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"Somebody help me, please?!" Interaction design framework for needy mobile service robots*

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Abstract—**Most humans expect robots to function autonomously and properly. Yet, even reliable robots need human help every now and then and must "ask" for assistance. This paper presents the development of an interaction framework for designing robots requesting help from time to time performing their original task. Based on a broad literature review, basic principles for help requests in human-human interaction (HHI) and human-robot interaction (HRI) are used to design a checklist. Starting from this checklist, the examples of two robots (service vs. industrial) are used to demonstrate the framework principles. At last we discuss the usefulness of this checklist and reflect the critical impact of implicit contradictions between its principles and of technological evolutions like artificial intelligence (AI).**

I. Introduction

In human robot interaction robots typically play the subordinate, supportive part of an assistant or the "helping hand" for the human operator [1-4]. However, even autonomous robots are not perfectly reliable and may need the assistance of a human to accomplish tasks beyond their capabilities [5, 6]. These limitations may be due to very complex or exceptional circumstances of a task which is normally accomplished smoothly, e. g. manufacturing robots that cannot reach a too distant work piece [7, 8]. On the other side, external circumstances may impose constraints the robot is not designed for [9], e. g. transportation service robots incapable of opening and passing doors. These limitations often arise from technological gaps, like actuators or sensors that are not perfectly reliable, insufficiently automated environments, or a lack of standardization of the setting the robot was originally designed for [10, 11]. Bridging this gap technologically is often far too costly or complex and therefore no practical solution. An alternative to overcome this gap may be to "turn the tables" in HRI. The robot asks humans for assistance [4]. Humans may help robots in two ways: (1) Increase capabilities by performing physical tasks a robot cannot perform autonomously or (2) reduce uncertainty about their state or the effect of their actions [5]. Robots asking for such kind of support increase their task performance significantly [12, 13].

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In this contribution, we address the problems that arise from a robotic request for help. We think that an appropriate design of the request is crucial for the human's willingness to help and for a successful assistance. Dialog design should be based on interdisciplinary knowledge about helping behavior from HHI. We transfer ideas from (social) psychology, communication studies, and linguistics to the design of robotic dialogs. The theoretical part begins with a review of different research fields and design aspects. The results are subsumed in a checklist for the design of robotic requests for help. Two use cases of an industrial and a service robot illustrate the checklist's design principles. An emphasis of the discussion is the use of artificial intelligence for the smart adaption of robotic requests for human help.

II. Related Work in Robotic Help Requests

We divide the interaction process in three basic skills: detection, HRI dialog, and navigation. From the human's perspective, the dialogic structure of the request and the interaction is the most relevant aspect and is therefore emphasized. However, detection and navigation are strongly interwoven with dialog design and should be considered as well.

A. Detection: Humans, Ability to Help, Attention, Avoidance, and Helpfulness

Before a robot can ask a human for help it has to detect humans in the environment. Detection, localization, recognition, and tracking of humans are features which have been worked on for a long time (for a review see [14]). Humans must be recognized (features, faces, gaze, body pose, activity, gesture). Two problems may arise in the case of a robot asking for help. First, no potential human assistant may be around. In this case the robot should be able to call for attention to itself. If the robot is able to navigate autonomously, he may also actively navigate the environment and seek for human assistance [5, 15]. Second, if there is more than one human available for the help request, pluralistic ignorance may emerge [16, 17]. The responsibility to help the robot is spread among possible assistants and reduces the perceived responsibility to help for each of them. This problem can be faced by addressing a person directly, that is most likely to help, e. g. a person that is attending the robot and capable to help. Here, the *ability* to help is important. In public environments, children, elderly people, and physically handicapped persons should not be addressed in the first place, since it is very difficult to detect whether they might be able to help. In industrial settings, people busy with work or carrying objects should not be asked as well. Next, *human attention* recognition is important [18]. It is more sensible to address persons that (visually) focus the robot and thus can directly perceive the need for help. Visual attention can be estimated by the orientation of the body and especially the continuous head pose respectively face orientation (viewing direction) [19]. People's engagement tells how much a person is distracted or busy. *Visual and behavioral avoidance behavior* should also be taken into account. Evasion or sidestepping may be a cue for the avoidance of help [20, 21]. Robots that detect evasive moving trajectories of humans can relinquish to ask for help. Drawing from prosocial behavior in infants, algorithms for detection of prosocial behavior may help to recognize human helping behavior [22, 23].

If the robot recognizes a person that is able to help, attentive and not avoiding the robot, it may ask the person for help. From that point on, the robot has to be capable of recognizing if help is granted and if it is appropriate. It has to monitor the ongoing help in order to correct the person and adjust the help so that the robot's problem is fixed properly.

B. Dialog: Human-Robot Interaction

The main focus of the dialog should be to reduce the assistant's uncertainty and to build up a shared mental model of the HRI in the helping situation [24, 25]. The potential helper derives HRI from HHI, i. e. helping robots is derived from helping humans (see media equation [26]). It should communicate clearly and unambiguously its need for help and how to be helped in order to avoid the bystander effect [27]. According to HHI, HRI is composed of verbal and nonverbal interaction. Verbal interaction is represented by speech output and recognition, as well as written dialogs in the graphical user interface (GUI) of the robot. Visual interaction is represented by visual stimuli in the GUI as well as other optical interfaces. A facial mimic GUI (the robot's "head"), LED lights, and a projector are discussed in this paper.

For the overall design of the HRI **dialog principles** of interface design (cf. [28, 29]) should be considered. Task suitability is important to support the potential helper effectively and efficiently since help should be made as easy and expeditious as possible. Since the assisting persons may not be involved respectively used to the robot ("out-of-the-loop"), self-descriptiveness is vital to ensure an immediate intuitive helping behavior. The aim of the robot should be to communicate clearly and transparently the need for help and the preferred assistant's helping actions. According to the barriers of prosocial behavior, the person has to know *if* the robot needs help and *how* they may help the robot in its needy situation.

1) Multimodal dialog design

Robots can communicate their helpfulness by different modality channels. A basic visual feature is the **motion** of the robot in the human's environment [18, 30]. Before requesting, movements (accelerating, rotating, approaching) in the proximity of potential helpers may arouse the attention of persons automatically (peripheral exogenous attention, see [31]). Frantic and fast movements should be avoided since they can be disturbing or misinterpreted as emergencies [30]. "Expressive" motions (path shapes) can also illustrate the "inner state" of the robot and alter the human perception of its task, focus, and confidence [32].

Gaining attention while approaching, the robot can send secondary signals parallel to the motion towards the user. The use of **lights** for persistent visualization of a robot's state has turned out to be effective for non-verbal communication [33, 34]. Researchers used different colors of light, blinking patterns, and progress bars to inform persons in the environment. Blinking might also attract peripheral-visual attention automatically (similar to acoustic stimuli), i. e. it can attract visual attention even if the robot is not in the visual focus or in a distance [34]. The color of the visual output should follow conventions and standards (e.g. [35, 36]). Red represents an error state (robot needs help) in contrast to green that represents a properly functioning system status (robot is operating autonomously). Light and colors are simple but intuitive and effective means of communication [37].

The use of LCD **projections** into the environment (floors, walls, objects) is rarely used in HRI. For autonomously navigating robots, the trajectories of the path can be displayed directly on the floor to avoid obstacles and show intended directions [38, 39]. This leads to an increase of situation awareness in dynamic situations [40]. Other researchers used projectors to highlight safe areas during human-robot collaboration [41, 42]. An important aspect is to find an adequate projection surface in the environment and to correct for distortions [40, 43].

A **robotic "face" (GUI)** should be able to show emotional expressions to display his needs e. g. looking sad when he needs help. On the opposite, showing a smile or happy face after he has been helped conveys happiness and gratitude. Emotional facial patterns are important in interpersonal nonverbal social communication and can be cross-culturally recognized [44]. Perceivers of facial emotions respond to these cues automatically. Eisenberg et al. [45] report sympathy and helping intentions for persons watching distressed and sad faces. Robots that express facial emotions increase social acceptability [46] and, as a result, prosocial helping behavior. Another way to elicit helpful behavior using the robot's face is to employ the schema of childlike facial characteristics (*Kindchenschema*). The combination of typical features from infants, babies, or small animals elicits instinctive caring behaviors in adults [47]. These effects are reported for "cute" robots as well [48]. Baby features are considered as naïve, honest, and helpless and evoke helping behavior [49].

Acoustic channels are composed of sound and speech output. Sound stimuli (e. g. bleeps or other alarm sounds) can be perceived even if the robot is not in sight. They can attract the attention of potential assistance automatically dependent on the volume and pitch [50]. Speech output (e.g. "I need help!") can be used, too. It works similar to sounds as to attention attraction, but it reduces ambiguity since it communicates the need for help directly [17]. Furthermore, the urgency of the situation may be transported by the prosody of the voice tone (e. g. sad or alarmed voice) [51]. If the robot speaks actively, it should apprehend human language. People will automatically respond to the verbal statements of the robot since they assume that the robot is capable of understanding spoken language.

2) Verbal dialog design

In order to design verbal communications between humans and robots the semantic structure of the verbal dialog should be considered. Politeness Theory as well as specific communication strategies provide anchors on how to design the dialog.

a) Politeness Theory: "It's not what you say, but how you say it."

Politeness is an essential factor when robots address people [11, 52]. It is to some extent culturally coined and socially normed [53], however some aspects are universally shared and accepted. In the following, we refer to politeness as the pragmatic features of spoken language which is engaged to preserve interpersonal relationships and to avoid social conflicts [54, 55]. Politeness is important for engaging in social interaction and building rapport [56, 57].

Robotic help requests are similar to interpersonal interaction, so robots should respect the same cultural and social norms that are used in human communication [58]. Next to technical failures, violations of social norms are severe errors and reduce acceptance in HRI [8, 59]. The use of Politeness Theory is a way to avoid social norm violations in HRI dialogs [54]. It focusses on the notion of the "face" as the public self-image of a person which can be attacked by "face threatening acts" like requests, critics, or positive comments. People employ polite communication strategies to mitigate face threats (see Table 1).

TABLE I. POLITENESS STRATEGIES (BASED ON [11])

Strategy	**Description**	**Example** (Door)
Direct Request	Baldly performed request (no face threat mitigation)	"Open the door for me"
Positive Politeness	Attending the positive face, make the listener feel good	"I am transporting your papers, help me with the door, will you?"
Negative Politeness	Attending the negative face, avoid imposition to the listener	"Would you mind opening the door for me?"
Indirect Request	Vague and ambigous language, no imposition	"The door is blocking my way."

HRI research shows that polite request leads to more helpfulness and a higher perceived appropriateness of the request [11]. The positive politeness strategy seemed to be the best alternative. Salem et al. [55] compared the direct and polite (positive politeness) strategy and found that the polite strategy led to higher perceived interpersonal warmth ratings but it had no effect on task performance. Castro-Gonzáles et al. [60] postulate that polite robots are more likeable and more engaging (motivating). Furthermore, the politeness effect is stronger in persons that are less familiar with the technological system ("strangers"). This is important when assistance is requested from uninvolved humans, e. g. in public settings.

b) Communication Strategy

Furthermore it seems promising to address the **reciprocity** of the assistance. Reciprocity and altruism is a basis for social exchange [61-63]. Supportive robots that request assistance may emphasize that they help humans and ask for help in return. This "tit for tat"-strategy has also been found to be effective in HRI studies [11]. Hayes et al. [64] found that persons were more open to assist robots that helped others than robots that only worked for themselves.

Cameron et al. [2] found that **limitation** statements as reasons for the request led to higher liking and willingness to help. If the robot explained *why* he is asking for help, it received higher liking ratings and the willingness to help was increased. Without giving a reason or recovery strategy, users are often confused about the request [3, 65]. Asking for help can be understood as a transparent way to communicate shortcomings and prevent errors. However, robots should not blame themselves repeatedly for their limitations since it can be understood as deficiency and reduce trust [66].

3) Robots Personality design

Apart from the dialog design aspects relating to the robot's overall "personality" can be taken into account. Persuasive behavior, the expression of emotions and the robot's morphology may contribute to the personality design.

a) Persuasive Robots

Robots need to motivate users with their request for help. Persuasive technology uses psychological knowledge from behavioral economics in order to influence people's behavior without coercion [67, 68]. Persuasive robots are developed to change the behavior, the attitude, or cognitive processes of people [69]. Nudging is the central persuasive strategy which tries to influence human behavior by changing the decision situation subtly without constraining the decision latitude of a person [70]. Based on Fogg [68] social cues can be adapted to technology in order to make them more persuasive and implement nudging:

- Physical attractiveness leads to higher liking and is more convincing,
- Psychological, human-like aspects (like personality, emotions, preferences, attitudes, motivation, empathy) lead to more persuasiveness,
- Gratefulness and praise as rewards for help make future helpful behavior more likely,
- Reciprocity ("tit for tat").

Robots can use bodily cues (spatial proximity, gestures, gaze behavior, posture, facial emotional expressions, touching), and verbal cues (tone and expression) to persuade humans (see above; cf. [71]). However, these persuasive strategies of dialogs may contradict other strategies, e. g. politeness [30, 72]. The study of Hammer et al. [72] showed that politeness increased helping behavior whereas persuasion was less effective – and even contradictory to politeness – since it may be interpreted as rude and impolite. Furthermore, nudging and persuasive robots may be morally and ethically questionable [69].

b) Emotions, and Anthropomorphism

Robots asking for help can use their limitations and imperfectness to reflect a more human-like behavior. In HHI, imperfect persons are often perceived more believable and attractive (*Pratfall Effect*, see [8]). In HRI, failure does not necessarily lead to negative affect or rejection of robots [73]. Users often prefer expressive and personable robots, even if efficiency is low and the robots make mistakes [74]. The need for help can make robots appear more human and increase the acceptance and likeability of a robot [8, 75]. Yasuda and Matsumoto [4] postulate that imperfect robots requesting help resemble children and therefore evoke positive responds. Brooks et al. [65] report that asking persons as a failure recovery strategy resulted in positive reactions (satisfaction, pleasure, reliability, etc.). In another study, asking for help was reported to be more enjoyable by the users [7].

C. Navigation: Approaching and Positioning

For mobile assistive robots, the navigation does not only have instrumental function in terms of map building, self-localization, or obstacle avoidance in order to accomplish the robot's service tasks. Especially in public, sometimes very crowded environments, e.g. supermarkets, the navigation is also part of nonverbal communication with a potential user and has socio emotional importance. To optimize the human-robot interaction (HRI), it is necessary that the robot's navigation behaviour is socially acceptable not only for the direct users but also for uninvolved bystanders. Particularly, assistive or guiding robots need to be comprehensible, kind, and non-intrusive. As an example, a shopping guidance robot can illustrate these navigation principals [76]. It is the robot's task to guide customers to goods they are looking for. The following behaviours proved to be important:

1) Polite approaching and person focused guiding

If the robot detects a person's willingness for interaction, it should approach the person in a socially acceptable manner. The approached person feels more comfortable, if the robot shows an approaching behaviour [77] while keeping certain distances [78], velocities and directions [79, 80]. This is especially important for walking persons [81]. Polite approaching also requires the robot's ability to predict the person's movement trajectory [20]. When a robot guides a person, it should adapt its speed depending on the distance to the person, so that the person can follow comfortably.

2) Regardful navigation

During navigation, mobile robots have to pass or avoid bystanders who are not interested in an interaction. Thereby, the navigation should conform to the proxemics [82] again. As a polite and attentive navigation is an important requirement for an assistive robot, the robot must be able to predict these situations and to trigger proactive reactions.

III. Benchmarking and Evaluation Criteria

The effectiveness of help requests should be assessed by several different benchmark criteria. Like HRI in general, subjective user- and expert-based measures can be combined with objective performance metrics. These metrics should address human, robot, and HRI holistically [83, 84]. Yet the evaluation criteria can be categorized according to their relevance regarding safety and health issues. All aspects are important for a human-centered design but should be addressed with regard to their sequence. Figure II shows evaluation criteria as well as their hierarchy. Requirements concerning safety and security should be addressed before functionality, usability, and finally user experience (UX) issues (cf. [85])

Different methodological approaches can be employed when evaluating benchmark criteria in order to assess the effectiveness of help requests. These measures can either be subjective targeting users' or experts' judgement or objective parameters. User studies (e.g. usability testing, experimental studies) provide insights to the acceptance of the help request [1, 2]. Beyond common measures of technology acceptance, perceived effort and demand, usability, and usefulness, perceived politeness and persuasiveness should be assessed. Standardized questionnaires [2, 86] and observational methods [59] can be used. Expert opinions can be useful in terms of usability [87], safety or risk analysis [88, 89]. Societal impact of robots (privacy, working conditions, cultural contexts) can be discussed in focus groups or interviews with potential users [90] as well as experts [89]. Effectiveness and efficiency can be quantified by objective time- or event-based measures (e.g. time to first help, helping behaviors per time unit) [91]. Time in search mode and time waiting for help maybe useful, too. Metrics from HRI like *neglect tolerance* and *interaction effort* are quantifying the interaction quality objectively and can be used in settings of collaboration between operator(s) and robot(s) [92].

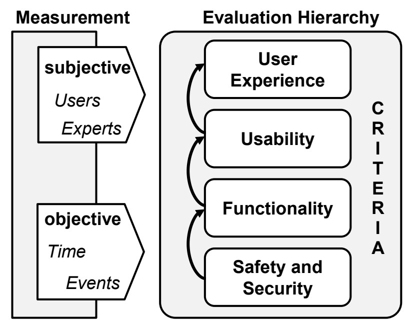

FIGURE I: Evaluation Criteria and Measurement

IV. A Robot Request for Help Checklist

The findings of the related work are summarized in a checklist below (see Table II). It can be used for the guidance of HRI designers to consider social implications and interpersonal aspects of asking for help:

TABLE II. Checklist for Needy Robots

Section[1]	Principles	Literature
II A	Recognize human, their attention and engagement, wait for assistance and seek actively after a short period (5 mins)	[5, 14, 18]
	Consider pluralistic ignorance and diffusion of responsibility in groups	[16, 17]
	Detect willingness to help and help in progress to offer adjustment	[22, 23]
II B	Avoid ambiguity in communicating need for help	[27]
	Stick to general design principles, though self-descriptiveness and task suitability should be given special attention	[28, 29]
	Visual cues are effective, if light colors are used follow conventions and standards relevant to your setting	[35, 36]
	Acoustic cues can attract attention, but might not be audible in every scenairo	[50]
	Polite requests and reasons for the request are vital for unfamiliar useres	[3, 60, 65]
	Do not over emphazise limitations, as this can reduce trust	[66]
II C	Approach politely with regard to distances, velocities, and directions, use prediction models of human movements for walking persons; navigation and guiding should be person focused	[20, 78-81]
	Passing and avoiding bystanders uninterested or uninvolved should be circumvented following the laws of proxemics	[82]

III	Prioritize evaluation criteria for a holistic human-robot interaction, following the evaluation hierarchy	[83-85].
	Evaluate objective effectiveness and efficiency, using multiple methods	[91, 92]
	Consider user reactions (perceived usability, acceptance, politeness, emotions, etc.)	[1, 2, 86]
	Ask experts (usability heuristics, risk and safety assessment, legal issues)	[87-89]

[1] relates to the sections in this paper

The discussed items of the checklist are now transferred to the specific interaction process of two real life use cases originating from the domains of service as well as manufacturing robots. Both use cases result from two research projects and illustrate the use of the checklist in diverse contexts.

A. A service use case

According to the International Federation of Robotics the main applications for service robots are logistic systems, field, and medical robots [93]. Although application numbers of service robots tentatively increase, one of the main, very concrete impediments which restrict a more common use is the robots' inability to interact with its technical environment as for example when experiencing the requirement to open doors or to use elevators. In order to overcome these problem two strategies can be employed. One aims at retrofitting doors and elevators in such a way that they can be opened remotely by the robot. Using the second strategy, the robots are equipped with manipulators that enable opening a door or operating an elevator [94]. Yet both strategies seem inadequate for a number of settings. Even if the willingness to create a robot friendly environment is high, environmental adoptions can be time-consuming and expensive [95]. Additionally state of the art use cases indicate that autonomously door opening in a realistic environment is still very difficult for robots (see for example the DARPA Challenge 2015). Therefore the conclusion is reasonable to include the human into the process as a "helping hand" for the robot. This issue has already been addressed using cobots that do not have manipulators which they can use for picking up objects or to push elevator buttons in order to travel between different floors [96]. The focus of this work mainly addressed probabilistic plan as where and when to seek for help. The cobots did not detect autonomously whether humans showed assistance willingness or were general available. Building on this work the project FRAME approaches the basic skills "elevator use" and "room entry" in real life situations. While completing tasks like guidance, transport or inspection they have to navigate between three to four floors and up to eighteen hallways, have to use two to three elevators and have up to 200 possible doors to pass.

According to the developed checklist, the FRAME robot has to detect a possible helper in a heterogeneous group and has to identify if the identified person is willing to help (see section A). When approaching the identified person the communication has to state clearly and polite that the person was identified as a potential helper and the robot has to bring forward its request. Within the FRAME scenarios interaction partners might be different each time and not be very familiar with the robot. Therefore the actions and dialogues of the robot have to be transparent and high in their self-descriptiveness (see section B). After a possible interaction with the FRAME robot, users will be asked to evaluate the interaction process regarding their perceived usability. A main focus will be put on system transparency as well as the overall acceptance of the help seeking robot. This will be done stepwise enabling an additional evaluation step of each system progression (see section III).

B. An industrial use case

Manufacturing environments typically show high levels of standardization. However flexibility becomes more important in future assembly systems. One reason is an increase in customization leading to higher flexibility demands regarding assembly methods and time parameters [97]. As many automation solutions cannot provide a required level of flexibility mobile robots are deployed in assembly workplaces. Above that creating more ergonomic workplaces motivates their application [98]. Within the research project HybriT a mobile robot will be deployed supporting assembly processes. In this manufacturing setting all three basic skills (detection, dialog, and navigation) are relevant as well, yet the environmental specifications have to be considered when designing the request for help. Industrial workplaces often face specific environmental conditions like background noise, big machinery and limited path ways. The detection of possible helpers on the shop floor can be difficult for the robot, as they might by masked by large assembly parts or manufacturing plants. Active seeking operations by the robot can be necessary especially in this setting. In a working context, especially one underlying product cycle-times, the correct detection of people's engagement with a working task is highly important. The robot's request for help should not intervene with the completion of a working task performed by the human. Therefore special emphasis has to be put on the correct distinction between large assembly parts and humans as well as their engagement with a specific task (see section A). When mobile robots navigate autonomously on the shop floor different methods can be applied. One possible method is *a priori* planning. Here the entire facility is mapped and routes are planned beforehand. Alternatively a dynamic plan can be used. The robot is equipped with sensors providing information about the environment, determines its own current position, and plans its way dynamically. When cycle times in the production process are critical and the environment is stable, a priori planning is preferred. In flexible environments with frequent task changes a dynamic planning should be used for navigation [99], (see section A).

When designing the dialog between human and robot in industrial settings surrounding sounds have to be considered. If the noise level is relatively high, the acoustic channel should not be used as the main interaction channel. A possibility to attract the human's attention towards the robot apart from the acoustic channel could be using wearable vibrotactile armbands [100]. An initial vibrating stimulus can be send to the human, creating an orientation reaction towards the robot.

Yet when designing the HRI dialog no social norm violations should be committed but a more direct request strategy could be useful. Statements about the robot's limitations should be expressed rarely, as they might have an impact on the perceived task suitability. When using different modalities other than speech, again system self-descriptiveness plays an important role. If colored visual keys are used, they should conform to standards used in the specific manufacturing plant, e. g. red lights indicating an error (see section B). Evaluating the request for help interaction within an industrial setting should emphasize the perceived effectiveness and correctness of the robots detection of possible helpers. Furthermore the evaluation of task suitability is an important evaluation criterion in the working context (see section C).

V. Conclusions and Outlook

To be asked for help by robots may appear "odd" for humans, since help and assistance are normally arranged the other way round. In order to avoid help neglects robots should address humans similar to interpersonal relationships, i.e. politely, and secondly bridge possible breakdowns in communication by reducing ambiguity. We present a literature-based checklist that can serve as a guideline for reducing ambiguity and increasing acceptance of robots asking for help. Following these instructions facilitates the implementation of needy robots. We exemplify the problem of robots asking for help by two use cases, a service and industrial use case. Considering the latest developments in the field of artificial intelligence and its link to robotic systems dialogue principles like self-descriptiveness as well as systems transparency get a higher significance and have to be considered accordingly to increase the chance for a needy AI robot to get help and foster a human-centered interaction in a complex world designed for humans not robots.

References

[1] D. Cameron *et al.*, "Help! I Can't Reach the Buttons: Facilitating Helping Behaviors Towards Robots," presented at the Conference on Biomimetic and Biohybrid Systems, Barcelona, Spain, 2015.

[2] D. Cameron, E. J. Loh, A. Chua, E. Collins, J. M. Aitken, and J. Law, "Robot-stated limitations but not intentions promote user assistance," presented at the 5th International Symposium on New Frontiers in Human-Robot Interaction Sheffield, UK, 2016. Available: https://arxiv.org/pdf/1606.02603.pdf

[3] P. J. Hinds, T. L. Roberts, and H. Jones, "Whose job is it anyway? A study of human-robot interaction in a collaborative task," *Human-Computer Interaction,* vol. 19, no. 1, pp. 151-181, 2004.

[4] H. Yasuda and M. Matsumoto, "Psychological impact on human when a robot makes mistakes," presented at the IEEE/SICE International Symposium on System Integration, Kobe, Japan, 2013.

[5] S. L. Rosenthal, M. Veloso, and A. K. Dey, "Task behavior and interaction planning for a mobile service robot that occasionally requires help," presented at the 9th AAAI Conference on Automated Action Planning for Autonomous Mobile Robots, Palo Alto, CA, 2011.

[6] M. K. Lee, S. Kielser, J. Forlizzi, S. Srinivasa, and P. Rybski, "Gracefully mitigating breakdowns in robotic services," presented at the 5th ACM/IEEE international conference on Human-robot interaction, Osaka, Japan, 2010. Available: https://dl.acm.org/citation.cfm?id=1734544

[7] R. A. Knepper, S. Tellex, A. Li, N. Roy, and D. Rus, "Recovering from failure by asking for help," *Autonomous Robots,* vol. 39, no. 3, pp. 347-362, 2015.

[8] N. Mirnig, G. Stollnberger, M. Miksch, S. Stadler, M. Giuliani, and M. Tscheligi, "To Err Is Robot: How Humans Assess and Act toward an Erroneous Social Robot," *Frontiers in Robotics and AI,* vol. 4, no. 21, 2017.

[9] R. Ventura, "Two Faces of Human–Robot Interaction: Field and Service Robots," in *New Trends in Medical and Service Robots: Challenges and Solutions*, A. Rodić, D. Pisla, and H. Bleuler, Eds. Cham, Switzerland: Springer International Publishing, 2014, pp. 177-192.

[10] B. Hayes, "Supportive behaviors for human-robot teaming," Doctoral Thesis, Yale University, New Haven, CT, 2016.

[11] V. Srinivasan and L. Takayama, "Help Me Please: Robot Politeness Strategies for Soliciting Help From Humans," presented at the CHI Conference on Human Factors in Computing Systems, San Jose, CA, 2016.

[12] S. L. Rosenthal, J. Biswas, and M. Veloso, "An effective personal mobile robot agent through symbiotic human-robot interaction," presented at the 9th International Conference on Autonomous Agents and Multiagent Systems, Toronto, Canada, 2010.

[13] J. Ji *et al.*, "Help Me! Sharing of Instructions Between Remote and Heterogeneous Robots," presented at the International Conference on Social Robotics, Kansas City, MO, 2016.

[14] L. Pérez, Í. Rodríguez, N. Rodríguez, R. Usamentiaga, and D. García, "Robot Guidance Using Machine Vision Techniques in Industrial Environments: A Comparative Review," *Sensors,* vol. 16, no. 3, p. 335, 2016.

[15] S. L. Rosenthal and M. Veloso, "Mobile robot planning to seek help with spatially-situated tasks," presented at the 26th AAAI Conference on Artificial Intelligence, Toronto, Canada, 2012.

[16] B. Latané and S. Nida, "Ten years of research on group size and helping," *Psychological Bulletin,* vol. 89, no. 2, pp. 308-324, 1981.

[17] D. C. Batson, P. A. M. van Lange, N. Ahmad, and D. A. Lishner, "Altruism and helping behavior," in *The SAGE Handbook of Social Psychology*, M. A. Hogg and J. Cooper, Eds. London, UK: Sage, 2007, pp. 241-258.

[18] E. Cha, M. Matari, and T. Fong, "Nonverbal Signaling for Non-Humanoid Robots During Human-Robot Collaboration," presented at the The Eleventh ACM/IEEE International Conference on Human Robot Interaction, Christchurch, New Zealand, 2016.

[19] L. Beyer, A. Hermans, and B. Leibe, "Biternion Nets: Continuous Head Pose Regression from Discrete Training Labels," presented at the German Conference on Pattern Recognition (GCPR), Aachen, Germany, 2015.

[20] A. Turnwald, D. Althoff, D. Wollherr, and M. Buss, "Understanding Human Avoidance Behavior: Interaction-Aware Decision Making Based on Game Theory," *International Journal of Social Robotics,* vol. 8, no. 2, pp. 331-351, 2016.

[21] U. Rafi, B. Leibe, J. Gall, and I. Kostrikov, "An Efficient Convolutional Network for Human Pose Estimation," presented at the British Machine Vision Conference (BMVC), York, UK, 2016. Available: https://www.vision.rwth-aachen.de/media/papers/rafibmvc16.pdf

[22] J. Baraglia, Y. Nagai, and M. Asada, "Prediction error minimization for emergence of altruistic behavior," presented at the 4th International Conference on Development and Learning and on Epigenetic Robotics, Genoa, Italy, 2014.

[23] J. Baraglia, N. Yukie, and M. Asada, "Emergence of Altruistic Behavior Through the Minimization of Prediction Error," *IEEE Transactions on Cognitive and Developmental Systems,* vol. 8, no. 3, pp. 141-151, 2016.

[24] K. Fischer, "How people talk with robots: Designing dialogue to reduce user uncertainty," *AI Magazine,* vol. 32, no. 4, pp. 31-38, 2011.

[25] E. Cha, Y. Kim, T. Fong, and M. J. Mataric, "A Survey of Nonverbal Signaling Methods for Non-Humanoid Robots," *Foundations and Trends in Robotics,* vol. 6, no. 4, pp. 211-323, 2018.

[26] B. Reeves and C. I. Nass, *The media equation: How people treat computers, television, and new media like real people and places*. Stanford, CA: CSLI Publications, 1996.

[27] R. D. Clark and L. E. Word, "Why don't bystanders help? Because of ambiguity?," *Journal of Personality and Social Psychology,* vol. 24, no. 3, pp. 392-400, 1972.

[28] ISO 9241-11, *Guidelines for specifying and measuring usability*. Geneva, Switzerland: International Organization for Standardization, 1993.

[29] ISO 14915, *Multimedia user interface design: Ergonomic requirements for human-centred multimedia interfaces*. Geneva, Switzerland: International Organization for Standardization, 2003.

[30] P. Saulnier, E. Sharlin, and S. Greenberg, "Exploring minimal nonverbal interruption in HRI," presented at the 2011 RO-MAN, Atlanta, GA, 2011.

[31] M. I. Posner and Y. Cohen, "Components of visual orienting," in *Attention and performance: Control of language processes*, vol. 32, J. B. Long and A. Baddeley, Eds. Oxford, UK: Psychology Press, 1984, pp. 531-556.

[32] H. Knight, T. Ravenna, and R. Simmons, "Expressive path shape (swagger): Simple features that illustrate a robot's attitude toward its goal in real time," presented at the IEEE / RSJ International Conference on Intelligent Robots and Systems (IROS), Daejeon, Korea, 2016.

[33] K. Baraka, S. L. Rosenthal, and M. Veloso, "Enhancing human understanding of a mobile robot's state and actions using expressive lights," presented at the 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), New York, NY, 2016.

[34] K. Baraka and M. Veloso, "Mobile Service Robot State Revealing Through Expressive Lights: Formalism, Design, and Evaluation," *International Journal of Social Robotics,* vol. 10, no. 1, pp. 65-92, 2018.

[35] IEC 73, *Coding of Indicating Devices and Actuators by Colours and Supplementary Means*. Genenva, Switzerland: International Electrotechnical Commission, 1993.

[36] IEC 60204-1, *Safety of machinery - Electrical equipment of machines - Part 1: General requirements*. Geneva, Switzerland: International Electrotechnical Commission, 2016.

[37] E. Cha, T. Trehon, L. Wathieu, C. Wagner, A. Shukla, and M. J. Matarić, "ModLight: Designing a modular light signaling tool for human-robot interaction," presented at the IEEE International Conference on Robotics and Automation (ICRA), Singapore, 2017.

[38] R. T. Chadalavada, H. Andreasson, R. Krug, and A. J. Lilienthal, "Empirical evaluation of human trust in an expressive mobile robot," presented at the Robotics: Science and Systems (RSS) Workshop, Ann Arbor, MI, 2016. Available: http://urn.kb.se/resolve?urn=urn:nbn:se:oru:diva-55259

[39] R. T. Chadalavada, H. Andreasson, R. Krug, and A. J. Lilienthal, "That's on my mind! robot to human intention communication through on-board projection on shared floor space," presented at the 2015 European Conference on Mobile Robots (ECMR), Lincoln, UK, 2015.

[40] R. Stricker, S. Müller, and H.-M. Gross, "R2D2 reloaded: Dynamic video projection on a mobile service robot," presented at the European Conference on Mobile Robots (ECMR), Lincoln, UK, 2-4 Sept. 2015, 2015.

[41] D. Liu, J. Kinugawa, and K. Kosuge, "A projection-based making-human-feel-safe system for human-robot cooperation," presented at the IEEE International Conference on Mechatronics and Automation, Harbin, China, 2016.

[42] C. Vogel, C. Walter, and N. Elkmann, "Safeguarding and Supporting Future Human-robot Cooperative Manufacturing Processes by a Projection- and Camera-based Technology," *Procedia Manufacturing,* vol. 11, pp. 39-46, 2017.

[43] R. Stricker, S. Müller, and H.-M. Gross, "Universal Usage of a Video Projector on a Mobile Guide Robot," presented at the 8th International Conference on Intelligent Robotics and Applications (ICIRA), Portsmouth, UK, 2015.

[44] P. Ekman and W. V. Friesen, "Constants across cultures in the face and emotion," *Journal of personality and social psychology,* vol. 17, no. 2, pp. 124-129, 1971.

[45] N. Eisenberg *et al.*, "Relation of sympathy and personal distress to prosocial behavior: a multimethod study," *Journal of personality and social psychology,* vol. 57, no. 1, pp. 55-66, 1989.

[46] J. M. Beer, C.-A. Smarr, A. D. Fisk, and W. A. Rogers, "Younger and older users׳ recognition of virtual agent facial expressions," *International Journal of Human-Computer Studies,* vol. 75, pp. 1-20, 2015.

[47] S. D. Preston, "The origins of altruism in offspring care," *Psychological bulletin,* vol. 139, no. 6, pp. 1305-1341, 2013.

[48] K. Dautenhahn, "Socially intelligent robots: dimensions of human–robot interaction," *Philosophical Transactions of the Royal Society B: Biological Sciences,* vol. 362, no. 1480, pp. 679-704, 2007.

[49] O. Demirbilek, "Evolution of Emotion Driven Design," in *Emotions and Affect in Human Factors and Human-Computer Interaction*, M. Jeon, Ed. London, UK: Academic Press, 2017, pp. 341-357.

[50] M. O. Watson and P. M. Sanderson, "Designing for Attention With Sound: Challenges and Extensions to Ecological Interface Design," *Human Factors,* vol. 49, no. 2, pp. 331-346, 2007.

[51] P. Schermerhorn and M. Scheutz, "Disentangling the effects of robot affect, embodiment, and autonomy on human team members in a mixed-initiative task," in *4th International Conference on Advances in Computer-Human Interactions (ACHI)*, Gosier, Guadeloupe, France, 2011: Citeseer.

[52] C. L. Sidner and C. Lee, "The Initiation of Engagement by a Humanoid Robot," presented at the AAAI Spring Symposium: Multidisciplinary Collaboration for Socially Assistive Robotics, Palo Alto, CA, 2007. Available: http://www.aaai.org/Papers/Symposia/Spring/2007/SS-07-07/SS07-07-017.pdf

[53] N. Lee, J. Kim, E. Kim, and O. Kwon, "The Influence of Politeness Behavior on User Compliance with Social Robots in a Healthcare Service Setting," *International Journal of Social Robotics,* vol. 9, no. 5, pp. 727-743, 2017.

[54] P. Brown and S. C. Levinson, *Politeness: Some Universals in Language Usage*. New York, NY: Cambridge University Press, 1987.

[55] M. Salem, M. Ziadee, and M. Sakr, "Marhaba, how may i help you?: effects of politeness and culture on robot acceptance and anthropomorphization," presented at the ACM/IEEE International Conference on Human-Robot Interaction (HRI), Bielefeld, Germany, 2014.

[56] J. Ruckert, P. H. Kahn, T. Kanda, H. Ishiguro, S. Shen, and H. E. Gary, "Designing for sociality in HRI by means of multiple personas in robots," presented at the 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI), Tokyo, Japan, 2013.

[57] C. Torrey, S. Fussell, and S. Kiesler, "How a robot should give advice," presented at the 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI), Tokyo, Japan, 2013.

[58] J. Meyer, C. Miller, P. Hancock, E. J. de Visser, and M. Dorneich, "Politeness in Machine-Human and Human-Human Interaction," *Human Factors and Ergonomics Society Annual Meeting,* vol. 60, no. 1, pp. 279-283, 2016.

[59] M. Giuliani, N. Mirnig, G. Stollnberger, S. Stadler, R. Buchner, and M. Tscheligi, "Systematic analysis of video data from different human–robot interaction studies: a categorization of social signals during error situations," *Frontiers in Psychology,* vol. 6, no. 931, 2015.

[60] Á. Castro-González *et al.*, "The Effects of an Impolite vs. a Polite Robot Playing Rock-Paper-Scissors," presented at the International Conference on Social Robotics (ICSR), Kansas City, MO, 2016.

[61] R. Cropanzano and M. S. Mitchell, "Social Exchange Theory: An Interdisciplinary Review," *Journal of Management,* vol. 31, no. 6, pp. 874-900, 2005.

[62] N. C. Krämer, S. Eimler, A. von der Pütten, and S. Payr, "Theory of Companions: What Can Theoretical Models Contribute to Applications and Understanding of Human-Robot Interaction?," *Applied Artificial Intelligence,* vol. 25, no. 6, pp. 474-502, 2011.

[63] R. Kurzban, M. N. Burton-Chellew, and S. A. West, "The Evolution of Altruism in Humans," *Annual Review of Psychology,* vol. 66, no. 1, pp. 575-599, 2015.

[64] B. Hayes, D. Ullman, A. Emma, C. Bank, and B. Scassellati, "People help robots who help others, not robots who help themselves," presented at the 23rd IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), Edinburgh, UK, 2014.

[65] D. J. Brooks, M. Begum, and H. A. Yanco, "Analysis of reactions towards failures and recovery strategies for autonomous robots," presented at the 25th IEEE International

Symposium on Robot and Human Interactive Communication (RO-MAN), New York, NY, 26-31 Aug. 2016, 2016.
[66] P. Kaniarasu and A. M. Steinfeld, "Effects of blame on trust in human robot interaction," presented at the The 23rd IEEE International Symposium on Robot and Human Interactive Communication, Edinburgh, UK, 2014.
[67] B. J. Fogg, "A behavior model for persuasive design," presented at the 4th International Conference on Persuasive Technology, Claremont, CA, 2009.
[68] B. J. Fogg, *Persuasive Technology: Using Computers to Change What We Think and Do*. San Francisco, CA: Morgan Kaufmann, 2002.
[69] J. Borenstein and R. C. Arkin, "Nudging for good: robots and the ethical appropriateness of nurturing empathy and charitable behavior," *AI & SOCIETY,* vol. 32, no. 4, pp. 499-507, 2017.
[70] R. H. Thaler, C. R. Sunstein, and J. P. Balz, "Choice Architecture," in *The Behavioral Foundations of Public Policy*, E. Shafir, Ed. Princeton, NJ: Princeton University Press, 2012.
[71] V. Chidambaram, Y.-H. Chiang, and B. Mutlu, "Designing persuasive robots: how robots might persuade people using vocal and nonverbal cues," presented at the 7th ACM/IEEE international conference on Human-Robot Interaction, Boston, MA, 2012.
[72] S. Hammer, B. Lugrin, S. Bogomolov, K. Janowski, and E. André, "Investigating Politeness Strategies and Their Persuasiveness for a Robotic Elderly Assistant," presented at the PERSUASIVE 2016: International Conference on Persuasive Technology, Salzburg, Austria, 2016.
[73] S. van der Woerdt and P. Haselager, "Lack of Effort or Lack of Ability? Robot Failures and Human Perception of Agency and Responsibility," presented at the BNAIC 2016: Benelux Conference on Artificial Intelligence, Amsterdam, The Netherlands, 2017.
[74] A. Hamacher, N. Bianchi-Berthouze, A. G. Pipe, and K. Eder, "Believing in BERT: Using expressive communication to enhance trust and counteract operational error in physical Human-robot interaction," presented at the IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), New York, NY, 2016.
[75] H. Y. Kim, B. Kim, S. Jun, and J. Kim, "An Imperfectly Perfect Robot: Discovering Interaction Design Strategy for Learning Companion," presented at the ACM/IEEE International Conference on Human-Robot Interaction, Vienna, Austria, 2017.
[76] H.-M. Gross *et al.*, "TOOMAS: Interactive Shopping Guide robots in everyday use - final implementation and experiences from long-term field trials," presented at the IEEE/RSJ International Conference on Intelligent Robots and Systems, St. Louis, MO, 10-15 Oct. 2009, 2009.
[77] M. Svenstrup, S. Tranberg, H. J. Andersen, and T. Bak, "Pose estimation and adaptive robot behaviour for human-robot interaction," presented at the IEEE International Conference on Robotics and Automation, Kobe, Japan, 12-17 May 2009, 2009.
[78] K. Dautenhahn *et al.*, "How may I serve you?: a robot companion approaching a seated person in a helping context," presented at the ACM SIGCHI/SIGART conference on Human-robot interaction, Salt Lake City, UT, 2006.
[79] Y. Kato, T. Kanda, and H. Ishiguro, "May I help you? Design of Human-like Polite Approaching Behavior," presented at the Annual ACM/IEEE International Conference on Human-Robot Interaction, Portland, OR, 2015.
[80] C. Shi, M. Shimada, T. Kanda, H. Ishiguro, and N. Hagita, "Spatial formation model for initiating conversation," presented at the Robotics: Science and Systems VII, Los Angeles, CA, 2011.
[81] D. Carton, W. Olszowy, D. Wollherr, and M. Buss, "Socio-Contextual Constraints for Human Approach with a Mobile Robot," *International Journal of Social Robotics,* journal article vol. 9, no. 2, pp. 309-327, April 01 2017.
[82] E. T. Hall, "A System for the Notation of Proxemic Behavior1," *American Anthropologist,* vol. 65, no. 5, pp. 1003-1026, 1963.
[83] R. Murphy and D. Schreckenghost, "Survey of metrics for human-robot interaction," presented at the 8th ACM/IEEE international conference on Human-robot interaction, Tokyo, Japan, 2013.
[84] H.-M. Gross *et al.*, "ROREAS: robot coach for walking and orientation training in clinical post-stroke rehabilitation—prototype implementation and evaluation in field trials," *Autonomous Robots,* journal article vol. 41, no. 3, pp. 679-698, March 01 2017.
[85] P. A. Hancock, A. A. Pepe, and L. L. Murphy, "Hedonomics: The Power of Positive and Pleasurable Ergonomics," *Ergonomics in Design,* vol. 13, no. 1, pp. 8-14, 2005.
[86] C. Bartneck, D. Kulić, E. Croft, and S. Zoghbi, "Measurement Instruments for the Anthropomorphism, Animacy, Likeability, Perceived Intelligence, and Perceived Safety of Robots," *International Journal of Social Robotics,* vol. 1, no. 1, pp. 71-81, 2009.
[87] J. Nielsen, "Usability inspection methods," presented at the Conference on Human Factors in Computing Systems (CHI), Boston, MA, 1994.
[88] ISO 12100, *Safety of machinery - General principles for design - Risk assessment and risk reduction*. Geneva, Switzerland: International Organization for Standardization, 2010.
[89] S. Oberer-Treitz, T. Dietz, and A. Verl, "Safety in industrial applications: From fixed fences to direct interaction," presented at the IEEE International Symposium on Robotics (ISR), Seoul, Korea, 2013.
[90] A. Weiss, R. Bernhaupt, and M. Tscheligi, "The USUS evaluation framework for user-centered HRI," in *New Frontiers in Human-Robot Interaction*, K. Dautenhahn and J. Saunders, Eds. Amsterdam, The Netherlands: John Benjamins Publishin Company, 2011, pp. 89-110.
[91] A. Steinfeld *et al.*, "Common metrics for human-robot interaction," presented at the 1st ACM SIGCHI/SIGART conference on Human-robot interaction, Salt Lake City, UT, 2006.
[92] D. R. Olsen and M. A. Goodrich, "Metrics for evaluating human-robot interactions," in *PERMIS*, Gaithersburg, MD, 2003, vol. 2003.
[93] I. F. o. R. (IFR), "Executive Summary World Robotics 2017 Service Robots," in "World Robotics 2017 Edition," 2017.
[94] R. Stricker *et al.*, "Interactive mobile robots guiding visitors in a university building," in *RO-MAN, 2012 IEEE*, 2012, pp. 695-700: IEEE.
[95] G. Schweitzer, N. Tschichold-Gürman, and S. Vestli, "Operating Experiences with Service-Robots—Examples from Mail Distribution," in *Proc. of ACRA Australian Conf. on Robotics and Automation*, 1999, pp. 216-221.
[96] S. Rosenthal and M. M. Veloso, "Mobile Robot Planning to Seek Help with Spatially-Situated Tasks," in *AAAI*, 2012, vol. 4, no. 5.3, p. 1.
[97] Å. Fasth, T. Lundholm, L. Mårtensson, K. Dencker, and J. Stahre, "Designing proactive assembly systems–Criteria and interaction between Automation, Information, and Competence," in *CIRP conference on manufacturing systems, Univ of Grenoble, France*, 2009.
[98] S. Angerer, C. Strassmair, M. Staehr, M. Roettenbacher, and N. M. Robertson, "Give me a hand—The potential of mobile assistive robots in automotive logistics and assembly applications," in *Technologies for Practical Robot Applications (TePRA), 2012 IEEE International Conference on*, 2012, pp. 111-116: IEEE.
[99] M. Shneier and R. Bostelman, "Literature review of mobile robots for manufacturing," *National Institute of Standards and Technology, US Department of Commerce,* 2015.
[100] S. Scheggi, M. Aggravi, and D. Prattichizzo, "Cooperative Navigation for Mixed Human–Robot Teams Using Haptic Feedback," *IEEE Transactions on Human-Machine Systems,* vol. 47, no. 4, pp. 462-473, 2017.