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Social Robotics for Nonsocial Teleoperation: Leveraging Social Techniques to Impact Teleoperator Performance and Experience

Daniel J. Rea [1,2] · Stela H. Seo [3] · James E. Young [3]

Abstract

Purpose of Review Research has demonstrated the potential for robotic interfaces to leverage human-like social interaction techniques, for example, autonomous social robots as companions, as professional team members, or as social proxies in robot telepresence. We propose that there is an untapped opportunity to extend the benefits of social robotics to more traditional teleoperation, where the robot does not typically communicate with the operator socially. We argue that teleoperated robots can and should leverage social techniques to shape interactions with the operator, even in use cases such as remote exploration or inspection that do not involve using the robot to communicate with other people.

Recent Findings The core benefit of social robotics is to leverage human-like and thus familiar social techniques to communicate effectively or shape people's mood and behavior. Initial results provide proofs of concept for similar benefits of social techniques applied to more traditional teleoperation; for example, we can design teleoperated robots as social agents to facilitate communication or to shape operator behavior, or teleoperated robots can leverage knowledge of operator psychology to change perceptions, potentially improving operation safety and performance.

Summary This paper provides a proposal and roadmap for leveraging social robotics techniques in more classical teleoperation interfaces.

Keywords Teleoperation · Social design · Interface design · Survey · Discussion

Introduction

There is an untapped opportunity to leverage social human-robot interaction techniques in traditional teleoperation interface design as a new way to shape interaction and operator performance. The field of social human-robot interaction has highlighted how people can embrace social interfaces as a natural feeling and easy-to-understand paradigm [1], with results indicating a broad range of benefits including increased user comprehension of robot communication [1–3], engagement [4•], motivation [5], and task performance [6]. This follows the well-established computers-as-social-actors paradigm [7], recently emphasized by the proliferation and acceptance of voice-based digital assistants. In this paper, we highlight how traditional teleoperation interfaces can likewise benefit from social design.

In teleoperation, the use of social interaction techniques has yielded similar benefits for supporting robot-mediated interaction with other people, such as telepresence [8, 9]. However, more traditional teleoperation applications such as inspection

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✉ Daniel J. Rea
daniel@robot.soc.i.kyoto-u.ac.jp

Stela H. Seo
stela.seo@cs.umanitoba.ca

James E. Young
young@cs.umanitoba.ca

[1] Department of Social Informatics, Kyoto University, Kyoto 606-8501, Japan

[2] Faculty of Computer Science, University of New Brunswick, Fredericton, NB E3B 5A3, Canada

[3] Department of Computer Science, University of Manitoba, Winnipeg, MB R3T 2N2, Canada

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or exploration, where the operator does not interact with other people through the robot, have yet to see widespread integration of social robotics methods.

We draw a link to video games, which share similarities with teleoperation: a gamer (the operator) similarly controls an avatar (like a robot) using a computer interface [10•]. In games, social techniques relating to controlling the avatar are widespread as a means to increase engagement, elicit social responses from the user, and encourage behavior patterns; game designers explicitly manage these techniques to shape user experience and action [10•] (Fig. 1). For example, there may be virtual co-pilots, on-board AI, or other techniques to facilitate social communication, shape empathy, and influence behavior. Pragmatically, and relevant for our application, these methods can also be used to support operator awareness, sustained motivation, performance, and more [11, 12]. Given the similarities between controlling an avatar or vehicle in a video game and remotely operating a robot [10•], we note that the success of social techniques in video game avatar control motivates the investigation of their use in teleoperation.

This paper establishes a link between potential benefits of social robotics approaches and application to inherently non-social teleoperation tasks. We develop a clear vision for how social robotics techniques can be used pragmatically to support teleoperation and operators, via shaping operator perceptions, emotions, and behavior. We present design avenues for social robotics in teleoperation: positioning the robot itself to be seen by the operator as an agent, including a virtual agent co-pilot, and having the robot monitor and model the operator mental state and mood to inform its social interactions.

Why Social Interfaces for Teleoperation?

Human-robot interaction has established a range of potential impacts of social interfaces. Of particular relevance to teleoperation is improved communication and shaping a person's mood and behavior.

Improved Communication

To successfully teleoperate a robot, an operator needs to monitor and understand a great deal of information while providing complex commands, all in real-time [12–14]. One design theme used to mitigate these issues is to create abstractions and easy-to-interpret visualizations and widgets to reduce cognitive effort (e.g., [15–17]). Relating to this, a standard approach in social robotics is to leverage the human capacity

Fig. 1 Video games leverage social communication techniques to shape gamer (i.e., operator) experience, mental state, and actions. **a** Two agents engage in a heated exchange, emphasizing the weight of the player's next decision (Mass Effect 2, BioWare, 2010). **b** A health indicator face reacts to injury to build empathy and shape player behavior and engagement (Kingdom Hearts Series, Square-Enix, 2002–2019). **c** A computer-controlled agent brings the player's attention to a nearby objective (StarFox, Nintendo, 1993)

a) Two agents engage in a heated exchange, emphasizing the weight of the player's next decision (Mass Effect 2, BioWare, 2010)

b) A health indicator face reacts to injury to build empathy and shape player behavior and engagement (Kingdom Hearts Series, Square-Enix, 2002-2019).

c) A computer-controlled agent brings the player's attention to a nearby objective (StarFox, Nintendo, 1993).

to quickly and intuitively process social interactions, by designing robots to communicate using human-like social methods [18•] through visual [19, 20], aural [21, 22], or haptic methods [23, 24], ostensibly increasing how much the person can process and understand [25]. While such abstractions may not fully represent underlying data (e.g., specific error codes), it provides a quick an intuitive communication channel.

Social robotics has been successful in applications where people are collocated with an autonomous robot, for example, where the person can directly read the robot's gestures, characteristic motions, facial expressions, etc., to read information and robot state [3, 26, 27]. Social signals can further be adapted and personalized to the user to increase trust and improve communication over time [22, 28, 29]. We suggest using similar approaches even when the person is not collocated with the robot and when the robot is not autonomous, as in teleoperation.

Further, people can use their existing social skillsets to naturally give commands to social robots such as by using gestures, voice tone, and pointing [19, 30, 31]. This reduces the need for the person to learn or use an intermediary communication technique, supporting comfort and ease of use [7, 32, 33]. For example, modern digital assistants have helped demonstrate how well-designed voice commands can increase accessibility and ease of use, as well as improve overall experience [34•].

Thus, we argue that teleoperation can and should likewise use this "social bandwidth" [25] alongside more commonly targeted cognitive abilities (such as map reading), to increase the operator's ability to intuitively understand and control robots. Only a few initial projects have begun to extend this approach to social interfaces for teleoperated robots, providing evidence for our proposed broad approach [2, 35]. However, we advocate for increased focus given the potential for social interfaces to mitigate core teleoperation challenges.

Shaping Mental State and Behavior

Operator workload is a core consideration of teleoperation [11, 12], often measured via self-report measures relating to feelings of work demand (e.g., cognitive and physical) and frustration (e.g., NASA TLX [36]). We note that such measures are intimately linked with a person's more general mood, enthusiasm, engagement, and motivation. These in turn can have effects on human behavior and performance [37–40].

People have natural tendencies to engage with robots as social entities, even when the robot is not designed to be anthropomorphic or zoomorphic [1, 18]; such designs are used to accentuate and leverage these tendencies. Thus, a key theme of social robotics research has been to leverage related social interaction techniques [2, 18, 41], social structures, and constructs [42, 43] to influence a person's thoughts, mood, and even their behavior. Example results include increasing a person's task engagement (e.g., [44, 45]), performance (e.g., [46, 47]), motivation (e.g., [48]), comfort (e.g., [49]), willingness to use robots again [1], and more [18•]. Further, social techniques can affect how someone perceives a robot, including trust in the robot [28, 50–52] and perception of a robot's abilities [53, 54]. These are all desirable teleoperation qualities [11, 12, 55], and we argue it is worth investigating how to purposefully employ social techniques in teleoperation design to influence the operators mental state and behavior, to support teleoperation.

All of this builds on the relationship between operator stress, engagement, and workload and their ability to sustain learning and working with a robot in the long term [56]. Thus, natural user interfaces that are perhaps more comfortable and intuitive to use [7, 32], such as the recent trend of digital personal assistants using voice to improve overall experience [34•], or in-car GPS devices conveying abstract navigational information in social means [33], can be expected to relate to operator stress, mental state, and therefore performance.

Challenges and Drawbacks

There are potential drawbacks, dangers, and other challenges with using social techniques for teleoperation. A simple reality is that poor social design can be annoying and distracting: social-focused interfaces in commercial products have sometimes been met with consumer derision, low popularity, and user performance [57, 58]. In some cases, social interfaces can *increase* cognitive load, such as when listening to a social in-car navigation system while driving [59]. Perhaps the key is to have social interfaces for meaningful performance and experiential improvements, rather than simply being an engagement "gimmick."

Another aspect of the robots-as-social-actors approach is that these techniques may be used for manipulation [4•]. Prior work has demonstrated that how a robot is introduced to people can impact how acceptable they find it (e.g., for a telepresence robot [60••]), and our own work has applied a similar approach, demonstrating how information about a robot can be curated and presented to engineer operator expectations and beliefs about robot capability, irrespective of actual ability [53]. Other examples include how a robot can be designed to talk in ways to influence how people speak [61•] or can have authoritative influence over people due to perceptions in status [43] or style of movement [62•]. We must consider the potential for social interaction techniques, when applied to teleoperation, to be used in a deceptive or seemingly "underhanded" manner and influence people toward dangerous or questionable behavior.

Social Robotics for Nonsocial Teleoperation

Social robotics provides a range of potential benefits that we argue can be useful for traditional teleoperation tasks. In this section, we establish a clear vision and detail a range of pragmatic examples for how social teleoperation can be used to support and aid operators in teleoperation tasks. We structure this discussion around three methods we propose for social teleoperation: designing and presenting the robot itself as an agent, including a virtual agent "co-pilot," and monitoring social cues from the operator.

Teleoperated Robots as Social Agents

We can design a teleoperated robot, its interface, and its interactions in ways that encourage the operator to see the robot as a social agent. This contrasts with the typical perception of teleoperated robots as mechanical tools that are considered first and foremost in terms of their form and capabilities. It is important to note that designing the robot to be a social agent does not necessarily imply robot autonomy, but rather that the operator has the *impression* that they are directing and operating an interactive agent.

Designing teleoperated robots, such as for industrial inspection and repair, to support operators using social techniques, opens a broad range of interaction possibilities—that is, if the operator sees the robot as an agent, then the robot can engage in productive social behavior. For example, a robot agent could chat and banter with the operator to stave off monotony and boredom, supporting engagement and potentially improving interaction comfort (in a video game–like fashion). In face of an important event (e.g., a warning sensor), the agent can change the mood, perhaps with an abrupt stop in banter or altering voice tone, leveraging social contrast to increase saliency and draw the operator's attention and focus to pertinent information.

Such a personality could help bolster engagement and focus by congratulating the operator after a difficult task or offering words of encouragement after a mistake. As the task progresses, the agent can create a sense of time pressure by appearing cautious (to indicate that it is okay to slow down) or impatient (needs to hurry), to encourage related operator behavior patterns (e.g., as in [63••]). The agent can further act in ways that garner operator empathy to influence behavior (e.g., as in [35, 64]). For example, upon scraping against a rock, the robot agent could yell "Ouch!" in surprise or use other social signals (e.g., Fig. 2) to express pain, creating an emotional reaction in the operator to encourage more careful operation. With sustained damage, the agent could, for example, use a strained voice to provide an ongoing emotional reminder.

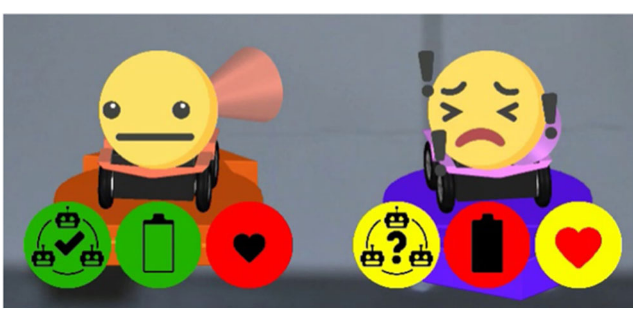

Fig. 2 Agents in the interface are used as a representative and summary of the robot's state. This leverages operator emotion recognition and empathy to understand, at a glance, how much attention they need to give to the robot (from [64••])

Designing the teleoperated robot as a social agent can further mitigate challenges relating to *mixed initiative* systems, where the robot autonomously takes control as needed to aid the operator (e.g., [65, 66]) and thus needs to clearly communicate why, how, and when it will take control. Designing the robot as a social agent provides an embodiment, context, and related social communication to provide transparency and awareness. For example, the agent could suddenly shout "Watch out!", looking scared and backing up, while pointing the camera at a dangerous hole; this clarifies to the operator why the action was taken.

The mixed-initiative autonomy itself could be purposefully designed using social interaction techniques to encourage desired operation behaviors. For example, if an operator unnecessarily takes control from the robot, the robot could try to encourage the operator to rely on it more in the future by acting stubborn or sulky, aiming to ultimately reduce operator workload.

In short, if we can design for operators to view teleoperated robots as agents—and not just tools—then this agent can use a wide range of social interaction techniques to support the operator and shape their teleoperation behaviors.

Virtual Co-pilot Agent

We can add a third-party agent to the interface—a virtual "co-pilot"—for social interaction. The key to this approach is that the agent is completely virtual and does not represent the robot (is conceptually disassociated from it), providing increased range of new complementary interaction possibilities.

As already explained, a social robotic agent can build operator empathy and garner emotional reactions; however, this may also result in undesirable emotional attachment and guilt if the robot gets damaged (as in [67•]). This may lead to a negative mood and anxiety when operating in dangerous situations where mistakes are inevitable. Operators may also become *too* careful, when they instead should be aggressive and take risks, such as in high-demand time-critical scenarios (e.g., nuclear reactor inspection), or search and rescue, where robots should be risked saving human lives. Using an agent co-pilot instead—disassociated from the robot—can still enable myriad social interaction techniques (via the co-pilot agent) without creating empathy toward the physical robot.

This co-pilot agent could further mitigate operator worry about the robot, for example, by being reassuring and calming after mistakes, reminding them that it is "just a machine," and encouraging more aggressive behavior (e.g., as in [35••]). This agent could alternatively still react in ways to mitigate risks given over-aggressive operator behavior [35••] (Fig. 3).

Fig. 3 An on-screen “virtual passenger” agent reacts to driving safety, using emotional dis-plays of anxiety in an attempt to create empathy and shape operator behavior (from [35••]). A screenshot from a working prototype, with facial emotion data from [94, 95]

A virtual co-pilot can also be useful when an operator is responsible for controlling multiple robots and regularly switches control between them. With each robot designed as an agent, switching likewise changes which agent the operator is interacting with. A virtual co-pilot would not change with this switch, increasing interaction stability. It could even support the transition by providing state summaries of the new robot and environment or draw attention to important information through action such as focusing intently on a map to indicate a point of interest the robot discovered while the operator was controlling another robot.

It may not be trivial to convince operators to see their robot as an agent (see section Teleoperated Robots as Social Agents). Giving a robot a social personality may conflict with existing mental models (and perhaps seem silly), particularly if an operator has existing interaction experience or technical knowledge. A disassociated virtual co-pilot may be more acceptable and thus a more appropriate path for integrating social interaction.

Similarly, a real robot has an existing physical form and capabilities that may limit the design of social interface. A virtual co-pilot could be given a face, voice, arms, or any arbitrary shape, even if no such components exist on the actual robot, avoiding conflict or inconsistency in how the robot is presented.

Thus, a virtual co-pilot, that is not associated with the robot itself, provides a range of complementary methods for integrating social interaction into teleoperation.

Reading Operator Social Cues

An integral component of social interaction is that it is a dialog between multiple actors; an agent (whether the robot or a virtual co-pilot) should likewise monitor, interpret, and respond to social cues from the operator. This includes leveraging natural input modalities such as operator voice and gestures (e.g., [21]) but also includes more subtle cues such as operator facial expressions (e.g., Fig. 4), voice tone, and other expressions relating to emotion (i.e., as well established in affective computing [68]). Thus, the agent should maintain awareness of the operator [69]; developing a model of the operator’s workload and mental state, including engagement, stress, and mood, will enable the agent to more appropriately when using social techniques to interact with the operator.

An agent that understands if the operator is stressed or has high cognitive load could, for example, adapt by slowing down the robot to reduce workload (e.g., [63, 70]) or simplifying visualizations to reduce the amount of information displayed (e.g., [16, 71]). Similarly, if the agent could know when the operator starts to show signs of boredom and disengagement, it could more aggressively employ social techniques to increase attention and focus.

Knowledge about the operator state can also be used in conjunction with sensor data, for example, if an operator is not reacting despite warning messages, or robot collisions, indicating a lack of attention, the agent could step up communication or step in with emergency measures (e.g., contacting a superior).

While developing a robot as an agent—or having a virtual co-pilot—is a powerful way to use social interaction to improve teleoperation, ultimately solutions will require a two-way dialog, with the agent both reading and exhibiting social behaviors.

Design Strategies to Create Teleoperation Agents

The prior sections provide a vision of how social robotics techniques can be used to support teleoperation. However, the question remains of how exactly to design and implement the agents themselves. In this section, we briefly discuss techniques for encouraging the operator to see the robot as an agent, for embedding a virtual co-pilot, and for monitoring social cues and model operator state.

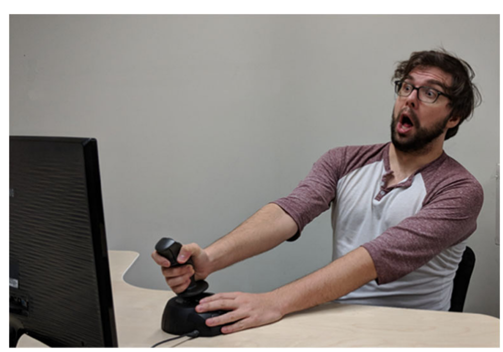

Fig. 4 An agent should read the operator’s face, posture, etc., using this information to adapt or take action to promote a safer attitude and reduce stress and workload (Courtesy of Daniel Rea, from [53••])

Design the Teleoperated Robot as an Agent

The straightforward way to encourage an operator to interact with a teleoperated robot as an agent is to specifically design the physical robot itself to encourage anthropomorphism. For example, it could be given arms or a face [72•], or a zoomorphic form, which shapes expectations on how it can be interacted with [54, 73]. Even if the robot itself (which may be remote) does not have these features, a picture or graphical representation could depict them (e.g., Fig. 2).

Another way to build a perception of social agency is to introduce or describe the robot to build expectations (e.g., [53••]) of its social abilities to encourage social interaction [54]. For example, one could simply call the robot an agent, talk about it using anthropomorphic language, or inform the operator that the robot has a personality.

The graphical interface itself could be modified, for example, with visual representations of the robot being altered to appear more anthropomorphic or animated (e.g., [64••], Fig. 2). Alternatively, the robot could be given a voice, perhaps disembodied if no on-screen representation is given.

Another strategy, well established in social robotics, is to modify otherwise mechanical motions to encourage anthropomorphism. How a robot moves (e.g., its path on a map) or performs actions (as shown via an on-screen 3D model of the robot) can be modified to convey emotion and personality [74, 75].

Finally, any actual robot autonomy, such as with semi-autonomous [76, 77] or mixed initiative [65, 66] systems, can be expected to promote a sense of robot agency. That is, when the robot acts autonomously, operators will naturally assign agency and related concepts (e.g., intelligence [78]) to those actions [55]. This autonomy could also extend to haptic interaction. For example, haptic feedback used for communication such as through the joystick [79, 80], a vibrating chair, or other types of equipment [81, 82] could be attributed to the robot's perceived autonomy (such as haptics in social human-robot interaction [23, 24]), further increasing the sense of agency.

How to Design Virtual Agent Co-pilots

Creating a virtual co-pilot is as simple as creating an on-screen character avatar, leveraging the large body of work from the Intelligent Virtual Agents community (e.g., [83, 84]). This agent could alternatively be disembodied, for example, speaking as a remote companion talking over radio. The agent should be designed to emphasize its disassociation with the robot, for example, by referring to the robot in the third person, such as saying "The robot's tire is punctured."

A co-pilot agent could instead leverage a physical embodiment, such as by being a robot companion robot sitting near the operator. This would allow similar freedom of design (not linked to the form of the operated robot) but leveraging social interaction possibilities of physical embodiment [85].

The virtual co-pilot does not need to be a fully interactive agent and instead can simply leverage one or more social interaction components, for example, using multiple on-screen facial expressions to visualize a high-level summary of operator driving safety [35••] (Fig. 3). Such a multiple agent or social display design can enable the designer to select the social modality based on what is most effective, instead of forcing a design to match an already existing virtual co-pilot.

How to Read an Operator's Social Communication and Signals

A wealth of technologies and research exist for sensing and monitoring a person's state and social communication (e.g., see [86–89]). Further, this has been broadly explored for use in HCI; for example, the use of gestures [90] or a person's skin conductivity [91•] can be used in a classroom to understand learner engagement, preferences, personality, and more. These techniques are still evolving and are quite complex (e.g., [87]); however, even simple approaches such as comparing response time against known typical values, or haptic inputs on the joystick or leaning on the chair or desk, can be used to gain insight [16, 92]. How social robots can leverage this input in their behaviors, however, is still not clear [87, 93], and this remains an open problem.

Given the specific task of interactive social agents for teleoperation, we envision that reading operator's signals will focus primarily on measures of workload, stress, and attention. As such, monitoring skeletal pose (and change over time, e.g., with a Microsoft Kinect [90]), voice tone [88•], facial expressions or eye gaze (and thus attention) through a webcam or eye tracker [93], and simple biometrics including EEG, heart-rate, and galvanic skin response are all feasible given a static seating configuration.

Conclusion

We argue that nonsocial teleoperation tasks (e.g., exploration and inspection) have a largely untapped potential to leverage established techniques from social human-robot interaction. By designing teleoperation to employ social interaction, the interface can better support the operator: it can shape their mental state, perceptions, and overall experience, leading to improved performance. As demonstrated by recent research, we can achieve such results with only simple design tools, and this approach does not require advanced learning or sensing methods still being developed.

In this paper, we motivated this approach and painted a detailed picture—including a wide range of concrete examples—of how teleoperation can use social interaction techniques to improve teleoperation. We envision that this exploration will serve as a springboard and call to action for increased exploration of social interaction techniques for teleoperation.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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