Humanizing Human-Robot Interaction:

On the Importance of Mutual Understanding

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1. Introduction

In conjunction with what is often called the industry 4.0, the new machine age, or the rise of the robots, the authors of this paper have each experienced the following phenomenon. At public events and round-table discussions, among our circles of friends, or during interviews with the media, we are asked on a surprisingly regular basis: “How must humankind adapt to the imminent process of technological change? What do we have to learn in order to keep pace with the smart new machines? What new skills do we need to understand the robots?”

We think that these questions are being posed from the wrong point of view. Not we, not the ever growing number of robot users should be the ones who need to acquire new competences. On the contrary, we want to ask how the robots that will soon be popping up all over the place can adjust to their human interaction partners in better ways. What do they have to learn to be considerate of people and, no less important, be perceived as considerate by people? Which skills do they need, what do they have to learn to make cooperation with us possible and comfortable?

Coming from various disciplinary backgrounds rooted in robotics, cognitive science, psychology, and communication, these are the shared questions on which we have based our approach to humanize human-robot interaction (HRI). It is an approach that ultimately leads us to the necessity of mutual understanding between humans and machines—and therefore to a new design paradigm in which collaborative machines not only must be able to anticipate their human partner’s goals but at the same time enable the human partner to anticipate their own goals as well.

We will be elaborating on several important design factors in each respective area. Even if they don’t constitute an all-encompassing concept, we are convinced that they build a solid basis and an effective strategy for the development of humane[1] robots. Moreover, we think that robots that are designed for mutual understanding can also make a positive impact on the subjective psychological experience of human-robot interactions and enhance public acceptance of robotic technologies in general.

2. People's Fears of Robots

At present, that is to say, there is still much skepticism on the part of some groups of potential users towards the increasing deployment of robots in domestic environments and, exceedingly, in workplaces. According to a recent large-scale survey in the European Union, approximately 70 percent of people think that robots will steal people's jobs and around 90 percent say that the implementation of robots in society needs careful management [1]. In relation to these numbers, a much smaller but still sizeable population could be called "technophobes" or "robophobes" [2], defined as individuals who are anxious towards smart machines on a personal level. The Chapman University Survey of American Fears [3] revealed in this regard that 29 percent of US residents reported to be very afraid or afraid of robots replacing workforce, a number comparable to the occurrence of the fear of public speaking in the US population. Furthermore, 22 percent of participants indicated being very afraid or afraid of artificial intelligence and 19 percent of "technology I don't understand." [3]. The imagined substitution of human beings by intelligent artificial agents has been repeatedly described as a strong fear, reaching from the fear of job loss comparably relevant to everyday life [2], [4] to much vaguer frights of an artificial "superintelligence" [N4] that on its own develops doubtful intentions, and, ultimately, a "robocalyptic" end of humankind [5]. Science fiction, of course, plays a role here. While some fictional stories have been shown to generate meaning and thereby increase recipients' acceptance of robotic technology [N1], [N3], many highly popular movies such as

“The Terminator”, “Blade Runner” or “Ex Machina” [N4] circulate dystopian outlooks and frequently encourage the audience to envision a militarized future of human-robot relations [N5].

Coming back to more contemporary, non-fictional developments in robotics, various fears and ethical concerns have been raised in view of so-called social or “emotional” robots, meant to be used, e.g., for the care of children or the elderly. A number of scholars and study participants have expressed their worries about such robotic companions as they might contribute to social isolation by reducing the amount of time spent with other humans, lead to a loss of privacy and liberty or to emotional manipulation of lonely, sensitive persons ([N4], [N6], [N7], [N9]).

Besides being afraid of robotic surrogates or caregiver robots, however, there is a number of other types of fears towards robots that have been described as relevant in the literature. These include anxieties towards the communication capabilities of robots (e.g., a robot may be unable to understand a complex conversation), anxieties towards behavioral characteristics (e.g., what speed a robot will move at or what it will do next), and anxieties towards the discourse with robots (e.g., being unsure how to talk to a robot or whether the robot has understood one’s utterance), with many of them summarized in the Robot Anxiety Scale [6]. In addition, Ray and colleagues [4] have identified technical dysfunctions and a felt loss of control as particularly strong fears towards robots—issues that recently even have been picked up by the European Parliament’s draft for a union-wide robot law [N2]. In there, the implementation of a mandatory “kill switch” in every robot is requested to prevent people from malfunctioning machines.

3. Reality of Robots

While some fears towards robots are provoked by social or “emotional” machines made for their users’ personal environments, many of people’s fears described above also derive by the machines currently deployed in the automotive and electronic industries. Those robotic platforms are usually bulky and frightful, positioned in cages where no man is allowed during operation and requiring an expert user perfectly trained to operate them. Although we can imagine that robot envisioned for diffusion in the society will be different in shape and applications, the idea that robots are built to work efficiently with no need of humans lingers in most people's mind. This kind of thought leads to the assumption that robots might replace humans or that, to interact with a robot, it will be responsibility of the human user to learn a potentially complex sets of instructions, with no adaptation from the robotic side. However, the conception of robots is deeply changed also from the industrial perspective. Current industries require flexibility and versatility, the capacity to change activity and learn new processes in relatively short time, something that humans are much better at than robots. Moreover, many human skills – as the ability to deal with unforeseen issues or some manual and creative skills – are still far from being matched by robotic devices. In other words, roboticists have realized that robots need humans! Leveraging on human-robot collaboration, rather than minimizing it, could be a possible solution to approach the desired level of adaptability and proficiency in dealing with complex tasks. As a result, now robots aim at exploiting the interaction (being it physical or cognitive) to learn complex concepts, as human good sense, and to complement their behavioral efficiency with the adaptability, intuitiveness and creativity proper of human–human interaction (e.g., see the Robotics2020 Strategic Research for Robotics in Europe[2]). Humans become therefore partners, not just "users", and the relationship is not unidirectional (or absent) anymore, but depends on both the interacting agents. We posit that for this dynamic equilibrium to work and bring the expected benefits, robots will have to become more humane, so as to establish an effective mutual understanding with their partners and carry part of the effort needed to maintain the interaction.

4. From Humanlike Robots to Humanized Interaction: A New Design Paradigm of Mutual Understanding

4.1 The Human in "Humanized"

Humanize human-robot interaction means that the machines will need to become considerate of humans. Much research has already been devoted to make computers and technology more respectful of human necessities, also from a socio-ethical perspective [N10, N11]. Now, robots will have to base their behavior on human needs by anticipating and understanding them, and they will have to communicate in understandable ways to humans (see Figure 1). To achieve this goal robotic research needs to move beyond the tradition of seeking more powerful and efficient systems, focusing instead on novel concepts as robot transparency, legibility and predictability and on skills entailing understanding and anticipating humans.

It is important to stress that *humanize* does not necessarily imply choosing an anthropomorphic appearance for a robot and does not require that robots replicate exactly all possible human activities or simulate human emotion. Rather, it suggests that robots need to "be considerate of people", i.e., maintain a model of humans in order to understand and predict which are their needs, intentions and limitations and use ways of communicating and cooperating that are intuitive for the human partner. This interactive model should work for robots with very different embodiments, ranging from humanoids, to robot cars and quadrirotors, to name a few.

The approach we suggest to increase the fluidity of human-robot interaction is to leverage on the interactive models humans have naturally developed to interact with other humans. When working together, *how* a certain action is performed allows the human partner to intuitively understand several unsaid properties of the ongoing interaction and to make it more efficient and synchronized. For instance from someone's motion it is possible to infer how confident the person is in what he is doing [7], how heavy or fragile is the object that is being manipulated [8] and also what he intends to do with the same object [9]. We posit that robots should be enabled to tap into such flow of information by both reading and sending these covert signals within the interaction.

Importantly, we need robots that can understand us but that at the same time can be easily understood and anticipated by us. Only through such a bidirectional, mutual understanding the interaction could evolve in a safe, natural and seamless way, similarly to what happens in human-human exchanges.

4.2 Designing Robots to Predict Human Needs

A key ability in humans is the capability to anticipate what others intend to do or might need. The formation of expectations about others' actions and intentions increases the efficiency of the interaction by limiting the need of elaborate verbal exchanges and cutting drastically the delays. To form expectations the robot needs to assess the internal, hidden status of the partners, in particular what's their intended goal and, to some extent, which are their motivation and feelings. Between humans this is achieved through a continuous exchange of tacit, covert signals, hidden in the way we behave. For instance, the direction of human gaze correlates with the position of the focus of attention, and is exploited for understanding the role of each participant in an interaction and to pace turn taking [10], whereas the velocity with which an action is performed can reveal the actors' emotional status or their intentions [9], [11]. Some of these signals are physiologically embedded in human behavior and do not need to be added voluntarily for the sake of communication, hence they do not even require sender's awareness. Others, still based on the way human move, have an explicit communicative intent (as waving the hand to say bye or pointing to indicate something relevant) but they are intrinsic to human culture and do not entail any conscious effort to be interpreted. A robot reading similar signals could decide when to act and what to do in an interaction without requiring any learning or adaptation from the human side, promoting a natural and intuitive (i.e., a more humanized) collaboration. There is already evidence that the sensitivity to these signals facilitates human-robot interaction (and makes it more pleasant and acceptable). For instance, it has been show that a robot monitoring head orientation can disambiguate verbal expression on the basis of the participants' gaze direction, making the interaction more natural, pleasant and efficient [12]. The ability to read eyes motion can inform the robot of which object the person might need in a collaborative joint task [10], with no need of processing explicit verbal or gestural instructions [13]. Beyond gaze, also the properties of body motion can help the robot be a more intuitive collaborator. The ability to detect regularities of biological motions in the scene enables a robot to detect human activities even when no human shape is in sight (e.g., when only the tool being used is visible [14]) and subtle variations in action kinematics can inform the robot of the human intention [15]. It has also been demonstrated that the combination of the anticipation of human motion trajectories with a modeling of the potential uses of common objects allows a robot to predict the next human actions with a sufficient detail to perform anticipatory planning of their reactive responses [16]. A robot able to "read" body motion will also be able to detect the affective state of the interacting partner, in order to use also this information to adapt its behavior accordingly (for a recent review on automatic recognition of body movements for affective expression, [11]).

In summary, the first step to make future robots considerate of humans will be to enable them to sense and understand the subtle signals that humans naturally exchange during everyday interactions. This ability is at the basis of the process required to develop robots gifted with the kind of intuition found in our best human collaborators. Conversely, as it is explained in the next section, in order for humans to be considerate of robots it is necessary to embed in robot motion the same implicit messages used by humans.

4.3 Designing Robots to be Predictable for Humans

One might easily assume that for a smooth human-robot interaction it is sufficient to have a smart robot, programmed to understand and react to the needs of its human partner in real-time. This is certainly true in a situation in which all actions are defined a-priori, for example when a swivel-arm robot at an assembly line perpetually repeats the very same movement. This is not the case when robots interact with humans in more dynamic, unconstrained situations that demand a mutual exchange of information and meaning-making, something which has long been investigated for interpersonal communication in the field of Language and Social Interaction [N8]. For example: if a pedestrian wants to cross the road, a self-driving robot car must be capable of inferring the person's intent by analyzing body direction or gestures and thus stop automatically. But beyond that, the car also has to send some message to inform the pedestrian of its intention to stop or to continue if stopping is considered more dangerous. As a result of this implicit dialogue, the person can cross the road safely—or wait.

The alternative to this situation is to adopt an ultra-safe strategy such as stopping whenever there is a pedestrian in view, with disadvantageous outcomes in terms of efficiency. In general situations however, especially with humans naïve to robot's functions or whenever there are more than only two potential outcomes of an HRI (contrary to the binary decision stop/move on), it is crucial for a robot to proactively communicate its imminent actions in order to reduce uncertainty on the part of its human vis-à-vis. Designing robots to be considerate of people therefore also means designing robots to satisfy the basic human longing for clarity, control and predictable events. To reach this goal, robots not only need to be able to anticipate our intents but at the same time need to give us the chance to anticipate theirs as well.

In the humanities and social sciences it is long known that—aside from a few exceptions—events, tasks, and agents that are characterized by high ambiguity and unpredictability often are evaluated as particularly uncomfortable and even may cause anxiety (cf. [17], [18]), sometimes intensified by an actual or perceived inability to adapt to the current situation [19]. In early experimental investigations, people have been found to show a significant preference for predictability in situations of potential physical threat, realized e.g. by means of preliminary warning signals [20]. Low predictability and controllability of animal movements repeatedly have been shown to correlate with the widespread fear of spiders [21], [22]. And even the much discussed *uncanny valley* effect in robotics, a negatively valued state of creepiness elicited by humanlike robots of high realism [23], has been attributed to a mismatch between user expectations and robot actions and thus an inherent ambiguity and low perceived predictability of android characters (e.g., [24]).

In the realm of HRI, a comparably new branch of empirical studies has been dealing with legible and predictable motion design for physical interactions in collaborative workplace settings, with most results in strong support of the importance of mutual anticipation between humans and machines. To be clear about the terms, *predictability* in this context is typically defined as a targeted outcome state once a robot's goal is clear to the interacting person, whereas *legibility* refers to a robot's easily "readable" behavioral cues (e.g., its motion trajectory) that allow the person to build an expectation of a robot's intended goal in the first place, thus making the robot predictable [25]–[28]. In several studies in which industrial robots and test persons collaboratively performed pick and place tasks, Dragan and colleagues [26]–[27] could show that the more people were able to predict a robot's next action, the more comfortable they felt while interacting with the robot. This is very much in line with other research that revealed a positive relation between legibility of robot motion and people's subjective safety [29] as well as people's trust in autonomous agents [30].

Yet, a highly legible and predictable motion design does not only seem to influence how positively people evaluate an HRI but at the same time how efficient a task can be carried out by a human-robot team: People and robots have been shown to need significantly less time for joint task completion when the human partner was able to predict the robot's imminent action early. This held true even if the legible motion design took the robot actually longer to execute its part of the task [26]. This somewhat counterintuitive efficiency effect can be explained by the test persons' increased ability to coordinate their own actions accordingly to the robot at an earlier stage. In practice, designing a robot's motion for optimal legibility for example means that the robot doesn't follow the most direct path, e.g. for grasping an object or approaching a person, but favors a curved trajectory by which the direction of the target location in many cases can be predicted implicitly by human observers [26], [27]. Interestingly, it has been shown that a self-learning swivel-arm robot that is only programmed to reward joint task completion efficiency with human partners ultimately lands at performing more legible motion [25].

A highly predictable robot behavior, however, can be established by various means. Aside from a robot's motion design, other channels of human-robot communication can be exploited as well. Light signals have been used in a flight path crossing task with a drone, for example, to proactively express the drone's intent to brake for a human pedestrian. With light signals given, people walked significantly faster and displayed fewer nonverbal cues of insecurity as in comparison to an unpredictable control condition [31].

All in all, it has to be noted that certainty and transparency in general are variables of high relevance for the perceived comfort of an HRI, not only in terms of the very next actions of a robot but also in a broader meaning of what can be expected of a robot, what it is able to sense, to decide, and to do autonomously. The more familiar people are with a robot, the more they are willing to accept it as a partner, no matter if in their personal or work environments (cf. [2]).

It is worth stressing, however, the relevance of mutual understanding in the sense that, even if we can think that humans could easily learn to predict non-humane robot behaviors (within the limits of our perceptual abilities) the ability of the robot to anticipate human behavior requires a very deep knowledge of the motor and cognitive bases of human-human interaction. It is easier to implement a robot moving in a humane way than to implement a robot able to interpret humane movement. However, only the effective combination of understanding and being understood will allow to establish a balanced interaction between the two agents, making any type of collaboration seamless and intuitive.

5. Discussion and Conclusion

In the consciousness of many people, we are facing the dawn of a new epoch. An epoch in which the images that we have long been familiar with from science fiction films start to correspond to the realities of everyday life. An epoch in which the robots—finally, really—arrive at our workplaces and in our households, at hospitals and entertainment parks, at the road and in the sky above our heads. Regardless of how realistic or starry-eyed many of these prospects of our impending high-tech future might seem—in any case, it is clear that autonomous machines will not been keeping to themselves very much longer. They will walk among us. And as they proceed to carry out their respective mission, they will no longer be segregated in machine-only realms; rather, they will be emerging in our quotidian environments and, accordingly, getting closer and closer to us human beings in a physical and psychological sense as well.

If robots would move amongst their own species, their behavioral design could be purely functional. There would not be any need for communicative signals meant to be detectable by the human senses. However, robots will be characterized by their co-existence and collaboration with human partners much more than it has been trumpeted for a long time. With this paper, we therefore called for a humane vision of human-robot interaction, fostered by a new design paradigm of bidirectional—mutual—understanding between humans and machines.

Designing robots to be considerate of human interaction partners implies that they should be able to infer what the human intends to do, what he or she needs and whether it is the right moment to intervene or it would be better to wait a little. However, this won't be enough: robots will need to be considerate also in their actions, selecting those behaviors that maximize human comfort, which implies not only aiming for safety and ergonomics, but also for an increase in intention expression and action understandability. It is worth stressing here that, in general, being considerate of humans requires the robot to be able to understand and adapt to human's skill at the individual/personal level in order to interpret and use a shared vocabulary as we do, for example, when exaggerating our movement in interacting with children or slow-down our movements when interacting with elderly. In this respect, roboticists will have to take into consideration not only behaviors that are common among all humans [N12] – as the way eye and hand motion are coordinated in a reaching action – but also signals that vary widely between cultural or ethnic groups. Therefore, if the direction of the gaze can be universally used by the robot to predict which object a person is going to take [13], the interpretation of hand gestures or of the amount of eye contact will need to be informed by the cultural context. This underlines the importance of empirical research into cultural differences influencing how people interact with robots. Only this way the effort of adapting to the partner in human-robot interaction will fall also onto the (powerful) robot's shoulders and not only on those of the human. As a result, experiencing a mutual adaptation during the interaction will make the robot behavior much more predictable and acceptable, putting to flight many of the fears caused by current uncertainties about these machines.

If a more humane interaction will be established, it will become more and more evident that robots, rather than replacing us, might support us performing task we don't like. Beyond replacing our household appliances, as already some robotic vacuum cleaners or lawn mowers do, robots might be attributed progressively more complex and relevant duties, as providing support to the elderly, in order to allow them a longer period of autonomous living in their home. A humane robot won't replace human contact, but will provide concrete support in coping with physical demanding tasks that the person cannot perform alone anymore, at the same time facilitating interaction with peers. For instance, it will be able to mediate the access of seniors to novel digital communication channels, making the interaction with the devices intuitive. Already current robotic platforms presented as "personal robots" promise to move in this direction, by autonomously dealing with the technical aspects of a video call and making them transparent to the users. Robots might also provide support to human therapists, since there are evidence suggesting that use of robots can bring social benefits to clinical populations. For instance, in the case of autism or dementia, it has been shown that they can facilitate group dynamics, by increasing the occasions of interaction between patients and leading to an increment in social exchanges between patients and the therapists [32], [33].

The task of humanizing the interaction is however challenging, because robots are currently not as good as humans at adapting to their partner's needs. There is a variety of examples of humans learning to predict non-humane machines, although with some effort, e.g., think of workers dealing with complex technical devices. To provide robots with a comparable ability to anticipate human behavior, roboticists will need a profound understanding of the basic mechanisms of human-human interaction. Robots, and in particular humanoid robots, might play an important role already in this effort, representing a valuable tool to investigate in a controllable and repeatable way the dynamics of human interaction and to derive and validate models of human social behavior [34].

We posit that the design of humane robots will bring concrete advantages to the society and will also change the common perception of robots. The more people know about robots, the less they fear them (cf. [2]) and a mutual understanding between human and robots increases the predictability and legibility of the machines, fostering a more relaxed and natural coexistence. Therefore, humanizing the interaction will be decisive to determine whether people will accept robots in their society and how close it is a future in which humankind and robotkind can co-exist in safe and peaceful ways.

Figure 1: Humanizing the interaction with robots implies a mutual understanding between the two agents, with the effort of adapting to the partner not falling on the human shoulders alone, but rather being shared between the two. Photo by Laura Taverna – Istituto Italiano di Tecnologia.

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Footnotes

1. We adopt here the "Cambridge Dictionary definition of humane: "showing kindness, care, and sympathy towards others, especially those who are suffering".
2. https://www.eu-robotics.net/cms/upload/topic_groups/SRA2020_SPARC.pdf

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