Human-cobot Teams: Exploring Design Principles and Behaviour Models to Facilitate the Understanding of Non-verbal Communication from Cobots

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Keywords: Human-robot Interaction, Human-robot Teamwork, Cobot Behaviour, Cobot-design Principles, Human–animal Team Metaphor.

Abstract: Now that collaborative robots are becoming more widespread in industry, the question arises how we can make them better co-workers and team members. Team members cooperate and collaborate to attain common goals. Consequently they provide and receive information, often non-linguistic, necessary to accomplish the work at hand and coordinate their activities. The cooperative behaviour needed to function as a team also entails that team members have to develop a certain level of trust towards each other. In this paper we argue that for cobots to become trusted, successful co-workers in an industrial setting we need to develop design principles for cobot behaviour to provide legible, that is understandable, information and to generate trust. Furthermore, we are of the opinion that modelling such non-verbal cobot behaviour after animal co-workers may provide useful opportunities, even though additional communication may be needed for optimal collaboration.

1 INTRODUCTION

The way factory workers work with robots in industrial environments is changing. Robots are no longer exclusively machines that are encaged or otherwise separated from the work force. They now enter people's workspace and they are becoming co-workers which are meant to collaborate with humans. Hence this type of robot is called cobot, short for collaborative robot. Currently most cobot applications are limited to coexistence, the cobot dwells in the same work area as humans, but it has its own tasks and there is limited or no interaction. However, it is to be expected that in the near future cobots and humans will cooperate, that is they will work on the same product in the same location. Eventually, true collaboration may be achieved, where cobot and human work at the same product at the same time in close and physical contact with each other.

These cobots have to function in less predictable environments than traditional industrial robots. Also, the users of cobots might be less technically literate than the operators of traditional industrial robots. Therefore cobots have to be able to interact naturally and intuitively with humans and to fit in the human work environment (Korondi et al., 2015). Much research on Human Robot Interaction (HRI) and robot design focusses on service robots interacting in social or public settings, for instance the work of Dautenhahn (2007), Hoffman et al., (2014), Dragan and colleagues (Cha, Dragan and Srinivasa, 2015) and Sisbot (Sisbot et al., 2010. Insights from this research can be useful, however applying them to human-friendly design of industrial collaborative robots may have its limitations and research in this area is not as widely available (Bartneck et al., 2009; Michalos et al., 2018; Sheridan, 2016). An important question is how and which design principles may be used for modelling the behaviour of robots in an industrial setting. Since in many industrial environments verbal communication is limited because of factory noise, our research focuses on non-verbal behaviour.

In our own research project we explore this approach to promote intuitive interaction with industrial cobots and improve collaboration in human-cobot teams. In this paper we propose to use design principles and cobot-behaviour modelling analogous to natural animal behaviour.

2 TEAMS AND TEAMWORK

The developments in industrial work environments imply that humans have to form teams with cobots, their new co-workers. To better understand what is needed to cooperate and collaborate with cobots, it is important to look at some key concepts of teamwork.

2.1 Human Teams

There is ample research concerning human teams and teamwork resulting in more than 130 models on teamwork (Salas, Cooke and Rosen, 2008). In spite of this variety in models, one can derive some common characteristics and concepts. Most approaches consider a team to be a group or unit with members with high task interdependency and shared and valued common goals. Members of a team have to share, integrate and synthesize information. Also they have to work together and coordinate their work to reach common goals (Costa, 2003). Thus, important concepts are (1) interdependency, i.e. failures of one member have effects on the work of others; (2) sharing information, which is necessary to guarantee a smooth process; (3) coordination and cooperation to reach common goals.

Interdependency occurs during the process of team performance, i.e. the process in which tasks are carried out. Such tasks may be performed independently (task work) or interdependently (teamwork). Teamwork concerns the interdependent components of performance required to effectively coordinate the performance of several team members (Salas et al., 2008). In addition, Costa (2003) stresses that task interdependence is required "such that individuals need to develop share[d] understandings and expected patterns of behaviour" (p.606).

Coordination is important for teamwork as well. Members of human teams provide feedback on whether the messages of other team members are received and understood or on the status and progress of the process at hand. Team members anticipate each other's need for information and provide such information proactively (McNeese et al., 2018). Some of the information may be verbal, but there will be a fair amount of non-verbal communication.

In well-functioning teams **Sharing Information** and coordination seem to take place with hardly any explicit verbal communication. This can be achieved because such teams have shared mental models, i.e. corresponding ideas on the work at hand and how to perform this work. **Shared Mental Models** and team cognition help team members anticipating as well as executing actions (Kozlowski and Ilgen, 2006).

In short, in the case of effective team performance team members cooperate and collaborate to attain common goals. Consequently they provide and receive information, often without using language, and coordinate their activities, resulting in a fluent intertwining of these activities.

Working as a team requires a willingness to cooperate. Research on human teamwork shows that **Trust** plays an important role in optimal cooperation and collaboration (see for instance Axelrod, 1984; Mayer et al., 1995; McAllister, 1995, Sheng et al., 2010). Humans infer trustworthiness from the behaviour and actions of others. As is often said "actions speak louder than words". Experiential trust between people develops if one can be sure that one can count on a partner, that his or her behaviour is logical, predictable and consistent, and that he or she means well (Mayer, Davis and Schoorman, 1995). Such experiential trust consequently is context dependent, one trusts a team member on the basis of his behaviour in a specific work setting. Trust is found to affect effective performance, satisfaction with the team and commitment (Costa, 2003). It may be clear that trust and optimal teamwork depend on the interaction and communication, whether it be verbal or nonverbal, between team members.

2.2 Teaming with Cobots

Given that cobots will work closely together with us, it may be assumed that several principles of human teamwork will apply in this situation as well. In research on human-robot collaboration the concepts of interdependency, trust, communication and coordination are studied to some extent.

Interdependency in human-robot teamwork is studied by Johnson and colleagues (Johnson et al., 2011; 2012). They point out that robots may be capable to execute individual tasks autonomously, but that in joint activities team members have to be aware of each other's states and actions. is required. Furthermore, careful orchestration of the transfer of tasks as well as continuous interaction to perform shared tasks are needed. This implies that it should be transparent what a cobot is doing and why.

Trust has been identified as an important element for the success of human-robot teamwork (Charalambous et al., 2016; Marble et al., 2004). Research on trusting robots shows that humans should be able to trust that a collaborative robot does not harm their interests and welfare. The factors to build trust are mostly related to performance factors of the robot, such as the behaviour, reliability and predictability of the robot, and robot attributes, such as proximity and (assumed) personality (Hancock et al., 2011; van den Brule et al., 2014). In this sense trust in robots parallels experiential trust in human teams.

With regard to **Coordination**, Christoffersen and Woods (2002) state that any automated system should cater for fluent and coordinated interaction, and should be a true team player. A breakdown in coordination will lead to accidents. As in human teams, good coordination depends on sharing **Information** in a timely and understandable manner. Just as in human teams, this information need not be linguistic. The work of Hoffman and Breazeal (2007; 2010) shows that the fluency of interacting behaviours between robots and humans can be enhanced if robot behaviour is designed in a way that its actions can be anticipated by humans.

However, the way a cobot communicates may not be the way humans are used to and readily understand. This is why Lichtenthäler and Kirsch (2016) call for "legible" behaviour, that is, behaviour that will help humans to understand the robots intentions. Like in human teamwork, much of the communication will be non-verbal, through the design and movements of the cobot.

3 DESIGN PRINCIPLES FOR COBOT TEAM MEMBERS

Whether intentional or not, the looks and behaviour of a robot, or cobot for that matter, provide information. Humans will try to interpret this, often non-linguistic, information. Moreover, they tend to attribute life to non-living objects (animism) and to interpret the behaviour of such objects in human terms (anthropomorphism) (Guthrie, 1993; Korondi et al., 2015). It may be assumed that the way humans experience the behaviour of and interaction with a robot will have important effects on team performance and individual wellbeing.

Research outcomes on robot behaviour can be transferred to cobot design without much problems since a cobot essentially is a robot that is limited in speed and strength. Robot studies show that the predictability of robot motions influences human task-performance and user experience: lower predictability results in lower performance (Koppenborg et al., 2017) and lower experienced comfort (Butler and Aga, 2001; Tan et al., 2009). Furthermore perceived safety and trust may vary depending on whether a robot, either social or industrial, meets the expectations of humans (Rios-Martinez, Spalanzani and Laugier, 2015; Eder, Harper and Leonards, 2014). This implies that deliberate design principles are necessary to consciously design the cobot and its behaviour to facilitate interaction and teamwork.

The design of communicative behaviour of social robots is often based on human-human interactions (Takayama, Dooley and Ju, 2011; Kittmann et al., 2015). Since human behaviour is well known and readily interpreted by others, it is assumed that imitating human behaviour, specifically motions, will help to understand and predict the actions of a robot (Lichtenthäler and Kirsch, 2016). For instance, Castro Gonzales et al., (2015) show that naturalistic movement makes an animate impression and increases the likability of a robot. Also, adding social cues, such as acknowledging a user by nodding, have been shown to help to enjoy working with the robot (Elprama et al., 2016).

Furthermore, in human-human interaction posture and movement are perceived as having meaning and intent (Pollick et al., 2001). Making industrial robots or cobots move like humans is not always feasible, however. The non-verbal behaviour a robot can display by its movements, is mainly determined by technical constraints and safety guidelines. This may cause limitations in realizing subtle details of movement in mechanical agents, despite the progress that is made in cognitive engineering to improve the interdependency in a human-cobot team.

In the design of social robots as well as cobots a head is often suggested to increase likability. People tend to look for and see a face in almost anything (pareidolia). This evolutionary feature is based in a network of cortical and subcortical regions (Hadjikhani et al., 2009), and is believed to enable humans to detect whether a person (or animal) is kind or angry and to detect danger. The face and the head are used as a focal point for interaction, it shows one where the attention of another creature is directed and helps one to infer intentions. In line with this approach gazing behaviour is used in robots, for instance to refer to objects or locations or to establish attention. However implementing human eye movement in robots is not always feasible because of cost and the needed degrees of freedom for such movements (Admoni and Scassellati, 2017). Furthermore, if an interface, like a screen, is used to display the gazing behaviour, this may distract the user from the task at hand.

A promising approach for designing interaction can be found in the tradition of animation (Lasseter, 1987; 2001). Animation helps to bring non-living objects to life. Though human behaviour is often used to animate object, this is not absolutely necessary. Behaviour found in animals and nature in general can be useful as well. Applying animation principles is found to be successful to increase likability and intuitive understanding. This approach was taken up by several researchers to animate robot behaviour (e.g. van Breemen, 2004; Hoffman and Ju, 2014; Saldien et al., 2013). For instance, the path of a movement becomes more predictable by using arcs. Usually the movements of natural objects, animals and humans follow an arched trajectory, whereas mechanical movement proceeds in straight lines. Also anticipation may be used to announce an action, like a person bending his knees before jumping or a baseball player who moves his arm back before making a pitch.

An important condition to allow for understanding and using intuition is that the character and behaviour of the robot are coherent. Since the appearance evokes expectations, emotions and interaction affordances (Hoffman and Ju 2014), the actual behaviour the robot displays should be coherent with and follow logically from its appearance (de Geus, 2017). Therefore, conscious and thought-out application of animation principles is required to match expectations and reflect the actual possibilities of a robot. Though animation seems a promising approach, it is essential to carefully consider which type of behaviour the robot can best be modelled after.

4 MODELING COBOT BEHAVIOUR AFTER ANIMALS

Modelling robots and cobots after humans may have drawbacks. Many believe that increasing the similarity of robots to humans will increase the chances that humans refuse interaction with or become frightened of very human-like agents. This so-called Uncanny Valley (Mori, 1970, essay translated by Mori, MacDorman and Kageki, 2012) seems to hold for western cultures in particular (Kaplan, 2004). Although recent developments in cognitive engineering and deep learning make it more feasible for cobots to become anticipatory, i.e. to understand the world and humans around them and act accordingly, today's robotics is not yet advanced enough to reach the physical and cognitive capabilities of humans (Korondi et al., 2015). Therefore, making a robot look and behave like a human may cause a mismatch between perceived and true capabilities of the robot (Cha et al., 2015). This means that the physical embodiment should not transcend the true capacities of the robot, and its behaviour should faithfully mirror its actual skills, be it mental or physical. To imply higher can result in disappointment, and a decrease in believability (Rose et al., 2010). Also, giving a cobot a face may divert the focal point of attention away from its actuators. If the use of humanlike faces or eyes has no further meaning, the resulting distraction increases cognitive load and hinders task execution.

These drawbacks lead us to agree that an alternative is needed for designing the behaviour of cobots. Drawing on human-animal interaction may offer such alternative. A note of caution is in place here, since a cobot cannot exhibit the full spectrum of behaviour of the model animal, just as it cannot fully imitate human, non-verbal behaviour. Yet, in an industrial setting, simple animalistic analogues may be helpful.

Looking at human-animal interaction has been suggested in literature, for instance by Phillips et al (2012) and Koay et al (2013). Historically, the most common human-animal teaming is focussed on replacing, augmenting or multiplying the physical capabilities of humans (e.g. horses, elephants, oxen, and dogs). This is similar to the use of robotics in an industrial environment. Robotic arms are used to lift, transport, and manipulate objects with a stamina and strength not present in humans. This is akin to the tasks mankind transfers to stronger animals, like elephants or horses. Automated Guided Vehicles (AGVs) or transport robots can fetch and transport products, which is similar to working dogs and donkeys.

Using an animal metaphor has some important advantages. For one thing, mankind's history of successful and continuing cooperation with animals can be of use to facilitate the interaction with cobots (Phillips et al., 2012). Metaphors serve to provide familiar entities that enable people to readily understand the underlying conceptual model and know what to do with a technology, how to approach it, what they can expect from it, in short; how to use it (Sharp, Preece and Rogers 2019).

Also, humans learned to interpret or read the behaviour of many animals. There is an intuitive understanding of what an animal communicates. Humans have developed the ability to form social contact with many creatures, in which signalling behaviour partly overlaps, and to use this in a cooperative setting. This means that the so needed "legibility" of robot behaviour (Lichtenthäler and Kirsch, 2016) may be improved by mimicking animal behaviour. Etho-robotics research, for instance, uses ethological principles and methods based on the study of animal behaviour, specifically in their natural environment, to derive complex behavioural models which can be implemented into robots (Korondi et al., 2015). The etho-robotic approach further stresses the strong functional relationship between embodiment and behaviour.

Furthermore, shaping robots in animal form or terms, zoomorphism, may help to activate existing mental models and to build new mental models of cobots (Phillips et al., 2012). As an extension thereof, biomimicry, imitating natural forms and processes (Benyus, 1997), can be taken as inspiration, like for instance the new Handle box handling robot, developed by Boston Dynamics that has bird-like features and behaviour.

Another advantage may be, that in contrast with cooperation between humans, for many forms of cooperation with animals it seems that an animal would not need mental representations (Gärdenfors, 2008). If there is common goal in the physical world such as finding food or averting danger, the collaborators do not necessarily need not have a joint representation before acting. Only when future and hypothetical goals have to be achieved, shared mental models are required. Thinking and planning beyond the present seems to be unique to humans and some hominoids like chimpanzees or orang-utan. Animals, and in our view also cobots, may not need to have a theory of mind for successful cooperation with humans.

Using the working animal metaphor can thus provide insight in the design of cobots and the training of humans who need to interact with them, because it taps into well-established mental models and human tendencies. Still, just as with modelling after humans, careful attention should be given to the chosen behaviour and consistency with the intended purpose of the cobot.

5 DISCUSSION AND CONCLUSIONS

The literature on teamwork shows that coordination and communication between team members are important to make teamwork effective. These aspects also help to build trust between team members. As was demonstrated this applies both to human teams and human-robot teams. Therefore facilitating communication and understanding the actions of cobots are important aspects of implementing cobots in an industrial environment. In this paper we focussed on non-verbal communication of the cobot. This does not, however, imply that all communication should be non-linguistic. Yet, as it is the cobot's primary way to communicate with humans, these humans have to find a way to interpret its, mostly non-verbal, behaviour. We claim that to make the behaviour of the robot more transparent and legible, one needs carefully thought out design principles. The tradition of animation can help to design such legible robot behaviour.

Models from which to deduce this behaviour can be found in the animal world rather than in human behaviour. This because mimicking human behaviour can be both misleading and uncanny since mismatches in both physical and mental capacities may be lurking. Experience in working with animals has taught humans to interpret and predict their behaviour and to estimate what they are capable of. Yet there may be complications with this approach if the context of use and the purpose of the design are not carefully considered. For instance, the design of a cobot may still suggest that it is strong while it actually is weak or vice versa. A design primarily aimed at evoking emotions and to look cute will not be very useful if the robot is to be employed in dangerous environment. In short, form and behaviour should still follow function. Therefore careful study of the situation and matching behaviour is essential. As developments in for instance artificial intelligence and deep learning are progressing, implementing more human-like behaviour may become feasible. Yet, one should still carefully consider which affordances are to be suggested by the design.

One of the issues that was not addressed here, concerns implementing cobots in industrial environments and training human co-workers. Humans need to build accurate mental models and trusting relationships. These can arise through exposure, experience building or more explicit training methods. Here training designs that resemble animal training/familiarization paradigms in which humankind has longstanding experience (Phillips et al., 2012) can be of use. Several assumptions could be beneficial for safe cooperation with industrial cobots. For instance, in the cooperation with animals one assumes that one needs some form of training, or at least experience, to work with them. Similarly, it may also be advantageous to make use of established training paradigms for human-animal teams (Phillips et al., 2016). Also, there is a respectful distance humans keep from larger working animals, knowing their physical strength is superior to ours (just like most industrial robots).

More research is needed to determine which models for cobot behaviour in industrial settings are most appropriate to ensure intuitive interaction and cooperative non-verbal communication in specific work contexts. Grounded use of cobot behaviour can bring safe and seamless interaction between human and cobot closer and make true teamwork possible.

ACKNOWLEDGEMENTS

This research is was funded by the Dutch Ministry of Economic affairs through the SIA-RAAK program, project "Close encounters with co-bots" RAAK.MKB.08.018.

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