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Social robot accessories for tailoring and appropriation of social robots

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Abstract
The design of robots for everyday use should take into account the specific nature of the individual end-user and the possibility of interactions with multiple users in diverse scenarios, promoting versatility and increasing the chances of their successful adoption in everyday environments. Most robots are designed, however, to perform tasks and interact in typical social scenarios with an abstract human user. We observed a recent surge in the use of accessories with social robots, which aligns with a broader trend of consumers' preference for personalizing the technologies they interact with. Drawing from the concepts of adaptability and customizability in collaborative systems, we explore the potential use of accessory-like items for social robots to enable low-tech customization and user appropriation, thus enhancing their value and suitability in various social situations. We draw from Human-Computer Interaction and Computer-Supported Co-operative Work literature to show how end-user customizability and appropriation are essential, but less frequently considered, in the study and design of social robots. We conceptualize Social Robot Accessories (SRAs) as a way for end-users to customize robots, and present three studies - (1) a literature survey on accessory-like item use with social robots, (2) a survey of commercially available robot accessories, and (3) a Twitter-based analysis of accessory use for AIBO and LOVOT robots by their users. We use findings from these studies to envision a design space of SRAs for use by Human-Robot Interaction (HRI) researchers.

Keywords Social robots · Accessories · Personalization · Appropriation · Customization

1 Introduction

Users often embellish, decorate [1], dress up, and personalize their robots [2], such as to fit their preferences or match the ambiance of their homes and workplaces [3, 4]. 'Mooba the cow', 'Slops the pig', and 'Zeb the zebra' are dressed up Roomba mobile vacuum robots [5], to whom the users have attributed personalities and social roles [1], and accepted as their family [6]. Clothing and accessories, placed on and around the robot, were used to give the 'roboceptionist' Valerie a unique and engaging personality as she greeted visitors to Carnegie Mellon University's Robotics Institute [7]. The mobile delivery robot TUG was outfitted to resemble a train in a children's hospital to make it less intimidating for children [8]. The robot Baxter [2] was given a wig and a jester hat by its human co-workers in industrial settings to appear more social and emphasize its human-like appearance and personality, thereby improving human-robot interaction [2] In a research setting, Fraune et al. [9, 10] showed that colored armbands worn by humans and robots [11, 12] signified shared team membership leading to participants favoring their ingroup robots over outgroup humans. Such examples of robot embellishment, from home, healthcare, service, and industrial settings suggest even small adaptations can help users situate and make sense of robots in their social environment, facilitating and enriching human-robot collaboration.

While this extension of human-robot interaction through accessorization aligns with the themes of tailoring, customization, and appropriation of technology [13–16] it only enables surface or 'skin deep' adjustments and does not significantly change the robot's functions or interactions. To increase their usefulness and successfully integrate into diverse multi-user settings, social robots need more versatile accessorization that goes beyond appearance and adapts their behaviors and interactions to suit the users and contexts.

Recently, companies producing commercial robots such as AIBO [17] and Nao [11] have started offering digitally interactive and non-interactive accessories (Fig. 1) to

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enhance personalization and interaction opportunities for users [18]. Inspired by examples of surface-level user adaptations from HRI studies [18], and the emergence of interactive accessories for social robots on the market [19–21], in this paper we explore and expand on the practice of accessorizing social robots. We review related work appropriation, tailoring, and customization of technology, and define and scope Social Robot Accessories (SRAs). We then present a survey of HRI research literature to discuss unique opportunities for adaption, interaction, and collaboration achieved through the use of accessory-like items by social robot users. We also survey commercially available SRAs to show how companies enhance their robot's appeal and long-term novelty with accessories. We present a Twitter-based analysis of interactions among users of AIBO [17] and LOVOT [22] robots, to show how they adapt and appropriate their robots and build a sense of community through the use of accessory-like items for their robots. Based on these explorations, we present a design space of SRAs and actionable guidelines for HRI researchers. Given the growing use and production of robots for multi-user settings, we present a timely conceptualization of a novel add-on interface as – Social Robot Accessories (SRA)s– for end-user tailoring, customization, and appropriation.

2 Background

Most social robotic platforms have been less successful in consumer markets [23] due to their inability to meet diverse consumer expectations [24]. Robots are often geared for broad applications and use contexts – such as delivery, assistance, or service [25, 26] in homes, offices, and commercial and public spaces. However, once put into use, they end up in unforeseen social roles and multi-user situations that require further adaptation to the unique needs and preferences of their users [11, 27–30]. Considering such unanticipated and emergent uses [2, 31] highly technical customization options for social robots can make them less appropriate for collaborative social situations, and force end users to adapt to generic capabilities of robotic platforms. This may negatively impact the quality of interactions among users and robots and make robot use burdensome for stakeholders, ultimately leading to the reduced or discontinued use of robots [32].

Studies on computer systems and software applications [33–36] suggest end-user customization supports freedom, sustained use, appropriation of technology in organizational multi-user environments [13, 14]. Users appropriate technology in innovative ways to fit into their work practices and activities [37] making tailoring and customization [13, 15, 38, 39] integral to their social practices. In contrast, social robot users have been passive beneficiaries of robotic technology devoid of provisions to customize their robots. To gain insights into the use of social robot accessories (SRAs) for end-user customization of robots, we draw on findings from studies on tailorable and customizable systems.

2.1 Tailorability and design of social robots

CSCW research has demonstrated that tailorable systems [40, 41] can offer varying levels of abstraction and complexity [42] that are suitable for diverse end users. For example, software platforms and applications with simple plug-and-play *components* such as buttons, text-boxes, and combo-boxes, allow end users to create domain-specific applications without having to write code [43, 44]. Similarly, user interface designs with kits or building blocks can enable customization by leveraging the user's domain knowledge or providing interactive instructions to guide end users with varying levels of expertise [45].

In contrast, until recently, robots have been perceived as personal artifacts designed to perform singular tasks, lacking tailorable systems that non-technical users can access. Probably the act of tinkering with robot hardware or programming seem counter-intuitive and may appear to harm the robot's autonomy and social presence. Additionally, tailoring a robot may require considering its aspects of sociality, embodiment, morphology, and communicative behaviors that play a crucial role in their suitability for a given context and determine its ability to achieve [46]collaborative goals.

MacLean et al [41] emphasized the creation of a supportive social environment and a tailoring culture that encourages users to adopt tailoring as a norm, overcome barriers to customizability and develop interests and skills in customization. They discussed how designers and mediators can play a role in promoting this tailoring culture by helping users understand the benefits of tailoring. Mackay [47] showed users who found programming mechanisms unappealing or lacking in empowerment [41]sought workarounds by building a tailoring culture of collaboration and borrowing within their organization. Similarly Gantt & Nardi et al [15] presented how some CAD organizations fostered a tailoring culture and community by formalizing recognition and status for different members of the tailoring group. However, such exchange of end-user robot customizations is difficult as social robots are complex in their hardware and software, making their programming unclear to end users and as such, the study of robot tailoring culture is largely non-existent in the HRI research.

In sum, research on the design and collaborative use of software systems has provided valuable insights and guidelines that can be used to inform customization of social robotic technology [16] without compromising usability and simplicity [13, 47] while still maintaining their perception as social actors. Key design considerations include a focus on designing for collective and collaborative aspects [13, 15, 48], incorporating elements, suitable for different lev-

Fig. 1 Social Robot Accessories (SRA)s [1-4]

els of expertise of end users, promoting opportunities for *situated creation*, i.e creation from items or objects from end-users own environment [48]and fostering a tailoring culture through recognition, support, and sharing of resources [41] while taking in account the unique characteristics of social robots.

2.2 Accessorization of robots for tailorability

Accessories such as jewelry, hats, and scarves, have a long history of serving as a means for expressing of identity, membership and belonging, social status, thoughts, and beliefs [49]. These accessories alter our social experiences and provide additional functionality. With the advent of digital technology [50], we have incorporated interactivity into accessories to track information, sync, interact, and connect with our surroundings, including other devices [51], and people [52, 53]. This enables cost-effective, secondary, or temporary interactions. We also accessorize other social beings, such as pets with breakaway collars and ID tags, cute bows and tuxedos, hiking gear, and sweaters, for functional and aesthetic reasons. Despite the widespread use of accessories in our lives and our treatment of robots as social actors, there has been little exploration of accessorization for social robots.

Accessories for robots could be thought as emerging from a broader culture of consumers' accessorization of their personal artifacts, and can encourage collaborative interactions and community culture of tailoring among users of diverse skills and expertise. For example, children can engage in dress-up or plug and play activities with robots using accessories, while tech-savvy users can use robotic and digital wearable-like accessories to tinker with the behaviors and interactions of robots. Accessories could provide robot users with ability to tailor their robots to their everyday practices and contexts. For example, using treat-like accessories to modify a pet-like robot's behavior could be an intuitive way to integrate mediation into daily interactions. Accessories can alter a robot's social role, embodiment, morphology, and behavior, such as adding a chef's hat to suggest cooking expertise or a team logo to signify belonging. Accessories can also extend the robot's functionality, such as using external sensors through accessories like a collar to enhance the robot's data collection [54]. n sum, accessorization holds potential for enhancing the robot's flexibility and facilitating human-robot collaborations.

2.3 Scoping social robot accessories

For the scope of this paper, Social Robot Accessories (SRAs) are defined as: external additions that accentuate the characteristics of social robots, allowing users to tailor, customize, appropriate, and adapt their robots to their usage and work contexts and support or enable Human-Robot Interactions in secondary ways, such as by (1) promoting engagement with the robot through opportunities for alteration and personalization of social robot features, interactions, social roles, embodiment, behaviors and capabilities and (2) extending its technical and interaction capabilities through added functionality. Note that items that are integral to the robot, such as internal hardware and software, and do not serve as external enhancements in terms of functionality, context, or aesthetics are not considered SRAs. For example, while a robot charger is an essential component, a cover for the charger that enhances its sociality or appearance could be considered an SRA, such as the pacifier-like accessory that can be mounted on Paro robot's charger [55]. (Appendices - row 1).

In the following section, we present findings from three exploratory studies of SRAs, which deepen our understanding of the topic and provide a basis for outlining the design space of SRAs.

3 Three studies of social robot accessories

Our goal was to investigate the design and use of available robot accessories and to understand their importance for HRI in various social and collaborative scenarios. We began by conducting web image searches for terms such as 'robot accessories', which frequently brought up images of robotic components, such as sensors, motors, and batteries. We then searched for specific terms using names of popular robots such as Nao or AIBO, along with keywords such as 'accessory', 'decorate', 'customize', or 'dress up'. These searches carried out over several weeks returned hundreds of pictures (from 38 robots) of commercially available robot accessories and accessory-like items used in HRI research. We also identified prominent virtual communities of robot

Fig. 2 Accessorized robots from research studies

accessory users on social media. Based on our explorations, we conducted three studies – a literature review of accessory-like items used with robots in research studies, a survey of available robot accessories sold by vendors and robot companies, and an analysis of Tweets posted by robot users to study their accessorization practices, as presented below.

3.1 Survey of SRAs in the HRI literature

For our literature survey on SRAs, we searched metadata and text from the ACM digital library search engine that provides comprehensive coverage of a significant number of conference proceedings and journals for HRI. We made a query for the primary term 'robot' combined with secondary terms including names of 38 different robots and tertiary terms related to "accessories" (14 keywords) based on our understanding of SRAs from extensive web searches (See Appendix for the search query). The search was conducted in January 2020 to identify any publications on robot accessorization in the ACM Digital Library between 1969 and Jan 2020. Out of 589 papers returned, we removed those that were not in English, works in progress, posters, doctoral colloquiums, and those with no images or relevance to SRAs as per our definition. Our elimination resulted in 48 full-text papers, dating back to 1999. We reviewed these papers to determine how accessory-like items supported social and collaborative contexts and encouraged tailoring and appropriation practices. The collected papers were coded for three pre-defined themes (1) stated purpose of use of accessories (2) practices of robot accessorization that may shape and mediate interactions in different work and life contexts, and (3) social interactions, collaborative practices, and shaping of community culture around the use of accessories for robots.

3.1.1 Findings

Out of the 48 articles we found from our literature search, 14 discussed the accessorization of robots in various collaborative environments, 9 discussed accessorizing to promote user engagement, and 7 discussed concepts or prototypes for accessory-like items on robots. Below, we present our findings from the main themes identified across the collected literature.

Shaping social identity and emotional connections
Accessorization in HRI is primarily associated with playful stances towards robotic technology [56], enhancement of expressivity and to make life-like associations with the robots [1, 56]. Several studies have shown that accessories provided to users could enrich their experience of HRI. One study with Roomba robots used stickers (Fig. 3A) with cartoonish facial expressions, stylized text, and icons to test social interaction with humans and showed that even superficial customization can allow the robot to express emotions [57], such as happiness, or states like having a low battery. In another study, the use of a 'personalization toolkit' of stickers and letters (Fig. 2B, C) facilitated a positive user experience, increased emotional connection with the robot, made the robot appear more committed to the household, and led to higher acceptance of the robot [1]. Users viewed the robot as their own, referred to as "our Roomba," and treated it as a helpful assistant, pet-like being, or valuable family member [6]. Personalization allowed users to attribute gender, personality, or individuality to the robot, and the stickers were used to express emotions such as gratitude. In yet another study, (Fig. 2E) knitted or crocheted clothing, swappable wooden ears, attachable facial features, and soft silicon arms [58], provided children with opportunities to customize Blossom robot's appearance, making it more suitable for playing different characters and enhancing its sociality [58].

Procuring accessories
When accessories are not provided, users have taken the initiative to accessorize their robots on their own. For example, in Gena et al. [59]'s study, primary school children co-designed an affective peer-tutor robot by adding a bow tie and buttons to enhance its appearance and playful qualities. Similarly, a virtual ethnographic study of Pleo robot's (Fig. 2D) blogging community [56] showed its users employed a diverse range of everyday clothing and fashion accessories to construct their own version of their robot's social attributes and personality and express their individuality and bonding with it [56]. In another example, Joshi Et al. [4] intergenerational care staff used pet beds for dog and cat robots to enhance their life-likeness and establish their sociability among a group of older adults and preschool children (Fig. 5B).

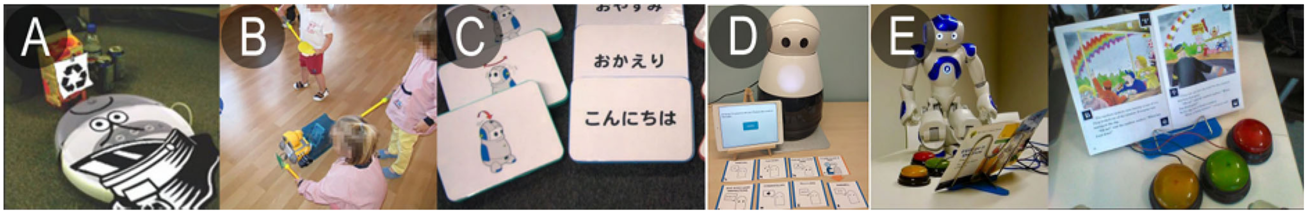

Fig. 3 Accessorized robots from research studies

A few studies described prototypes of accessory-like systems to tailor social robots. For example, [60] used Velcro-based robotic animal parts (Fig. 4A) that children could snap together to program emotions and stories for a robotic pet. Another study used paper-based and virtual accessories (Fig. 4B) to encourage children to engage in story-telling activities with the Pleo robot [61]. Removable accessories, such as garments or jewelry (Fig. 4C), were also used to control robot behaviors and program robotic objects [62], such as exchanging a bracelet accessory for a pajama to transition a Pleo robot from watchdog mode to sleep mode or using a bracelet to shape a Roomba-like robot's movement and interactions.

Studies that are not typically focussed on accessory use or design still have robots accessorized as a part of research set-up (Fig. 2A), to make the robot appear amicable, such as by dressing it in a T-shirt [59]. In general, accessories have enabled stronger social bonding and relationship building through the personalization and anthropomorphization of the social robot, which is crucial for sustained and effective interactions in social and collaborative settings.

Multi-user and collaborative aspects

Tangible items, like programmable blocks from robotic kits, are frequently employed to engage users with technology in multi-user educational and play settings [63]. These items can motivate users to control the robot's interactions, facilitate collaborative interactions and the repurposing of robots without requiring programming skills. Garcia-Sanjuan et. al [64] conducted a study in a kindergarten class where they used playroom objects, such as colorful sticks with foam characters, as accessories for a robot (Fig. 3B). These accessories allowed children to have control over the robot's interactions leading to engaging, tangible and playful interactions between the children and the robots. Children demonstrated collaborative behaviors such as helping and correcting one another on the use of accessories, coordinating their actions to complete tasks using the accessories, and even re-inventing the use of these accessories for sword fighting play highlighting their potential for repurposing robots.

Accessories, both interactive and non-interactive, have been found to enable and support collaborative activities between different users and stakeholders. In a study by Hoffman et al. [58], children collaboratively engaged with their customizable social robot, Blossom, through accessorization during a robot-building workshop. The children took turns crafting accessories from provided materials and controlling the robot, and the parents also participated by making their own accessories or helping their children with the control of the robot. In another study, Joshi et al. [65] described a dress-up play activity for a seal-like robot, Paro, where staff in an intergenerational daycare used non-interactive accessories like scarves, bows, angel wings, and bunny ears to decorate the robot and facilitate interactions and collaboration between older adults and children. The use of accessories increased verbal conversations and sharing of likes and dislikes and provided novel interactions with the robot.

Boccanfuso et al. [66] conducted a study with children diagnosed with autism spectrum disorders (ASD) using a socially assistive robot and hat accessories for a Hat Game (Fig. 4D, E). The hat accessory was used to initiate the child's interaction with the robot and with others, such as caregivers and researchers, by taking turns placing the hat or other accessories on their heads which lead to unintended collaboration. To further enhance the study, the researchers developed additional activities that incorporated multiple accessories, including different types of hats, sunglasses, a scarf, a flower clip, wolf ears, and a bus toy for a Wheels on the Bus activity [66]. The accessories became a crucial component of the study and were found to drive most of the interactions between the children and the robot by providing multiple interfaces for interaction by different users.

In another example, Yadollahi Et al. [67] used a book and three tangible feedback buttons (Fig. 3E) as accessories for Nao in reading while listening (RWL) activity with children. The buzzer-like feedback buttons served as a simple and intuitive way for the child to interact with the robot, giving it feedback and allowing the child to exercise agency. The buttons allowed the child to notify the robot of mistakes, request a repetition of a page, or provide positive feedback, which the robot could respond to through verbal, physical, and emotional gestures.

Finally, in one study conducted by Davison et al., [68], the triadic relationship between a child, a robot, and an accessory (a smart book as a learning material) was conceptualized to understand the individual dyadic interactions in the triad. The study aimed to show how the individual interactions between the child and the robot can shape and mediate the child's interaction with the learning materials, ultimately influencing its effectiveness. The study highlights the potential of accessories to mediate collaborations between humans and robots and shape their interactions, while also emphasizing the broader affordances of accessories for mediating engagement and agency of the robot, presenting them as potential actors in the interaction.

Researchers have developed special card-based accessories (Fig. 3C, D) for designing scenarios with robots [69–71]. For instance, children were given cards with phrases, greetings, and stories to teach social behaviors to the robot or make it tell a story using a storybook [69]. These cards allowed multiple users to collaborate and control the interactions with the robot, extending its functionalities within the task. The cards (Fig. 3C) were also designed to change the children's relationship with the robot, displaying odd behaviors in response to the incorrect use of the cards.

Similar tangible cards with symbols and brief descriptors were used in a study to help neuro-psychologists create customized social roles and interactions for robot therapy sessions for people with varying cognitive abilities [71]. The cards allowed automatic conversion to code, enabling users to use them in any order in parallel with the activity and prompt the robot to react. The cards facilitated collaborative goal setting between clinicians and Persons with mild cognitive Impairment (PwMCI) and provided opportunities for collaboration between PwMCI and clinicians, as well as multiple healthcare providers, to program the robot and meet the needs of PwMCI.

The use of robots with special accessories has shaped the interplay of people and robots in a community, such as in the example of inter-generational care facility, where the staff and teachers used pet beds (Fig. 5B) to transport their pet dog and cat robots to interact with elderly residents during inter-generational activities. The use of accessories allowed the staff to manage the robots and let all residents take turns in interacting with them and reinforced the robots' position as social actors in the community [4]. Similarly, in Jacobsson's [56] ethnographic study of a virtual blogging community of Pleo robot users, members were highly engaged in accessorizing their robots, sharing their practices and engaged in presentation of stories around it, leading to further engagement within the community.

3.1.2 Discussion

Our findings show everyday items used as social robot accessories can provide opportunities for personalization and customization to enhance robot embodiment and perceived sociality. Accessorization of robots seems to be primarily driven by personalization, adaptation, and mediation of robot interactions through the use of non-programmable robotic accessories. Users were also motivated by emerging opportunities for creative expression through user involvement in making social robot accessories.

Most examples of customization in prior research was motivated by requirement of low skills and efforts such as adding stickers or using plug-in and swappable mechanisms. Easy access to design and material support, such as the 'Personalization toolkit' (Fig. 2C) used in Roomba studies (*see* Sect. 3.1.1), encouraged users to customize their robots [1]. Additionally, the use of art activities especially in child users led to the creation of a range of accessories from simple embellishments to dioramas that shape the robot's actions [67]. Even without design support, the sociality of the robot motivated users to adapt everyday accessories and props [62, 64, 66, 67] to engage in a relationship and add life-likeness to their robot [56]. Users customized them primarily through simple actions such as waving or dressing up the robot [64, 66]. Use of accessories allowed to tailor robot's programming, giving them the ability to shape and control robot behaviors, encouraging them to sustain interactions [60, 61, 66] and influencing their perceptions towards the robot [4].

Despite having support, in some cases, such as with the in-home users of Roomba robots [1] customization effort was not rewarding enough to alter it more frequently [1]. On the other hand, social and community engagement around accessorization generated greater interest among those who enjoy making, crafting, and decoration, such as children and making enthusiasts. Such interest could be sparked among other users [4]by providing them with community support.

Recent research is shifting from the use of accessories for mere participant engagement to the use of accessories for mediation of specific interactions, and tailoring of robot-specific behaviors, sociality, and appeal by end users.

3.2 Survey of commercially available social robot accessories

Our non-exhaustive survey of commercially available robot accessories is based on initial web searches which turned up images of accessorization of 38 social robots that we used to retrieve URLs, names, and official websites of robot companies and vendor's web pages for 14 robots with commercial available SRAs. We analyzed the data from the company and vendor websites, including the types and varieties of SRAs, their explicit and inferred purposes, customization options, and how SRAs are promoted

3.2.1 Findings

Our survey of commercially available robot accessories revealed a diverse range of SRAs, including clothing and interactive toys, for pet-like and humanoid robots. These SRAs are sold by various providers, such as the robot creator

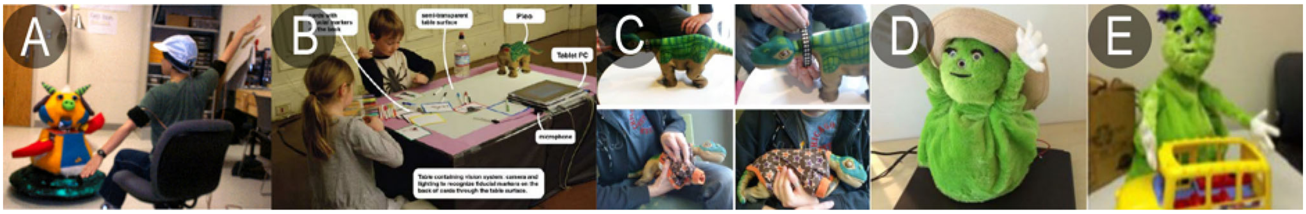

Fig. 4 Accessorized robots from research studies

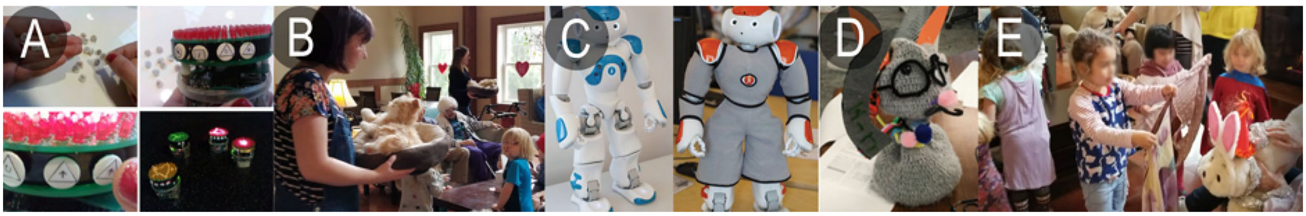

Fig. 5 Accessorized robots from research studies

company (CC), partnered vendor (PV), independent vendors (IV), and individual makers (IM) on DIY community platforms like Etsy [72]. Our analysis focuses on four robots with exemplar commercially available SRAs and a summary of accessories found for 10 robots provided in the Appendix.

Roomba
Accessories for the Roomba robot, one the earliest commercially available domestic vacuum robot [1] are available through the robot's creator company iRobot and various independent vendors and individual makers. iRobot [5], offers thousands of design options to modify Roomba's aesthetics through vinyl skin accessories, to *"make it personal"* for Roomba owners (Fig. 6A), have their robot reflect their personality or match the aesthetics of its surroundings. On the other hand, accessories offered by IVs and IMs are much more diverse in design and materials used, often with playful features such as a 'Mario-inspired mushroom skin' (Fig. 1) [73] and 'pizza skin'(Fig. 6B) or zoomorphic or anthropomorphic features that turn Roomba into animals such as cats (Fig. 6C, D) and marketed as a way to personalize the robot through easy application and removal [74]. Some accessories also convey Roomba's role in the household, such as a 'maid costume' (Fig. 6E) or a sticker of a cleaning robot (Fig. 6F).

LOVOT
Groove X, the creator of LOVOT robot [22], provides customers with an impressive line of clothing and fashion accessories, in addition to the mandatory 'base wear' (Fig. 7A) that comes with the robot upon purchase. The clothing items are stated as digitally interactive, allowing the robot to sense the accessory and respond with emotions. The company encourages using accessories to increase social bonding between the owner and the robot stating - "A scene of everyday life, changing clothes, will bring you and your LOVOT closer [75]". Some other accessories available for the LOVOT include zoomorphic clothing items (Fig. 7B), different colored aesthetic noses (Fig. 7C), bow ties, shoulder bags (Fig. 7D), jackets, and customizable T-shirts that can be mixed and matched (Fig. 7E). The company's website leads visitors to its 'fashion' store and promotes Tweets and social media content posted by LOVOT users as they share their accessorizing of the robot. The company also provides tips and design support on its website, suggesting mix-and-match options for clothing items and providing information on to accessorize the robot without interfering with its functionality [19]. IMs [76] can also be found creating and selling handcrafted, non-interactive clothing items for LOVOT (Fig. 7F).

AIBO
Sony, the manufacturer of AIBO robot [77] offers a range of accessories for AIBO, including interactive items [20] such as an AR-based feeding Bowl (Fig. 8A) and Dice toys (Fig. 8B), as well as non-interactive items such as collars (Fig. 8C) and carriage cases (Fig. 8D) in various colors. The AR-based feeding Bowl allows a feature"AIBO's friends" for AIBO owners to connect with each other on an App, or by exchanging contacts through QR codes, and let their robots have special behaviors, such as having AR-based food together [78]. SONY supports user engagement with these accessories through tips and feature explanation illustrations and videos on its website [79]. Different types of clothing items such as professional uniforms and shirts (Fig. 8E, F) are also available from PVs [21] and IMs [80] to suit different occasions and user preferences. The interactive accessory-Aibone is marketed to generate predictable dog-like playful and fun interaction that AIBO loves and looks forward to, while the Dice toy is designed to allow AIBO to suggest its 'mood' and change its interactions over time, suggesting some life-like growth. Overall, SRAs for AIBO range

Fig. 6 **A** vinyl skin(CC), **B** pizza skin(IV), **C**, **D** zoomorphic covers(IV,IM), **E** maid costume(IM), **F** cleaning robot sticker(IM)

Fig. 7 **A** 'base wear', **B** leopard suit, **C** aesthetic nose, **D** shoulder bag, **E** customizable shirts (**A–E** CC), **F** Aloha shirt (IM)

from those that integrate socializing aspects among owners and robots to accessories that add real pet-like behaviors for AIBO.

RoBoHoN

Sharp [81] - the creator company of RoBoHoN, offers only a few non-interactive accessories such as decorative bibs (Fig. 9A) and carrying cases (Fig 9B). However, some PVs offer a range of items from furniture to clothing items of different attire (Fig. 9C–E) and other IVs and IMs make all kinds of non-interactive fashion items such as hats and dresses (Fig. 9F). These items such as 'casual' shirts (Fig. 9D) or a formal suit (Fig. 9E) provide RoBoHoN with life-like and adaptive qualities for different social settings. For example, PV ROBOUNI provides a formal suit to celebrate special events like graduation ceremonies and weddings with RoBoHoN [82] that they suggest are "in accordance with TPO (time, place, and occasion) [83]". In general, clothing and accessories sold by IMs are more diverse and extravagant in designs ranging from leather-made travel bags to hand-made multi-layered suits, making RoBoHoN's appearance unique and eye-catching.

3.2.2 Discussion

The market for SRAs (social robot accessories) seems to be growing, from non-digital accessories like stickers and skins, clothing and outfits to highly sophisticated robotic toys. These SRAs are mainly targeted for individual engagement in home-like or personal environments, where robots would be treated as a companion or pets. Some professional work clothing is available for RoBoHon and a service apron was seen for Roomba.

Companies seem to be approaching the design and use cases of SRAs differently. For Roomba and the RoBOHOn, companies, and vendors provide accessories for personalization and attachment to the robot or to match it to the context, while for AIBO or LOVOT SRAs aim to encourage users to practice love, care, intimacy and bonding with their robots, in ways familiar to them, or suggesting that the robot needs them through playful engagement. Many accessories for LOVOT and RoBoHon also encourage users to integrate their robots into their everyday life, celebrations, culture, and festivities.

The promotion of these accessories is done mainly through the company's and vendors' websites and social media. The use of designer branding and packaging, elaborate accessory shops, and gaming and fashion events indicate that companies and vendors envision SRAs as more than just an addition or enhancement for the robot, but as a medium for luring users into long-term relationships with the robots. A common strategy is to make accessories easy to use and provide a variety of choices through mix-match customization to allow users to practice their choice, expressivity, and creativity. Design support through templates, drawings [78, 84] and in-person workshops also encourage customization and accessorization and bring more life-likeness and novelty to HRI. While collaborative situations may emerge from the use of these accessories in multi-user contexts, or social media engagement, such an intention is not necessarily embedded in the design of SRAs. The commercial availability of SRAs aligns with robot manufacturers' broader business interests, such as showcasing their technical solutions or keeping users engaged through inexpensive transactions, a tailoring culture, and a network of other SRA users.

3.3 Analysis of twitter posts from social robot users

Our initial web searches for SRAs revealed a strong presence of SRA users on Twitter, especially for Japanese social robots

Fig. 8 **A** Bowl, **B** Dice, **C** leather collar, **D** carrying bag, **E** tuxedo, **F** handmade dress

Fig. 9 **A** decorative bib, **B** carrying case, **C**'RoBoHoN chair', **D** knit shirts, **E** uniform, **F** handmade outfit

- AIBO [17] and LOVOT [22]. We then used Twitter's Search Application Programming Interfaces (APIs) to collect publicly available tweets posted in the seven days prior to data collection. From May 22nd, 2020 to July 31st, 2020, the collection was done every four days to ensure that newly posted tweets were retrieved before they became inaccessible. The search included keywords - aibo, lovot, and Japanese characters for both and the unit of collected Twitter data was a Twitter object, consisting of a list of attributes including text, user id, embedded media entities, and other meta-data. The tools used to retrieve and save the Twitter data were pre-programmed scripts in R with the rtweet package.

We collected 198,296 tweets for AIBO (13, 618 in English and 184, 651 in Japanese), and 18, 843 tweets (516 in English and 18,327 in Japanese) for LOVOT. Using rtweet, we applied filters on the tweet components and eliminated irrelevant tweets, such as when the keyword was username but was unrelated to SRAs. This resulted in 90,380 tweets (3614 in English and 86,766 in Japanese) for AIBO, and 6318 tweets (33 in English and 6285 in Japanese) for LOVOT. Since most SRA users' Twitter posts had less textual content but often contained images of robots adorned and embellished with accessories, we excluded tweets without images and re-tweets, which resulted in 3997 tweets for AIBO, and 1308 tweets for LOVOT. We then randomized and selected 600 tweets for AIBO and LOVOT each to enable further manual exclusion of unrelated tweets resulting in 295 tweets for AIBO and 365 tweets for LOVOT. Finally, we limited the tweets by the same user to up to 5 tweets and achieved a final set of 153 tweets for AIBO and 154 tweets for LOVOT robots.

We conducted a qualitative analysis of the final batch of tweets by applying themes from our literature review and survey of consumer social robot accessories to our coding scheme, such as personalization, social acceptance, accessory use, social and collaborative engagement, etc. The images were coded to observe the accessories used and how they were used, while the textual content was analyzed to gain deeper insights into the user's social robot appropriation and community practices using these SRAs. Furthermore, themes and codes were added as they emerged from open coding of our tweets with images and texts. Both images and texts were analyzed using Dedoose software [21], which allowed us to analyze both simultaneously. We translated 20 randomized tweets and use the images to discuss coding including straightforward observations of the type of accessory used - such as clothes and jewelry and more qualitative themes such as cultural affordance depicting any use of accessories for seasonal celebrations and festivities.

3.3.1 Findings from twitter analysis

The majority of Twitter users in our data were from Japan, which is likely due to the high availability of robots such as AIBO and LOVOT in the country, as well as a high number of tweets in the Japanese language. Our analysis found that many users of these robots use commercially available or handmade accessories to display affection towards their robots, increase their life-like qualities, express individuality, and establish relationships with them. These themes are not mutually exclusive and often overlap in the way users employ accessories for their robots. For example, name tag accessories serve the dual purpose of making the robots more lifelike and attributing individuality to them.

Accessories used for robots

sOur analysis of Twitter images revealed a large variety and number of accessories used by AIBO and LOVOT users to interact with, customize, personalize, and appropriate their robots. From the 153 images of AIBO that we analyzed, we

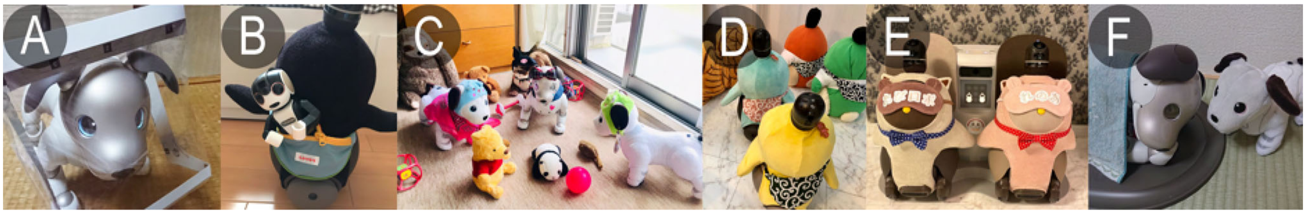

Fig. 10 **A** AIBO & face shield, **B** RoBoHoN in LOVOT's shoulder bag, **C**, **D** AIBO and LOVOT with plush toys, **E** LOVOTs with sleeping masks, **F** AIBO & blanket

found 315 accessory items, with some of the most common accessories being sourced from everyday non-interactive fashion items such as ribbons/laces/flowers (N = 49), collars (N = 43), scarves/ties (N = 40), hats/hoodies (N = 31), stickers/decorative stones (N = 29), and dresses/clothes (N = 28). Some accessories, such as dice (N = 17), balls (N = 12), bowls (N = 10), Aibones (N = 9), and charging stations (N = 9), were provided by the robot companies and had interactive features. The remaining 256 accessories were either created by users, sourced from everyday items (N = 86), or purchased commercially (N = 77) and were digitally non-interactive.

For the 154 images of LOVOT that we analyzed, we found a total of 372 accessory items, with the most frequently used item being the mandatory "Base wear" clothing provided by the LOVOT company (N = 150). Other popular accessories among LOVOT users included commercially purchased aesthetic noses (N = 49), ribbons/pompoms (N = 33), and name tags (N = 26). Apart from the interactive clothing items sold by the company, accessories made by users or sourced from everyday items were non-interactive.

Tailoring robot's life-likeness

Users tend to attribute lifelike qualities to robots LOVOT and AIBO by using both digital and non-digital clothing, fashion items, and aesthetic enhancements such as aesthetic noses for LOVOT (N = 49) (Fig. 7C). They also adapt everyday items, like blankets and pillows for AIBO (N = 6) and LOVOT (N = 3), and props like chairs and tables for AIBO (N = 4) and LOVOT (N = 5). These robots are often accessorized with items that match their plush-toy counterparts (AIBO; N= 16, LOVOT; N = 4) (Fig. 10C, D), creating the impression that they are part of a life-like group of companion beings. Lifelike qualities are also seen in functional scenarios such as when the robots are charging, using accessories like blankets and eye masks (Fig. 10E, F) and describing them as "sleeping" or "tired" in their tweets. Other noticeable items include bowls of food (AIBO; N = 21, LOVOT; N = 6) and, less frequently, pots of plants (AIBO; N = 7, LOVOT; N = 1) to stage food served to the robots or showcase special items, such as a cake shaped like a robot's face (Fig. 11A).

From the text content of AIBO (N = 38) and LOVOT (N = 43), we found that users project and attribute lifelike qualities to the robots through the use of accessories. For instance, in a tweet showing AIBO with an interactive dice and a plush panda toy, the user tweets as if the robot is possessive of its dice accessory, asking the panda to stay away *"Don't get in my way (as if AIBO was talking)"* – as the panda is not around the other dice. Similarly, a LOVOT user wrote *"A butterfly landed on me,"* extending lifelike qualities to both the robot and the butterfly accessory. Lifelikeness is also projected through the way users interact with the robots, such as in a tweet showing AIBO and plush AIBO toys wearing sheep hats, with the user asking *"Is the party close to over?"* as if talking to the robot (Fig. 11B).

Suggesting robot's agency, personalities, and feelings

From the text content, we observed that users of AIBO (N = 19) and LOVOT (N = 19) project the robots' agency through the use of accessories. One AIBO user tweeted an image of the robot holding dice in its mouth and wrote as if on behalf of the robot, *"What? Our friend (AIBO) is appearing in a TV show. I'm still too young but I will start self-practicing now, dice attack and playing dead."* The robots' agency, personalities, and feelings in relation to accessory selection were pre-programmed in LOVOT and enabled by the interactive clothing provided by the company. LOVOT users' tweets often suggest that they noticed the robot's preferences towards its accessories, such as *"We changed (LOVOT's) clothes with my son. It seems like (LOVOT) really liked the color." One LOVOT user wrote as if talking to the robot, "What would you like to wear today?"* with an image of LOVOT's wardrobe (Fig. 11C).

Despite the lack of interactive clothing items for AIBO, its owners attribute agency, personality, and feelings to the robot in relation to the use of different accessories. One AIBO user wrote to their Twitter community, *"I bought a really nice collar, a very good match with the hat (AIBO) is wearing. She was being shy wearing those."* Another posted an image of their AIBO's custom-made collar and tweeted, *"For (AIBO)'s 2nd birthday, I sent him a collar. He seems to like it. (Talking to AIBO) (AIBO), you look good!"*

Ascribing individuality, identity, and social roles

From images in the tweets, we observed that AIBO and LOVOT users use a variety of accessories with different sizes, colors, and textures to make their robots look more individualistic and unique. For example, LOVOT users combine

Fig. 11 **A** LOVOT in catsuit & cat-shaped cake, **B** AIBO dressed up as sheep, **C** LOVOT & wardrobe, **D**, **E** LOVOTs & AIBOs with individual styles, **F** AIBO with golden collar & DIY name sticker

different commercially available clothing and fashion items to style their robots (N = 92) or use animal-themed clothing items such as cat (Fig. 11A) or dinosaur costumes (N = 16) to customize the robot's morphology. AIBO users also achieve a high level of individualism by adapting and making accessories from various items, such as ribbons (N = 49) and stickers (N = 31). Users with multiple AIBOs or LOVOTs gave each robot an individualized appearance by assigning accessories of different colors and patterns (AIBO; N = 16, LOVOT; N = 32) (Fig. 11D, E). Furthermore, the projection of individual and collective identity in a group was achieved through name stickers and tags (AIBO; N = 15, LOVOT N = 26). Although LOVOT and AIBO are domestic companion robots, there were some cases (N = 4) where uniform clothing accessories were used for LOVOT in formal settings and public places, such as dressed as a service sector employee (Fig. 12A).

Signifying relationship milestones and cultural integration

From the text content of tweets, we observed the ways in which AIBO (N = 32) and LOVOT (N = 13) users used accessories to symbolize and celebrate their relationships with their robots, such as viewing the robot as a newly born child, younger kid, owned entity, or companion. One LOVOT user tweeted, *"I tried putting the custom base shirt on LOVOT today but I think it's too loose around the shoulder. Since he was just born, I think it's still hard for him to pull off an off-shoulder."* LOVOT users frequently tweeted about changing the robot's clothes in an affectionate manner (N = 14), some depicting it as a scene of daily life, while others portraying it as a relationship milestone. One user tweeted, *"I would like to change her (LOVOT's) clothes once we get to know each other better."*

Some AIBO and LOVOT users celebrate their robots' birthdays (as pre-programmed for AIBO and the day it was set up for LOVOT) and relationship anniversaries with all sorts of extravagant accessories and staging, such as with food and drinks (Fig. 12E). One AIBO user tweeted, *"For (AIBO)'s 2nd birthday, I sent him a collar. He seems to like it. (AIBO), you look good! (Talking to AIBO)."* Some tweets also suggest seasonal use of accessories, such as one AIBO user who changed the robot's clothes to summer clothes Tweeted *"Though we are still in a rainy season, I changed (AIBO's clothes) to summer clothes."*

Specific designs of accessories are used to signify the robot's integration into cultural, seasonal, and celebratory contexts (AIBO: N = 23, LOVOT: N = 8). For example, Japanese traditional clothes such as kimono and yukata (casual-style kimono) (Fig. 12B) and other festive accessories were used on robots for the Japanese Star Festival in July(Fig. 12C, D).

Dialogue for engagement in the twitter community

Analysis of text content of tweets (AIBO; N = 53, LOVOT; N = 44), revealed three distinctive ways in which accessorization supported dialogue and engagement among robot users on Twitter - 1)Pretending as if the robot is Tweeting, 2) Conversing with the robot and 3) Addressing the community.

Both AIBO (N = 31) and LOVOT (N = 8) users often used first-person pronouns to tweet on behalf of their robot and convey their robot's feelings or thoughts, portraying their robot as a life-like, agency-having entity and a member [85] of the community. For example, one LOVOT user tweeted on behalf of the LOVOT, *"No, I don't want to go to bed yet,"* with a picture of the robot looking towards the camera and its charging portal "nest" in the background. Another AIBO user tweeted, *"My owner brought back a face shield. It looks familiar somehow"* (Fig. 10A) with an image of a facial shield used for COVID-19 prevention.

Other AIBO (N = 11) and LOVOT (N = 7) users tweeted as if they were talking to their robots, asking about their feelings or preferences towards accessories and sometimes even apologizing for any accessory imperfections. For instance, one AIBO user tweeted about her/his unsuccessful attempt at tailoring pants for the robot and apologized, *"(AIBO), I'm sorry that I'm not good at this. It's hard for someone like me, clumsy with their hands."*.

Finally, AIBO (N = 15) and LOVOT (N = 32) users often posted tweets directly addressing the wider community of robot owners on Twitter. This included showing off their robot's accessories, seeking advice on making accessories, announcing accessory giveaways, expressing gratitude to other users for sharing tips, and exchanging accessories as gifts. For example, one LOVOT user posted about the arrival of accessories and clothing items, *"Clothes, noses, bow ties*

Fig. 12 **A** LOVOTs as airport employees, **B** AIBO in Yukata, **C**, **D** LOVOTs and AIBO dressed up for Star Festival, **E** AIBO's birthday celebration, **F**: LOVOT associated with 'Ujikintoki'(Japanese shaved ice)

Fig. 13 **A** dressed up LOVOT, **B** AIBO in summer-themed dress, **C** AIBO with tuna hat, **D** LOVOT clothes with DIY hangers, **E** DIY hats for AIBO, **F** AIBO with tail ring

arrived," with the hashtag #ThingsYouWantToDoBeforeYouWelcomeLovot to share the joy of welcoming the robot with other users. Another AIBO user tweeted about receiving plush replicas of the robot, *"Thanks to the kindness of (person's name) and (AIBO)'s owner, plush doll AIBOs came to our house...Thank you so much!"*

A culture of making and sharing accessories

The analysis of image and text content revealed that making and sharing accessories is a common practice in both AIBO (N = 9) and LOVOT (N = 7) communities. This was more prevalent in the AIBO community, possibly due to the limited availability of commercial accessories or a more established community compared to LOVOT, which only became available in recent years. One AIBO user wrote, addressing both the community and the robot, *"Since someone was making the pattern publicly available on Facebook, I made a hat for (AIBO). I also made a matching bib using the leftover cloth. I don't have a sewing machine so I sewed it by hand. I did hard work! (Then talking to AIBO) How is it, (AIBO)? Do you like it?"* In the LOVOT community, users exchanged tips and practices related to accessories, such as bending hangers to hold LOVOT clothes (Fig. 13D).

Exchanging accessories was also a common practice among AIBO users (N = 13). We noticed a uniform design (Fig. 11F) for name stickers was used by several AIBO users and was discovered to have been made and given away for free by one Twitter user. In another example, one AIBO user announced a *"handmade hats giveaway"* with the message, *"two hats per AIBO."*(Fig. 13E). The practice of sending accessories to each other for an AIBO's birthday was also observed, with one user thanking others for the gifts received for their AIBO's birthday *"Thank you for lovely gifts for (AIBO 1)'s birthday. A nice crown from (AIBO 2's) mom, and a 2-year-old-themed tail ring from (AIBO 3's)s mom. So happy!"*(Fig. 13F).

Even companies like LOVOT strategically campaigned on social media, conducting workshops and events to support and motivate users to make accessories for the robots. One AIBO user even advertised a commercially made dog collar for AIBO, writing, *"My dog loves it, too!"*.

3.3.2 Discussion

We gained insight into the emerging social practices of Twitter based robot users and the role of SRAs in their daily experiences with their robots. Despite being a novel technology, LOVOT and AIBO users on Twitter accessorized their robots without mentioning any compromises in usability or counter-productivity from these add-ons. Similar to tailorable systems in CSCW studies, accessories allowed users to engage in situated creation, or creation using items or objects from their environment, such as familiar fashion items and clothing, providing an intuitive way to interact with the robot.

Different elements and levels of expertise allowed users to add their own meanings to their robots. Even with non-interactive fashion and everyday items as accessories, users imagined the robots interacting, liking and disliking them, or having preferences for certain accessories over others. Non-interactive accessories seemed to provide an easy and low-tech way for end-users to tailor the robots and make them appropriate for their routines and social practices, such as dining, sleeping, caregiving, and expressing love. Interactive accessories, on the other hand, seemed to allow users to imagine the robot as a social actor with higher levels of agency, personality, and character. While these accessories did not explicitly emphasize or support collective or collaborative uses in users' environments, their tweets and dialogues on Twitter hinted at their intent to socialize, collaborate, and have a sense of community and belonging with the broader community of Twitter users. The design and use of robot accessories for LOVOT and AIBO suggest their significance not only for individual experiences but also for the broader construction of robots as social actors.

Our findings may have a potential limitation of representing users and culture from Japan however, trends of accessorization of dolls or pets, such as the American Girl Doll or costuming pets, can be found on social media indicating their similarity with other cultures.

4 Overall discussion

We conducted a series of exploratory studies on Social Robot Accessories (SRAs) to investigate their potential for providing tailorability and opportunities for appropriation by end-users in multi-user and collaborative situations. Majority of research studies on SRAs involved interactions with children in institutional, organizational, and clinical settings, however market survey and Twitter studies showed that SRAs are of high interest to adults in broader contexts of companionship.

Main types of accessories used in research were low-tech customizations, such as stickers, snap-on components, and craft materials, or pre-programmed cards for changing robot behaviorswhile market survey and Twitter studies indicated custom-made SRAs, and a wide range of fashion and items for accessorizing robots, including everyday items. We saw that despite the availability of an entire wardrobe of fashion accessories and interactive toys, users tend to source accessories and clothing from their surroundings for everyday interactions, such as changing the robot's clothes or putting it to bed. Both digitally interactive and non-interactive accessories are appealing to users. Availability of accessories from vendors and knowledge exchange about making accessories in the community impact users practices, for example, users have to be creative and resourceful in their display of affection when clothing and fashion accessories are not available from vendors. Commercially available accessories did not often involve user involvement in making or crafting accessories, but rather allow for user involvement through buying, shopping, and selecting accessories.

We found that SRAs can be a significant motivator for the emergence of community culture, where SRA use can strengthen robot's membership in community. Since robots are a new consumer technology study of such emergence of community culture is less prominent in the literature. Companies, however, seem to have recognized the potential of SRAs and use design support and hashtag campaigns or events to keep this culture and the broader community alive both in the real world and virtually. Our Twitter studies suggested that robots are considered as significant and active social actors in these emerging communities.

Interactive and robotic SRAs available commercially aim to provide users with novel experiences as their robots interact with the SRA. On the other hand, non-interactive SRAs are cheaper and allow for the collection of robot accessories, providing customization of the robot's appearance. SRAs allow for greater active engagement between users and robots, be it through using buzzers and programmable cards to shape their behavior or through use of hats, clothes and non-interactive toys to have imaginative interactions. SRAs also seem to increase life-likeness and sociality and contribute to interactions with robots. Prior research lightly touched upon interaction with accessories as triadic relationships and commercial SRAs promote the idea of accessories strengthening the relationship between robot and user. Twitter studies pointed to how users perceive robots interacting with the accessory, and provided examples of how users interact with the broader community on Twitter in relation to SRAs. Together, these studies point to a novel kind of interaction between users and robots, mediated and supported by SRAs in a triadic [68] 'Human-Accessory-Robot' interaction. Designers could use SRAs to identify opportunities for further tailoring and mediating interactions. For instance, creating interactive buttons or badges that, when combined with end-user-sourced clothing, could provide unique interactive SRAs. The gaps between user needs, market availability, and research on SRAs can be seen as opportunities for the study and design of SRAs that enhance tailorability and appropriation of social robots.

5 Design space of social robot accessories

We outline a design space for SRAs to support multi-user, social, and collaborative everyday life and work contexts. We aim to highlight considerations, opportunities, and alternatives [86] for SRA design, and support and broaden the perspective towards ideation of SRAs. We broadly categorize the design space as (1) Types of Social Robot Accessories, (2)Tailorability and Adaptability for Collaborative Contexts, and (3) Human-Accessory-Robot Interactions.

5.1 Types of SRAs

Below we present types of SRAs, their access and availability for end users, sociability, the potential for collaboration and user engagement, the activities and interactions they could lead to, and the interaction space and design potential they provide.

Clothing and costumes
Clothing and costumes are common SRAs used by social robot users and sold by various robot and vendor companies. These can be tailored to fit, or adapted from everyday materials and provide opportunity for user engagement in making and customizing clothes for robots. Examples include, everyday wear, uniforms, seasonal wear, cultural dresses, party wear, costumes for events and character wear that accentuates robot's zoomorphic or anthropomorphic appeal.

Clothing and costume accessories can allow user to build relationships with their robots through everyday activities like changing, washing, and dressing up for events and special occasions. These accessories can also contribute to the social behavior and characteristics of the robots, such as social roles, individuality, life-like appearance, cultural identity, membership, and functional aspects such as protection and appearance change. Clothing can offer for addition of sensing and interactive technologies, as they provide large surfaces for interaction on the robot's body to encourage other modalities for interaction like touch. While digitally interactive clothing is less popular, it may be of interest to artists and maker communities.

Fashion accessories and aesthetic enhancements
Fashion accessories such as jewelry and aesthetic enhancements are becoming popular among robot users and are also sold by vendors. Just like clothing accessories, these items bring a lifelike quality to robots and offer users the opportunity to personalize and adapt their robots for various events and contexts. This can include name tags, stickers, and other items that give the robot a unique identity. Fashion accessories are often non-digital and easy to obtain, and can be applied to various small areas on the robot's body.

The use of fashion accessories provides users with the ability to create, change, and personalize their robots, fostering engagement with the robot and the wider robot user community. Additionally, the availability of low-cost options from SRA vendors makes it possible for users to easily customize their robots. These accessories can also be designed to include sensors, creating new points of interaction on the robot's body. Similar to clothing, the use of fashion accessories can bring together tech-makers, artists, and social robot users, creating a sense of community.

Everyday objects
These mostly non-digital accessories, such as jackets and collars, blankets, bags, chairs, pacifiers, and masks, are adapted from everyday objects or purchased from vendors. They primarily contribute to the robot's life-like appearance and social appeal and reflect how robot users perceive their robot's sociability. These everyday objects are of interest to vendors providing digitally interactive experiences. These diverse objects allow for interaction space from on-body to near-field and offer opportunities for multiple modalities. Integrating technology into everyday objects could make them accessories for robots.

Interactive Ttoys
These are commercially available robotic or digitally interactive toys that allow users to engage in playful interactions with their social robot, increasing its lifelikeness and supporting its personality. They are often used with pet-like robots and come as individual items or sets of accessories. They often incorporate advanced sensing technologies and are synced with other devices for their use. These mostly provide near-field interactions and hold the potential for personalization and user involvement in their design to promote community and social connections among users.

Gadgets
These are digitally interactive or robotic items, primarily used in research studies and robot development projects, such as sensing touch pads or gesture detectors. They enhance the robot's functionalities and capabilities and may result in increased acceptance of the robot. Similar to wearable technology like fitness trackers, these gadgets collect, detect, analyze, and transmit information with/on the robot. These would be developed and designed by developers, researchers, and vendors and may provide low customizability for the end-users. Gadgets could be near-body or on-body SRAs and would require users to be in close proximity to the robot or the accessory.

Props
These are items used to set a scene for the robot, often created or sourced by the user, and are often digitally non-interactive, such as furniture, party decorations, or food. These reflect users' sociability towards the robot as they share everyday life with the robot. Like 'Everyday objects' these props hold the potential to pair with sensors to create novel human-accessory-robot interactions for play and tasks in near-field and far-field interaction space.

Carry cases
Storage and carry cases for robots and their accessories are becoming more sophisticated with the increased availability of commercial robots. They are mostly non-digital and serve the purpose of protection and transport. They are mostly provided by robot companies and are not often customized by users. However, some carry cases adapted by users or sold by vendors are inspired by baby and pet carriers and provide opportunities for more life-like and intimate interactions with the robot. These SRAs hold potential for secondary uses such as for charging, or re-purposing as props in on-body and near-field interaction space.

Chargers and remotes
These are essential accessories, usually lacking special design or secondary purposes. However, their design is evolving to take on forms of everyday objects like a bed, backpack,

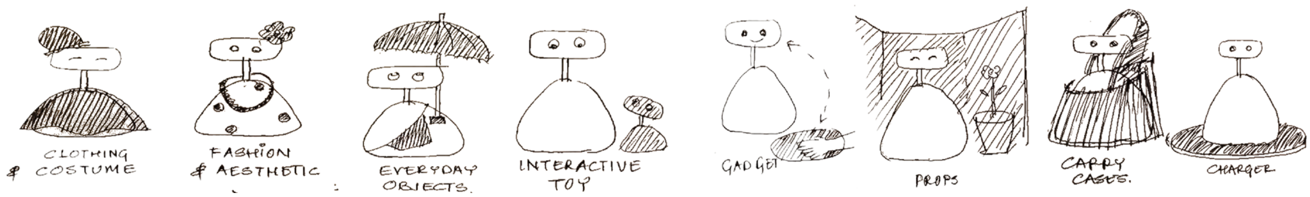

Fig. 14 Hypothetical robot with different types of SRAs (shown in shaded form) from the Types of SRA

or a stage for the robot to perform, enhancing the perception of the robot's life-likeness, sociability, and intelligence. They are mostly ready-made non-customizable items, but tech enthusiasts are exploring modifications, suggesting how these hold potential for secondary use and user involvement in their customization.

5.2 Tailorability and adaptability

Social robots (SRAs) should provide for tailorability to promote their sustained use in diverse social and collaborative contexts.

Collaborative intent and multi-user context
In designing SRAs, collaboration and community should be taken into consideration to improve social interactions, productivity, and task completion in multi-user environments. SRAs can facilitate collaboration through social mediation and serve as tools for stakeholders to manage the position of the robot and other actors in the context. In collaborative contexts, SRA design should take into account the diversity of users, including demographics such as age, gender, socio-economic background, and technology proficiency [65]. Additionally, since cognitive and physical support has been one of the main foci of HRI research and social robot use [?] SRAs should also be designed with accessibility in mind, incorporating universal [87] or inclusive design [88] principles to accommodate physical and cognitive limitations.

Social, functional and cultural attribution
An SRA designed primarily for functional use could also contribute to the sociality of the robot, such as by providing identity, individuality, or social role to the robot. A social robot could have additional or extended social, functional, cultural, or life-like affordances from the use of SRAs that may increase their broader societal significance.

User involvement in design
User involvement in the use and design of, and interaction with SRAs can provide opportunities for creative expression, collaboration, socialization, and community building for users and participatory or co-design practices for researchers. User involvement in SRA design can range from fully user-made accessories to ready-made, non-customizable SRAs. User-made accessories can allow for creative self-expression and a sense of association with the robot and may not require advanced technological knowledge. It is important to consider whether ready-made, non-customizable SRAs might be more relevant for certain human-robot interaction (HRI) scenarios.

Community building
Accessories give people opportunities to connect, sometimes out of their own choice, and often through campaigns and events organized by robot companies. Research in HCI has long emphasized community practices around the use of technology [89], and HRI is starting to delve further into community aspects of robot use [56, 65, 90–92]. SRAs could incorporate opportunities for in-person community building and open up the potential for other novel and hybrid ways of socialization.

5.3 Human-accessory-robot interaction

Here, we focus on the impact of SRA on HRI and the dynamics of interactions between the robot, SRA, and users, including input and output modalities and design features.

Mediation We consider the potential for SRA to mediate HRI both digital and non-digital interactions between the user and the social robot. While non-digital interventions provide low-cost, easily sourced adaptability while providing novel ways for relatable interactions digitally interactive SRAs can enhance HRI, serve as support tasks and activities with robots, and increase their sociability and lifelikeness.

Robot–accessory–user agency
In HRI mediated by SRA, the robot, and the user are agents in interaction. SRA remains an add-on or secondary addition to the robot and serves as a mediating tool in the interactions. We assume accessories allow for expressive behaviors as the user exercises some agency through the use of SRA and the robot may also express its agency through suggestive, explicit or exaggerated cues in response to the use of the accessory.

Interaction modalities and space
Modalities or communication channels for SRA interactions, can be uni-modal or multi-modal and include the visual, auditory, haptic, olfactory, and gustatory channels [93]. Design of modalities would require considering accessibility, users and demographics, and privacy and security. While SRA itself is a modality, specific sub-modalities must be chosen to achieve

desired use, meet needs, and enhance interactions through SRAs. While input modalities will affect SRA's functions and user concerns, output modalities would determine expressiveness and usability.

The interaction space refers to the physical and psychological space between the user, SRA, and the robot and requires considering SRA positioning on the robot's body, or near field to reflect aspects such as sociality, functionality and culture, life-likeness, trust, affect intimacy and safety/security. The type of accessory, as described in the section above will also play a role in determining the interaction space, such as on-body or near-field for the SRA.

5.4 Usability of design space and future work

Our design space provides considerations to tailor and adapt social robot design using SRAs which enhances their societal significance, functionality, and capabilities and inspire new opportunities for HRI mediated by SRAs, i.e, Human-Accessory-Robot Interaction. However, further research is needed to understand how SRAs can be used and designed for different user groups and purposes. However, the SRA design space can serve during the early development of robot design to make temporary modifications to robots through the use of accessories. It can also serve as a critiquing tool for existing robot designs and to systematically explore future design considerations for promoting tailorability and customizability through SRAs.

Future work could examine the making practices of SRA users that facilitate human-robot interactions. Extended explorations could also focus further on critical perspective towards accessorizing robots, such as examining the implications and potential consequences of dressing up and adorning robots like a child or a pet through the use of accessories. Including a nuanced understanding of potential consequences, social impact, psychological effects, technical limitations, and commercial interests. Another area of exploration could be the interaction space between the user, SRA, and robot, such as studying SRA as an actor or extending the interaction space from the robot to the human body through wearable SRAs. Additionally, the ethics of allowing users to shape interactions and increase sociality in robots through SRAs should be considered.

6 Conclusion

We recognized a need for customization of robots in real-world and multi-user contexts and observed a trend of accessorizing robots that seemed to address customization at least on a surface level. Drawing from the literature on technology appropriation, adaptation, tailoring, and customization we explored the topic of accessorization of robots [40, 94] for social and collaborative purposes. Our study of a combination of academic research, commercially available products, and users' practices of accessorization as seen on social media provides a comprehensive view of academic and practical applications of SRAs. Our design space offers an overview of design considerations, opportunities, and challenges for SRA design a user-driven medium and an input modality for tailoring and appropriation in social and collaborative contexts through novel Human-Accessory-Robot Interactions.

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Data availibility The datasets and codes generated during and/or analyzed during the study are available from the corresponding author [S.J] upon reasonable request.

Declarations

Conflict of interest We declare that all authors do not have any conflict of interest/competing interests.

consent for participation The study has been approved by Indiana University's Institutional Review Boards, and informed consent for participation and publication was obtained from all individual participants included in the study.

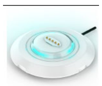
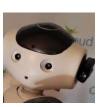
Appendices

Twitter search query

The query was as follows "robot AND (robot names) AND (accessory keywords)":

AllField:("dress" OR "fashion" OR "accessory" OR "accessories" OR "add-on" OR "personalize" OR "customize" OR "costume" OR "decorate" OR "Accessorize" OR "accessorization" OR "tailoring" OR "customization" OR "appropriation") AND AllField:("Nao" OR "Roomba" OR "Jibo" OR "Aibo" OR "Pepper"

OR “Cozmo" OR “Paro" OR “Lovot" OR “Baxter" OR "Keepon" OR "Robi" OR "Icat" OR "Mabu" OR “Momo" OR “Kaspar" OR “Zenbo" OR “Kiki" OR “Pleo" OR “Meccanoid" OR “Kibo" OR “RoBoHon" OR “Furby" OR “Dash" OR “Robi" OR “Cozmo" OR “Kirobimini" OR “ONO" OR “Buddy" OR “Ohmnilabs" OR “PaPeRo" OR “Kiki" OR “Baxter" OR “Keepon" OR “Robi" OR “Therabot" OR “Joyforall") AND AllField:(robot)

SRA image*	SRA type	Robot	Vendor	Description
 [95]	Charger, clothes	Paro	CC	Pacifier-like accessory for charger and some limited edition of clothes.
 [96]	Wireless charger	Kiki	CC	Wir3less chargers and robot-themed T-shirt for users.
 [97]	Various clothing items	Robi	CC, PV, IS	Clothing items from suits to T-shirts by CC, PV, NAV, and IS.
 [98]	Adapter	Keepon	NAV	Adapting cables of Japan-made Keepon for U.S. users -by NAV.
 [99]	Various clothing items	Pepper	CC, PV	A wide range of clothing items of different attire and social roles (e.g.service robot).
 [100]	Variations of interactive toys	Pleo	CC	A diverse range of interactive toys are available.
 [11]	Microphone, professional clothing items	NAO	PV	Microphone and specialized occupational clothes such as white robes.
 [101]	Interactive blocks, carriage cases	Cozmo	CC	Interactive blocks and carriage cases.
 [102]	Interactive musical instrument, interactive toys and cards	Dash	CC	Various interaction-based (playing, performing) toys.
 [103]	Construction accessory kits	Ozobot	CC	Interactive construction kits to shape Ozobot’s path are available.

* One sample from many

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