Department of Energy, Grant Support, the University of Southern California

Applications of Surgical Robotics

Overview

This grant is to support a research in robotics at three major medical centers: the University of Southern California-USC- (Project 1); the University of Alabama at Birmingham-UAB-(Project 2); and the Cleveland Clinic Foundation-CCF-(Project 3). Project 1 is oriented toward cardiovascular applications, while projects 2 and 3 are oriented toward neurosurgical applications.

Project 1 (USC): Constant Stress during Magnetic Resonance Studies to detect Cardiovascular Disease

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Summary
The main objective of Project 1 is to develop an approach to assist patients in maintaining a constant level of stress while undergoing magnetic resonance imaging or spectroscopy. The specific project is to use handgrip to detect the changes in high energy phosphate metabolism between rest and stress. The high energy phosphates, ATP and phosphocreatine (PCr) are responsible for the energy of the heart muscle (myocardium) responsible for its contractile function. If the blood supply to the myocardium in insufficient to support metabolism and contractility during stress, the high energy phosphates, particularly PCr, will decrease in concentration. The high energy phosphates can be tracked using phosphorus-31 magnetic resonance spectroscopy (^{31}P MRS).

Background

Physical signs and symptoms, provide a means, albeit inaccurate means, to diagnose myocardial ischemia. We are well aware that the major cause of myocardial ischemia is obstructive coronary artery disease (CAD). Recent innovations in the application of ^{31}P MRS have provided a means for monitoring changes in the myocardial high-energy phosphates (HEP). With physical stress, ^{31}P MRS can provide a sensitive means for detecting myocardial ischemia, potentially more sensitive than any other diagnostic modalities. Stress ^{31}P MRS is regarded as a reference standard that can identify abnormal cardiac metabolism resulting from myocardial ischemia.

The most widely available systems use magnetic fields of 1.5 Tesla (T). Recently, the major manufacturers have developed 3T systems to enhance signal intensity. This allows the generation of images with higher spatial resolution and improved contrast, and improved ability to perform ^{31}P MRS. At present, the use of ^{31}P MRS, particularly ^{31}P MRS at 3T, allows visualization of the HEPs, PCr, and ATP, and inorganic phosphate

(Pi). Measuring HEP turnover has been employed to evaluate myocardial energy metabolism, and chemical shift of the Pi to evaluate myocardial intracellular pH.

Concept/Goal

To induce metabolic abnormalities, such as reduction in PCr, increase in Pi and decrease in pH, medium-level handgrip stress is frequently used. To use handgrip stress, the maximal voluntary contraction (MVC) is determined. Then the patient is coached to squeeze the handgrip until 30% of the MVC is achieved and maintained for the duration of the spectral acquisition, approximately 5 to 10 minutes. When the stress is greater than 30%, the patient is verbally asked to reduce the grip pressure. Likewise, when the stress falls to less than 30%, the patient is verbally coached to increase the grip pressure.

Among the major technical difficulties are the use of the low level of stress (with 30% MVC) and induction of such stresses in the high field magnet bore (1.5 or 3T). In such a low level of stress test, it is critical to maintain the stress at a constant level. Otherwise, the level of HEP tends to recover quickly and any HEP changes disappear whenever the subject involuntarily loses the stress level. In practice, it is very difficult for patients to maintain a constant pressure level with verbal coaching. There has always been time lag in such verbal communication. Moreover, involuntary adaptation of the patient would compromise the measurement of such changes.

Materials and Methods

It is clear that in order to allow optimal performance of the ^{31}P stress test, a robotic approach must be employed. In the present project, the development of a system was initiated, to optimize the maintenance of a stress level that is as close as possible to constant. As an essential component for reliable stress ^{31}P MRS, a robotic operation has patients maintain the stress level by themselves. This approach offers precise measure of the stress level and integrated work load. Well-controlled stress level would minimize the physiological noise that easily degrades the quality of the study in current circumstances.

We designed a system that used two types of handgrip dynamometers for continuous monitoring of pressure. One consists of a hydraulic compressor that is simple and less accurate. This type of handgrip stressor, however, doesn’t produce any electrical noise and/or inductive coupling with other rf components. The hydraulic type is useful as a reference for the second digital component. The second type of stressor consists of a compression-load-cell handgrip. The load cell handgrip would generate a signal source from the system illustrated in the Figure below.

Results

The input signal of the stress level goes to a PC through an interface and output signal generated by the program to actuate the audio/visual component. The system is controlled by a PC with the prior-set control variables. This strain gauge takes 10 to 20 samples per second from the handgrip. The output from this handgrip is connected to a pre-amplifier and calibrated as psi or kPa. Physiological parameters such as blood pressure and heart rate may be received and integrated during the stress to estimate total load of the stress.

We anticipated that by the completion of the project the whole system would be optimized for handgrip stress testing performed within the MRI milieu. The performance of this handgrip would be tested in our newly NIH/NCRR 3T high field research magnetic resonance system.

Conclusions:
During this first project we developed a plan to construct a non magnetic handgrip that would provide a means for patients to most effectively maintain a constant force for optimal phosphorus-31 magnetic resonance myocardial spectroscopy.

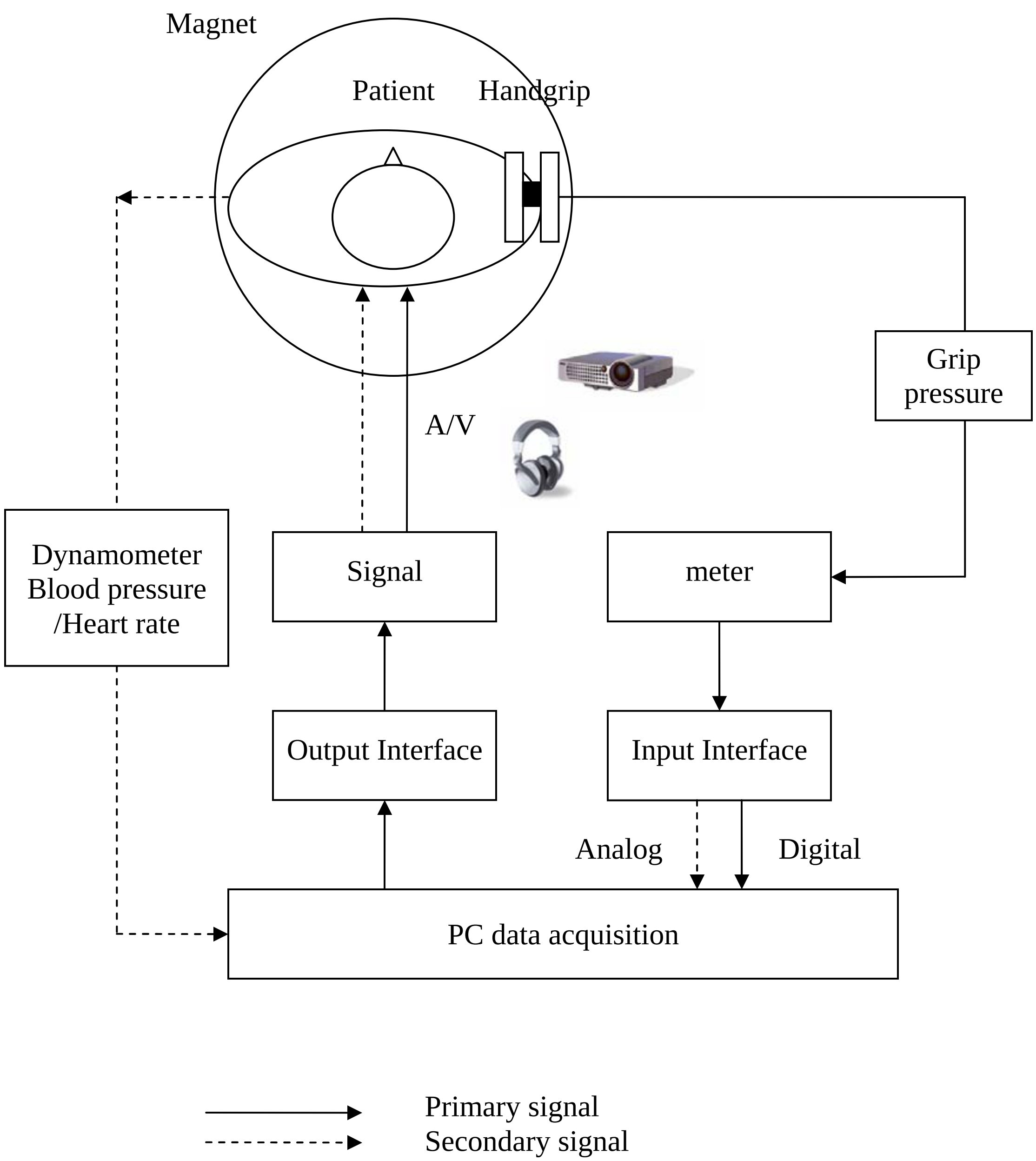

Figure: System diagram

Project 2(UAB): Surgical Robotics – The Feasibility of Virtual Presence in Surgical Assistance and Training

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Summary:
The UAB Surgical Robotics project focuses on the use of virtual presence to assist with remote surgery and surgical training. The goal of this proposal was to assemble a pilot system for proof of concept. The pilot project was completed successfully and was judged to demonstrate that the concept of remote surgical assistance as applied to surgery and surgical training was feasible and warranted further development.

Background:
Surgical training and assistance is a major focus of surgical medical programs and clinical practice. To date, training is carried out primarily by having the trainee present at surgery and performing tasks of escalating complexity. Expert surgical assistance (transfer of expertise from one surgeon to the other), requires that the expert be physically present at the site of surgery. The current project attempts to reduce the need for actual physical presence for some forms of surgical assistance and training. Successful completion of this Year 1 project will prove that a system that can transact expertise remotely is feasible. Such a system will have a tremendous impact on the field of surgical training and assistance.

Concept / Goal
The concept of the pilot is 'virtual presence'. Under this paradigm, the expert surgeon is rendered virtually present by a device called the Surgical Videoscope, the prototype of which was the goal of the pilot. The Surgical Videoscope is a binocular viewing device much like an operative microscope. However the oculars provide binocular, stereoscopic high-resolution video. The primary surgeon views the operative field through the primary surgical videoscope. The stereoscopic image of the operative field is sent to a remote surgical videoscope and viewed by the trainer or expert surgeon, who sees it as a virtual operative field in full stereoscopic video. The training (expert) surgeon inserts his/her hands into the virtual field in context with the ongoing surgery. The stereo-video image of the trainer's (expert's) hands are sent back to the primary videoscope and are seen as virtually present in the operative field by the primary surgeon. In this manner, the remote expert, or trainer, can render assistance by being virtually present in the operative field, guiding the actions of the primary surgeon (see FIGURE 1).

The goal of the pilot is to develop a prototype surgical videoscope system to determine whether the

Materials and Methods:
The DOE grant money was used to purchase material for the prototype videoscopes and pay for development effort. A total of two videoscope prototypes were constructed. Each videoscope station consisted of a binocular video camera that sent images to binocular videoscopic goggles. When looking through the goggles, the user sees a 3D representation of the field of interest as sent from the camera. Other equipment included two computers programmed to process the images from the cameras. Processing included: smoothing/enhancing the images from the binocular cameras, networking the images from each videoscopic support computer to the other, superimposing the images and then sending the composite image to the respective videoscopic goggles. In this manner, each videoscope displayed the composite field with the local field of each being the 'real field' and the overlay from the other scope being the 'virtual field'.

Two tasks were designed. In the first, the viewers were simply to use the videoscope system for extended periods of time to assess the experience of viewing a field with stereoscopic video. The second task was designed to test the feasibility of virtual presence in guiding a remote user through a task. For this task, a collection of Lego blocks were placed under the "trainee' videoscope and viewed as the real filed by the trainee. The 'remote' expert viewer used the other videoscope to view a blank field with the trainee's field superimposed. The task of the expert was to use his real hands within the virtual Lego field to instruct the trainee how to construct the system of Legos. In this paradigm, the trainee saw the real Legos through his scope and the virtual hands of the expert superimposed. He then followed the virtual hands as they guided him through the construction process.

Results:
The prototype videoscopes were successfully constructed and performed as intended. Issues that were encountered were: lack of detail of the field as a result of budget-constrained low resolution cameras, delay in constructing and networking the composite image due to relatively low-end computers acquired for the pilot. The tasks were completed successfully. The results indicate that users can view binocular video for periods of time. In addition, the second task clearly demonstrated that a remote 'expert' could be rendered virtually present in a local field to assist with a task. This was readily confirmed by the fact that the local trainee easily constructed lego objects under the guidance of the remote expert (exemplified in Figure 2). Issues that arose were low resolution of the image, delay ion image transfer as mentioned above. The second task demonstrated no problem in scaling the composite image with respect to size, but illuminated an issue with respect to depth. The system could not accurately place virtual objects at the correct depth within the real local field.

Conclusion:
The pilot project successfully demonstrated that using virtual presence for remote assistance is feasible. Future development will include upgrading cameras, goggles and computers to address issues of resolution and signal delay. As a result of the pilot, the investigators have begun exploring solutions to appropriate depth rendering in mixed virtual-real environments.

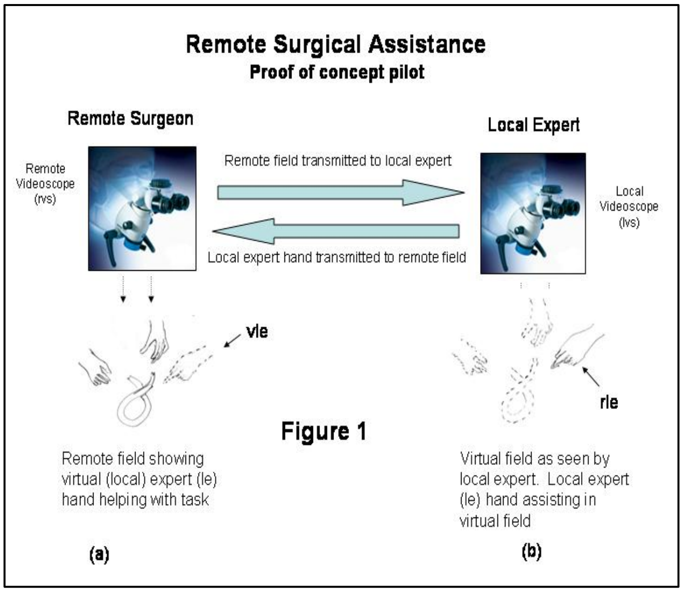
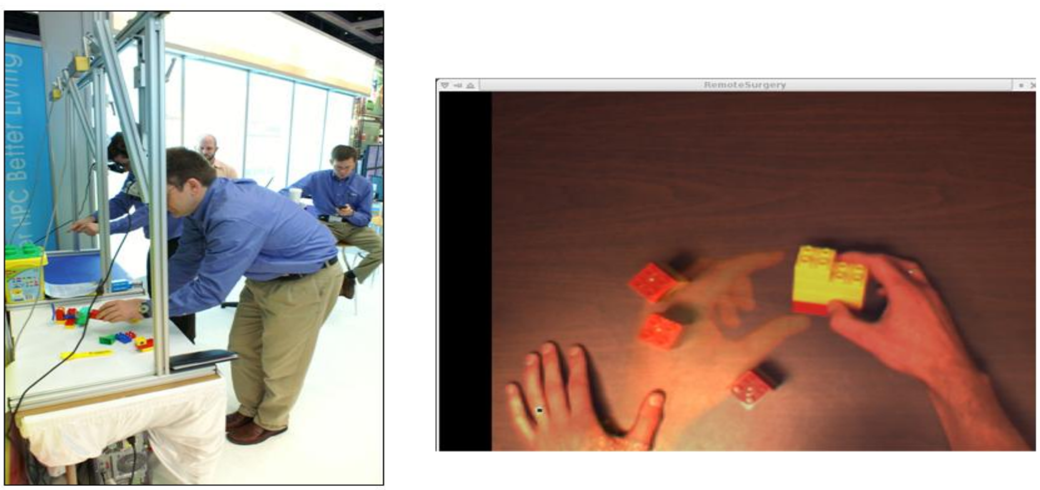


Figure 1



Prototype Videoscopes. The view from each videoscope is superimposed. Each viewer sees his/her own real field with the remote field from the other scope superimposed an dvirtually present.

This view is through scope that is looking at real Legos. The expert assistant's hand is virtually present and guidin th eprocess of cnostruction (e.g., surgery)

Figure 2

Project 3 (Cleveland Clinic Foundation): Tele-Robotic DBS Delivery System (TRDDS)

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Background and Objective
The main objective of Project 3 is to develop a system to allow for the tele-robotic delivery of instrumentation during a functional neurosurgical procedure (Figure 3). Instrumentation such as micro-electrical recording probes or deep brain stimulation leads. Current methods for the delivery of these instruments involve the integration of linear actuators to stereotactic navigation systems. The control of these delivery devices utilizes an open-loop configuration involving a team consisting of neurosurgeon, neurologist and neurophysiologist all present and participating in the decision process of delivery. We propose the development of an integrated system which provides for distributed decision making and tele-manipulation of the instrument delivery system.

Concept/Results

This pilot project involved the identification of functionality and the characterization of performance for the TRDDS. The experience of our center in the field of DBS provided a rich environment for collecting potential use and functionality data. This is typically referred to as the product requirements and specifications phase of any product development process. We collected operational use data on over 200 DBS procedures and have summarized the functional requirements as follows:

Data Element/Control	Type of Information	Type of Control
Physiological Waveform	Visual & Audio	Passive Display
Instrument Control	Rotary Control	Two-way, Non-haptic
Current Depth	Visual	Passive Display
Current Stereotactic Position	Visual	Passive Display

The required performance of the telemetry system was then assessed through a series of mock demonstrations where recorded procedures were presented to a group of typical clinicians using a range of anticipated performance measures. In all cases a full rate demonstration was preferable however; a suitable for use measure was obtained by survey of the acceptable/non-acceptable presentation of information in the simulation system. The results are summarized here:

Data Element/Control	Minimum Useable	Maximum Tested
Physiological Waveform	640x480 Display, 15Hz Refresh	1024x768 Display, 60Hz
Instrument Control	120Hz update	500Hz update
Current Depth	15Hz	60Hz
Current Stereotactic Position	640x480 Display, 15Hz Refresh	1280x1024 Display, 60Hz

After collecting and assessing the user requirements and performance data the over system specifications were developed and a prototype design document was prepared. The overall design was built upon a currently available stereotactic instrument delivery system that has wide market acceptance and sales penetration.

The following functional description of the overall TRDDS was then developed. This system utilizes a hospital network capable of providing 5Mbps of communication bandwidth.

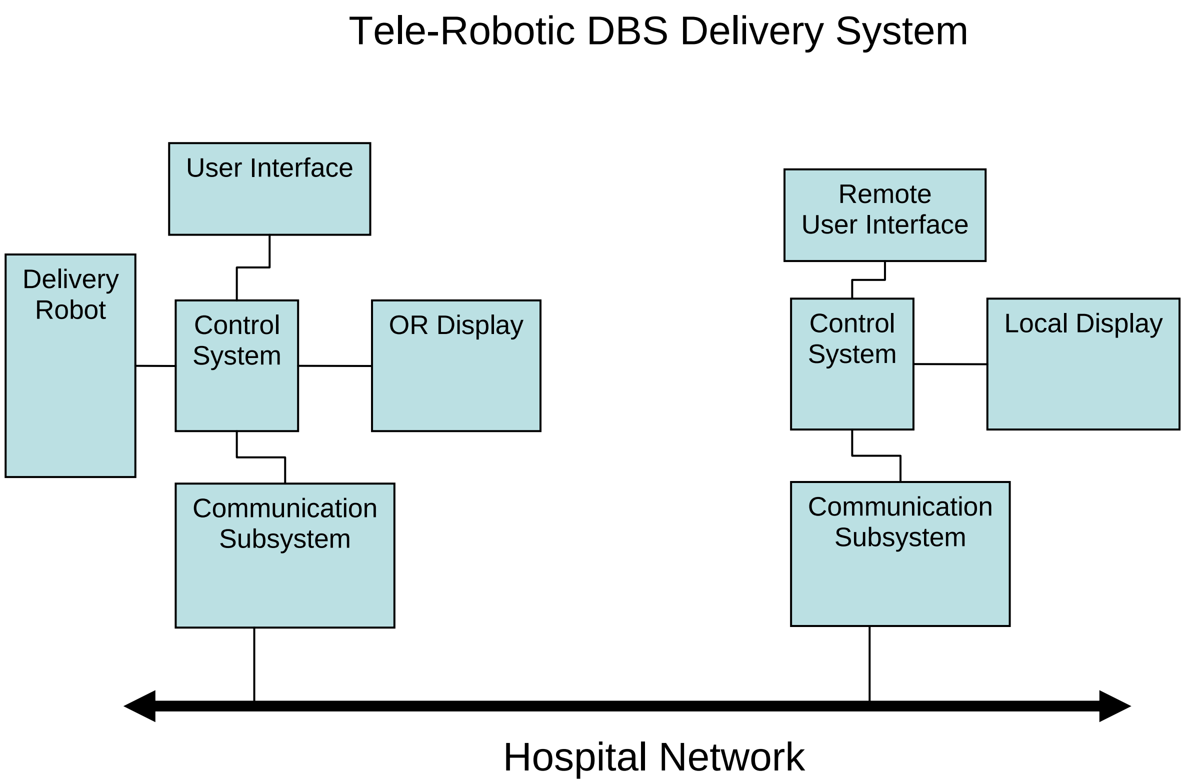

Figure 3. The next phase of this project will focus on development of the individual subsystem components, integration of these components and then testing of the integrated system.