

Telepresence Robots for Dynamic, Safety-Critical Environments

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ABSTRACT

Robots are being introduced into dynamic, safety-critical spaces, like emergency departments (EDs). In EDs, healthcare workers (HCWs) must manage multiple tasks while making decisions that directly affect patient outcomes. If robots are not well-situated in EDs, they could exacerbate existing problems and increase the risk of patient harm. Our work explores how robots can integrate into these spaces to support HCWs. We investigate important factors for situating robots in EDs without disrupting workflow, explore how to support HCWs during interruptions, and develop methods to increase safety and reduce errors during robot control. By informing the development of robots that are designed for safety-critical spaces, we hope to increase access to care and reduce patient harm.

CCS CONCEPTS

• **Computer systems organization** → **Robotics**; • **Human-centered computing** → **Interaction design**.

KEYWORDS

Human-Robot Interaction, Robotics, Healthcare robotics, Teleoperation, Telemedicine, Emergency Medicine

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1 INTRODUCTION

Emergency departments (EDs) are fast-paced, complex, uncertain environments. They vary considerably, with different patient demographics, space constraints, and noise levels. Even within a single department, these factors may vary unpredictably [5, 20, 35]. ED healthcare workers (HCWs) simultaneously perform multiple tasks that directly affect patient outcomes. They are also interrupted as often as every six minutes on average [8, 22, 32], which allows for fluid information flow, but can lead to preventable patient harm, decreased patient satisfaction, and increased HCW stress [33, 34].

In light of the COVID-19 pandemic, interest increased in robotic applications in hospitals [23, 27, 28, 30, 31], many in telemedicine

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Figure 1: Our work explores designing robots for safety-critical environments, like the ED, to support remote teleoperators. We provide insights into how robots integrate into these spaces without disrupting workflow.

[26]. Researchers have explored telepresence robots in many settings [2, 6, 17, 25], and they can promote safety by enabling HCWs to interact with infectious patients remotely, and potentially reduce their workload by assisting with less critical tasks. They could also increase access to specialists for patients in underserved areas [15].

However, there are many challenges to introducing robots into EDs. Most telepresence robots were not designed with EDs or hospitals in mind and cannot be customized. This can make them difficult to use since HCWs need the system to fit within their unique care delivery setting [10, 29]. Furthermore, ED HCWs often experience high cognitive workload and will inevitably be interrupted while operating these robots. Robots that are not designed for these variable, interruption-driven environments could exacerbate existing problems and cause errors or delays, which, due to the safety-critical nature of EDs, could lead to grave harm or death for patients.

Our work informs the design of robots in safety-critical spaces to support overburdened HCWs and reduce the risk of patient harm. We present three main contributions. We identify important factors for integrating robots into EDs, explore how robots can support operators when they are interrupted, and develop new methods to better support users and reduce the risk of errors while using the system. This will enable safer, more robust human-robot interaction (HRI), which could decrease errors that lead to patient harm.

2 OUR WORK TO DATE

For several years, we have collaborated with colleagues in the ED to design robots that support overburdened HCWs.

2.1 Designing Telepresence Robots for EDs

Our first foray into this area was to explore how to situate robots in the ED without disrupting HCWs' workflow. We wanted to develop an open-source telemedicine robot that ED HCWs found usable and understand what factors are important for robot integration into EDs. We iterated on the robot's design with ED collaborators. We evaluated the system with 15 ED HCWs, most of whom had little to no experience with robots. The participants (average age 35 years) had 1-30+ years of experience working in a variety of EDs. They

remotely teleoperated the robot in the ED, and conducted a patient interview and exam with a mock patient (a researcher).

All participants were able to complete the patient interview and exam, and revealed further considerations for deploying telemedicine robots in EDs. Participants emphasized the importance of integrating robots into their existing workflow to avoid adding to their already high cognitive workload. They also suggested use cases we had not previously considered, such as enabling HCWs to provide more compassionate care or allowing them to multitask more easily.

Based on participants' feedback, we developed seven design recommendations for deploying robots in EDs. For instance, robots should lower the cognitive burden of HCWs by being easy to learn and use; support adaptability in the system to allow HCWs to customize it to better fit different healthcare settings; and cultivate familiarity and trust so people from different backgrounds feel comfortable using and interacting with the robot [20].

2.2 Supporting Interrupted Users

From discussions with ED HCWs, we knew HCWs operating robots will likely be interrupted and need to manage multiple tasks at once. Thus, robots must be thoughtfully designed to integrate into EDs without exacerbating the effects of interruptions. HRI researchers have explored how to mitigate the impacts of robot-induced interruptions [1, 3, 4, 7, 12, 14], but we still do not understand mitigation strategies for interruptions from other people.

We explored how telemedicine robots might mitigate the effects of interruptions and support people in interruption-driven environments. We focused on mobile telemanipulator robots (MTRs). We created a realistic simulation prototype in which a HCW conducted a patient exam via Stretch [16]. Through insights from HCWs and the literature, we designed three realistic interruptions that ranged from less urgent (discharging a patient) to very urgent (attending to a critical patient). They occurred during distinct task contexts: interpersonal interaction, physical manipulation without direct interaction, and physical interpersonal interaction. We designed behaviors for the robot to perform during interruptions. Afterwards, the robot displayed a prompt to reorient them to the primary task.

We recruited 12 ED physicians (average age 38 years) who had 1-20+ years of experience in different hospitals. Participants completed the simulation, and then we conducted semi-structured interviews to better understand their decisions and thoughts on how the robot might support them during interruptions.

Participants provided valuable insights on how MTRs might support people in environments with frequent task switching and the place of autonomy in safety-critical spaces. Participants generally thought the prompts after interruptions helped quickly reorient them. Participants were also concerned about when it might (not) be appropriate to use the robot, and most did not want to use it for more safety-critical tasks, like attending to an unstable patient.

Participants also felt it was important that the robot help make them more efficient. They imagined the robot enabling them to multitask by performing certain tasks, like navigation, autonomously while they attended to other tasks, or by allowing them to quickly switch between the robot's interface and tasks on their computer. However, as one participant suggested, these robot capabilities could encourage HCWs to task switch more than they currently do, which can increase cognitive load and errors [34].

Our work informs the HRI community on broader implications of appropriately designing MTR behaviors for integration into HCW workflow. These contributions provide a basis for developing robots that are well-situated in EDs, promote patient safety, and support HCWs experiencing high cognitive workload [19].

3 ONGOING AND FUTURE WORK

Our work to date provides guidelines for situating robots in EDs and reducing workflow disruptions. It indicates that HCWs will inherently attempt to complete multiple tasks at once. This could lead to errors while controlling the robot. Thus, robots must be able to support them and enable them to do this as safely as possible.

We are designing new methods to enable HCWs to more safely teleoperate robots, even when experiencing high cognitive workload. Shared control systems assist users in controlling robots and have shown promise in many applications, including robot-assisted feeding, manufacturing, and autonomous driving [18, 21]. However, current methods generally assume the operator only pays attention to the task they are completing with the robot. We expect HCWs to manage multiple tasks while using robots, so we will explicitly account for their shifts in cognitive workload as their tasks change.

In developing this shared control method, we are mindful of the potential for unintended negative outcomes. We do not want to encourage users to multitask more than they currently do or contribute to worker displacement, as this could increase the potential for errors, burnout, or preventable patient harm. Thus, throughout our method development, we will continue to consult with ED stakeholders and use their input to incorporate features to encourage safe robot usage when under high cognitive workload.

Our new method, Workload Informed Shared Autonomy for Remote, Distracted operators (WISARD), will estimate a user's cognitive workload via physiological signals, such as heart rate variability [13]. As workload increases, we will shift control authority to the robot using blending techniques that are common in shared control, with different parameters for navigation and manipulation [9, 11, 24]. We will also enforce stricter safety constraints. These can be implemented via boundaries, such as virtual fixtures, that prevent the robot from getting too close to objects or people. As a user experiences higher workload, we could expand the size of the virtual fixtures to reduce the risk of collisions.

We will evaluate WISARD on Stretch, which we will deploy in a medical simulation center. HCWs will perform several key tasks, including interpersonal interaction and physical manipulation. During these tasks, we will simulate the high cognitive workload they typically experience, such as monitoring several sources of information and managing multiple tasks at once. We will measure the number of errors that occur, how close they come to colliding with obstacles, and the perceived usability of the system.

By accounting for HCWs' cognitive workload and the interruption-driven nature of the ED, the methods we develop could allow robots to appropriately support HCWs in EDs. By closely working with ED stakeholders and designing for dynamic, safety-critical environments, this work will inform the development of robots that enable improved access to care and reduced patient harm. It also has implications for other dynamic settings, including autonomous driving, manufacturing, and disaster zones.

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