Practical, Ethical, and Overlooked: Teleoperated Socially Assistive Robots in the Quest for Autonomy

Saad Elbeleidy
MIRRORLab
Colorado School of Mines
Golden, CO, USA
selbeleidy@mines.edu

Terran Mott
MIRRORLab
Colorado School of Mines
Golden, CO, USA
terranmott@mines.edu

Tom Williams
MIRRORLab
Colorado School of Mines
Golden, CO, USA
twilliams@mines.edu

***Abstract*—Socially Assistive Robots (SARs) show significant promise in a number of domains: providing support for the elderly, assisting in education, and aiding in therapy. Perhaps unsurprisingly, SAR research has traditionally focused on providing evidence for this potential. In this paper, we argue that this focus has led to a lack of critical reflection on the appropriate level of autonomy (LoA) for SARs, which has in turn led to blind spots in the research literature. Through an analysis of the past five years of HRI literature, we demonstrate that SAR researchers are overwhelmingly developing and envisioning *autonomous* robots. Critically, researchers do not include a rationale for their choice in LoA, making it difficult to determine their motivation for fully autonomous robots. We argue that defaulting to research fully autonomous robots is potentially short-sighted, as applying LoA selection guidelines to many SAR domains would seem to warrant levels of autonomy that are closer to *teleoperation*. We moreover argue that this is an especially critical oversight as teleoperated robots warrant different evaluation metrics than do autonomous robots since teleoperated robots introduce an additional user, the *teleoperator*. Taken together, this suggests a mismatch between LoA selection guidelines and the vision of SAR autonomy found in the literature. Based on this mismatch, we argue that the next five years of SAR research should be characterized by a shift in focus towards teleoperation and teleoperators.**

***Index Terms*—robot teleoperation, wizard of oz, autonomy, socially assistive robots**

I. Introduction

Socially Assistive Robots (SARs) show significant promise in supporting individuals across a variety of domains. SARs can support people receiving therapy [1], [2], [3], [4], students in education [5], [6], [7], and elderly individuals [8], [9]. Across these fields, SARs are able to provide support through social interactions with individuals in need of assistance.

Much of the foundational work on SARs has been motivated by a vision of a future with fully autonomous SARs [10], [11] but this is not the only path that SAR researchers could have chosen. Alternatively, SAR researchers could have chosen to focus their research efforts on developing teleoperation interfaces that were accessible to non-expert users, and that were better suited to handle the complexity of SAR domains. These non-expert users are often caregivers who are already providing the assistance that individuals need. The distinction between developing better autonomy or better teleoperation interfaces is critical since these two research paths suggest fundamentally different futures for caregivers, with caregivers as teleoperators or supervisors.

Fully autonomous SARs and teleoperated SARs represent two distinct endpoints on the scale of possible levels of autonomy. Over the past decade, frameworks have been developed for selecting the ideal Level of Autonomy (LoA) in a given domain [12]. We argue that these frameworks can be leveraged to facilitate critical reflection on the field's choice to focus on autonomous rather than teleoperated SARs.

LoA researchers argue that for each domain, a robot's LoA, from fully teleoperated to fully autonomous, must be carefully selected. LoA selection guidelines suggest that three primary dimensions should be considered when deciding what LoA is appropriate: task criticality, task accountability, and environmental complexity [12]. When robots are used for highly critical tasks that have potential for human safety concerns, less autonomous robots are recommended due to these safety concerns. When robots are used in tasks which require a clear chain of accountability, less autonomous robots are recommended so that blame can be appropriately attributed. When the robot's environment is dynamic and complex, the use of autonomy needs to be carefully considered because using autonomous robots requires advanced sensing capabilities, and because a human supervisor may be needed anyway when important aspects of the environment are unpredictable.

These guidelines should be used to reflect on the field's LoA choices. Since LoAs are domain-specific, this first requires an understanding of the domains in which SARs are used in recent literature, which are broader than those that were considered in foundational SAR research. With an understanding of the domains for which SARs are being developed, one could determine the recommended range of LoAs for SARs and compare them to the LoAs chosen in current research.

In this paper we follow precisely this research plan to critically reflect on the LoA choices made in recent SAR literature. Our results show that the SARs community (as viewed through the lens of work published in the Human-

Robot Interaction field's primary conference and journal) is overwhelmingly focused on fully autonomous SARs, while working in domains in which teleoperation would be better justified according to LoA selection guidelines. Researchers generally do not include a rationale for their choice in LoA and seem to instead be defaulting to a vision of fully autonomous SARs. Based on these findings, we argue that the next five years of SAR research should be characterized by a shift in focus towards teleoperation. Moreover, we provide recommendations for all SAR researchers to ensure that not only are researchers acknowledging and specifying their choice in LoAs, but that those LoAs are appropriately motivated.

II. Motivation

A. Levels of Autonomy (LoA)

In this paper we use Beer et al.'s definition of autonomy: "The extent to which a robot can sense its envrionment, plan based on that environment, and act upon that environment with the intent of reaching some task-specific goal without external control" [12]. Describing autonomy as an "extent" implies the existence of a continuous range of autonomy containing multiple Levels of Autonomy (LoAs). This theory of levels of autonomy builds on the theory of levels of automation [13] by additionally considering robot capabilities such as social interaction [12]. To understand appropriate LoA choice for SARs, we used the guidelines proposed by Beer et al. [12]. These guidelines were designed to help robot developers identify the ideal Level of Autonomy (LoA) for their application domain, from fully autonomous to fully teleoperated[1]. Following these guidelines, researchers determine the appropriate LoA for a robot in a particular application domain by making several key considerations.

As described earlier, these guidelines suggests researchers examine three dimensions of the domain in which the robot will be deployed: task criticality, task accountability, and environment complexity. Importantly, these three decision dimensions correspond to the three central robot capabilities of sensing, planning, and acting. That is, environmental complexity mainly influences sensing; task accountability mainly influences planning; and task criticality mainly influences acting. And, just as sensing, planning, and acting are invariably entwined, so too these factors must be considered in tandem when evaluating a particular domain, as they are certain to influence each other. We will now consider how each of these three dimensions influences the choice of an ideal LoA.

1) Task Criticality: Task criticality is central to choosing a robot's LoA because of the relationship between automation and task failure. Automation has direct consequences for task failure rates [14], and increased automation can introduce unique risks in the context of highly critical tasks [15], [16]. Moreover, even when autonomy is otherwise low, introducing temporary increases in autonomy can negatively impact an operator's Situation Awareness and their ability to exert control [17]. Robots with less autonomy are recommended in domains with highly critical tasks.

2) Task Accountability: When task errors occur, it is important to identify who should be held accountable so that future errors can be mitigated. Task accountability can therefore also influence the appropriate LoA. When robots are perceived as more autonomous, people give them more credit or blame for the resulting outcomes of a task [18]. In clinical environments, for example, some have been reluctant to adopt automated technologies since they would be liable for errors caused by those technologies [19]. Robots with less autonomy are recommended within domains where accountability is important.

3) Environmental Complexity: Finally, a robot's environmental context can also influence its ideal LoA. Robots deployed in complex and dynamic environments would require higher sensing capabilities if they are to be autonomous [20]. However, even given high sensing capabilities, a high LoA may only be justifiable when a complex environment is predictable. When an environment is unpredictable, a robot may need to be teleoperated or, at minimum, supervised [21].

These three dimensions can be used to carefully guide the selection of a robot's Level of Autonomy with respect to sensing, planning, and acting, and in turn, an overall LoA for the robot as a whole [12].

B. Perspectives on SAR Autonomy

Much of the foundational work on SARs has been motivated by a vision of a future with fully autonomous robots. This vision was influenced by the challenges of practically deploying teleoperated SARs and the perceived limitations of teleoperation interfaces. Feil-Seifer and Matarić [10] argued for autonomous SARs in order to minimize training and operation difficulty for non-expert users. Similarly, Scassellati et al. [11] argued that SAR teleoperation might be infeasible given the complexity of the domains in which SARs were to be deployed. As such, they viewed teleoperation as a short-term solution but impractical for wide-scale deployment and adoption. And at first glance, the field has overwhelmingly continued within this autonomous tradition. In fact, some have recently argued that SAR research continues to rely on *too* much teleoperation [22]. However, some of those same researchers who advocated for a vision for autonomous SARs, have published arguments that could suggest a need for teleoperation. Specifically, Matarić [23] has advocated for SARs to support caregivers through human augmentation rather than automation.

Importantly, researchers using teleoperated SARs today may be using them for vastly different reasons and motivated by vastly different futures. One researcher may use teleoperation as a present-time cost reduction approach to research that is motivated by an autonomous future. Whereas another researcher may be using teleoperated SARs because of a belief that teleoperated SARs are the appropriate LoA for their domain both in the present and the future. Similarly, this applies to researchers currently developing autonomous SARs. One may be developing autonomous SARs now motivated by

[1]Or, at limit (though not considered in this work), perhaps no robot at all.

a vision for future autonomous SARs. However, others may be developing autonomous SARs now solely to overcome present challenges in teleoperation. As such, it is unclear whether the SAR community is still working towards a vision of fully autonomous robots; and moreover, it is unclear whether, based on the LoA selection guidelines described above, researchers *should* continue to move in this direction.

In this paper, we seek to answer these open questions by analyzing the state of SAR research with regards to Levels of Autonomy. Since LoA choice is domain and application-specific, we first review recent SAR literature to answer **(RQ1)** What SAR domains are most prevalent in recent research? We then examine recent work in those domains to answer **(RQ2)** What LoAs are researchers currently applying to SARs and envisioning for the future of SARs? Next, following LoA selection guidelines, we then answer **(RQ3)** What range of LoAs would be recommended for SARs in the most commonly researched domains? Finally, using our answers to these questions, we address a final overarching question: **(RQ4)** Is there a mismatch between LoAs chosen in the literature and LoAs recommended by LoA selection guidelines?

III. Qualitative Approach

To answer these questions, we conducted a literature review in which we examined all papers mentioning Socially Assistive Robots that were published within the past five years in the Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction (HRI) or in the ACM Transactions on Human-Robot Interaction (T-HRI). This literature review identified 20 papers from HRI and 26 papers from T-HRI that matched our criteria.

To maintain sensitivity to the fact that different types of perspectives might be held in different parts of the HRI community, we first coded these papers into four categories:

- **User studies** - Papers that focus on a human subjects / user study and its results.
- **Design** - Papers that focus on design approaches or introducing a novel robot design.
- **Technical Advances** - Papers that focus on novel computational techniques.
- **Ethics / Analysis** - Papers that focus on applying an ethical framework or presenting an argument through analysis without experimentation.

Within each of these categories we coded for themes that could answer our research questions. To answer RQ1, we coded papers for the domains in which the presented SARs were intended to be deployed. To answer RQ2, we coded papers for the current LoA used for their robots (and if provided, why), and the future LoA motivating the work (if specified). To answer RQ3, we applied LoA selection guidelines to the domains identified in answering RQ1 (see Section V). To answer RQ4, we compare our answers from RQ2 and RQ3 and present our discussion in Section VIII.

We began with a set of codes we expected to find in the literature as determined by the first and third author. The first author then conducted an initial coding of all papers, creating additional labels as necessary throughout the coding process. Finally, the first and third author discussed all labels and paper codes and arrived at a consensus. Eleven of the 46 papers were excluded for lack of relevance. The remaining papers are referenced in Table I at the end of this document. As shown in Figure 1, the remaining 35 papers consisted of 20 User Studies papers, 7 Design papers, 5 Technical Advances papers, and 3 Ethics / Analysis papers. These numbers are proportional to what we might expect, given that user studies have comprised about 50% of papers in recent HRI conferences.

IV. SAR Domains in Recent Research

Across paper types, SAR research papers covered diverse domains in which robots provided social assistance. We identified 16 themes of SAR domains that fell into six major groups:

- **Target Age** - Papers that focused on assisting individuals based on their age. Subthemes: *Children, Elderly*
- **Activities** - Papers that focused on assisting individuals with a particular activity. Subthemes: *Education, Therapy, Fitness, Interventions, Playing Games, Activities of Daily Living*
- **Needs or Disabilities** - Papers that focused on assisting with resulting needs. Subthemes: *Autism, Dementia, Parkinson's, Depression, Loneliness, Non-verbal Communication*
- **Location** - Papers that focused on assisting individuals based on their location. Subthemes: *Home, Work*
- **General** - Miscellaneous papers that targeted general SAR applications

Based on our grouping shown in Figure 2, we can see that recent SAR research has been predominantly focused on providing assistance in conducting particular activities or assistance for target age groups. Figure 3 shows that SARs in recent research cover a wide range of domains. Assisting elderly individuals, children with their education, and individuals in therapy were the most prevalent domains. As such, we have chosen to focus our analysis on these three domains.

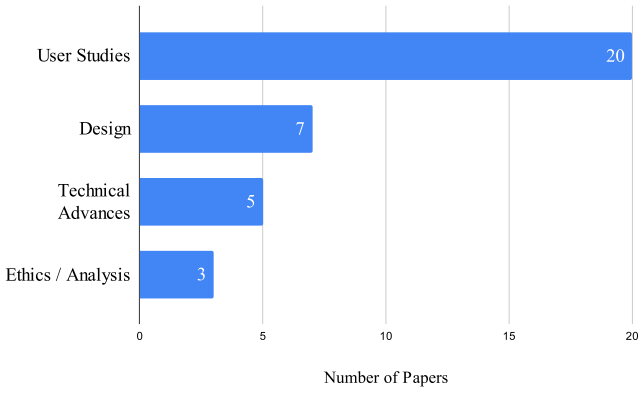


Fig. 1: Paper frequency by research category.

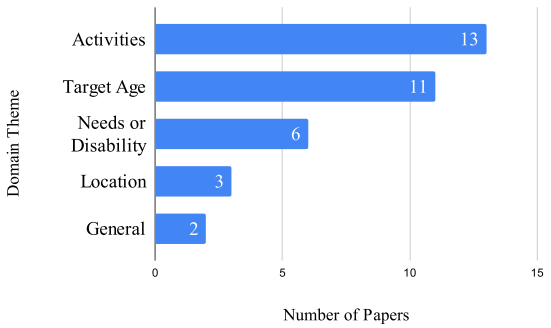


Fig. 2: Paper frequency by SAR domain theme.

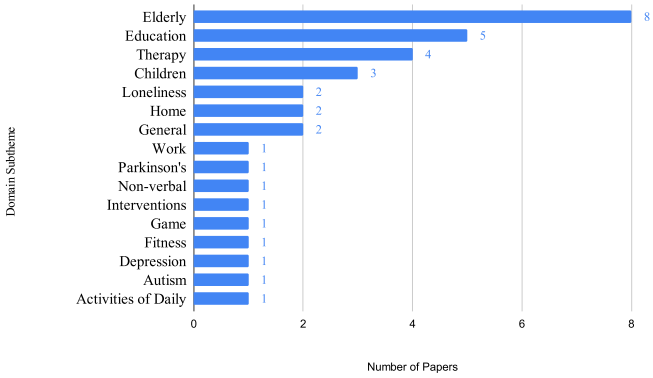


Fig. 3: Paper frequency by SAR domain subtheme

V. Applying LoA Selection Guidelines

Now that we have identified the most prevalent SAR domains in recent research, we can determine recommended robot LoAs in these domains. Our aim here is to determine broad ranges of recommended LoAs for each of these three domains; either closer to teleoperation or closer to full autonomy. Because we are specifying ranges, when we state low LoAs we mean a focus on teleoperation with possibility for some autonomy, and when we state high LoAs we mean a focus on autonomy with possibility for some teleoperation. As described above, LoA choice is not binary.

A. The Elderly

When SARs are used to support the elderly, they can be used for companionship, engagement, supporting activities of daily living, health guidance, initial health evaluations, and therapy [8], [9]. When interacting with a companion SAR, elderly individuals experience high levels of attachment [24] and decreased levels of loneliness [25], [26]. Moreover, SARs have been shown to reduce many symptoms of dementia [27], [28], [29] and increase assisted individuals' cognitive activity [30], decrease response time [31], increase social engagement [32], and improve overall quality of life [33]. These are especially important benefits as SARs are often used to support elderly individuals who suffer from Dementia or Mild Cognitive Impairment (MCI).

When supporting the elderly in companionship, task criticality is fairly low, and the need for accountability is also fairly low. However, when supporting elderly individuals with MCI or Dementia, task criticality may increase since these individuals are more vulnerable. Task accountability becomes important as well since if an issue were to occur, it would be important to identify its cause so that it can be prevented in the future. When working with the elderly, stationary robots are often used and these robots generally exist in a controlled or static environment; therefore environmental complexity is low. Based on this brief analysis we would expect companionship robots to have higher LoA and robots supporting individuals with MCI or Dementia to have low LoAs.

B. Education

SARs have also been successfully deployed in educational domains, which traditionally rely on social interaction [5], [6], [7]. SARs can help children learn a variety of different skills, including handwriting [34], sports [35], drama [36], arithmetic, mathematics, and science [37], [6] sign language [38] and spoken second languages [39]. Not only are robots capable of teaching these skills, but in some cases the introduction of a SAR can result in increased engagement [37], [39], more learning gains [40], [41] and more efficient learning [42].

Children's education is a crucial part of their upbringing and socialization. When SARs are deployed in education contexts they may have varying roles. When robots are dispensing educational content, task criticality may vary greatly based on educational topic and based on the likelihood of erroneously communicating information. For example, content from quantitative topics such as mathematics may be easier to correct or verify than content from socially-oriented subjects such as history. Similarly, task accountability is therefore dependent on the topic of choice. Since education involves children, and children are a vulnerable population, parents will often view task accountability as high. Finally, a classroom environment may vary in its complexity. Some classrooms are highly dynamic environments that are fairly unpredictable. Autonomous robots may require high sensing capabilities to navigate classroom interactions but even these robots, based on the suggestions by LoA researchers, would benefit from a human supervisor (likely the teacher or teacher's assistant in this case). However, when educational SARs are used in the home, environmental complexity may be lower. Based on our analysis of the three dimensions, we would expect SARs used in education to vary greatly in their level of autonomy. While in many educational contexts a high LoA might be recommended, we expect SARs used in teaching highly sensitive content to have a low LoA.

C. Therapy

Similar to education, therapy is another domain that may involve a high degree of social interaction. SARs have been used in a variety of different therapies, such as rehabilitation [1], [2] and mental health [3], [4] SARs have also been used with great success in therapy with specific populations, including autistic

individuals [11], [43], [44], children in pain or distress [45], [4], and children with cerebral palsy [46]. Therapy is an umbrella domain that covers a variety of different needs.

By the very nature of therapy, task criticality is high since it is likely supporting a recovering and/or vulnerable individual. For example, if a SAR is supporting an individual receiving rehabilitative physical therapy by motivating them, motivating the individual to continue with an exercise that they are poorly executing may have severe consequences on rehabilitation. Task accountability is also high since trust and accountability in clinical settings are crucial. As we mentioned previously, clinicians are sometimes reluctant to adopt automated technologies for fears of misplaced blame [19]. Environmental complexity, however, may vary greatly depending on the type of therapy. A physical therapy or gym environment may contain substantial complexity and dynamic interactions, however a talk therapy environment may be fairly static. Given the high task criticality and accountability we would expect SARs in therapy to have low LoAs resulting in a fair amount of research discussing teleoperated robots.

Our brief analysis of the most prevalent SAR domains suggests that in many cases an LoA that involves at least some teleoperation would be recommended. Next, we will present our findings about LoAs chosen in the literature to see whether the LoAs chosen align with this recommendation.

VI. Current and Envisioned Future LoAs in Recent SAR Research

Through our literature analysis, we identified the LoAs of the robots used in the papers examined and researchers' rationale for their choice in LoA. We also identified, when possible, the LoAs that served as motivation for researchers; that is, whether researchers envisioned future SARs to be teleoperated, autonomous, or somewhere in between. Note that as previously discussed, the LoA of a robot used in a research paper does not imply the same LoA for the researchers' envisioned future. Each paper was coded with respect to whether the robots used were described as fully **autonomous**, **semi-autonomous**, **teleoperated**, **both** autonomous and teleoperated, **not explicit or unclear** LoA, whether the authors were **ambivalent** about the robot's LoA, or whether the LoA was **not applicable** because no robot was used in the paper.

A. Current LoA in SAR Research

A plurality (15 out of 35 papers) of recent research on SARs investigates the use of autonomous robots as shown in Figure 4. By comparison, eight papers cover teleoperation, with six of them using Wizard of Oz style teleoperation and two using clearly teleoperated robots. The clearly teleoperated robots were used in domains that necessitated teleoperation, since they were teleoperated by the assisted individual, which we will discuss in more detail in Section VII-B. Importantly, a large number of papers (5) do not explicitly mention their chosen LoA. This shows how some SAR researchers are often focused on evaluating the assistive impact that robots have without discussing the robots themselves.

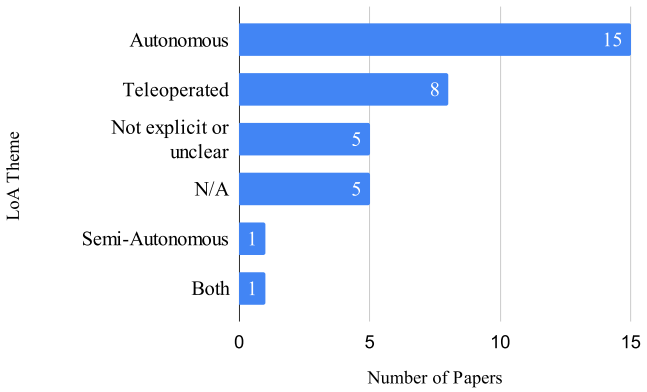


Fig. 4: Current LoA of SARs in Recent Research

B. Researcher's Rationale for LoA in SAR Research

The plurality of papers (17 out of 35), as shown in Figure 5, did not include a rationale for their LoA choice. The 10 papers labeled as N/A for the presence of LoA rationale are comprised of the five papers labeled as not explicit or unclear, and the five papers labeled as N/A (with respect to current LoA). Since only 8 papers presented their rationale for LoA, we will briefly detail each rationale. Of the eight papers that mentioned LoA rationale, four used autonomous robots, three used Wizard of Oz teleoperation and one was not explicit about their LoA choice but still presented a rationale surrounding robot autonomy. The papers' rationales are as follows:

Autonomous 1: A user study conducted to compare the efficacy of autonomous robots to teleoperated robots when used with elderly individuals suffering from Dementia. This study showed that autonomous robots may be superior in that context [47].

Autonomous 2: A design methods paper that showed that therapists and technology developers wanted a stand-alone solution that did not require technical expertise and did not hinder therapist activities [48].

Autonomous 3: A user study on autonomous robots for cognitive stimulation of elderly individuals that used autonomous robots to avoid human facilitation for adults living alone [49].

Autonomous 4: A technical advances in robot autonomy paper about autonomous SARs for individuals with Parkinson's Disease that briefly states that autonomy will be necessary when robots are deployed in homes [50].

Teleoperation 1: A user study that described Wizard of Oz as a way of verifying robot effects before investing in robot autonomy [51].

Teleoperation 2: A novel robot design paper that presented teleoperation as an accessible method for robot control by non-technical HRI researchers [52].

Teleoperation 3: A novel robot design paper that used Wizard of Oz to enact realistic system responsiveness to demonstrate the robot's effectiveness [53].

Not explicit LoA 1: A user study that was not explicit about their robot's LoA but argued that while there is a common

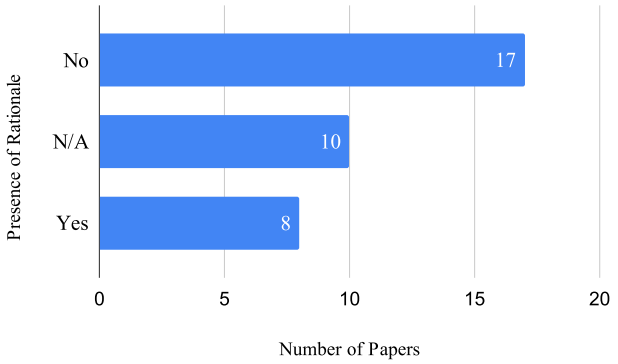


Fig. 5: Presence of Rationale for SAR LoA Choice

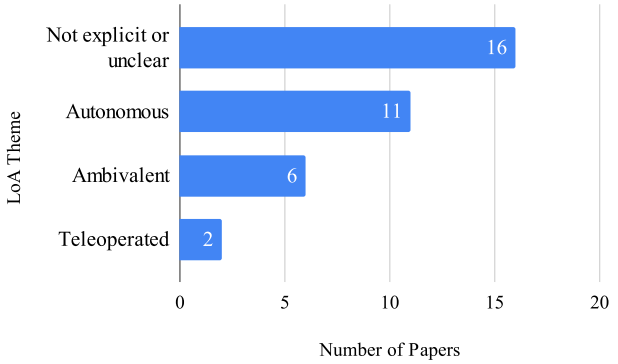


Fig. 6: Future LoA of SARs Motivating Recent Research

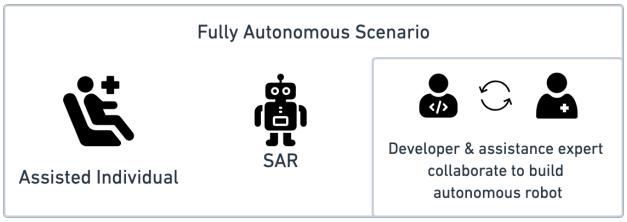
vision for autonomous robots in the SAR community, their necessity is questionable [54].

C. Future LoA in SAR Research

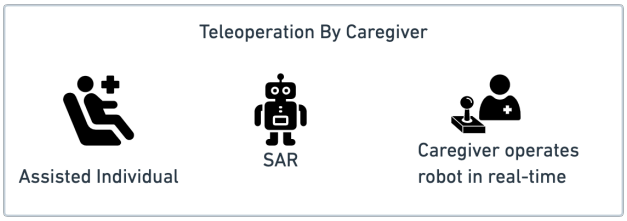
As described previously, we also identified researchers' vision for LoAs of future SARs. Researchers are mostly either not explicit (16 of 35) or ambivalent (11 of 35) about the LoA they envision for future SARs within their domain. When researchers are explicit, most (11 out of 13) expect a future with autonomous robots. Of the remaining two papers that expect a future of teleoperated systems, one involved telepresence robots and the other involved a robot that delivered its assistance through teleoperation by the assisted individual; both applications that necessitate at least some teleoperation.

VII. Trends in LoA Deployment

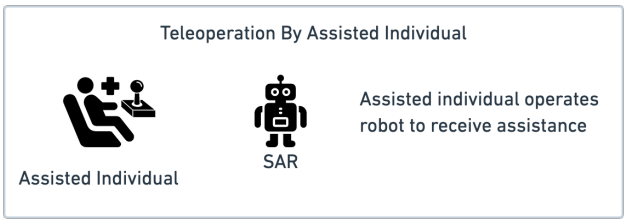
In this section, we detail patterns we identified about the two major LoAs (autonomous or teleoperated). Specifically we describe how robots are developed, how they are used and by whom, and examples of domains in which they are deployed. Importantly, in this section, we focus on the users of SARs and how they differ across chosen LoAs. We present a diagram of the different modes of deployment in Figure 7.



(a) Deploying fully autonomous SARs: The robot interacts with the assisted individual directly providing assistance.



(b) Deploying teleoperated SARs: The teleoperation mode where the SAR is teleoperated by a caregiver who delivers assistance through a teleoperating interface that allows them to control the robot.



(c) Deploying teleoperated SARs: The teleoperation mode where the assisted individual uses a teleoperation interface to operate the SAR and receive assitance.

Fig. 7: Three modes of deploying SARs.

A. Trends in Autonomous SAR Deployment

When using a fully autonomous SAR, the robot is often left with the assisted individual and can autonomously provide the assistance the individual needs. These robots are often left with the elderly or with children to support them with companionship, cognitive stimulation, or education. To develop these robots, developers usually collaborate with an assistive expert to ensure that the robot is capable of meeting these needs.

As part of developing these robots, researchers verify the robot's autonomy by evaluating its assistive capabilities. Technical advances papers about autonomous SARs introduce ways of implementing the robot autonomy. In one paper, however, instead of describing the development of the autonomous robot, researchers propose a development language for non-expert coders to program robot autonomy [55].

Limitations: When using this approach, developers often have to limit the scope of activities of the robots in order to ensure they are effective.

User spotlight: For autonomous robots, the assisted indi-

vidual is the primary user of the robot and other stakeholders have minimal interactions with the robot.

B. Trends in Teleoperated SAR Deployment

When SARs are teleoperated they can be characterized as either of two teleoepration modes: teleoperated by a caregiver, or teleoperated by the assisted individual.

Mode 1: Teleoperation by Caregiver

When the assisted individual is receiving assistance from a teleoperated robot, the robot is commonly teleoperated by a caregiver in real-time. Research implementing this mode mostly focused on evaluating the assistive impact of the robot. These papers implied that the real desired outcome would be to have a fully autonomous SAR. However, because the desired technology was not yet available or was too costly for the purpose of the experiment, researchers teleoperated the robots instead. Examples of these papers explored interactions such as incorporating a robot mediator for conflict in children, or controlling a plant robot that can support individuals dealing with depression. Some papers describing their implementation of this mode were design papers introducing a novel robot design. In those papers, the teleoperation interface was described, almost as a requirement, to explain to other researchers how to use the robot as motivation for the robot's adoption. No papers implementing this mode had focused discussion of how their SAR was teleoperated, suggesting that these researchers approached SAR teleoperation as an undesirable necessity.

Limitations: This approach requires teleoperation interfaces that enable caregivers to achieve the necessary control over the robots. This approach also requires the presence and availability of another human; the caregiver.

User spotlight: In this mode, the interaction is really between the caregiver and the assisted individual as mediated by the physical robot and the teleoperation interface. The physical robot is designed to meet the assisted individual's needs whereas the teleoperation interface is designed to meet the caregiver's teleoperation needs.

Mode 2: Teleoperation by Assisted Individual

In the second teleoperation mode, SARs were operated by the individual receiving assistance. Examples of this mode include when robots were used as communication devices for non-vocal individuals or as telepresence robots controlled by the assisted individual. Papers that implemented this mode present robots that are accessible to the individual receiving the assistance and are effective at creating behaviors that meet their assistive needs. In these cases, teleoperation is a necessary component of the robot; while some autonomy may be introduced, these robots could not be fully autonomous.

Limitations: When using this approach, developers have to design and build a teleoperation interface for the assisted individual to achieve the necessary control over the robot.

User spotlight: In this mode, the interaction is between the assisted individual and other individuals or the environment as mediated by the physical robot and the teleoperation interface. Both the robot and the teloperation interface in this case are designed to meet the assisted individual's needs.

VIII. Discussion

A. SAR researchers are clearly interested in fully autonomous SARs but rarely present a rationale for autonomy

Current SAR research is predominantly focused on fully autonomous SARs. Researchers seem confident in the ability of autonomous technologies to deliver social assistance. Most researchers already explicitly describe *how* their robots are controlled; however, it is also necessary that they explain *why*.

Researchers may use teleoperation as a proof of concept approach to investigate assistive capabilities or because it is the more appropriate solution. We encourage researchers conducting WoZ style experiments to describe why they are using a WoZ system and clarify if they expect that to be the eventual real world usage of these robots.

Autonomy may sometimes be the appropriate choice for a SAR. Autonomous robots can provide assistance in scenarios when no human is available. Autonomy may also be a reasonable choice until teleoperation capabilities are available [11]. In some cases, autonomous robots may be used in comparison to teleoperated robots to determine which LoA is more assistive [47]. However, this research would then raise important questions for the community to answer, such as: (1) How are we measuring effectiveness of SARs? (2) Which stakeholders are we considering (or not considering)? (3) When autonomous robots are evaluated positively in comparison to teleoperated robots, is this due to the benefits of the particular autonomy used, or the shortcomings of the teleoperation interface used? (4) How do we compare autonomous robots and teleoperated robots on equal footing?

Papers where researchers use the same LoA may appear to envision the same future for SARs. However, as we have said there are multiple reasons for a specific choice in LoA, whose rationales might be motivated by vastly different visions for the future. Researchers need to explicitly state both their LoA choices and their visions for the future, not only to allow other researchers to critically assess and evaluate their research, but also because of the impact these explicit statements can have on the field. By explaining their rationale, researchers motivate and encourage additional research by their colleagues. This effect can be seen years later as we have demonstrated in this paper: early SAR research suggesting autonomy was followed by the majority of SAR papers a decade later implementing autonomous robots in their research.

B. Autonomy is not always the right answer, and teleoperation is often the recommended LoA

As discussed in Section V, lower LoAs are often more appropriate in commonly studied SAR domains. Even in domains where full autonomy is achievable, teleoperation by a caregiver may often be a more appropriate choice. This is especially true in assistive contexts like children's therapy which are highly sensitive and in which the consequences of mistakes can be dire. If mistakes happen in these domains,

it is critical for blame and accountability to be appropriately ascribed. Questions of accountability for autonomous robots are longstanding in academic literature and do not have easy answers. When teleoperation is used, the ascription of blame is more obvious. Additionally, there are already human experts in these domains who are explicitly trained to adapt to unusual situations and mitigate potential harms. Roboticists can and should rely on these human experts, rather than replacing them [23]. In this way, teleoperated robots can leverage human expertise while keeping power in their hands.

SARs are in practice teleoperated by caregivers [56]. Not only is this an effective way of delivering assistance but it is also a practical step towards the widespread adoption of robots in assistance contexts. That is, the caregivers who would be teleoperating these robots are the ones already providing assistance to individuals today. Deploying teleoperated SARs is a more feasible way of deploying robots in the near future and to immediately benefit vulnerable communities.

C. Teleoperation changes design objectives and target users

When SARs are mostly autonomous, their target user is the assisted individual. Interactions with caregivers are generally limited to extracting their expertise ahead of time and translating that into robot autonomy. When SARs are teleoperated, they introduce additional stakeholders and design factors. Most importantly, teleoperated SARs introduce a teleoperation interface that a caregiver can use to control the robot. Since evaluation of SAR assistance includes the impact on caregivers [57], and caregivers would be more involved if they are teleoperating the robot, factors surrounding interface evaluation should also be considered such as Situation Awareness, workload, and latency. In summary, researchers' choice of robot LoA requires careful consideration, and requires prioritizing different users and understanding these users' needs.

D. Ethical Implications of LoA Choices

By considering the users of teleoperated SARs, we identify new implications for the decision to develop fully autonomous SARs. In most scenarios, the SAR teleoperator is a caregiver; an expert trained to provide assistance who can use the SAR to deliver assistance more effectively. By replacing caregivers with fully autonomous robots, developers potentially cause harm by shifting power away from domain experts. The replaced caregiver is expertly equipped to handle critical tasks, complex environments, and offer accountability for their actions; the precise scenarios for which LoA guidelines suggest human reliance. By replacing the human in the loop, roboticists not only make it difficult for these individuals to earn a living, but also lower the quality of assistive interaction for the robots' potentially vulnerable users.

IX. Limitations

In this paper, we used LoA selection guidelines to determine appropriate ranges of LoA for several domains. However, the process for LoA selection as outlined by Beer et al. [12] does not end with the selection of a range. Researchers identifying the recommended LoA for an application would need to continue following the remaining guidelines. Additionally, we used guidelines for levels of robot autonomy, whereas, more recent research suggests using levels of human control abstractions (LHCA) [58]. Since LoA selection guidelines suggest more teleoperation in SAR domains and therefore more attention given to teleoperators (caregivers), it could be advantageous to use that same lens to determine the recommended level for human control. However, our choice in using an LoA framework rather than the LHCA framework was due to the LHCA framework being framed primarily around missions involving unmanned aerial drones. More research is needed into alternative frameworks like LHCA to make clear how they can be applied within broader Human-Robot Interaction contexts. Finally, we only examined work from HRI and T-HRI in the last five years. Whereas SAR research is published across a wide variety of venues [5], [2], [59], [60], [61], [62], [63].

X. Conclusion

Most Socially Assistive Robotics research assumes we are working towards a future where SARs are fully autonomous. Our analysis of recent Socially Assistive Robotics research shows a mismatch between the recommended LoA for SAR domains and the chosen LoA in research about these domains. We show that while the research community is interested in fully autonomous SARs, they do not present clear justification for this choice, which research has shown to not necessarily be the appropriate choice. Following guidelines from LoA researchers, we show that teleoperated SARs are the appropriate choice for the majority of SAR domains. We argue that in addition to being a more appropriate LoA choice to serve individuals in many SAR domains, teleoperation is also more respectful to caregivers currently providing assistance and support, and more likely to lead to widespread SAR adoption that can transfer the researched benefits of SARs to a wider audience. We therefore argue that the next five years of SAR research should be characterized by a shift in focus towards teleoperation and teleoperators.

TABLE I: Papers Included in Literature Analysis

Venue	Year	Publications
HRI	2017	[64], [65], [54]
HRI	2018	[66], [51], [67], [68], [69], [70], [71]
HRI	2019	[72], [73]
HRI	2020	[47], [74], [75], [55], [76], [77], [78]
HRI	2021	[79], [80], [81], [82]
T-HRI / JHRI[2]	2017	[36]
T-HRI	2018	[48], [83], [84]
T-HRI	2019	[52], [85], [86]
T-HRI	2020	[50], [87]
T-HRI	2021	[49], [53], [88]

[2]NB, in 2017 T-HRI was the Journal of Human-Robot Interaction (JHRI).

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