Ebolabot: Progress toward a Tele-nursing Robotic System for Ebola Patient Treatment

Zhi Li[1] and Kris Hauser[2]
Department of Electrical and Computer Engineering, Duke University, Durham, NC, 27708
Email: [1] zhi.li2@duke.edu; [2] kris.hauser@duke.edu

I. Introduction

Healthcare workers, including nurses, EMTs, and aid workers, are exposed to highly infectious viruses when attending Ebola patients. Infection risk is significantly increased due to their routine and/or repetitive clinical duties, including removing personal protective gear, and handling contagions and other bio-hazards. These risks can be reduced by developing a tele-nursing robotic system, which reduces the frequency and duration of personnel's exposure to hazardous clinical areas, and potentially make available more healthcare workers that can attend Ebola patients via teleoperation. The use of such a tele-nursing system would not be restricted to Ebola treatment, but would also be generally applicable to other highly-infectious diseases. Developing such a system fosters an integration of recent robotic research progress in the fields of mechanical design, sensors, motion planning & control, and human-robot interaction, and may further contribute to advance human-guided/controlled robots for household service and material handling in industry and logistics.

In previous research, robots have been demonstrated assisting in elder and disabled care in homes and hospitals [1], and for replacing rescuers to access dangerous and hazardous sites [4]. The major challenge in developing tele-nursing robotic system is usability. Medical robotic systems are generally difficult to control for complex manipulation tasks, even with training and high-fidelity robots and input devices [2]. Furthermore, concerns about patient safety and robot approachability in close human-robot interaction add to the difficulties of system development and integration [5].

This project (NSF Award IIS-1513221) proposes a tele-nursing robotic system that attends patients with highly infectious diseases. We focus making the system human-safe, versatile, usable by novices, rapidly assembled, and relatively inexpensive. Thus, we integrate a mobile manipulator robot, nick-named Ebolabot, using an off-the-shelf humanoid robot and an omnidirectional mobile base. This Ebolabot is remotely controlled via an operator console with a variety of input devices including a telepresence screen, haptic devices, and traditional mouse & keyboard. It also serves as a research platform for developing operator assistance modules that fully or partially automates tedious and error-prone tasks, and reduces user training time. This paper describes our plans and preliminary efforts toward developing the Ebolabot system.

II. Proposed System

A. Hardware

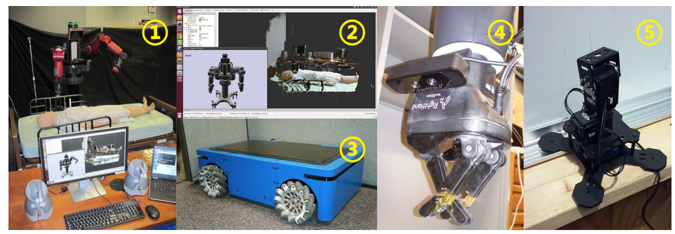

Fig. 1: Hardware components of the proposed tele-nursing robotic system: (1) Ebolabot and its current operator console; (2) operator console GUI; (3) omnidirectional mobile base; (4) compliant gripper augmented with 3D camera; (5) precise positioning unit.

Fig. 1 shows the major hardware components of Ebolabot system. The robot manipulator Rethink Robotics Baxter, a humanoid robot with a torso and two arms, is chosen for its capability to conduct the light-to-moderate duty tasks expected of patient care. Two three-fingered compliant grippers (Right-hand Robotics Reflex Hands) are attached as Ebolabot's hands. The Ebolabot will be mounted on an HStar Technologies AMP-I mobile base for omnidirectional navigation.

1) Sensors: Ebolabot is designed to operate in cluttered environment. Close physical interaction with patients also intensively demands sensory feedbacks to ensure task accuracy and safety. The Baxter robot comes with ultrasonic rangefinders to avoid humans around the robot, and torque sensors on the arm to detect collision. The mobile base has two LIDAR depth sensors (Hokuyo URG-04LX) for ground obstacle avoidance. In addition, the Ebolabot is augmented with one Microsoft Kinect 2 in front of its chest, and two Creative Senz3D depth and gesture recognition cameras at its wrists. All of them contribute to building 3D maps.

2) Precise Positioning Unit: The Baxter robot has end effectors with cm-level accuracy. It is not capable of performing task like instrument pressing and needle insertion, without the augmentation of a precise positioning unit. The precise positioning unit in Fig. 1 will be augmented to Baxter robot for mm-level accuracy. In addition, Takktile tactile sensors may be mounted on the grippers' fingers if such sensory feedback can significantly improve manipulation capabilities.

3) Operator Console: The operator console supports the control of Ebolabot and communication between operator and patient. The control GUI enables switching controller states via mouse, keyboard, and buttons on the haptic device styluses. It displays the robot's cameras, 3D maps, robot status, and will potentially assist the operator by suggesting manipulation pathes and marking safety regions. Currently, the operator console has two 6-DOF haptic devices (Geomagic Touch) for tele-operating the Ebolabot. Additional input devices (e.g., 3D mouse, sliding joint controller, robopuppet, etc.) will be added and their manipulation capabilities will be compared. The operator console is connected to Ebolabot using Ethernet cable. Internet access is not necessary unless the operator is not available immediately outside the quarantine area. Operator and patient communicate via webcam & microphone, using two Google Nexus 9 tablets, one attached to the Baxter's face screen, and the other with the operator.

4) Accessories: Additional protective coverings will protect the robot hardware from contamination and liquid spills. For reusability and easiness to clean, Candidate designs can either be flexible, inexpensive, disposable plastic coverings, or sealed rigid surfaces that can be disinfected via UV light or autoclave.

B. Software

An operator assistance module will developed to relieve users from tedious repetitive tasks, and to enable tasks that would be otherwise impossible to control via human hands. Preferably, this assistance module should lower the learning curve, improve usability and reduce user error impact. With adjustable autonomy [3], users can choose the desired level of assistance, ranging from no assistance to high-level supervisory control. Low-level assistance will take advantage of existing softwares (e.g., the Klamp't motion planning package) for tremor filtering, Cartesian end effector control, enforcing actuator limits, and collision avoidance. High-level assistance will be developed to support automation of procedural tasks, human-guided or point-and-click grasping, and visual scanning. Mobile base navigation algorithms in cluttered environments will be added to the assistance module. Motion control strategies based on study human handover tasks will be implemented for seamless robot-patient handover.

An operating console GUI will be developed with novice, nontechnical users in mind, to reduce the training time to the order of minutes to a half hour. To avoid cognitive overload, the GUI will translate raw user input into robot motion, and provide parsimonious feedback to the operator. Candidate feedback channels, including video streams of different cameras, a 3D display of the robot's cognitive map, and haptic feedback during teleoperation, can be toggled according to the user's need. Cameras and 3D display synchronization will be studied.

C. System Evaluation

Table I shows the clinical tasks that Ebolabot system aims at, with their estimated technical difficulties. To validate our system evaluation plan, we will consult with medical professionals at the Duke University School of Nursing (DUSON) to establish a priority list of clinical tasks expected of a nurse in an Ebola quarantine area. A primitive clinic-like testing environment has been setup in the lab (as shown in Fig. 1).

Targeted Task	Estimated Difficulty
Verbal and visual worker-patient interaction	Easy
Decontaminate workers with disinfectant spray	Easy
Push wheeled carts	Medium
Press buttons on instruments	Medium
Object handoff with human coworkers	Medium
Instrument tray prep	Medium
Bring food, water, and medication	Medium
Take blood pressure	Medium
Administer oxygen	Medium
Insert IV needles	Hard
Change IV drip bags	Hard
Sample collection	Hard
Clean up bodily fluids	Hard
Change patient clothing	Very Hard

TABLE I: Candidate clinical tasks and their estimated technical difficulty.

III. Current Progress and Future Work

Ebolabot system has had its major hardware components integrated. The operator console can display 3D camera feedback and robot status, and supports teleoperation of Ebolabot hand position and orientation using Geomagic Touch haptic devices. A slider controller is developed to control individual joint. Smooth trajectories can be planned and executed by the robot hands. Control of the mobile base using a wireless joystick has been tested. Research on human-to-human handover is in progress, which aims to predict the end time and position of human hand, so that the robot can give and/or receive objects from a patient seamlessly.

In future work, we will invite medical professionals to operate the Ebolabot to perform clinical tasks on the patient-care in our in-lab testing environment, and provide feedback on user experience on manipulation capability and the user interface, so that we can changes improve its usability. After several rounds of in-lab system evaluation and modification, we will compare task performance with and without Ebolabot system, to validate system efficiency in nursing tasks, and test Ebolabot system in simulated hospital in nursing school, by users with different levels of nursing experience.

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