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Advancing Human-Robot Interaction Within Industrial Settings; What role might social cues play in the future of robotic interface design?

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Understanding the role of social cues and social signals within human-human communication and the potential application within human-robot interactions (HRI) will first require a definition of the term and a brief review of the literature and theories that underpin the concept. This overview will be followed by an examination of the use of these terms within HRI research.

Social Cues and Social Signals

Social cues are described as discrete biologically or physically determined features of a person or group that act as information channels. These cues can be categorised as either physical or behavioural cues (Wiltshire et al., 2013). By comparison, social signals are described as the meaningful interpretation of social cues, where the perceived information signal considers the mental states and attitudes attributed to another agent within a social exchange and is thus dependent on various contextual factors (Byom & Mutlu, 2013; Fiore et al., 2013; Krauss & Fussell, 1996; Wiltshire, Lobato, et al., 2013). Therefore, social cues and social signals are related terms where the former is the display, and the latter is the interpretation of that display within the context of social interactions.
Social cues encompass a range of behavioural and physical information displays. For example, behavioural cues refer to peoples expressions, gaze, gestures, postural behaviours and actions (Fiore et al., 2013; Vinciarelli et al., 2012). In contrast, physical cues consist of aspects such as physical appearance and environmental factors, such as the distance and spatial relationship between a social agent and an observer (Cartmill et al., 2012).

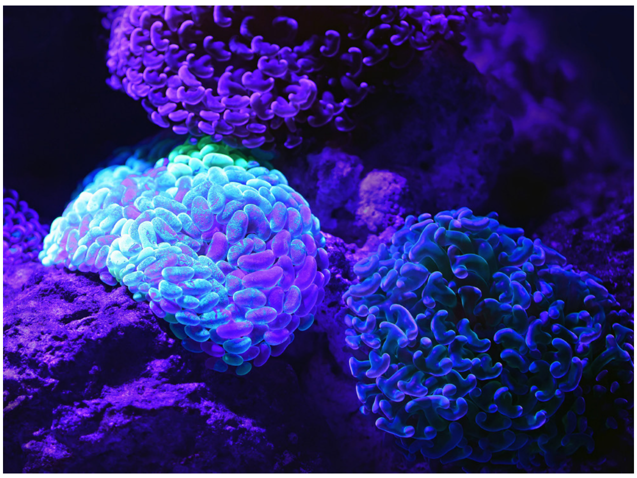

Figure 1. *Glowing coral* [Photograph] by David Clode, 2017 (https://unsplash.com/photos/75CxJTYeUYs)

Social Skills & Emotional Intelligence

While social cues are a commonly accepted term now used across multiple disciplines, it is important to highlight their emergence within literature under the overarching concept of social cognition and socio-cognitive skills. A large body of research has developed around socio-cognitive neuroscience through the cross-fertilisation of social psychology and cognitive neuropsychology (Mitchell & Phillips, 2015). This development has helped to further our understanding of the human mind and behaviour.
Social cognition is an umbrella term that covers a series of psychological processes that encompass the mental operations that underlie social interactions, including perceiving, interpreting, and generating responses to the intentions, dispositions, and behaviours of others (Green et al., 2008; Mitchell & Phillips, 2015). These socio-cognitive skills or “social skills” are seen as crucial for successful interpersonal interactions between humans (Mitchell & Phillips, 2015).
The two underlying processes relevant to this discussion are Theory of Mind (ToM), and Emotion Perception (EP). ToM - also referred to as mental state attribution - can be defined as; the ability to understand or interpret peoples intentions, thoughts, dispositions, desires, beliefs, plans, and behavioural reactions (Frith & Frith, 2012; Green et al., 2008).
In contrast, EP refers to the capacity to identify emotionally significant and noticeable information in the environment (Mitchell & Phillips, 2015; Phillips, 2003). This includes verbal and nonverbal information such as intonational, facial, visual, and body movement cues, which act as signals for emotions (Mitchell & Phillips, 2015; Phillips, 2003). To relate this to social cues and signals, EP can be thought of as the ability to perceive social cues, and ToM is the process by which we understand others through the interpretation of cues as signals of information within interpersonal interactions or communications.

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Within certain theories, these processes are thought to be core components of “emotional intelligence”, a facet of human intelligence that is arguably indispensable and perhaps the most important for success in life (Mitchell & Phillips, 2015; Vinciarelli et al., 2009). Furthermore, from an evolutionary perspective, socio-cognitive skills are seen as essential to survival within social animals. This is because they provide crucial information about the environment and allow for the quick and intuitive exchange of information with a high degree of precision (Frith & Frith, 2012; Leadner et al., 2021). Therefore social cues and signals are seen to be the basis of highly effective communication essential to human interaction (Loth & De Ruiter, 2016).

Social Cues in Human-Robot Interactions

The application of socio-cognitive theories and the use of social cues within HRI has been most prominent with the field of social robotics, with research primarily focused on domestic and medical applications with the aim of establishing “re¬lationships” between humans and robots (Jung, 2017; Landi et al., 2018). This research has explored the detection and synthesis of emotional and so¬cial information such as; facial expressions, body language, and natural speech. These social cues create a sense of social presence which help to establish robots as social agents within HRIs (Fiore et al., 2013; Jung, 2017; Landi et al., 2018; Wiltshire, Lobato, et al., 2013; Wiltshire et al., 2015; Wiltshire, Snow, et al., 2014).

The two most relevant theories for this discussion are Social Presence Theory (SPT) and Social Signal Processing (SSP). SPT was first described by Short et al. (1976) in their book “The Social Psychology of Telecommunications”, which explored the nature of social interactions through telecommunication. SSP emerged from a research milieu that merged computer scientists and social scientists in parallel with human-computer interaction, affective computing, and embodied conversational agents (Poggi et al., 2012). In order to understand the relevance and application of these theories within social robotics, it is first helpful to describe these theories briefly.

SSP has arisen as the new research and technological domain that aims to imbue computers with the ability to sense and understand human social signals. However, current computing devices do not account for the socially situated nature of human-human communication or how these interactions sit within the more extensive social interplay (Vinciarelli et al., 2009; Wiltshire, Lobato, et al., 2014). Furthermore, these computer systems lack the socio-cognitive skills required for social intelligence. However, as Vinciarelli et al. (2009), argues not all computers will need social intelligence; furthermore, it is unlikely that any will need all of the related socio-cognitive processes and skills. SPT describes the processes through which humans can understand the intentions of others through social interaction within mediated communication. Clarity of intention is dependent on the degree to which individuals are perceived as socially present within a given medium. While, an individual’s “level” of social presence is a factor of a medium’s ability to transmit social cues during a mediated interaction (Short et al., 1976). Transmission of social information is dependent on the available “bandwidth”, which by extension is determined by the number of sensory channels utilised (Daft & Lengel, 1986). For example, a video conference call has more available sensory channels and bandwidth than a text message. Video can therefore embed more social information through nonverbal social cues than text alone, allowing for greater clarity of intention. Within the broader umbrella of “Cues filtered-out theories,” such as SPT and Media Richness Theory (MRT), the argument is that a lack of nonverbal cues is detrimental to relationship development within mediated interactions (Daft & Lengel, 1986; Short et al., 1976).

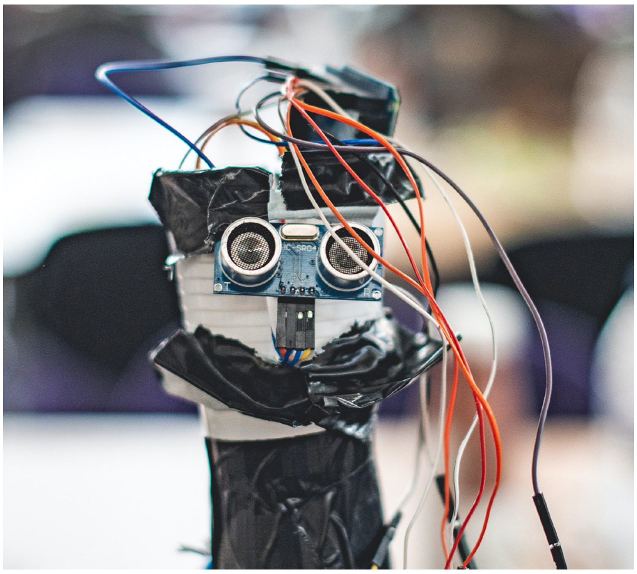

Figure 2. *Robot Gaze* [Photograph] by Valentin Petkov, 2019 (https://unsplash.com/photos/uKS_wcTAMZU)

These theories have since been applied to interactions with artificial agents (Fiore et al., 2013). Fiore et al. (2013) argue that the perceived social presence of a robot directly relates to a humans ability to understand its intentions (Loth & De Ruiter, 2016; Wiltshire et al., 2015). The degree to which robots can convey a sense

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of social presence is a function of the social cues they display and the social signals that the cues convey to an observer (Fiore et al., 2013). Drawing from SPT and MRT, a robots ability to display social cues is related to the bandwidth they have to channel social information. In robotics research, perceived social presence has been measured using a modified Networked Minds Social Presence Inventory (NMSPI) adapted in prior research to evaluate the level of social presence felt in human-robot interactions (Biocca & Harms, 2002). These concepts were applied through the work of Fiore et al. (2013), and Wiltshire et al. (2013, 2014, 2015), studying social cues with non-humanoid robots, which looked at how social cue methods such as proxemic and gaze behaviour influenced participants perceptions of the robots as a social agent. These studies are relevant to the proposed research as they demonstrate the value social cues have during HRI between a non-humanoid mobile robot and a human agent.

While the application of these theories has primarily occurred within social robotics, there are also examples of application to commercial and industrial robots, such as the Baxter Robot (Elprama et al., 2016; Rahman, 2019; Sauppé & Mutlu, 2015). However, it can be argued that these often leverage anthropomorphic features and humanoid forms within their design to allow the robot to communicate in ways that are more "human" (Złotowski et al., 2015). The findings from these studies are therefore not easily transferred to industrial robots more generally. Furthermore, this research is focused primarily on human-robot collaboration (HRC) with robotic arms, with limited research on industrial Autonomous Mobile Robots (AMRs), which are becoming more common in the industry.

The critical underpinning for this research is the assertion that human-robot interaction requires a clearer understanding of social cognitive constructs to optimise HRC (Warta et al., 2016). This assertion has arisen from a shift in perception within industry and research from robots as tools, extending human capabilities, to the perception of robots as teammates, collaborating with humans (Hoffman, 2007; Morrow & Fiore, 2012; Schaefer et al., 2017; Warta et al., 2016; Wiltshire et al., 2017; Wiltshire, Barber, et al., 2013). Warta et al. (2016), argue that for robots to operate in this manner, they will require the display of complex social cognitive processes. In this way, SSP and SPT provide the theoretical groundwork for robots to engage in socially intelligent interactions. This "intelligence" will require both the detection and synthesis of social information.

Understanding the Effect of Anthropomorphism

However, there remains an underlying question in these assertions that needs to be addressed. Namely, how do humans perceive robots and, at a more fundamental level, inanimate and animate objects within their environment? Understanding this relationship helps lay the groundwork for whether humans can perceive robots as social agents capable of fulfilling the role of teammates or co-workers, given that they are fundamentally a complex autonomous tool. To address these questions, it is helpful to discuss the concept of anthropomorphism, beginning with a definition followed by an outline of its relevance to robotics.

Anthropomorphism can be defined as the tendency to interpret non-human agents' behaviours, whether real or imagined, as having human-like characteristics, motivations, intentions, or emotions (Epley et al., 2007). These "agents" include anything that is perceived as having independence or autonomy, such as non-human animals, natural forces, religious deities, and mechanical or electronic devices (Złotowski et al., 2015). Epley et al. (2007), explain that this extends beyond behavioural descriptions to generating representations of an agent's mental or physical characteristics using human-like descriptors. The example Epley et al. (2007), provides is when an animal is perceived as being affectionate that this perception is also evidence that the animal "loves me". Therefore, the tendency to attribute conscious experience, metacognition, and intention to non-human agents are central aspects of anthropomorphism (Epley et al., 2007; Gray et al., 2007). Furthermore, these attributions can be seen to link back to the social cognitive processes of ToM or mental state attribution. The concept that people tend to see non-human agents as human-like has a long history and has been noted by scholars from a wide array of disciplines, including prominent figures such as Freud, Darwin and Hume (Epley et al., 2007).

Within robotics, anthropomorphism can lead people to misinterpret the nature of robots intentions by attributing meaning and intent to neutral behaviours and actions. An example is provided by Breazeal et al. (2013), where they observed a series of instances in which participants reported the robot as "condescending". Even though the robots AI's could not model emotion, display emotional expressions or generate an internal emotional state. However, the robot's behaviour was attributed as being condescending and showed a "lack of respect or interest towards the participant" (Breazeal et al., 2013; Jung, 2017).

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Figure 3. *Airplane* [Photograph] by Steladotio, 2020 (https://www.canva.com/photos/MAEHyqVPqZs/)

Bartneck & Keijsers (2020), argue that these acts are perceived as aggression towards humans, which can be measured through minor transgressions of social norms or "rude" behaviour. These transgressions generally do not cause physical or severe psychological harm but result in negative associations. For AMRs working within shared spaces, movement through space is a part of social interaction. Therefore, a lack of consideration for socially normative pathway planning could result in paths that, while efficient, could be seen as "rude" or even frightening (Rios-Martinez, 2013). Evidence for this can be found in Mutlu & Forlizzi (2008) study that showed participants felt "disrespected" by the mobile service robot when the robot took precedence in the hallways, expecting the robots to follow common social norms within the space.

These types of interactions can lead to negative attributions and forms of abuse towards a robot and create both real and perceived risks in industrial contexts, increasing operator stress and risk of injury (Villani et al., 2018; Złotowski et al., 2015). Therefore, it is necessary to counteract these effects by understanding the impact of anthropomorphism on HRI and HRC. This understanding could be leveraged within industrial applications to promote HRC acceptance and effectiveness (Rahman, 2019; Złotowski et al., 2015). Using affective displays from robots to communicate internal states and intention can help explain the unknown through familiarity; this approach extends to how a robot's physical attributes, such as form, can communicate physical cues and proj¬ect human values such as reliability and safety (Złotowski et al., 2015). Złotowski et al. (2015), posits that robots with human-like qualities in appearance and behaviour are treated less harshly than machine-like robots. This disposition could be related to higher empathy expressed towards anthropomorphic robots, allowing humans to relate to them more easily.

To conclude, further research in this space would allow us to better understand and embed social cues and social signals within robot designs, which would in turn help to improve HRI and HRC in a variety of contexts, including industrial and advanced manufacturing settings. This would lead to more efficient, effective, safer practices and enhanced experiences for people working alongside robots within these spaces.

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