

# Robotic Telementoring/Telesurgical System and Randomized Evaluation Study

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**Abstract**—The paper presents a new telementoring system incorporating audio-video communication and remote robotic control. The system was developed around an off the shelf ISDN video conferencing system enhanced with video annotation and remote robot control features. The user can remotely control a robot to perform needle alignment and insertion in a percutaneous access procedure. Particular attention was devoted to ensure the safety of the procedure. The data connection is continuously monitored and in the event of a failure the robot control is switched to the local operator. Two series of randomized trials were performed between Baltimore and London. The accuracy and procedure time were evaluated for manual needle placement, local robotic needle placement and remotely controlled robotic needle placement. The test showed that while the procedure time is not improved by the robotic approach there is an improvement in the accuracy of the procedure. The study showed also that there is no significant difference between the locally controlled robotic needle placement and the remotely controlled robotic needle placement. Thus, the proposed system can be safely used for remote robotic percutaneous access procedures.

## I. INTRODUCTION

The current medical practice requires highly skilled personnel and the rapid absorption of new technology. Doctors become familiar with new procedures and instruments by training with a more experienced surgeon. However, the number of training hours is limited and while the trainees acquire the basic skills required in performing a certain procedure, they can be challenged by particular real life situations. In this context, the concept of telementoring emerges as an intermediary step between training and fully independent practice. The trainee is monitored and receives advice from a more experienced clinician via an enhanced video conferencing system. Telementoring experiments have been conducted with applications to urology [5], [3] and endoscopic surgery [10], and a commercial system Socrates™ was available from "Computer Motion Inc.". One step further from the telementoring concept is the telesurgery concept where the procedure is performed completely by the remote surgeon by means of remote manipulation of a surgical robot.

Buthner and Ghodoussi adapted a Zeus™ surgical robot for remote operation [1]. The remote control station was located in New York USA and the patient side was in

Strasbourg, France. The system was successfully tested in the widely publicized "Operation Lindbergh" for the first human transatlantic operation. While the remote operator is theoretically able to complete a full procedure, there is still a need of a fully qualified team on the patient side that can complete the procedure in case of a malfunction. Thus, the overall procedure costs can hinder the benefits of telesurgery. The telementoring/telesurgery can be beneficial in minimally invasive image guided surgical procedures.

In a minimally invasive procedure, an instrument, usually a needle, is placed at a desired anatomical target, and therapy is delivered. Usually, the needle is inserted under X-Ray imaging guidance. The critical stage of the procedure is the insertion phase that needs to be very accurate. The accuracy of the procedure depends mainly on the experience of the surgeon requiring extensive training. Thus, a telementoring/telesurgery system designed for image-guided interventions can be an efficient tool in the process of learning new techniques. Robot use can have multiple benefits, like improvement of needle placement accuracy, reduction of radiation exposure, and it can be controlled from a remote location. The robot can be used by an experienced surgeon to accurately insert the needle from a remote location while a less experienced surgeon performs the other steps of the procedure.

The telementoring system presented in this paper was developed purposely for image guided minimally invasive procedure. In addition to the common features encountered in telementoring systems this one incorporates a PAKY-RCM robot [9] that is used to accurately position and insert an instrument to a specific anatomical target. The performance of the proposed system have been assessed in a randomized trial. Parameters describing the procedure time and needle placement accuracy were compared between manual needle insertion, local robotic assisted needle insertion, and remote controlled robotic needle insertions.

## II. MATERIALS AND METHOD

The telementoring and telesurgery system comprises two PC computers equipped with Zydacron video-conferencing boards as presented in Figure 1. The video, audio and data

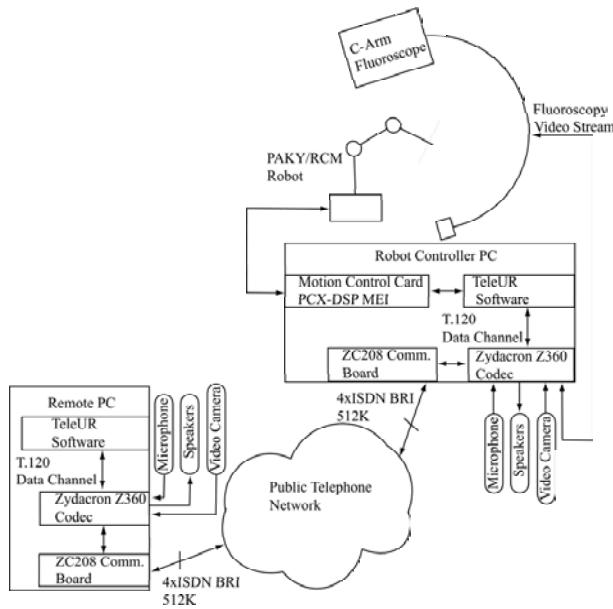


Fig. 1. Overall system diagram of the URobotics Telementoring System

coding and decoding are performed by a Zydacron Z360 board and the ISDN communication is performed by a Zydacron ZC208 Quad-BRI Communication Board. The system uses the Zydacron OnWan video-conferencing software. The overall communication bandwidth is 512Kbps among which 384Kbps are used by the video and audio communication and 128Kbps are used for data communication. OnWan implements the H.320 video-conferencing standard and provides an interface through NetMeeting to a T.120 data channel.

The telesurgery/telementoring software TeleUR runs as a separate application from the Zydacron OnWan and is connected to the data channel using a COM interface [7]. Two instances of the TeleUR program run in the same time, one on the local computer and one on the remote computer. The local computer is also the robot controller. The TeleUR program loads a configuration file that describes whether it is remote or local, and if it is local what equipments are connected to the computer- PAKY-RCM robot, CArm machine, AESOP robot. The TeleUR program provides the following functions

- Local and remote PAKY-RCM robot control
- Video annotations
- X-Ray command
- Electro Cautery control
- Aesop control

#### A. PAKY-RCM Robot

The telesurgery program provides the ability to control a PAKY-RCM Robot from a local or a remote computer. This robot has two components; the PAKY (Percutaneous Access of the Kidney) needle driver and the RCM (Remote Center of Motion) robot. PAKY is a radiolucent needle driver used to guide and actively drive a trocar needle in X-Ray guided percutaneous access procedures. The needle driver is radiolucent allowing unobstructed visualization of

the anatomical target and radiological guidance of the needle [8]. An electric motor performs automated needle insertion. PAKY has been successfully used in numerous clinical cases [2]. The RCM robot is a compact robot for surgical applications that implements a fulcrum point located distal to the mechanism [9]. The robot can precisely orient a surgical instrument in space while maintaining the location of one of its points. This kinematic architecture makes it proper for minimally invasive applications as well as trocar/needle orientation in percutaneous procedures. In the current configuration, the PAKY-RCM robot is used to orient a needle while maintaining its initial tip location and performs the insertion of the needle. Two degrees of freedom (DOF) are used for needle alignment and one translational DOF is used for needle insertion. For safety, the orientation and insertion stages may be independently enabled/disabled by hardware means. The robotic assembly is fixed into a passive arm. This is mounted on a fixture attached over the fluoroscopy table. The passive arm allows for the support of the mechanism in close proximity of the targeted kidney. In this setting, only two rotations and one translation are required for accessing any nearby target. The robot is controlled through a motion control card PCX-DSP Motion Control Card by Motion Engineering Inc. by the TeleUR program.

#### B. TeleUR program

The surgeon moves the robot through a user interface. The user interface has six main controls that correspond to the motions of the robot. For example, if the user selects “Rotate Left” the robot will rotate to the left as long as the user has the mouse over the button and keeps the left mouse button pressed. The motion is performed with a constant velocity. The velocity for the rotational motion is  $5 \text{ degrees/sec}$  and the velocity of the needle insertion is  $10 \text{ mm/s}$ .

The program running on the local station transforms directly the “button pressed” information in robot motion command. If the remote user selects a “Rotate Left” button, for example, then the program sends “MOVE.LEFT” messages with a prescribed frequency through the data channel to its peer running on the local station. The local station acknowledges each message received and moves the robot accordingly. The sender keeps generating “MOVE...” messages while the corresponding button is pressed and all messages are acknowledged within a prescribed time interval. When the user releases the move button on the remote station the program sends a “STOP” message to the local station. The local TeleUR will keep the robot moving while it receives “MOVE...” messages or until a “STOP” message is received.

The TeleUR program controls the other devices connected to the local computer through the digital outputs of the PCX-DSP Motion Control Card. The control strategy is similar with the one used for robot control. The remote program sends trains of messages according to the required operation. All messages must be acknowledged or the sequence is interrupted.

Another functionality of the TeleUR program is a video overlay system. This is implemented by drawing on a special transparent floating window that is created as a child of the OnWan main window program. The user can draw lines, circles and free-forms on the video overlay window. When a drawing entity is created by one TeleUR instance, the drawing coordinates and attributes are sent to the peer TeleUR instance. This ensure the consistency of the two overlay displays.

With all the previously presented functions the TeleUR program is the core of the distributed telementoring system. The critical nature of the surgical procedure requires for all surgical systems to operate safe and reliable.

### C. Safety Mechanisms

In order to ensure the safety of the procedure the system is provided with several safety mechanisms. The first level of safety is provided by the acknowledgement of all “MOVE...” messages described in the previous section. A second level of safety is provided by a watchdog mechanism. If a “MOVE...” message is not followed by other “MOVE...” or “STOP” message for a predefined time period, the motion will stop. These algorithms ensure that the motion of the robot is safely controlled even in the case of a communication failure.

The overall quality of the data connection is continuously monitored. The transmission delay is continuously monitored using time stamped messages going back and forth between the two stations. The transmission delay was in average one half of a second which is less than the maximum acceptable delay for tele-operation as reported by Fabrizio et al. [4]. This allows the detection of an eventual communication failure.

On the hardware side, the robot is provided with a manual joystick control. The user has access to a switch that changes the robot from computer control to manual joystick control. Last but not least, there is an inherent safety in the mechanical design of the RCM robot. During the alignment process the needle/instrument is completely out of the body and the needle can only rotates around its point. Thus, it is impossible to induce tissue damage.

The functionality and reliability of the system was first assessed in connections between different buildings of our institution. The next step was to evaluate the system in performing image guided robotic assisted interventions between two remote locations.

## III. RESULTS

The system was evaluated using a randomized test involving the simulation of percutaneous access to the kidney. In this type of procedure an eighteen gage trocar needle is percutaneously placed in a kidney calyx under X-Ray fluoroscopy guidance. The standard approach to orient the needle to a target using X-Ray fluoroscopy is the needle superimposing technique. In this technique the CArm is initially placed such that the tip of the needle is superimposed over the target and the needle is projected as a line in the

	Median Time	Mean Time	First Attempt Success Rate
Manual	35 s	46 s	79%
Robotic	57 s	65 s	88%
Local Robotic	56 s	66 s	91%
Remote Robotic	58 s	63 s	83%
US to UK			
Remote Robotic	54 s	56 s	96%
UK to US			

TABLE I  
SUMMARY OF THE STUDY RESULTS

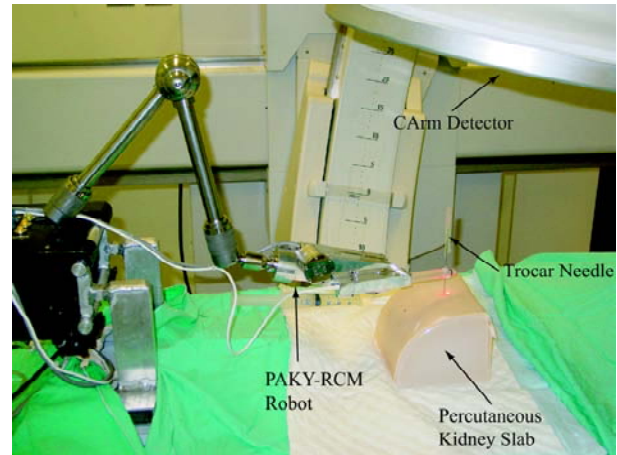


Fig. 2. Tests setup

image. Then, the needle is rotated around its point until it is projected in the X-Ray image as a point, and the needle is aligned with the target. Finally, the C-Arm is rotated for a lateral view and the needle is inserted. In the presented study the kidney target was simulated using a ‘Percutaneous Nephrolithotomy Slab’ by Limbs and Things Inc shown in Figure 2.

The test involved manual needle insertions (human = 152) and robotic assisted needle insertions (robot = 182). Among the 152 robotic insertions sixty were remotely performed (tele-robot = 60, local-robot = 122). The tests were performed in two configurations. In the first series of trials, the robotic station was at the London Guy’s Hospital and the remote station was at the Johns Hopkins University, Baltimore. All human insertions, all locally controlled robotic insertions and thirty tele-robotic insertions were performed in this configuration. A cross-over trial was performed in which the robotic station was at the Johns Hopkins University, Baltimore and the remote station was at the London Guy’s Hospital. In each trial one urologist was required to insert a needle in a specific kidney calyx manually, using the TeleUR program in local mode or in remote mode control. A summary of the test results are presented in Table I.

The telesurgery system proved to be robust and the experiments were finished without incidents. The interquartile range for the time taken in human attempts was from 25 to 52 seconds (*Median* = 35) compared to an interquartile range

of 41 to 80 seconds ( $Median = 57$ ) for the robotic attempts ( $p < 0.001$ ). The robot inserted the needle successfully on the first attempt 88% of times compared to the human operator who succeeded first time only 79% of attempts ( $p = 0.046$ , Chi-squared test).

Of the  $n = 30$  robotic procedures conducted from Baltimore, all were successful within 2 passes and the time for proven access was 10 – 182 seconds ( $Median = 58.5$  seconds). When compared to the 122 local robotic procedures with a time range of 8 – 220 seconds ( $Median = 56$  seconds), there is no statistical difference between the groups ( $p = 0.602$ ). With regard to accuracy, the trans-Atlantic group took 1.17 (83% first pass success) passes per successful puncture compared to 1.15 (91% first pass success) for the local robotic group with no significant difference between them ( $p = 0.441$ ). If the Trans-Atlantic robotic insertions are compared to the local human insertions, the local human trials have a time for access of 15 – 80 seconds ( $Median = 28$  seconds) and accuracy of 1.3 (77% first pass accuracy). The robot is slower ( $p < 0.001$  Mann-Whitney U test) but again there is no difference in accuracy ( $p = 0.519$ ) between the local and trans-Atlantic group.

In the crossover trial, the mean time to proven access was 56.37 and the mean number of passes 1.033. The data was analyzed for time and needle passes using a parametric paired t-test. The results showed no statistical significant difference (Time  $p = 0.225$ ; Passes  $p = 0.103$ ).

The important findings of this study are:

- The proposed system is robust and can be used for telementoring/telesurgery in percutaneous access procedures.
- Robotic insertion is slower than the human insertion. Median 56.5 vs. 35 secs,  $p < 0.0001$ . This outcome can be explained by the limitation imposed on the robot velocity. The robotic procedure time can be reduced using automated alignment algorithms [6].
- Robotic insertion is more accurate than the human insertion. 79% (first attempt success) vs. 88% (first attempt success),  $p = 0.046$
- The robot performs equally locally and remotely controlled.

Time: 56 seconds (locally) vs. 58.5 seconds (trans-Atlantic)  $p = 0.602$

Accuracy: 89% (locally) vs. 83% (trans-Atlantic)  $p = 0.441$

#### IV. DISCUSSION AND CONCLUSION

The paper presents a robotic telesurgery/telementoring system and the results of a randomized study designed to assess the performances of the system. The study evaluated if the proposed system was benefic for performing/teaching percutaneous needle insertion in a kidney model. The proposed system was compared against the standard manual approach and a locally controlled robot approach. The system proved to be reliable and accurate. When comparing the accuracy and the procedure time no significant statistical

difference were observed between the locally controlled robot and the remotely controlled robot. The accuracy of the robotic assisted needle placement was better for the robotic needle placement. The procedure time was better for the manual case. We believe that the robotic alignment took longer because its velocity was limited for safety reasons.

The experiments showed that the system can be used for telementoring minimally invasive image guided procedures. To the best of our knowledge this is the first system purposely designed for these applications. The presented randomized study provides a realistic and objective evaluation of the system. Future developments of the system address the problem of automatic needle placement and the integration of a haptic interface for robot control.

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