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Feasibility of Intercity and Trans-Atlantic Telerobotic Remote Ultrasound

Assessment Facilitated by a Nondedicated Bandwidth Connection

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ABSTRACT

We discuss the concept of ultrasound imaging at a distance by presenting the evaluation of a customized, lightweight, human-safe robotic arm for low-force, long-distance, telerobotic ultrasonography. We undertook intercity and trans-Atlantic telerobotic ultrasound simulation from master stations located in New York, New York and Munich, Germany, and imaged a phantom and a human volunteer located at a slave station in Burlington, Massachusetts, using standard Internet bandwidth <100 Mbps and <50 Mbps, respectively. The data from the robotic arm were tracked for understanding the time efficiency of the human interactions at the master stations. Comparison of a beginner in ultrasound operation with a professional sonographer revealed that although proficiency in using ultrasound was not a prerequisite for operating the robotic arm, previous experience in using clinical ultrasound was associated with progressively lower probe maneuvering time and speed due to an enhanced ability of the veteran operator in adjusting the finer angular motions of the probe. These results suggest that long-distance telerobotic echocardiography over a local nondedicated Internet bandwidth is feasible and can be rapidly learned by sonographers for cost-effective resource utilization. (J Am Coll Cardiol Img 2014;7:804–9) © 2014 by the American College of Cardiology Foundation.

Clinical applications of ultrasound have grown and become an integral part of contemporary clinical medicine. In addition to diagnostic applications, ultrasound is widely used for procedural planning, guidance, and patient monitoring. However, the obvious advantages in safety, cost, and portability of ultrasound systems are offset by the need for education and training for providing high-quality examinations and proper interpretations. This is particularly relevant for clinical assessments in underserved areas (where resources and skills are limited), evaluation of patients with complex disease (such as guidance for acquired structural and congenital heart disease interventions), and workflow-related scenarios (such as performance of ultrasound imaging after-hours).

Improvements in computer and digital technology have revolutionized the storage, transmission, and interpretation of medical images, including ultrasound, allowing images to be reviewed at remote locations (1). The combination of digital imaging and telerobotics may expand the use of ultrasound even further, allowing an expert to perform an examination from a distance, virtualizing both ultrasound image acquisition and interpretation. The robotic arm of the telerobotic ultrasound system must be intrinsically safe for patient interaction (i.e., limited in weight and force-generation capability), able to hold a stable contact position on the body, and able to be manipulated

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with very fine adjustments through the necessary degrees of freedom for optimizing image quality.

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It will require safety systems that prevent accidental movement of the probe or robotic arm, and it must be able to provide the operator with precise spatial location (e.g., infra-red localization) and force-feedback (e.g., pressure sensors, haptic). Although robotic ultrasound systems have been under investigation for a long time, most were developed as guidance systems for surgical procedures. Recent technological advances and cost reductions in robotic hardware and control systems have enabled development of affordable and effective telerobotic ultrasound systems to cater to broader clinical practice. These updates will help bring much-needed resources and expertise to remote (e.g., rural, frontier) and dangerous (e.g., battle zones) locations and expand the applicability of community screening procedures (e.g., carotid intima-media thickness and plaque imaging), which are currently largely constrained by the availability and throughput of trained operators. In addition to remote locations, tele-echocardiography can aid practice within institutions, providing timely studies for patients who are hospitalized or waiting in emergency triage locations. Moreover, it could also allow the cardiologists to collaborate virtually and on-demand during advanced procedures (e.g., elective cardiac structural interventions). During the structural interventions performed under fluoroscopic guidance, the ability to hold an ultrasound probe in a stable position over prolonged periods may be particularly helpful in reducing undue radiation exposure.

There are several factors that may affect the performance of remote telerobotic ultrasound. First, exercising remote control of electromechanical systems through software over long distances requires optimal bandwidth. The majority of systems in the past have advocated the use of a high-bandwidth, dedicated telecommunication line or a dedicated high-speed terrestrial fiberoptic network for remote operations, which may limit applicability (2). Although the Internet is low-cost and widely available, there are few data on using it with nondedicated bandwidth for long-distance telerobotic ultrasound. Second, remote telerobotic ultrasound is dependent on the intrinsic capabilities of the robotics, as well as the human factors that influence the interaction with the control systems and the software interface. The robotic arm does not perform the examination but simply acts as an extension for mechanizing the remote operator's intentions. The amount of training required for successful navigation of the remote robotic arms over the Internet by clinical personnel may vary. In particular, it is unclear whether experience with clinical ultrasound will affect the performance of steering the ultrasound probe with a robotic arm.

In May 2013, we used a new prototype medical telerobotic ultrasound system and tested the feasibility for long-distance imaging over local Internet service. A vascular ultrasound phantom at a slave station in Burlington, Massachusetts (near Boston), was imaged successively from 2 long-distance master stations, 1 created in New York, New York and 1 at a trans-Atlantic site in Munich, Germany. We also examined the blinded interactions of a beginner sonographer and an expert sonographer in their operation of the robotic arm's software control system to determine the learning curve for the control system and understand the nuances of robotic arm motion that correlated with the overall efficiency of remote ultrasound probe navigation.

ABBREVIATIONS AND ACRONYMS

CCA = common carotid artery

eHealth = electronic health

mHealth = mobile health

THE SLAVE STATION

The telerobotic platform (TeleHealthRobotics, Chicago, Illinois) had several core components including a lightweight (2.0 kg), 7-degree-of-freedom, servo-actuated robotic arm (Cyton Gamma configuration, Energid Technologies Corporation, Cambridge, Massachusetts) (Fig. 1). The arm was capable of (low) 1.5 kg payload, low force, and composed of minimum power servos operating at its joints. The robotic arm

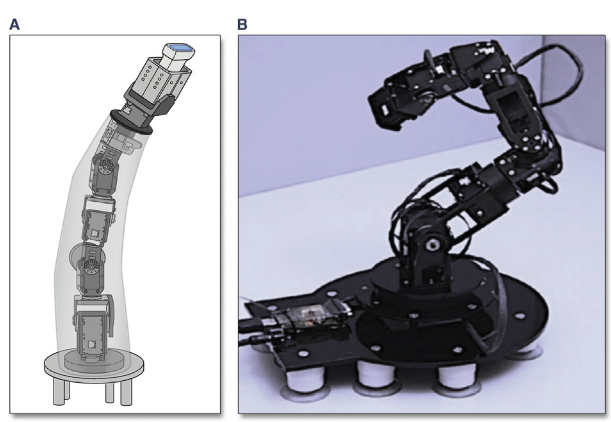

FIGURE 1 Design of the Robotic Arm Used at the Slave Station

(A) The intended design and **(B)** the actual appearance of the 2-kg, 7-degree-of-freedom, modified Dynamixel servo-actuated Cyton Gamma robotic arm customized with an end effector holder for a vascular ultrasound transducer. Note that the final design for human trials currently underway has a cloth cover that serves as an electrical, wire, and splash guard for the device.