Magellan: Technical Description of a New System for Robot-Assisted Nerve Blocks

Joshua Morse*, Mohamad Wehbe‡, Riccardo Taddei†, Shantale Cyr§, and Thomas M. Hemmerling§¶
*Department of Electrical and Computer Engineering, McGill University, Montreal, QC, Canada
email: joshua.morse@mail.mcgill.ca
‡Department of Experimental Surgery, McGill University, Montreal, QC, Canada
†Department of Anesthesiology, University of Pisa, Pisa, Italy
§Department of Anesthesia, McGill University, Montreal, QC, Canada
¶Institute of Biomedical Engineering, University of Montreal, Montreal, QC, Canada
email: thomas.hemmerling@mcgill.ca

***Abstract*—Nerve blocks are common procedures used to remove sensation from a specific region of the body via injection of local anesthetic. Ultrasound-guided nerve blocks are common-place in anesthesia, but require specialized training and advanced bi-manual dexterity. This paper describes a system designed to robotically assist in ultrasound-guided nerve blocks. Robot-assisted nerve blocks could allow for more precise needle placement, and therefore a higher efficacy of blocks. This system is the first step in developing a completely automated nerve block system, which would also require the incorporation of ultrasound image recognition of nerves and other physiological markers.**

***Index Terms*—Regional anesthesia, nerve blocks, robotic anesthesia.**

I. INTRODUCTION

NERVE blocks are a procedure of regional anesthesia used to remove the sensitivity from an area of the body via the injection of an anesthetic drug into the nerve innervating the target area. Nerve blocks were first used in surgery in 1885 [1] and are now a common procedure performed routinely around the world.

Performing regional nerve blocks requires special training. Anesthesiologists performing regional nerve blocks only on an occasional basis have a significant failure rate, as high as 45% [2]. Most regional blocks are performed using ultrasound guidance; this necessitates careful bi-manual operation of the ultrasound probe and the nerve block needle. Precise movement of the needle is important for successful blocks. One centimeter movement in any direction can make the difference between a failed and a successful block.

Mechanical robots have been used in surgery for more than 10 years, the da Vinci Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA) being the latest. These mechanical robots are shown to increase precision of movements and improve outcome [3]. Recently, Tighe *et al.* have used the da Vinci Surgical System to perform successful nerve blocks in an ultrasound phantom [4]. We present the first robotic system, called Magellan, designed specifically to perform routine nerve blocks.

II. MATERIALS AND METHODS

The Magellan system is designed to perform robot-assisted, ultrasound-guided nerve blocks. The system has 4 primary components: a standard nerve block needle and syringe mounted via a custom clamp to a robotic arm (JACO robotic arm, Kinova, Montreal, QC, Canada), an ultrasound machine, a joystick (ThrustMaster T.Flight Hotas X, Guillemot Inc., New York, NY, USA), and a software control system. The system is designed to work with any ultrasound machine with a video output. The ultrasound video signal is captured via a USB video capture device (Dazzle DVC100, Pinnacle Systems, Mountain View, CA, USA).

The software system is designed on a client/server model so that nerve blocks can be performed remotely. Both the client and server programs were written in C# and communicate using UDP/IP. The client software interfaces with the ultrasound machine, robotic arm, and a webcam (Lifecam HD, Microsoft Corporation, Redmond, WA, USA). The ultrasound and webcam video feeds are streamed from the client to the server, where they are displayed in a graphical user interface (GUI) created in LabView (National Instruments, Austin, TX, USA). The webcam is positioned in order to provide a direct view of the target nerve insertion area and the ultrasound probe. The server software interfaces with the joystick and transmits the joystick commands to the client over the IP network. The client and server, as well as their software subsystems, are detailed in Fig. 1. Further explanation of the individual subsystems of both applications are presented below.

A. Software Control System

1) Server Application: The Controller Subsystem implements an interface that decouples the precise controller's driver from the system, allowing for the controller to be easily changed. This subsystem reads the state of the controller and provides it to the Server Networking Subsystem.

The Server Networking Subsystem is responsible for

© 2013 ACADEMY PUBLISHER
doi:10.4304/jcp.8.6.1401-1405

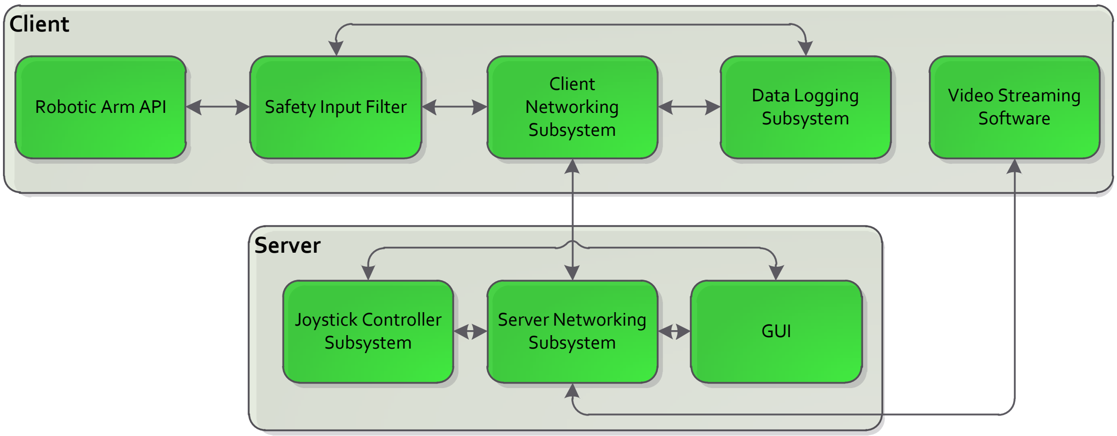
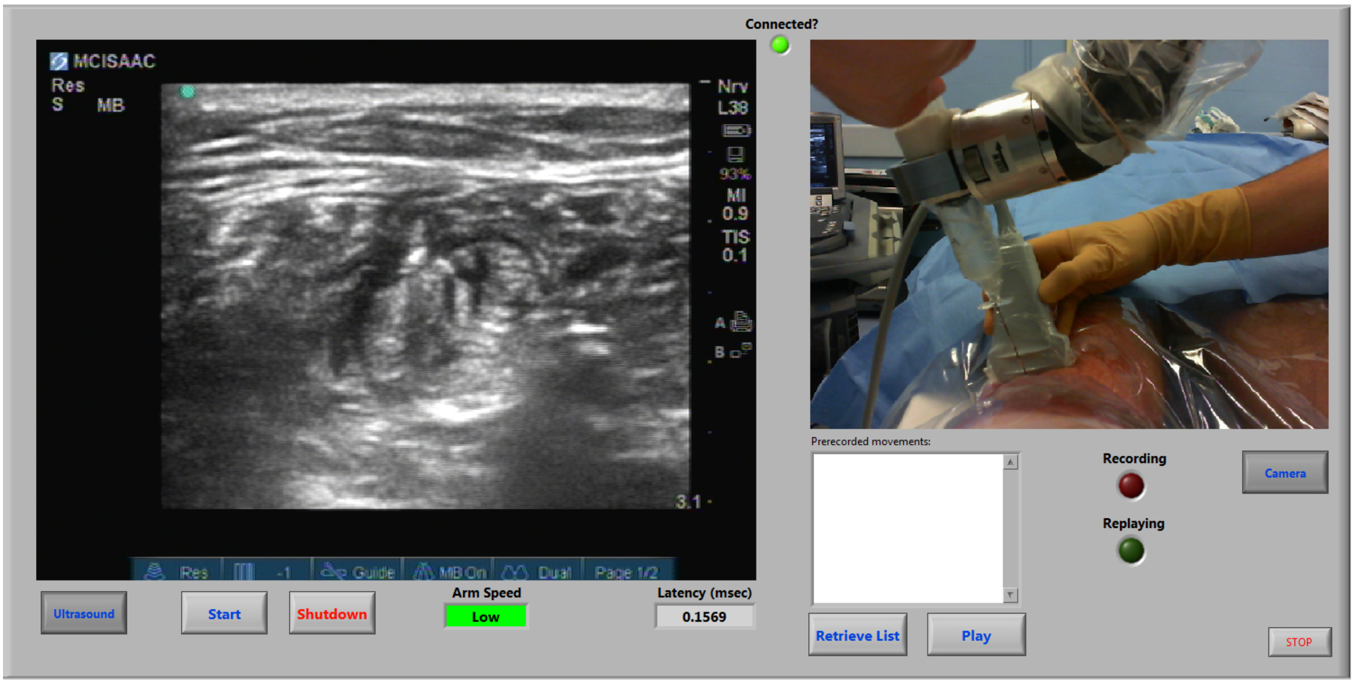


Fig. 1. Logical View of the Magellan system detailing the individual software subsystems of both the client and server applications.



Arm Speed: Low

Latency (msec): 0.1569

Fig. 2. GUI of the Magellan system. Left: Ultrasound video feed. Right: Webcam video showing ultrasound probe and insertion area. The arm speed and network latency are displayed beneath the ultrasound video.

transmitting the controller data to the client over the network. Furthermore, this subsystem encrypts all packets to be sent to the client and decrypts those received from the client. This subsystem also works with the client to monitor the latency of the network. The latency information is displayed prominently on the GUI in order to allow the user to estimate the lag between the commands they send using the joystick and the resulting movement on the video displays. The latency display is color-coded to provide a clear, visual indication of the latency status: grey for latencies less than 200 ms, yellow for latencies between 201 and 400 ms, and red for latencies greater than 400 ms.

The GUI is detailed in Fig. 2. The GUI prominently displays the ultrasound video feed and the view of the target area, as well as the network latency and current arm speed. The arm speed can be toggled between three different modes: high, used to place the needle initially in position above the target area; medium, used to descend the needle towards the insertion point; and low, used to drive the needle through the skin and to the nerve sheath. The arm speed display is also color-coded, with green, yellow, and red denoting low, medium, and high speeds, respectively. The arm moves .15 m/s, 0.075 m/s, and 0.0425 m/s for high, medium, and low speeds, respectively.

© 2013 ACADEMY PUBLISHER

2) Client Application: The Robotic Arm API subsystem is responsible for transmitting commands to the robotic arm. This subsystem also provides details on the location and status of the arm to the Client Networking Subsystem.

The purpose of the Safety Input Filter subsystem is to prevent unsafe commands from being sent to the robotic arm: by pressing a specific button on the joystick, the operator puts the system into a needle insertion mode that limits the depth that the needle can move; these limitations are dependent on the target nerve. For example, for the popliteal nerve, maximum depth is set to 4 cm. This feature prevents the needle from descending below the maximum depth of the target nerve. This subsystem also scales the magnitude of movement speeds to allow for small and precise changes in the orientation of the needle in order to provide the anesthesiologist with fine control. Additionally, this subsystem implements the control scheme for the system as it is responsible for translating controller commands received over the network into individual commands to be sent to the robotic arm.

The Client Networking Subsystem is responsible for handling all communications with the server application. This communication includes the reception of controller packets from the server, the monitoring of latency in the network, and updates about the status of the robotic arm. Additionally, this subsystem handles the encryption of all data being transmitted to the server and the decryption of all data received from the server.

The Data Logging Subsystem records all data that is received by the client from the server. Additionally, it records the output of the Safety Input Filter so that all commands that are transmitted to the robotic arm are logged.

The Video Streaming Software subsystem streams the local ultrasound and webcam video feeds to the server.

B. Safety Features

There are two safety classifications of medical robots: fail-safe and fault-tolerant [5]. A fail-safe robot is one which enters a safe state when an error occurs; a fault-tolerant robot is one which continues to operate in the presence of errors [5]. This system is fail-safe as it will enter a state that poses no risks to the patient if any errors occur.

In the event of a disconnection of any critical device (i.e., the joystick is disconnected from the server PC or the JACO arm is disconnected from the client PC), the robotic arm will immediately stop moving and remain stationary until a connection can be re-established. The motors of the robotic arm cannot be manually moved while powered on. This same protocol is followed if a network connection is lost between the client and server PCs. Similarly, the robotic arm will also stop all movement if any critical exceptions occur in the client or server applications.

A second important safety consideration of a medical robot is the magnitude in error between the actual, measured position of the motors of the robot and the position that motors were commanded to go [5]. The JACO robotic arm has a relative position tolerance of 1.6 mm, meaning that the maximum error between the commanded and actual positions of the needle will be, within 1.6 mm of the target. Additionally, the anesthesiologist can activate a safety limitation which will prevent the needle from going below the maximum depth of the current target nerve.

The arm features several important safety features which make it suitable for use in this application: it has redundant error checks for each joint and the control system, it recalculates the position of each motor every 0.01 second, recovers automatically in case of a system fault, has zero backlash on each of its six axes, and is back drivable when shutdown. The arm also has a maximum translational speed of 15 cm/s and a maximum joint rotation speed of 8 rpm.

The arm is powered by a 24V DC power adapter and is plugged into an uninterruptable power supply (Back UPS XS 1300, APC, W. Kingston, RI, USA) that provides power to both it and the client computer in the case of a power failure. The arm draws between 1.7 and 10 A while in use and the UPS contains a battery with sufficient capacity to allow for a safe reversal of the procedure should power be lost.

The JACO arm is connected to the client PC using a standard USB cable. In the case of a computer failure, the robotic arm also has a backup joystick that can be used to directly control it, independent of the client PC. This joystick allows full control of the arm and will operate as long as the arm has power.

C. Robotic Arm

The JACO robotic arm was developed to provide mechanical assistance to wheelchair-bound people and is certified by Health Canada as a medical device. The robotic arm has 6 degrees of freedom and can support a payload of 1.5 kg or 1 kg at full extension. The arm is built of carbon fiber, making it lightweight at 5 kg. It has a reach of 90 cm at full extension and contains 6 independently-controlled motors. The arm can also operate in both a left-handed and right-handed mode. These features make the JACO robotic arm versatile and allow great flexibility in the placement of the robotic arm.

D. Control Scheme

In order to provide an intuitive control scheme to the user, each of the six primary movements available via the robotic arm were mapped to specific buttons and/or axes of the joystick.

The left/right and forward/backward movements of the primary joystick handle are mapped to the same movements of the robotic arm. Twisting the joystick handle to the left or right will cause the robotic arm to rotate the needle in a similar fashion. The throttle control of the joystick is used to rotate the tip of the needle forward or backwards, while rotating a slider bar on the rear of the throttle will rotate the syringe about the point of the

© 2013 ACADEMY PUBLISHER

needle. The hat switch is used to ascend or descend the needle. The trigger button informs the system that the nerve block procedure is beginning, and thus engages the safety limitations described in section II-B. Two buttons on the top of the joystick are used to either increase or decrease the speed of the robotic arm.

E. Operational Setup

The JACO robotic arm is mounted to the rear of the operating table and placed in the handedness mode that would provide the easiest approach to the leg that will receive a block: left-handedness for performing a nerve block on the right leg, or right-handedness for performing a nerve block on the left leg.

The ultrasound machine is placed so that the probe can be manipulated manually to locate and identify the target nerve. The ultrasound machine's video output is connected to the client PC using a composite video cable and a USB video capture device. For all local tests performed with the system, the same PC was used as both the client and server. The PC and joystick were installed on a mobile cart which was placed close to the mannequin. The webcam was then placed with a clear view of the intended position and connected to the PC.

III. TESTING & RESULTS

The Magellan system was tested on an ultrasound nerve phantom (Blue Phantom Select Series Peripheral Nerve Block Ultrasound Training Model, Blue Phantom, Redmond, WA, USA). This nerve phantom is designed to realistically mimic human tissue, both physically and in an ultrasound image. These tests were made to ensure that the control scheme was easy to use and that the needle could be placed in the correct location by the robotic arm. An experiment was conducted to record and analyze the first 20 nerve blocks performed on the nerve phantom. These trials were performed by an anesthesiologist who had never previously used the Magellan nor been formally trained in its control scheme. In this experiment, the anesthesiologist verbally guided an assistant to maneuver the ultrasound probe until the nerve was located and identified on the ultrasound screen and then directed the needle, using the joystick, from a resting position, to the proper insertion position, and then directly into the nerve. Success was defined as the introduction of the tip of the 22 gauge needle into the nerve. The trial times are shown in Fig. 3. The success rate for the first 20 trials on the nerve phantom was 90% with an average time of 95.2 s with a standard deviation of 49.9 s. The data was analyzed using linear regression and a trend line with a slope of -5.5 s was found, denoting that the anesthesiologist was able to perform a block 5.5 seconds faster with each successive attempt that was made. The failures in these trials were identified to be due to improperly aligning the tip of the needle with the center of the ultrasound probe. Further tests performed by another anesthesiologist resulted in a 100% success rate.

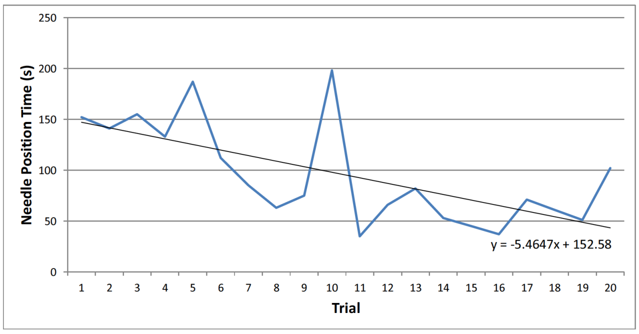


Fig. 3. Blue: block times for first 20 phantom trials of the Magellan system. Black: trend line and equation.

IV. CONCLUSION

We present the first mechanical robotic system specifically designed to perform nerve blocks using a joystick and computer control center. Using the Magellan, a 90-100% success rate was achievable using a standard nerve block phantom. In addition, a rather steep learning curve was determined indicating great ease of learning to operate the nerve block needle using a joystick with rapid improvement of the operation times of the Magellan.

A study of anesthesia residents studying regional anesthesia techniques showed a success rate of 89% for ultrasound-guided nerve blocks after performing 40 blocks on patients [6], showing a similar success rate between the nerve phantom tests performed with Magellan and success rates by anesthesia students.

Clinical tests will show whether the success rates achieved in dummy testing can be confirmed in human testing; further research needs to focus on automated nerve recognition, as well as automated nerve block performance – without human intervention. Combining these two approaches, a completely automated nerve block system will be possible.

ACKNOWLEDGMENT

The authors would like to acknowledge the Department of Anesthesia in the Montreal General Hospital for their financial support of this project.

REFERENCES

[1] W. S. Halsted, "Practical comments on the use and abuse of cocaine," *New York Medical Journal*, vol. 42, pp. 294–299, 1885.

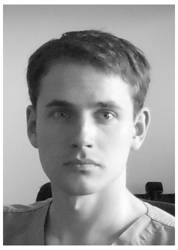
[2] P. Marhofer and V. Chan, "Ultrasound-guided regional anesthesia: current concepts and future trends," *Anesthesia & Analgesia*, vol. 104, no. 5, pp. 1265–1269, 2007.

[3] D. Willis, M. Gonzalgo, M. Brotzman, Z. Feng, B. Trock, and L. Su, "Comparison of outcomes between pure laparoscopic vs robot-assisted laparoscopic radical prostatectomy: a study of comparative effectiveness based upon validated quality of life outcomes," *BJU international*, 2011.

[4] P. Tighe, S. Badiyan, I. Luria, A. Boezaart, and S. Parekattil, "Robot-assisted regional anesthesia: A simulated demonstration," *Anesthesia & Analgesia*, vol. 111, no. 3, pp. 813–816, 2010.

[5] P. Kazanzides, "Safety design for medical robots," in *Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE*, Sept. 2009, pp. 7208 –7211.

[6] C. Luyet, G. Schupfer, M. Wipfli, R. Greif, M. Luginb&, U. Eichenberger *et al.*, "Different learning curves for axillary brachial plexus block: Ultrasound guidance versus nerve stimulation," *Anesthesiology research and practice*, vol. 2010, p. 309462, 2010.



Joshua Morse is currently an undergraduate student in the Department of Computer Engineering at McGill University, Montréal, QC, Canada.

In 2010, he joined the Intelligent Technology in Anesthesia Group (ITAG) as a research assistant. His research interests include robotic anesthesia, telemedicine and bioinformatics.

Mohamad Wehbe received the B.Sc. degree in biomedical engineering from the American University of Science and Technology, Beirut, Lebanon, and the M.Sc. degree in biomedical engineering from the École Polytechnique de Montréal, Montréal, QC, Canada, in 2006 and 2009, respectively.

In 2010, he joined the department of Experimental Surgery at McGill University, Montréal, QC, where he started working toward the Ph.D. degree in the Intelligent Technology in Anesthesia Group (ITAG). His research interests are focused on intelligent biomedical devices and robotic anesthesia.

Riccardo Taddei received the MD degree from the Faculty of Medicine and Surgery, University of Pisa, Pisa, Italy in 2008.

During 2011, he worked as a research fellow in the Department of Anesthesia in the Montreal General Hospital, McGill University, Montreal, Canada. He is currently a third year resident in the department of Anethesiology and Intensive Care in Cisanello Hospital, University of Pisa. His research interests include automation in anesthesia.

Shantale Cyr holds a PhD degree from the University of Montreal, Montreal, Canada.

Since 2007, she has worked as a research associate in the ITAG laboratory, Department of Anesthesia in the Montreal General Hospital, McGill University, Montreal, Canada. Her research interests include closed-loop anesthesia, device design and user interaction and telemedicine.

Thomas M. Hemmerling received the MD degree from the Faculty of Medicine, University of Saarland, Germany, in 1990. He leads the ITAG laboratory, Department of Anesthesia, McGill University. He is currently an Associate Professor in the department of Anesthesia at McGill University and the Institute of Biomedical Engineering at the University of Montreal, Montreal, Canada. His research interests are automated and robotic anesthesia.

© 2013 ACADEMY PUBLISHER