-guided Robotic Prostate Intervention using Open IGT Link

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Abstract

We propose a software and hardware integration strategy for MRI-guided robotic prostate intervention using an open network communication protocol. In the MRI-guided robotic intervention, the robot, navigation software and MRI scanner communicate one to another via Ethernet to exchange various data e.g. robot position, commands and MR images. Since the components were developed in the different sites including academic and industrial in our research partnership, establishing interoperativity among them with standardized communication protocol was essential in the collaborative development. As a key technology for the collaboration, we developed a new open network protocol called Open IGT Link. The specification of the protocol is simple enough for the developers to implement the interface to any kinds of software including embedded system, but extensible to transfer any types of data for image guided application in the standardized way. We report our system integration for MRI-guided robotic prostate intervention using Open IGT Link.

Introduction

MRI is an ideal image guidance tool for prostate biopsy and local therapy due to its high sensitivity and specificity to focal prostate lesions and surrounding tissues, and its radiation safety. Because of its limited access to the patient in the high-field closed-bore MRI, there is a strong need for MRI-compatible devices that enable precise placement inside the MRI scanner bore. Indeed, numbers of manual and automatic devices have been proposed to guide the biopsy needle to the prostate under MRI-guidance [1-3]. In the MRI-guided robotic prostate intervention, integration of hardware and software component e.g. robotic device, navigation software and MRI scanner, is crucial to achieve "closed-loop" therapy, where the robot's action is immediately captured in semi real-time MRI and instantaneous feedback is provided to a physician for the next operation. In this study we report our software/hardware integration strategy for robotic transperineal prostate biopsy and brachytherapy in 3T MRI, which has been presented in our previous work [3], under the research partnership among three academic and industrial research sites. The goal of the study is to provide a standardized software / hardware communication mechanism that allows integration of various components developed in the different sites, and establish an interoperativity among them for a collaborative project and hence to make a smooth transition from experimental system to commercial product.

Methods

Open IGT Link Protocol. We defined an open network protocol for IGT, called Open IGT Link [4]. The Open IGT Link is a peer-to-peer communication protocol designed to work in the application layer of the TCP/IP stack or other network protocol model. The protocol itself does not have a mechanism to establish and manage a session. Instead, a message, which is a minimum data unit exchanged in the protocol, contains all information that is necessary for the receiver to interpret it. The message begins with a header section, which is common to all types of data, followed by a body section. The format of body section varies by data type specified in the header section. Since the header section can be interpret by any receivers and it contains size and data type of the body, every receivers can at least skip the body section if they don't know the data type. Therefore, this two-section structure allows developers to define their own data type, keeping compatibility with software that cannot interpret their data types.

System Integration for MRI-guided Robotic Prostate Intervention. The system consists of three major components: 1) the control unit for the needle placement robot (Fig. 1), 2) closed-bore whole body 3T MRI scanner (GE Excite HD 3T, GE Healthcare, Chalfont St. Giles, UK), and 3) open-source surgical navigation software, 3D Slicer [5]. The navigation software serves as a user interface for the entire system; it displays pre-operative 3D images for planning and intra-operative semi real-time MR images for guiding the procedure. The physician interactively specifies target points on the pre-operative image set; the current position is indicated on the 3D view of the navigation software. All components are connected to one another via 100Base-T Ethernet. The Open IGT Link is used to exchange commands to the robot and scanner, semi real-time images, and positional data (Fig. 2). The positions of the target lesion are specified on the navigation software interface and transferred to the robot control unit. While the robot control unit is driving the needle towards the target, the needle position is calculated from the optical encoders and sent back to the navigation software every 100 ms. The navigation software calculates the imaging plane that intersects the needle's axis and transfers it to the scanner, which in turn acquires semi real-time images in that plane. Since all positional data exchanged among the components is represented in the image coordinate system, the robot coordinate system needs to be registered to the MR image coordinate system prior to the procedure.

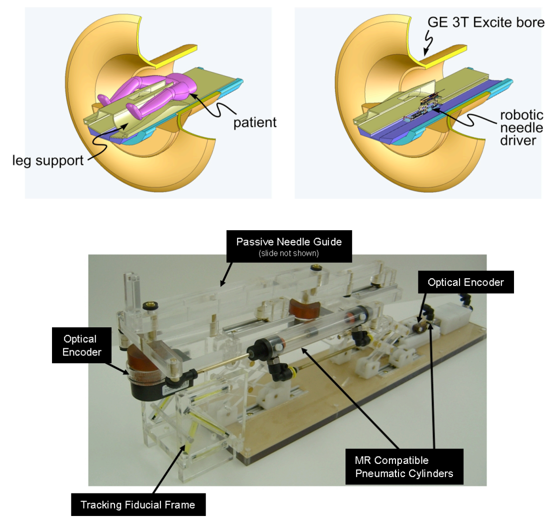

Fig. 1: A robot for transperineal prostate biopsy and treatment. Pneumatic actuators and optical encoders are used for MRI-compatibility.

Results and Discussion

The open network protocol, Open IGT Link, enabled the integration of the software and hardware components in the proposed system. Its simple specification allowed the developers to implement the Open IGT Link interfaces into their software without any difficulty, improving the interoperativity of the components. This is very important merit of using Open IGT Link, especially when one considers making a transition from research prototype to commercial product by replacing each of the components in the system. In deed, we have also been working on integrating commercial navigation software, which replaces the 3D Slicer, and the Open IGT Link plays a key role to switch the component from the experimental prototype to the product for smooth transition.

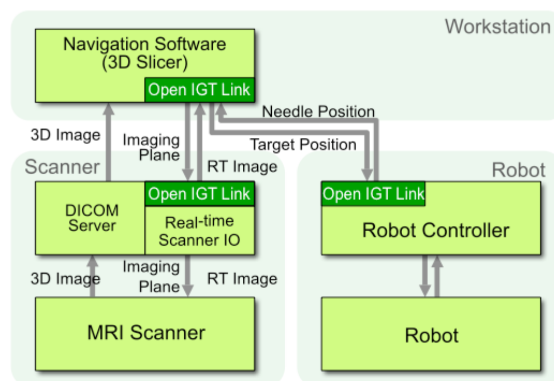

Fig. 2: System diagram for the robot for transperineal prostate biopsy and brachytherapy.

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