

Theory of Robot Communication: I. The Medium is the Communication Partner*

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When people use electronic media for their communication, Computer-Mediated Communication (CMC) theories describe the social and communicative aspects of people's interpersonal transactions. When people interact via a remote-controlled robot, many of the CMC theses hold. Yet, what if people communicate with a conversation robot that is (partly) autonomous? Do the same theories apply? This paper discusses CMC theories in confrontation with observations and research data gained from human-robot communication. As a result, I argue for an addition to CMC theorizing when the robot as a medium itself becomes the communication partner. In view of the rise of social robots in coming years, I define the theoretical precepts of a possible next step in CMC, which I elaborate in a second paper.

Keywords: Robot communication theory; human-robot interaction; language; extent of cues; adaptation to cues.

1. Introduction

Currently, the development and application of social robots in real-life settings rapidly increases. Whereas robots initially were the domain of science-fiction, today, social robots are tried out in service-oriented professions in healthcare, education, and

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commerce.¹ Habitually, general-purpose robots are readied for a particular task in a particular environment such as guidance through an exhibition or reception in a hotel.¹

To date, social robots usually are studied from the angle of care, education, hospitality or from the side of technology. That basically is a case-by-case approach. Even the review articles (see, e.g., Ref. 1), excellent in their own right, group robots on particular application domains or technologies. In my view, this is not the potential of social robotics. They are a novel, human-created communication entity, playing their own social role, with their own style of interpersonal communication: human-like, but non-human. In the remainder of this paper, I will assess the potential quality of a robot as a social partner from a communication viewpoint. Yet, I also want to emphasize an aspect often overlooked, which is the position of the robot in the upsurge of new technology.

The qualities of a social robot, I presume, will come to full expression once people realize that all application domains will become part of one worldwide Internet of Things (IoT), Cloud, or other data technology that regular users cannot handle any more information-wise. But the robot can.² Therefore, social robots should be placed in the context of advancing data technology because the robot is our only analog link to an otherwise completely digitized world of information. Therefore, the importance of social robots may increase still in view of the development of Cloud computing and IoT, as an intermediary between the digital and analog world. This is where communication design and communication science can make a valuable contribution.

Household appliances are increasingly equipped with embedded software. There are smart thermostats controlling home temperature, CO₂ measurement devices, and pillboxes that administer medicine intake. Devices and apps each have their own interfaces: buttons, bars, charts, beeps, blinks. This IoT sends data to the Cloud, where they are analyzed, usage patterns identified, and returned to the user. This feedback at a given point is so massive that valuable signals and recommendations are ignored.

Communication is where social robots can play a major role. Social robots evoke strong affective responses in human beings, which CO₂ devices and thermostats do not do. It is more likely that people take their medication when the robot tells them to than when their pillbox blinks a light. Someday, social robots may physically accompany the user as the interface between Cloud computing, data analytics, and embedded software on the one hand and the analog world of human communication on the other.²

Therefore, Human-Robot Interaction (HRI) will probably grow in the direction of designing natural communication between the digital and the human world. There are plenty of HRI studies into communication with the aim to improve the interaction between human and robot (see, e.g., Ref. 3). Yet, HRI mainly works from practical considerations and may apply but hardly develops communication theory. A notable first attempt was proposed by Edwards *et al.*⁴ and Westerman *et al.*⁵ According to Gunkel,⁶ however, HRI does not have that obligation because Computer-Mediated Communication (CMC) may take that role. Yet, Gunkel⁶ also notices that CMC focuses on communication and interpersonal relationships with real people rather than with artificial, non-human beings. This is the area of media

psychology, which covers topics as diverse as narrative immersion, presence, reality perception, and moral conflicts related to media fare. I will focus on media psychology explanations of how people become attached to or detached from avatars, movie and game characters, as well as social robots.

CMC theorizes about the communication aspects of using various media but CMC is not engaged with robots. CMC envisions media as channels of information exchange. Walther *et al.*,⁷ for example, state that early CMC believed that technology would restrict the social and emotional quality of communication. Sundar *et al.*⁸ confirm that initially, CMC saw machines as deficient compared to face-to-face (FtF) communications but that later approaches emphasized user adaptation and uniquely media-related communicative features (e.g., emoticons).

HRI is directed at fixing the problems CMC observes and formulates interaction theory that is case-based rather than general. HRI is concerned with the question how humans and machines interact. Where are the borders and how do we optimize our “technologized relationships” (see p. 2 of Ref. 9)? HRI assumes that the human mind cannot follow the machine and tries to make sense of machine behavior in human terms.¹⁰

Media Psychology studies the bond someone may feel with the representation of a human (a depiction, a rendering) and focuses on the psychology of mediated communication. Users may affectively become attached to media characters (e.g., TV interviewers or soap characters). The way they relate to machinery (a mere channel, “another human being,” or mixes thereof) directs the way they communicate.¹¹ If the robot is regarded more as socially similar to a human being (not necessarily completely), theories such as media equation and computers as social actors come into operation (see, e.g., Ref. 12), stating that humans treat media the same way as they do humans. If robots are regarded more as dissimilar to humans (although not completely), there is actually no systematic communication theory available, which is the deficit the current paper wishes to fix.

To arrive at a systematic theory of robot communication, this paper provides a synthetic review, critique, and application of CMC theory and research. I will synthesize CMC theories, extract principles, propositions, and results, and extend these to the communicative aspects of robotics. Where CMC falls short, I will devise new theoretical formulations.

In Ref. 13, I will go deeper into the psychological consequences of the different robot communications for the relationship someone may develop with a machine up to the stage of becoming friends. Hoorn¹³ does not discuss how robots and humans may become each other’s adversaries, the central plot device of many science-fiction stories.

The next section outlines a fundamental difference between two modes of processing robot communication. One is the robot seen as a means to transmit messages between a sender and a receiver. Here, the robot is regarded as a communication device with a human as the source of the message. The other is that the robot itself is assumed the sender of the message, regarding the robot as communication partner

and autonomous source. This division is independent of unidirectional or multidirectional communication and counts for monologs and turn-taking interactions alike.

1.1. Robot design and user perception

There are two ways of operating a communication robot: in remote control or with autonomous software, typically Artificial Intelligence (AI). In remote control, the person who handles the robot is the “roboteer” who types in texts that are rendered by the robot in speech and gestures; an acted-out chat session so to speak. An example is Softbank’s Nao with Zora software installed [Fig. 1], which therapists use to exercise with older adults. This form of communication is *via* a robot rather than *with* a robot.

When a robot is equipped with AI, a human converses *with* an intelligent system embodied by sensors and actuators. A simple example is a chat bot and its embodied version would be Hanson Robotics Sophia. Deep neural networks, a kind of AI, let Sophia track and recognize faces and do movements. The neural nets are dynamically integrated with Sophia’s dialog decision trees, so that for the user it feels as if the robot “understands” the conversation (see Ref. 14). Scientifically, the idea is to model the robot after the human system (“emulation”) so to understand what we do not know about human communication yet.

Of course, mixes exist as well and sometimes researchers use a remote-controlled robot in a Wizard of Oz (WOz) set up to find out what users want from a robot



Fig. 1. Nao robot with Zora software mounted on a Roomba vacuum cleaner.

without coding a full-sized AI. Hiroshi Ishiguro's Erica is a case in point, where users think they talk to an autonomous machine but in the back (literally behind the curtain), a roboteer handles the speech and movements. An actor impersonating a robot in a movie follows the same idea. Rather than emulation, all kinds of artistic and engineering tricks establish the *suggestion* of speaking to an autonomous system. The suggestion paradigm is easier put to practice than emulation but theoretically, it forwards interesting questions on social perception, (false) attributions, and ethical conduct.

How users perceive remote-controlled robots, AI-machines, or WOz arrangements is a completely different matter. Basically, there are two ways to go about the problem. The first is that people stay aware of human interference, whether they see a roboteer handle a remotely controlled machine or suspect a human coder behind the AI. After CMC, where people are aware that the medium forwards messages between people, I dub this mode of processing robot-mediated communication. During robot-mediated communication, users remain consciously aware of the robot as a communication device between humans and this is where CMC theses directly apply (cf. telepresence or *second life*).

The second mode of processing I call human-robot communication. During human-robot communication, users are *unaware* of the human behind the system. They treat the robot as if it were a human communication partner, irrespective of its technical design (remote control, AI, or WOz). Obviously, it is more likely that robot-mediated communication coincides with remote-controlled robots and human-robot communication with AI-driven machines but it is also possible that hybrid experiences occur, where occasionally, the user perceives the robot as a technical medium as well as an autonomous social actor.¹⁵ Hence, if people *do* assume a human being behind the AI, they are in robot-mediated communication mode. If people (rightfully or not) *do not* assume a person behind the machine (not even a programmer), they are in human-robot communication mode. The main question, then, is whether users *believe* they talk to a human-made program or to an autonomous social actor.

At face value, it may seem that remote-controlled robots and WOz are outdated approaches and that the robot-mediated communication mode of processing soon will become obsolete. This seems so because robot manufactures and implementers make people believe that their machines have perhaps not sentient but at least autonomous AI. However, the opposite is true. Most robots have little AI and lots of remote control. Moreover, it is not so much about the technology as it is about what people believe about the technology. If people are aware of the human origin of a full-blown AI, robot-mediated communication is still in place.

1.2. *Synthetic review*

Robots miss a number of human characteristics in their communication. In terms of CMC, cues to FtF contact are filtered out from the communication of current

Table 1. CMC in social robotics (remote-controlled, WOz, AI-driven). RMC = Robot-mediated communication. HRC = Human-robot communication.

Theories of CMC	Awareness of human source?		
	Yes	No	HRC
Extent of cues			
Social presence theory	Flaws in robot communication (e.g., pronunciation, intonation) reduce comprehensibility. People may fear dehumanization because robots would lack empathy and other human qualities. Users may feel disgruntled because the sender is not addressing them directly. Yet, certain robots have more expression possibilities than other so that the “damage” differs.	Not all cues-filtered-out necessarily evoke negative effects. The absence of judgment and other negative human qualities may enhance the robot’s source credibility. Empathy and human interference are not necessarily wanted in each situation. Dis- tance and neutrality may be appreciated as well. Emotional expression may distract from task and content matters. The robot is forgiven for doing things wrong.	
Missing social context cues	Possible mistrust against those who want to employ robots for communication and interaction. Possible damage to human freedom and dignity, not taking personal responsibility.		Intimate robot companionship may reduce human contact, increase social isolation, and invite normless behaviors (e.g., extreme violence). Plea for robot legal rights.
Social identity model of deindividuation effects	Effect on relation with person behind the robot depends on group identification and salience of group norms. When communicating via a robot, users may feel they are not communicating as individuals but as a group representative. Ergo, they comply with ingroup norms.		Robot supposedly does not belong to a social group; has no personal judgments. Thus, “deindividuation” of the sender does not lead to ingroup behaviors of the user. In fact, deindividuation does not occur at all because the robot itself is taken for an individual. That the human behind the robot is forgotten, is a loss of awareness of the other. Anonymity may lead to loss of awareness of self but also to self-disclosure.

Table 1. (Continued)

Awareness of human source?		
	Yes	No
Theories of CMC	RMC follows CMC	HRC
Signaling theory/ Warranting	Most assessment signals cue communicative incompetence and so robots seem harmless. Deception may occur in cases of fraud, spying, and gathering user information. Checking the robot's conventional signals is necessary to evaluate the credibility of the human driver.	People assume that in being non-human, robots do not deceive so that users assume warranting is unneeded. Robot's poor communication is compensated by assumed source credibility. Disclaimer features manage user expectations. Deception is acceptable for entertainment or to prevent crime.
Adaptation to cues		
Electronic propinquity theory	If robots are the remaining medium, closeness to the human sender, the feeling of relationship with the sender, and the inclination to adapt the communication may increase.	The robot itself feels close. People feel in a relationship with the machine. This may be stronger for lonely and socially isolated people. Communications are adapted to make the robot a proficient and pleasing conversation partner.
Social information processing	The sender may compensate robot communicative shortcomings by letting it sing, dance, or play a game. Becoming friends with the roboteer should be faster than via other CMC.	Compensation may be achieved by extra functionality such as automatic information retrieval and verbalization but also by using social media (the robot may send a text message).
Media richness theory	Dependent on task and context, a robot as mediator of the communication between people may exert positive effects. Social robots come closest to FtF in terms of turn-taking, synchronicity, natural language, touch, personalization, etc.	To make robots richer communication partners and more effective communicators, natural-language processing, personal focus, social cues, and immediate feedback should improve. Yet, there may exist an optimum to human-likeness, dependent of use context and user groups. Cues-filtered-out may improve communication if cues to humanness are undesired.

Table 1. (Continued)

		Awareness of human source?	
		Yes	No
Theories of CMC	CMC theses	RMC follows CMC	HRC
Social influence theory	People rely on significant others what the medium is about and how to use it.	Inexperienced users rely on family and friends to know what a social robot is for. Different groups may create different social constructs. The robot is probably conceptualized as an extension of the communicator and accepted in certain domains but not in other.	People fear autonomous machines. Societal debates concern ethical and occupational issues. People think that general-purpose machines are developed for one single task or user group. Oversimplifications subside with experience.
Channel expansion theory	People learn to handle media to increase expressiveness. Communication improves with more knowledge about the conversation partner.	Sender learns how to be a more expressive roboteer (e.g., sentence constructions, timing of movements). Communication improves when sender and receiver become better acquainted.	With experience, technology acceptance grows. If systems are applied that adapt robot behaviors to user preferences, people accept the robot as a “normal” partner. Because the medium is the conversation partner, learning about expression possibilities is knowing the conversation partner better, which is more effort-efficient than CMC/RMC.
Hypersocial CMC	The distant other is idealized. Overestimations, projections, attributions of high appeal and attractiveness occur frequently. Asynchronous messages can be fine-tuned before sending (channel effects). Feedback tailored to the receiver via behavioral (dis)confirmation. More media may be used for message effectiveness.	Receiver attributes positive qualities to sender because the robot behaves nicely. Sender may use the robot to confirm those perceptions or to disconfirm an unhappy receiver. RMC is not asynchronous and communicative repairs may be hard to execute for the human sender. More time, then, has to be invested in the robot’s gestures and expressions (e.g., sorry face). Extra communication channels (display, texting) may increase effectiveness.	Re channel effects, HRC resembles FtF more than other CMC. Communication is immediate, dyadic, but slower than FtF. Robots do not judge, so people have ample time for repair. Robot feedback can <i>always</i> be positive. These encouraging effects make people think that robots can outperform humans. People expect more from one another than from robots so that eventually robots may be surprising and humans disappointing. Overestimations of robot’s competencies may instill visions of superior AI.

Note: The first four theories envision FtF as the ideal; the other theories emphasize user adaptation and contingency.

state-of-the-art robots, which is something the emulation paradigm tries to avoid. CMC theories deal differently with media that do not match human communication and in the overview of CMC theories offered next, they are roughly divided into two sets: Extent of cues and adaptation to cues.

Extent of cues focuses on what is missing out from (mainly text-based) media as compared to FtF communication. I will discuss Social Presence Theory,^{16,17} Missing Social Context Cues,¹⁸ Social Identity Model of Deindividuation Effects,¹⁹ Signaling Theory,²⁰ and Warranting²¹ for cues that are filtered out. Adaptation to cues is directed at what people do to make up for missing cues: Electronic Propinquity Theory,²² Social Information Processing,²³ Media Richness Theory,²⁴ Social Influence Theory,²⁵ Channel Expansion Theory,²⁶ and Hyperpersonal CMC.^{27,28} Table 1 compiles the basic principles of the theories followed by a discussion of their applicability to robot communication.

2. Cues-Filtered-Out from Robot Communication

In CMC, communication with another human being goes through media, which is also the case in robot-mediated communication, where a human operator drives the robot and texts are typed in on the spot. In robot-mediated communication, CMC theses should apply straightforwardly. In human–robot communication, however, people humanize the medium and take the robot for an autonomous social actor, which is an issue CMC does not address. In those cases, I will rely on theories of media psychology. Next, the first stream of CMC theories that I discuss focuses on the extent of cues.

Social presence theory^{16,17} is one of the early approaches to CMC and focused on cues that are *filtered out* from FtF communications (see, i.e., Refs. 29 and 30). Cues-filtered-out theories state that (text-based) media have fewer means to convey non-verbal messages, deteriorating the quality of the communication. During a teleconference, for instance, fewer social and affective cues would supposedly diminish feelings of involvement and friendliness towards the conversation partner.

In Table 1 (extent of cues), the consequences of these considerations are tabulated: Adverse effects of cues-filtered-out may be experienced with some technical aspects of robot communication: Poor natural-language processing, weak speech engines, and imperfect intonation may make a robot less understandable. Yet, people also may fear dehumanization of emotionally sensitive tasks. Think of care and education. Because robots lack empathy and other human qualities, they would not be fit to the job (cf. Ref. 31). In robot-mediated communication, users may feel shed off because “that person behind the robot is not talking to them personally.”

It also depends on the kind of robot one encounters. A Nao machine [Fig. 1] or a DARwIn-OP with a fixed plastic head and machine appearance has less expressiveness than Alice R50 [Fig. 2] or Milo R25, which have flexible faces and

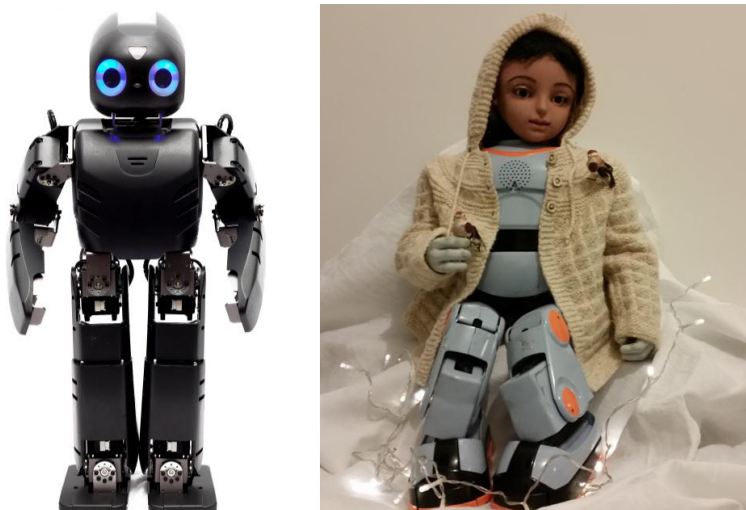


Fig. 2. DARwIn-OP (left) and Alice R50 (right).

human-like appearance. For robot-mediated communication, then, it depends on the machine. Even Nao has more expression possibilities (e.g., hand gestures, gaze) than texting.

In human-robot communication, on the assumption that no human communicator handles the machine, not all cues that are filtered out evoke negative effects because people expect less communicative skillfulness from a robot. In human-robot communication, empathy and human interference may not always be wanted. Sometimes, distancing effects are appreciated [Table 1]. For example, people may prefer neutral treatment to empathy or sympathy (e.g., when being bathed by a caretaker). Participants preferred the delivery of bad-health news by a robot to the delivery by a human doctor.³² Weaker students of arithmetic benefitted more from a non-expressive robot tutor than a more expressive robot, because the latter distracted them from the contents.³³ Arguably, one may say that an empathic machine would know when not to be empathic but to keep its professional distance. If what is filtered out are undesired qualities, robots may be appreciated more than humans despite the robot's communicative deficiencies such as misinterpretation of the user's internal states (see, e.g., Ref. 34) or lack of coherence and logic (see, e.g., Ref. 35). The robot is "forgiven" and the absence of disapproval may in fact enhance the robot's source credibility.

Missing social context cues¹⁸ posits that cues-filtered-out lead to disinhibition, causing a variety of negative effects. People would become uninhibited, normless, self-centered, conflict oriented, and negatively biased. In ethical discussions on applying robots to empathetic tasks (e.g., nursing, teaching) similar worries can be observed [Table 1].

With respect to robot-mediated communication, for example, Whitby fears that people will mistrust those who want to replace human interaction by machines (see p. 238 of Ref. 36). Unethical application of robots could easily damage human freedom and dignity (see p. 245 of Ref. 36). Allen and Wallach suspect a possible “abdication of human responsibility” (see p. 55 of Ref. 37).

In human–robot communication, Whitby has moral reservations against intimate robot companionship, which would cause considerable psychological damage (see p. 238 of Ref. 36). Partnering with a robot would reduce human contact, increase social isolation, and make people do things to it that are unacceptable to do to humans (i.e., normless behavior). In anticipating extreme levels of violence against robots (see p. 240 of Ref. 36), certain authors plead for robot rights.³⁸

Social identity model of deindividuation effects¹⁹ assumes that when a communicator cannot see the other person or that person is anonymous, people lose a sense of awareness of self and others. Loss of individuality would shift focus towards the identity of the ingroup and the salience of group norms, responding to others according to prevalent ingroup norms (stereotyping, prejudice) rather than someone’s personal opinions and attitudes. One might add that open debate and positive group goals also may be a result but that is not the focus of such theorizing.

With respect to robots [Table 1], people would comply more with ingroup norms in robot-mediated communication mode than FtF. The remote-controlled robot would anonymize the human communication partners. For instance, the remote operator would be seen as anonymous, which may invoke some kind of projected social identity. If a nurse at the ward handles more remote machines placed in people’s homes, they may feel they are addressed as a group rather than an individual (all the more if group identity is made salient such as a care robot specifically designed for “older adults,” cf. stigmatizing).

In human–robot communication mode, there is no person behind the robot assumed but the robot self is the conversation partner. In human–robot communication, the robot is not supposed to belong to some social group, not to have personal judgments: It is neutral (cf. the “panhumanism” of robots, reducing ingroup–outgroup thinking, Ref. 39). That does not mean that group identification is absent. In Ref. 40, older students were motivated more than younger students by an AI agent that sounded older. The older students also thought that the older AI was more credible and socially present.

In human–robot communication, the human (designer/programmer) behind the robot is forgotten and users are not aware of the mediated nature of the interaction any more.¹⁵ This may count as a loss of awareness of the other; of the human communicator that is. However, the robot itself is seen as the sender so deindividuation of the communication partner perceptually does not occur and so does not lead to conformity to an ingroup. While not talking to another human being but to a social actor that emits just enough human-like cues, the user becomes off guard. This may count as a loss of awareness of self. Yet, the consequence is not feeling dehumanized; in fact, the anonymity leads to self-disclosure.¹⁵ In human–robot

communication, users tend to treat the robot as a social being of its own.¹⁵ Psychologically, deindividuation in the CMC sense probably does not occur in human–robot communication [Table 1].

The HRI literature reports plenty examples of robots perceived as group members. For example, when robots are placed in human–robot teams and group membership is explicitly cued and asked for, people commence social categorizations of robots.⁴¹ Robots can be made part of the ingroup or outgroup when explicitly programmed as such or when competing human–robot teams are deliberately set up (see, e.g., Ref. 42). In aggressive tasks, ingroup robots are favored even over outgroup humans.⁴³ Rau *et al.*,⁴⁴ however, manipulated aspects of group membership that were irrelevant to the task or clearly fictitious. In a marine survival task, the robot was said to come from the same/different university as the user. In such cases of irrelevance and fabrication, effects of group membership were not significant.

Different from my theorizing, however, the HRI work on human–robot teams makes membership unambiguously salient and relevant to a competing, survival, or aggressive task. The situation I theorize about is different in that in an unforced and harmonious non-group but one-to-one situation the medium itself may exert social categorizations; in robot-mediated communication rather than in human–robot communication mode.

Signaling theory²⁰ and **warranting**²¹ are concerned with the reliability and sincerity of the signals communicators transmit. Central concerns are honesty of communication as opposed to deception. People do not care too much about small insincerities in a simple conversation (“How nice of you to write”) but in, for instance, financial transactions (cf. eBay) people ask for warranties.²⁰ Assessment signals, which are directly accessible, are seen as more reliable than *conventional* signals, which are more abstract and symbolic. That a conversation partner has a paralyzed face (assessment signal) explains why s/he does not smile; that s/he says s/he is stressed out (conventional signal) may need more validation. Because on social media, people can assume another personality and pretend to have all kinds of qualities, “warranting” or fact-checking is highly relevant (see, e.g., Ref. 21). However, many people do not feel that they have to check with other sources whether the personality performed online matches with the person offline.

These points may remain in robot-mediated communication. Assessment signals in current social robots mainly (willingly or not) cue the communicative incompetence of robots (unnatural speech, poor language understanding, clumsy movements), which may make them seem not only incompetent but also harmless. However, the robot may be used for a song or a dance whereas the unobserved person behind the machine may ridicule the entertained user. With the advance of IoT and data-mining techniques, the robot may be used to spy upon people, to phish for log-in codes, or it is used for direct-marketing purposes (cf. My Friend Cayla, the market-intelligence doll for kids).⁴⁵ In robot-mediated communication, conventional signals should be checked to warrant the credibility of the robot’s human driver [Table 1].

In human–robot communication, this may be different. Perhaps mistakenly and this may change while users gain experience, but from my personal observations so far people usually assume that what you see is what you get (see, e.g., Ref. 46); that robots in being non-human do not deceive. Because seemingly there is no person behind the machine, what I observe is that robots raise little mistrust in human–robot communication mode. Hence, users may feel little need for warranting. Perhaps people assume that robots lack desires and goals. Yet, particularly when robot goals are not aligned with those of the user, users may suspect the robot of lying and deceit, rendering the robot less trustworthy.⁴⁷ Buhlmann and Gisler⁴⁸ indicated that an audience forgives communicative inability if a public speaker is regarded trustworthy (ethics high). Meta-analysis of trust in robots revealed that robot performance itself affected trust more than characteristics of the environment or the user.⁴⁹ Robot designers sometimes even “filter in” disclaimer features (“So sorry, I’m but a robot. . .”) to manage the user expectations [Table 1].

On an ethical note, not all deception (whether robot-mediated communication or human–robot communication) is perceived as bad. The context of use is decisive. Insincerity and deception may be highly appreciated in arts, performance, and entertainment but also in security and policing. Lee *et al.*⁵⁰ found that participants regarded human-like robots as highly useful to ward off burglars by suggesting they were home. Terre des Hommes commissioned advertising bureau Havas Lemz to create the life-like avatar Sweetie, which impersonated a 10-year-old Filipino girl to capture thousands of pedophiles.⁵¹

3. User Adaptation to Cues-Filtered-Out from Robot Communication

The second stream of CMC theories I term adaptation to cues. These theories look into the ways people adjust their communications to repair the shortcomings or exploit the advantages of not facing the human communication partner.

Electronic propinquity theory,²² for example, proposes that although people may be far apart physically, they may feel close by emotionally; as if they were in the room (cf. “social presence”). Part of Propinquity Theory emphasizes the scarcity of communication channels: The fewer options, the more important the remaining channel. If the number of communication possibilities decreases, the feeling of closeness becomes stronger through the remaining medium (see p. 11 of Ref. 22). For instance, without electronic media, writing postcards gains importance and establishes more “relationship” than it did before. People adapt their communications to the “remaining medium” to optimize adequacy and pleasantness.

If a robot is the only medium left to keep in contact with others, in robot-mediated communication, the feeling of closeness to the human sender may increase as well as the inclination to adapt the communication to the robot’s capabilities [Table 1]. This effect may be so strong that initial robot-mediated communication becomes human–robot communication and not just the sender but the robot itself feels close; particularly for people who feel lonely (see, e.g., Ref. 52). This is perceptual. Because

people feel lonely and the remote-controlled robot is the only contact to others, warm feelings are transferred to the robot. As a result, communications will be adapted to the robot so to make it more adequate and pleasing as a conversation device [Table 1].

Social information processing²³ supposes that what may be lost in CMC is compensated over time. People compensate for cues-filtered-out with means that the medium does offer (e.g., insert an emoticon in a text). In doing so, CMC users bring their communications to the level of FtF interaction with, for instance, portrait pictures and personal profiles. Social information processing states that sometimes CMC takes more time to gather the same amount of information as people do offline but the net results will be the same in terms of richness of communication, interpersonal relationship, or the quality of the social interaction (see, e.g., Ref. 53).

In robot-mediated communication and human–robot communication, compensation for cues-filtered-out may be to let the robot sing, dance, or play a game. The robot might present itself on Facebook⁵⁴ with background information (“I was designed by. . .”) and robot selfies (e.g., camera eyes taking portrait pictures in the mirror) [Fig. 3]. In being richer media than avatars or other CMC, from a social information processing perspective, the speed of image building and making friends with a robot driver (robot-mediated communication) or with the robot (human–robot communication) should be higher [Table 1].

Media richness theory²⁴ emphasizes that a medium is most effective when it fits its task and context. Each medium has its own way of resolving ambiguity and improving interpretation. There supposedly is a hierarchy in richness of

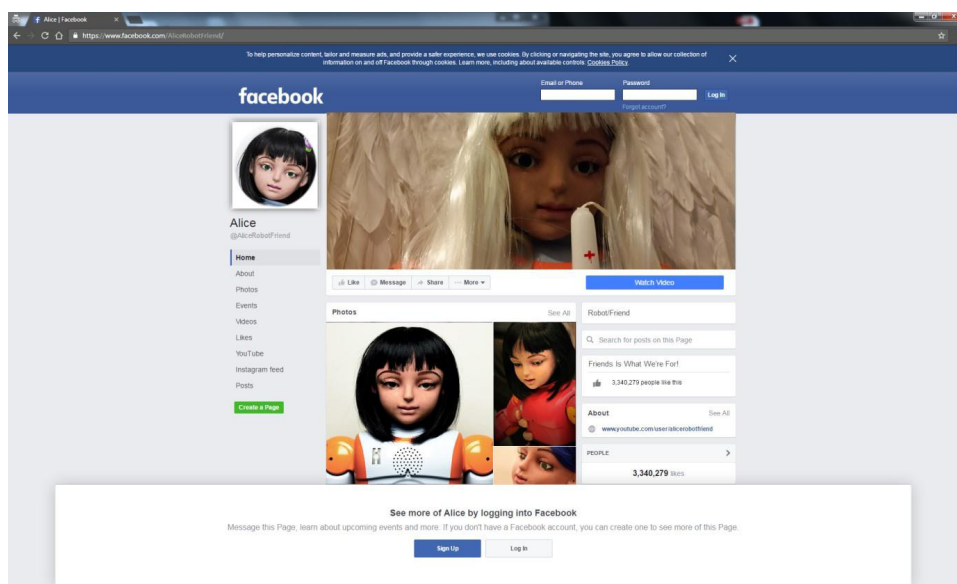


Fig. 3. Mock-up of a Facebook page for robot friend Alice.

communication from FtF, smartphone, email, letters, notes, to fliers, and leaflets. The richness lies in the medium's personal focus, number of different cues (e.g., non-verbal communication), immediate feedback, and natural-language use.

Of all media, social robots come closest to FtF contact in terms of media richness, particularly when an affect recognition and emotional expression system (through non-verbal cues) is installed.⁵⁵ There is turn-taking and synchronicity in interaction, the machine uses natural language, there are more social cues available (e.g., touching the robot), and the communication can be personalized (e.g., more extraverted versus introverted, see Ref. 56).

As media richness proposes, in robot-mediated communication, it depends on the task and context whether communication is served by putting a robot in between two people. One can think of situations where it works better than without. For instance, a robot may be conducive in teaching autistic children what facial expressions mean emotionally (see, e.g., Ref. 57). However, Lee *et al.*⁵⁰ observed that their participants were rather scared by a remote-controlled robot that looked like a real person (cf. FtF). These people thought the life-like robot was useful only to ward off intruders.

For human-robot communication, it probably means that improved natural-language processing, more personal focus, more social cues, and immediate feedback make robots richer communication partners and hence, more effective communicators (cf. Refs. 58 and 59). As media richness states, however, there may be an optimum to human-likeness, which may differ in every context of use⁶⁰ and for different user groups. Cues-filtered-out may improve communication if those cues pertain to undesired human qualities such as display of superiority or tactless remarks about race and gender [Table 1].

Social influence theory²⁵ asserts that apart from cues offered by the media, social influence is a communication process in which people rely on significant others to understand what a medium is about in lack of personal experience. Family and close friends are more important for such concept formation than less significant others. From that, social construction of technology may follow, where people negotiate among themselves what a medium is for and how to use it. For example, Instagram began as a photo-editing app but evolved quickly into a social network for lifestyle; Twitter today is used as a political instrument although it was never meant that way. Different groups may create different social constructs.

Applied to robots, inexperienced users rely on family and friends to know what a social robot is for: Commonly, people accept robots for household chores but not for emotional care. Others do not mind to let robots help autistic children (see, e.g., Ref. 61). In other words, different groups create different social constructs around robots; about what you can do with them (their affordances) and what they are allowed to do (their ethical boundaries).

In robot-mediated communication, the robot is probably conceptualized as an assistive instrument of the sender such as a telephone even more so if its appearance is less human-like.⁶² Therefore, the use of robots in certain domains is accepted.

For example, a robot may be used by the physical therapist to demonstrate exercises to older adults. Or it may call out the numbers during a bingo evening.

In human–robot communication, people may fear the robot’s autonomy, probably more so when robots are connected to Cloud and IoT. Societal debates concern ethical and occupational issues (“robots taking over”) (see, e.g., Ref. 60). Over-simplifications of what a robot is or can do tend to vanish the more experienced a user becomes (cf. Ref. 63) [Table 1].

Additionally, Channel Expansion Theory²⁶ focuses on experience: with the channel, the topic of the message, context, and CMC partner. While gaining experience, people start to know better how to interpret and transmit affect-laden messages, which expands the expressiveness of the novel medium.

Over time, then, the sender in robot-mediated communication should become a more expressive roboteer [Table 1]. For instance, s/he will know better which sentence constructions the speech engine pronounces well and which not. The roboteer will have a better feeling for the timing of the movements, for example, when to place a high-five or “dab”. Additionally, communication improves when roboteer and user become better acquainted.

With experience, technology acceptance grows.⁶³ If learning systems are implemented that adapt robot behaviors to user preferences and the robot expresses itself accordingly, then, a growing perception of communication possibilities may explain why over time people start to accept the robot as a “normal” conversation partner. In human–robot communication, getting to know the expression possibilities of the medium also is to get to know the conversation partner better. In human–robot communication, effort that is put into the medium does not have to be invested in the sender as is the case in robot-mediated communication. In that sense, human–robot communication is communicatively (and possibly affectively) more cost-effective than robot-mediated communication [Table 1].

Hyperpersonal CMC emphasizes that CMC sometimes outperforms FtF communications.^{27,28} At times, appeal, confidence, and awareness in CMC are higher than in FtF. These idealizations and overestimations of a distant other (e.g., pen pals or holiday flings) are projections and attributions by the message *receiver*. Hyperpersonal CMC concurs with signaling theory in that *senders* may portray themselves overly positive, hiding their imperfections (cf. enhanced and retouched snapshots).

Particularly in asynchronous media (e.g., email, texting), communicators can edit, rephrase, or check the “delay delivery” box so to optimize their messages before sending. Hyperpersonal CMC calls these *channel* effects. Work that goes into fine-tuning the text does not have to be invested in gestures and facial expressions. Hyperpersonal CMC follows the behavioral confirmation hypothesis⁶⁴ with regard to the *feedback* communicators provide. Particularly when people are unacquainted, users of CMC attempt to live up to the positive expectations of the other. For example, if someone has an idealized image of a holiday love across the ocean, that person will try to amplify the qualities s/he was attributed so to confirm the positivity bias of the admirer. It goes even so far that if people think, based on a fake

photo, that an unknown other is pretty and responds accordingly with compliments, the flattered person shows increased self-conscious behavior during conversation.⁶⁴ In anticipation of negative responses of a communication partner, there is evidence for behavioral *disconfirmation* as well.²⁸ People may start to flatter and compliment a discontented receiver to positively influence his or her mood.

CMC users may also employ complementary communication channels to convey a message.⁶⁵ An email may be followed up by a text message, while sending a handwritten letter thereafter. A sequence of messages sent over different channels would be more effective than one single message or using the same channel repeatedly (e.g., a barrage of emails).

If in robot-mediated communication, the distant other is represented by a robot (cf. teleconferencing), it might be that the sender at one point is attributed positive qualities (e.g., nice person, technically gifted) because the robot seems friendly and helpful while the sender may confirm those qualities by letting the robot say so [Table 1]. Or the robot could be used to praise and compliment a receiver that is unhappy about the faulty communication. Yet, communication is not asynchronous in robot-mediated communication. It may be hard then to repair miscommunication. On the one hand, a human is assumed as sender but on the other hand, time has to be invested in the robot's gestures and facial expressions. An extra communication channel may be helpful here, such as a robot with a tablet on its chest to show pictures and clips (cf. SoftBank's Pepper).

When it comes to the possibilities of what hyperpersonal CMC calls *channel* effects, communication with robots in human-robot communication resembles FtF interaction more than other CMC. Here also, the communication is almost immediate, dyadic, but not as fast as with humans. By this I mean that communication between two able humans is way faster and can achieve a speed of interaction impossible to achieve between an able human and the best of current robotics. But different from robot-mediated communication, users can take their time in saying things the way they want: They can stammer, repair, and are not judged for being slow or when things come out the wrong way. In human-robot communication, there is no time pressure on dividing attention among communication tasks (e.g., proper speech), functional tasks (e.g., looking up information), and maintaining the interpersonal relationship (e.g., being polite). Moreover, the feedback a robot provides in human-robot communication can *always* be positive irrespective of a user's bad mood [Table 1].

In view of these channel and feedback effects, people sometimes think that robots do a better job than humans do (see, e.g., Ref. 66). Because no human sender is assumed in human-robot communication, there seems to be a floor effect, whereas human-human interaction hits a ceiling of expectations. People expect a lot of care and consideration from their fellow humans, who may not always be able to deliver. From humans, we hope and expect that they are great communicators ("performance over par"), which actually increases the likelihood that they fail. In facing an increased risk to fail and not living up to expectations, sometimes humans

may seem to be more disappointing than certain robots with their advantageous channel and feedback effects. From robots, we expect little (“performance under par”) and hope for something better but if not, there is no harm done. Given the lower standards for robots, they sometimes are more likely to succeed as communicators than humans [Table 1].

In turn, the surprise of a disproven floor effect may lead to overestimation of the robot’s competencies (“he listens to me”) despite evident failures. People need but little stimulus to make great overattributions (cf. Ref. 67). Perhaps this explains unwarranted conclusions that robots (potentially) are more moral, decent, attentive, intelligent, etc. (cf. Ref. 68). Perhaps that futuristic visions of a robot utopia and the dawning of “the singularity” are instances of hyperpersonal human–robot communication.

4. Results and Discussion

4.1. Overview of CMC for robotics

There is missing communication theory on robots as a medium and how robots might fit into the “bigger picture” of CMC theory. Such theory may serve as a springboard for new lines of research, which are germane once robots become our intermediaries in the IoT and Cloud. In the previous, I have attempted to describe where CMC-theory extensions matter for the different forms of robot communication and how robots may depart from the functionalities of more conventional CMC. Remote-controlled robots, WOz, and AI-driven robots may be perceived as robot-mediated communication or human–robot communication. Sometimes, people may switch back and forth between robot-mediated communication and human–robot communication, which will be discussed in Ref. 13. Table 1 presents an overview of the various forms of social robotics in relation to CMC and FtF on the dimensions raised by the CMC theories reviewed.

In column 1 of Table 1, the names of the CMC theories are mentioned. Column 2 provides the tenets of each theory. Column 3 is split into two, based on the awareness of the user of another human being that drives the robot. If aware of the human conversation partner, robot-mediated communication follows basically the CMC theses. If people are unaware of the human communicator or software designer, human–robot communication departs from CMC because now the medium itself has become the communication partner. Note that perceptually it may be so that a remote-controlled robot is taken for an autonomous machine and that human–robot communication commences. Reversely, users may suspect that an AI machine is steered by a human being, so that robot-mediated communication hypotheses are in place.

CMC seems most informative for social robotics, particularly in robot-mediated communication mode. Owing to the physical presence of the robot, however, not every aspect of CMC applies. For human–robot communication as well, CMC is still

useful as a springboard to novel theory. The big difference with CMC and robot-mediated communication on the one hand and human–robot communication on the other is that in human–robot communication the user is not aware of the human sender anymore (the roboteer, the software designer). During an interaction, users may switch between the two levels of awareness so that actual robot-mediated communication may be (temporarily) experienced as human–robot communication and vice versa.

In looking at the extent of cues theories of CMC in Table 1 and how they play out in robot-mediated communication, robots may have a number of drawbacks in communication. Because in robots, a number of cues to FtF communication are filtered out, there may be difficulties in comprehensibility. Dependent of the expression possibilities of the robot, the communication may feel impersonal, without much empathy, while group norms prevail at the cost of communicating individual perspectives. There is a potential danger of spying on others. The communicative incapacity of the robot (e.g., it cannot blush) may hide the true intentions of the human sender/robooteer when s/he tells a lie. Warranting may be vital but will not be performed quickly.

From the CMC theories that emphasize communicative adaptability, the conclusion may be drawn that when robot-mediated communication forms the only connection to the outside world, feelings of closeness to the human sender increase. When users are inexperienced, they will rely on significant peers to know how to conceive of the robot as a medium and how to use it. Time will be invested to adapt communication to the limitations of the robot but also to exploit the things it does offer (e.g., a game, a dance). Because social robots come closer to FtF than other CMC (e.g., gestures, eye contact), communication probably is more effective although there may be contingency effects. Yet, communicative repair is harder because the interaction is not asynchronous. The way the robot behaves may be transferred to its sender, making the receiver attribute all kinds of qualities to the sender that may be non-existent.

In human–robot communication, the medium is source and messenger. The robot is conceptualized as a social actor of its own. Hence, deindividuation may not occur. By contrast, people may fear the robot's independent decisions and become concerned with ethical and occupational issues. Overestimations of a robot's capacities may prompt visions of singularity and superior intelligence.

Missing cues to negative human behavior (e.g., not showing disdain) may increase the source credibility of the robot as a communication partner, making it a benevolent social partner irrespective of its communicative flaws. Disclaimer features that are filtered in enhance the effect of being apologized for poor performance. Users are not inclined to check the facts in the robot's communications. Dependent of the context of use, positive human qualities such as empathy may not always be appreciated (e.g., during instruction) and seemingly negative qualities such as detachment may be desired in certain situations (e.g., where professional distance is required). Deception and other supposedly negative qualities are acceptable

whenever they serve a user's interest, for instance, for entertainment purposes, learning, as placebo, or for protection.

With respect to communicative adaptation in human-robot communication, Table 1 shows that communication is adapted to the robot's possibilities. Compensation comes from features the robot does have, for instance, calendar keeping or exercising. The robot also may use social media as an extra. Human-likeness is appreciated for basic communication technicalities such as natural-language processing but finds its limitations in the context of use: too human-like may become uncanny (cf. Ref. 69).

With experience and experimentation, appropriation and domestication, acceptance of the robot as a normal communication partner grows (see, e.g., Ref. 70). The lonelier and socially isolated people are, the closer the robot may feel as "a person". To become acquainted with a robot costs less effort than other CMC because knowing the medium is to know the conversation partner. If programmed well, robots are patient with communicative flaws of the user and always provide positive feedback. People have higher expectations of other people than of robots so that robots easily please compared to humans.

5. Conclusions

With the advent of Cloud computing and embedded software, social robots may likely become the universal interface between the digital and the analog world.² Research into human-robot communication should address a number of topics that further its basic theory and that could underpin its general design. Next I draw three conclusions and raise some related research challenges:

- (i) Human-human relationships are not always ideal or preferred. Obviously, the point is to demarcate to which degree a robot should simulate human behaviors and where it starts to deteriorate communication. Cues-filtered-out from FtF do not have to be detrimental; filtering out negative cues may improve communication. Additionally, certain cues-filtered-in may enhance communication. Disclaimer features may serve as assessment cues to signal non-human behavior and communicative incompetence, which may lower expectations. Countering anticipated floor effects may positively surprise a robot's users.
- (ii) A robot is a social actor of its own, not another human, animal, plant, or conventional computer. Social robots complement rather than replace human beings. Perhaps we should celebrate the differences (cf. "the value of difference," p. 114 of Ref. 71). Here, the issue is what position a robot will take socially. Do we "mindlessly" apply human social rules and norms in dealing with them,¹² or do we treat them not as if they were human but as a social entity of its own, applying different rules and norms? What social role (a novice, expert, child, adult) should the robot play in which setting to improve communication and what differences to human behaviors are conducive to

communication? Context of use determines the positive or negative effects on communication of cues-filtered-in or -out. For instance, the uncanniness of a human-like robot may be appreciated in entertainment or in security tasks but not in a family setting (cf. Ref. 50).

- (iii) The medium is the source and the messenger. People tend to take the robot itself as the source of communication,⁶ not the human driver or designer behind it. Which human-like qualities do people ascribe to a robot, compensating by attribution what actually is not there (cf. Ref. 12)?

As CMC moved beyond radio and TV, we should move beyond CMC if social robots are to become the communication interface of the future. To arrive at a theory of robot communication, several aspects of CMC may apply but this is dependent on the user's awareness of the sender (robot-mediated communication follows CMC) or not (human-robot communication makes predictions of its own). Important insights of the current paper are that cues-filtered-out from FtF are not necessarily bad and that absence of negative qualities enhances, for instance, source credibility. Much depends on the context of use. Hoorn¹³ will go deeper into the issue of awareness of the human behind the machine and how people may build up a relationship with what essentially is a communication medium.

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