A Review on Communicative Mechanisms of External HMIs in Human-Technology Interaction

Peter Thorvald
School of Engineering Science, University of Skövde.
Skövde, Sweden.
peter.thorvald@his.se

Ari Kolbeinsson
School of Engineering Science, University of Skövde.
Skövde, Sweden.
ari.kolbeinsson@his.se

Emmie Fogelberg
School of Engineering Science University of Skövde
Skövde, Sweden
emmie.olofsson@his.se

***Abstract*—The Operator 4.0 typology depicts the collaborative operator as one of eight operator working scenarios of operators in Industry 4.0. It signifies collaborative robot applications and the interaction between humans and robots working collaboratively or cooperatively towards a common goal. For this collaboration to run seamlessly and effortlessly, human-robot communication is essential. We briefly discuss what trust, predictability, and intentions are, before investigating the communicative features of both self-driving cars and collaborative robots. We found that although communicative external HMIs could arguably provide some benefits in both domains, an abundance of clues to what an autonomous car or a robot is about to do are easily accessible through the environment or could be created simply by understanding and designing legible motions.**

Keywords—Operator 4.0, Collaborative Robot Applications, Autonomous Driving, Legible Motion, Human-Machine Trust.

I. Introduction

The Cognitive Operator 4.0 [1] described three topics of particular interest for future R&D, aligned with the Industry 5.0 hallmarks [2] that emphasize human centricity, mental workload, cognitive embodiment, and communication (or human-technology communication rather). The latter of these – *communication* – outlines how information exchange and interaction between humans and technology is becoming increasingly important to enable efficient work practices for the Operator 4.0 [3]. Human-Technology Interaction (HTI) and communication are topics that are present in many, if not all, of the scenarios in the Operator 4.0 typology [3], and for good reason. Fluid interaction between humans & technology is essential for effective technology utilization and use which is also identified in Industry 5.0 [2] through its emphasis on "human-centricity". This paper looks deeper into two types of human-technology communication (interaction) where one of them, *collaborative robot applications,* is more industrial by nature while the other, *autonomous cars,* is less industrial but provides valuable insight into *human-robot interaction,* and perhaps sheds light on some "common truths" worthy of questioning.

This paper investigates the basis for using communicative HMIs (Human-Machine Interfaces), sometimes even "anthropomorphic", features such as light ramps and a smiling face or eyes in an autonomous vehicle to indicate to pedestrians what the car is about to do and how using lights and/or virtual eyes has also become popular in collaborative robot applications.

Levels of *Human-Robot Collaboration (HRC)* can be seen as ranging from (i) *co-existence,* where the actors work close to each other but do not share a physical workspace; to (ii) *synchronization* – where the actors are sharing a physical space but it is not occupied simultaneously; to (iii) *cooperation,* where a physical workspace is shared among and simultaneously occupied while performing separate actions; to finally (iv) *collaboration* – where a physical workspace is shared and the actors work simultaneously on the same product or component [4, 5]. To reach the highest level of HRC, several interaction issues need to be addressed. From the *human side,* a robot must understand humans' preferred way of interacting and communicating, and humans should ideally be allowed to use different communication channels and languages that should be intuitive and natural for them. The ability of a robot to understand human interaction could also greatly affect the feelings of trust that a human has towards the robot and thus increase the levels of comfort and efficiency of collaborative work. Furthermore, robots that work in collaboration with humans today have safety systems that recognize contact, or even just proximity, with a human and automatically shut down the robot before dangerous situations occur. These security systems are essential from a safety perspective but can lead to lowered time efficiency as frequent shutdowns due to proximity or shutdown lead to reduced equipment utilization (i.e., machine utilization). The ability of a human worker to intuitively understand and recognize the movements and intentions of the robot will allow us to minimize these events and positively affect down time. It is plausible that efficient human-robot interaction requires designed elements that clearly communicate objectives and intentions, which might include additional components on the robot, as well as designing the motions of the robot itself to be understandable and predictable by the collaborating human.

II. Trust, predictability, and intentions

It is a common opinion that trust in machines, in this case feeling comfortable working alongside a collaborative robot, is achieved through "predictability" and "transparency" [6]. It is commonly hypothesized that if a human can predict what a (collaborative) robot is about to do and perhaps even has a rough understanding of why it is doing it, or to what end, this will result in "trust" in the system. While this is a reasonable simplification of the concept of trust, the truth is probably not so simple. Let us imagine that *predictability* is a good criterion for trust, being able to predict a dangerous or threatening action that a person or an object is about to do does not necessarily make you feel safe working alongside them or it. That being said, predictability or, as we will discuss later on, legibility, is important for trust, it is just not enough.

Brinck and Balkenius point to three steps towards achieving mutual recognition of actions: identification, confirmation, and turn-taking [7, 8]. The former, *identification,* is arguably also the most important one since it deals with the recognition of another individual based on available attributes such as movement, actions, direction of gaze, language, gestures, etc. These clues are used to predict the coming interaction and to infer the goals of the other party, and can also be based on contextual information [8]. The second step, *confirmation,* is about assuring the other party that *identification* has occurred. The third and final step, *turn-taking,* is the establishment of an immediate and dynamic coupling between a human and a robot, unfolding smoothly where the actions and behaviours of each party are dependent on the actions and behaviours of the other [7, 8].

III. Interaction with autonomous cars

The interaction between pedestrians and drivers has long been an interesting topic of research and it is increasingly finding itself in the spotlight as autonomous cars are starting to make their entrance onto our roads. There seems to be some kind of consensus that autonomous cars will fundamentally change the interaction dynamics of pedestrians and cars, largely because *eye contact* has been established as a very important interface for communication between pedestrians and drivers [9]. The issue of whether pedestrians are comfortable enough to "trust" autonomous cars while crossing in traffic without getting traditional acknowledgement from drivers has been raised by several authors [10, 11].

According to Rothenbücher et al. [9], pedestrians presumably wish for a similar acknowledgement from autonomous cars as they do from drivers. This statement, however, is based on mere assumptions and expectations of what people want and do not refer to further research involving for example questionnaires or qualitative interviews with pedestrians. Rasouli et al. [12] mention in their introduction that pedestrians who cross outside of designated stop signs or traffic signals will often interact with drivers by making eye contact to guarantee safe passage (again, without referring to other sources), and according to Šucha [13], as many as 84% of pedestrians seek eye contact with drivers before passing. However, out of 1584 observations, Šucha also found that 61% of drivers do not make any attempt to communicate with the pedestrian which begs the question, who are the pedestrians making eye contact with, or are they simply not very successful in their attempts at eye contact? Furthermore, the word *eye contact* in this particular context is quite deceptive seeing that Rasouli et al. [12] actually found that pedestrians (90% versus 10% out of the time) *looked* or *glanced* at drivers and made eye contact only in some cases. When pedestrians look or glance, it is more like an inspection of their environment to assess their safety for crossing and there could be, and probably are, a vast number of clues that could be perceived to aid in assessing a traffic situation. The wording is problematic since other researchers refer to [14] the aforementioned study, and conclude that pedestrians' eye contact is the most commonly used cue whilst interacting with drivers.

Pedestrians' reaction and feelings toward autonomous cars have yet to be studied to a great extent. The interaction between driver and pedestrian can be understood and investigated from the perspective of the *Implicit Interactions Theory* [15], which can be applied to autonomous vehicles. The framework is explained as daily human interactions being partially based on previous patterns and understandings of how the world (interactions) works. Rothenbücher et al. [9], used the Implicit Interactions Theory and created a step-by-step pattern to explain and predict ordinary interactions between drivers and pedestrians. Ju and Leifer [16] make the example of immediately being able to understand certain *rules* entering a new restaurant, knowing how to order, pay, etc., even though it is your first visit. The *implicit interaction theory* proposes that researchers create new technologies and derive knowledge in accordance with previously known interactions between humans to make technology as smart and similar to human interactions as possible. For example, it has been suggested that autonomous cars with human features such as eyes or a smile [17], can be greatly beneficial for pedestrians' perception of safe passage because it resembles human behavior. It was previously found that autonomous cars with eyes made pedestrians feel safer crossing and they further became quicker interpreting the car's intentions [11].

Rothenbücher et al. [9] undertake the assumption that pedestrians desire some type of sign from the driver, indicating they have been noticed. It is unclear where this assumption has its roots but perhaps the authors base their statement on the U.S. Department of Transportation's [18] report which, in part, contains "safety reminders" and encourages pedestrians to make eye contact while being approached by a driver and never to assume that you as a pedestrian have been seen. It is also well established that in a face to face communication, eye contact and gaze trajectories play a significant role in facilitating effective communication [19]. However, the interaction between drivers and pedestrians could not easily be argued to be a face to face interaction. In a controlled experiment [14], pedestrians initially sought eye contact with the autonomous vehicle and then continued to seek it even as they passed. Multiple studies indicate that pedestrians who make eye contact in traffic create more time for drivers to react and significantly increase the chances that they also stop or slow down [20, 21]. However, with autonomous vehicles, eye contact between car and pedestrian does not contain the two way (dyadic) communication normally associated with eye contact between people, being only a one way "status signal" from the car to the pedestrian. As such, eye-contact-communication from autonomous car to pedestrian may not provide the expected benefits. A field observation in China found that almost 70% of pedestrians crossing unmarked crosswalks do not seek out drivers' attention and do not even check for vehicles [22]. Pedestrians at crosswalks however, look left and right before passing and did not seem to attempt communicating via eye contact or hand signals but simply looking for moving vehicles [22]. Human behavior in relation to traffic varies depending on country, region, and culture and must be taken into consideration when using and implementing autonomous vehicles [23]. It is further important to differentiate whether pedestrians cross the road at a crosswalk or outside designated crossing zones [24] since this affects both drivers' and pedestrians' behavior.

Some of the studies that have been presented here indicate that pedestrians would not necessarily wish for additional communication with autonomous cars. The same conclusion can also be observed in Rothenbücher et al. [9], who contradict their earlier assumptions since they could see that pedestrians' interaction with the (seemingly) autonomous car went smoothly. The subjects appeared to have little to no problems interacting without the assumed *established communication signals.* Towards the end, the authors argue that it might be because pedestrians also are used to interfering with traffic during nighttime. When dark, or in heavy rain, it might be impossible to communicate with traditional signals such as eye contact. Blind or visually impaired pedestrians are also able to interact with traffic by finding a crosswalk and then listening for the signals demonstrating it is safe to cross. According to Persson [25], and Zhuang and Wu [22], drivers are more likely to stop and let pedestrians pass if they for example show their intentions by physically taking one step out in the street. This supports the view that interactions between a pedestrian and a driver do not necessarily need to be a two-way communication or even any form of explicit communication at all. Most interactions in traffic follow a certain flow and a set of non-verbal rules. Pedestrians, bicyclists, and drivers all rely on these social patterns which also makes them able to predict one another's intentions in traffic [12], supporting the idea that eye contact, *per se*, from pedestrian to driver and driver to pedestrian is not as vital in traffic as commonly assumed.

Dey and Terken [26] set out to investigate this specific idea that explicit communication such as eye-contact and body language are an inherent and important aspect of driver-pedestrian communication. What they found, however, was that [26 p.109] *"eye contact does not play a major role in manual driving, that explicit communication is rare to non-existent, and that motion patterns and behaviors of vehicles play a more significant role for pedestrians in efficient traffic negotiations."*

From the literature and as it has been presented here, the assumption that eye contact is of utmost importance in driver-pedestrian interaction is at best heavily overrated and empirical evidence supporting this is largely missing. Still, this seems to be one of the major reasons for putting anthropomorphic, human features such as a smiling face or eyes on autonomous vehicles to facilitate communication [27]. Several other concepts that simply utilize light ramps to indicate speeding up or down have also been proposed but they seem to lack the same empirical support [28, 29]. *Cues* such as posture and head movement seem to be more than enough to indicate pedestrians' intentions [30], suggesting that body language is at least as important as eye contact in conveying intent in traffic. One could assume also that recognizing a vehicle accelerating or decelerating is key information when pedestrians assess their situation. In fact, Risto et al. [29] observed how driver intentions were recognized simply through vehicle movements, corresponding with the findings of Dey and Terken [26]. Their results show how similar vehicle movement patterns can be observed in a variety of situations. Drivers tended to stop far before they were legally obliged to in order to clearly signal their intention to allow right of way. Rolling their cars forward slowly to indicate their intention of taking right of way. Additionally, interviews suggested that movement is interpreted as an attempt to communicate a message and in development of automatic vehicles, these behaviors must be understood.

Another case, not describing automatic road vehicles but rather Automated Guided Vehicles or AGVs [31] investigated the use of light projections on the floor to indicate an AGV's upcoming trajectory. The idea was to allow humans to interact with or near the AGV without disturbing its path. However, the study found that rather than being more comfortable being around or moving close to the AGV, as a result of being able to see its forward path, the light projection was rather seen as an extension of the AGV's physical space, resulting in people not wanting to cross the projected path even when perfectly safe to do so.

IV. Collaborative robot applications

When it comes to interaction between a human and a robot and how task-dependent information should be communicated from robot to human, it is always necessary to look at some of the basics of communication and collaboration. Core concepts include, for instance, *dyadic* and *triadic interactions*. *Dyadic interactions* involve turn-taking based on emotional displays and can be thought of as attentional sharing rather than intentional sharing [32], while *Triadic interactions* involve shared attention on a common aspect of the interaction, and as such is heavily context-dependent, thereby relying on a shared understanding of that context [32]. A dyadic interaction can be as simple as a parent waving to a child and the child smiling, with the central aspect being attention on each other. Triadic interaction, however, involves both actors (in this example the child and the parent) to look at another person or object, and interact with that object from a shared perspective. This can be as simple as noticing that another person is looking at something interesting and looking at the same thing, or a shared activity such as collaborating on moving furniture through a doorway. This can be coupled with how humans perceive each other's intentions, often focusing on gauging the other person's motion rather than maintaining eye contact [33]. Human motion has been found to be identifiable even when only a grid of points is shown, not a whole human, and that this motion not only follows reasonably simple rules but that people also use the motion to gauge intentions [33, 34]. An important note is that some studies on this kind of motion identification or intention identification focus on general motion, while others focus on a context-specific motion such as e.g., identification of cyclists' intentions in traffic.

People generally prefer collaborative robots that use biologically inspired motion [35, 36], this being down to humans finding it more difficult to predict robot intentions when the robot does not implement biologically inspired motion [37] which likely stems from humans' familiarity with these motions. This suggests the use of the robot arm itself, in the case of industrial robots, to communicate intentions during HRC, as allowing the person to keep their attention on the motion itself instead of needing to split attention between the robot arm and separate communication devices can be expected to reduce cognitive load and increase *perceived safety.* The same is likely to apply to autonomous vehicles and other autonomous systems that require complex interactions with people, where people are familiar with the normal motions associated with specific contexts.

TABLE 1. INDEPENDENT VARIABLES OF LEMASURIER ET AL. [41]

Light signals			Movement signals			
Gaze	***Arm light***	***Gripper light***	***Head pan***	***Forearm movement***	***Gripper movement***	***Control***
Movement of the animated eyes.	Light source fitted on the forearm.	LED bracelet fitted just by the gripper.	Movement of the entire display screen.	Slight movement of the forearm.	Opening and closing of the gripper	No movement or signal.

This has been tested by e.g. Arntz et al. [38], who tested various interfaces, including a text-based interface and mounting simple OK / not OK lights on the robot arm, and found that these basic systems led to mostly increased positivity towards the robot's motion, but did not necessarily increase trust or efficiency. These systems were, however, limited, and showed only binary status as "the robot is performing the activity as expected" or "deviating from the activity", or text information, as opposed to being designed to complement the readability of the motion itself.

Another notable example is the HRC pioneering Baxter robot (see FIGURE *1*), launched in 2012 by Rethink Robotics. Baxter was designed with two arms to be more human-like, and a monitor where a human's head would be, which can display animated eyes and facial features. Interestingly, Baxter was designed for safety, but some design aspects, namely the design of the robot's joints, led to a reduction in the *perception* of safety as well as lowering the quality of work [39].

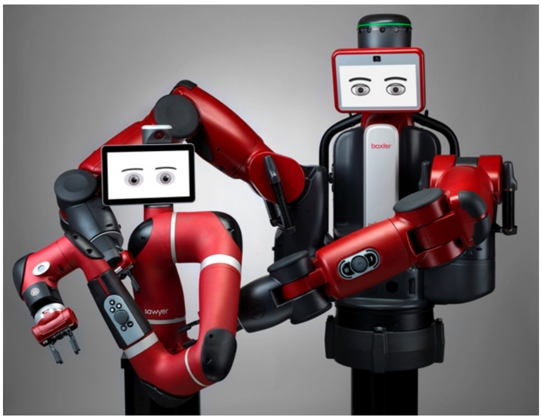

FIGURE 1. BAXTER ROBOT (RIGHT) AND ITS ONE-ARMED LITTLE BROTHER, SAWYER (LEFT). PHOTO BY JEFF GREEN/RETHINK ROBOTICS

One of the more innovative and original features of Baxter was its animated eyes and facial features. These were meant to be used as a way of interacting with users [40] and were arguably one of the main reasons why Baxter became fairly popular in academia while not very successful in industrial applications. Baxter was able to show a confused look when waiting for a task or gazing at a moving target. It was even designed to show sadness or to close its eyes to imitate rest between tasks [40]. Unfortunately, research on the interaction between Baxter's facial expressions and human actors is quite scarce although some sources do exist on the matter. Lemasurier et al. [41] investigated and compared the use of light emitters and motion clues of a Baxter robot and found that it is primarily light signals in close proximity to the end effector that is most efficiently caught by a human actor. Their variables included two instances where the robot's screen was used, one instance where the eye gaze was the clue and one instance where the actual pan of the "head" or screen was the factor. Additionally, they compared light sources mounted on either the robot arm or very close to the end effector (gripper) and movement signals of said limbs, robot arm and gripper, as priming clues to upcoming behavior. See table 1 for their independent variables.

Results indicated that proximity to the end effector was the main predictor of noticeability of light signals whereas the head pan was most noticeable for movement signals. The light source on the gripper proved most noticeable, followed by movement indication of the head pan and the arm respectively and a light signal of the arm and gaze coming up on a joint fourth place in noticeability. While the authors recognize a potential confounding in the gripper movement signal, it would seem that light signals are better noticed in proximity to the end effector whereas movement signals are better noticed in relation to the head and the central mass of the body. It should also be pointed out that all instances of the independent variables were significantly better than the control in noticeability, indicating that using either movement or light signals are both reasonable approaches. While Lemasurier et al's [41] study does provide valuable information (more than what has been covered here) it should be kept in mind that it is a study simply looking at whether a robot limb is to be moved or not and has very little to say on the trajectory or goal of said movement. To be able to work with movement trajectories of robot limbs, either additional light sources to indicate direction, speed, etc., or a deeper look at the nature of movements, would be required.

V. LEGIBLE MOTION

While adding light fixtures as a communicative feature on either autonomous cars, AGVs, or collaborative robots could provide some clues that an action is to take place, they seem to be limited in their communicative capabilities when interacting with humans. They might even complicate and change the interaction as seen in the AGV example [31], or they might simply be insufficient in providing the human with information about the upcoming motion [41]. Understanding and predicting, not only that the robot is about to move, but also what the goal of the action is, requires better and possibly more 'natural' communicative features of the robot.

Anca Dragan and colleagues have studied the *legibility* of robot motion [6, 37, 42, 43] which essentially addresses the human assessment of a robot's motion through the motions themselves. *Legibility* – is often described as a result of predictable, unsurprising, or even expected motion [6] and findings have shown that the planning of robot motion is essential for the legibility of robot actions. In this research, it is clear that *legibility,* refers to being able to infer a goal from the movement of a robot, and *predictability,* being able to predict a path from a known goal; both are fundamentally different goals [6, 43]. A *predictable path* taken when the goal is known is less complex and more direct, thereby being predictable, whereas a *legible path* taken when the goal is unknown, requires a more elaborate trajectory, perhaps even different acceleration paths similar to ones found in biological motion [19], but in return, allows the human to infer the goal from the path (see Figure 2).

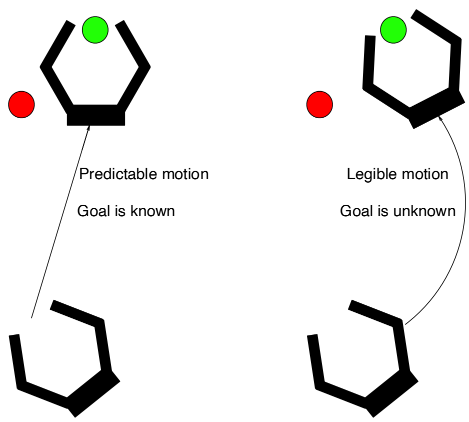

FIGURE 2. PREDICTABLE AND LEGIBLE MOTION (MODIFIED FROM DRAGAN ET AL. [6]).

So, depending on the context of work, different strategies might be taken. Arguably, in *fully collaborative work* [4], while the higher-level goal or objective might be known, sub-goals of individual movements are most likely not known and as such, legible motion would probably present the best support for collaboration to unfold seamlessly and effortlessly.

In the study of driving by Risto et al. [29], discussed earlier, one could easily see parallels between *legible motion* and a driver slowing down early to signal that a pedestrian or another car has been noticed and that they are free to cross the road. In this example, it is not the trajectory of the movement so much as the deceleration pattern that carries information and communicative value. Similarly, in human-human interaction, acceleration patterns of movements are of great significance for the recognition of biological motion [19].

VI. CONCLUDING REMARKS

This brief article aimed to investigate and compare *human-technology interaction* in the two related but still separate areas of automated vehicles and collaborative robot applications. We set out to investigate the widely spread idea that eye contact is an essential mode of communication between drivers and pedestrians and argue that this idea is the reason why it seems very popular to equip self-driving cars with external HMIs such as light fixtures to emulate eye contact communication. We have not been able to find strong evidence for either the importance of eye contact or the success of light fixtures as a communicative replacement. On the contrary, we have found empirical studies that suggest explicit communication to be close to non-existent in driver-pedestrian interaction [26]. Studies are still not in abundance and while it could be plausible that using light or possibly some kind of anthropomorphic replacement will help with communication, we argue that there is an abundance of other clues that are equally or perhaps even more intrusive and important facilitators of communication in traffic. Similarly, the use of light fixtures (and eye gaze) in collaborative robotics is perhaps not as studied as we would have thought but it is clear that also in this domain, communicative clues to a robot movement or trajectory could be introduced simply by utilizing the movement of the robot, both for signaling an upcoming movement [41] and communicating the nature of this movement through legibility [42, 43]. The argument could also be made, while still very speculative, that introducing external HMI features such as light cues to either collaborative robots or self-driving cars, could compete with other, more natural behavior clues for cognitive resources. Thereby making it harder to recognize the action intentions of an autonomous system.

On a final note, while understanding how human-human interaction and communication unfolds might provide great insights into *how human-autonomous system interaction could be designed,* the question of whether this is desirable is still to be answered, or perhaps even still to be asked. Is it a good idea to try and replicate human communicative behavior in an autonomous system, would humans be comfortable with that, would communication be facilitated as it is in human-human interaction, or are we limiting ourselves to conventional interaction modes while missing new interaction opportunities offered by the system?

In summary, one of the more pertinent scenarios of the Operator 4.0 typology [3] regards "collaborative robot" applications, and for these applications to be implemented effectively, for collaboration to run smoothly and effortlessly, the communication between human and robot is essential [1]. We have discussed how this collaboration can be further enhanced by understanding how human-machine interaction actually unfolds and how the behavior of the robot itself might prove a valuable clue to predicting its movements.

VII. REFERENCES

[1] P. Thorvald, Å. Fast-Berglund, and D. Romero, "The Cognitive Operator 4.0," presented at the International Conference on Manufacturing Research, Derby, UK, 2021.

[2] European Commission (2021). *Industry 5.0 - Towards a sustainable, human-centric and resilient European industry.*

[3] D. Romero *et al.*, "Towards an operator 4.0 typology: a human-centric perspective on the fourth industrial revolution technologies," in *Proceedings of the International Conference on Computers and Industrial Engineering (CIE46), Tianjin, China*, 2016, pp. 29-31.

[4] A. Kolbeinsson, E. Lagerstedt, and J. Lindblom, "Classification of Collaboration Levels for Human-Robot Cooperation in Manufacturing," in *Advances in Manufacturing Technology XXXII: Proceedings of the 16th International Conference on Manufacturing Research, incorporating the 33rd National Conference on Manufacturing Research, September 11–13, 2018, University of Skövde, Sweden*, 2018, vol. 8: IOS Press, p. 151.

[5] W. Bauer, M. Bender, M. Braun, P. Rally, and O. Scholtz, "Lightweight robots in manual assembly–best to start simply," *Frauenhofer-Institut für Arbeitswirtschaft und Organisation IAO, Stuttgart,* 2016.

[6] A. D. Dragan, K. C. Lee, and S. S. Srinivasa, "Legibility and predictability of robot motion," in *2013 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 2013: IEEE, pp. 301-308.
[7] I. Brinck and C. Balkenius, "Recognition in Human-Robot Interaction: The Gateway to Engagement," in *2019 Joint IEEE 9th International Conference on Development and Learning and Epigenetic Robotics (ICDL-EpiRob)*, 2019: IEEE, pp. 31-36.
[8] J. Lindblom and B. Alenljung, "The ANEMONE: theoretical foundations for UX evaluation of action and intention recognition in human-robot interaction," *Sensors,* vol. 20, no. 15, p. 4284, 2020.
[9] D. Rothenbücher, J. Li, D. Sirkin, B. Mok, and W. Ju, "Ghost driver: A field study investigating the interaction between pedestrians and driverless vehicles," in *2016 25th IEEE international symposium on robot and human interactive communication (RO-MAN)*, 2016: IEEE, pp. 795-802.
[10] H. Lipson and M. Kurman, *Driverless: Intelligent cars and the road ahead*. MIT Press, 2016.
[11] C.-M. Chang, K. Toda, D. Sakamoto, and T. Igarashi, "Eyes on a Car: an Interface Design for Communication between an Autonomous Car and a Pedestrian," in *Proceedings of the 9th international conference on automotive user interfaces and interactive vehicular applications*, 2017, pp. 65-73.
[12] A. Rasouli, I. Kotseruba, and J. K. Tsotsos, "Agreeing to cross: How drivers and pedestrians communicate," in *2017 IEEE Intelligent Vehicles Symposium (IV)*, 2017: IEEE, pp. 264-269.
[13] M. Sucha, "Pedestrians and drivers: their encounters at zebra crossings," in *8th International Tra c Expert Congress*, 2014, vol. 8.
[14] H. Verma, G. Pythoud, G. Eden, D. Lalanne, and F. Evéquoz, "Pedestrians and visual signs of intent: towards expressive autonomous passenger shuttles," *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies,* vol. 3, no. 3, pp. 1-31, 2019.
[15] W. Ju, "The design of implicit interactions," *Synthesis Lectures on Human-Centered Informatics,* vol. 8, no. 2, pp. 1-93, 2015.
[16] W. Ju and L. Leifer, "The design of implicit interactions: Making interactive systems less obnoxious," *Design Issues,* vol. 24, no. 3, pp. 72-84, 2008.
[17] C.-M. Chang, "A Gender Study of Communication Interfaces between an Autonomous Car and a Pedestrian," in *12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 2020, pp. 42-45.
[18] (2014). *Traffic safety facts*.
[19] E. Billing, A. Sciutti, and G. Sandini, "Proactive eye-gaze in human-robot interaction," in *Anticipation and Anticipatory Systems: Humans Meet Artificial Intelligence, Örebro, Sweden, June 10-13, 2019*, 2019.
[20] N. Guéguen, S. Meineri, and C. Eyssartier, "A pedestrian's stare and drivers' stopping behavior: A field experiment at the pedestrian crossing," *Safety Science,* vol. 75, pp. 87-89, 2015.
[21] Z. Ren, X. Jiang, and W. Wang, "Analysis of the influence of pedestrians' eye contact on drivers' comfort boundary during the crossing conflict," *Procedia Engineering,* vol. 137, pp. 399-406, 2016.
[22] X. Zhuang and C. Wu, "Pedestrians' crossing behaviors and safety at unmarked roadway in China," *Accident analysis & prevention,* vol. 43, no. 6, pp. 1927-1936, 2011.
[23] F. Weber, R. Chadowitz, K. Schmidt, J. Messerschmidt, and T. Fuest, "Crossing the Street Across the Globe: A Study on the Effects of eHMI on Pedestrians in the US, Germany and China," in *International Conference on Human-Computer Interaction*, 2019: Springer, pp. 515-530.
[24] M. Šucha, "Road users' strategies and communication: driver-pedestrian interaction," presented at the Transport Research Arena 2014, Paris, 2014.
[25] H. Persson, "Kommunikation mellan fotgängare och bilförare: 1 litteraturstudie," 1988.
[26] D. Dey and J. Terken, "Pedestrian interaction with vehicles: Roles of explicit and implicit communication," in *Proceedings of the 9th international conference on automotive user interfaces and interactive vehicular applications*, 2017, pp. 109-113.
[27] C.-M. Chang, K. Toda, T. Igarashi, M. Miyata, and Y. Kobayashi, "A video-based study comparing communication modalities between an autonomous car and a pedestrian," in *Adjunct Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 2018, pp. 104-109.
[28] M. Nilsson, S. Thill, and T. Ziemke, "Action and intention recognition in human interaction with autonomous vehicles," in *" Experiencing Autonomous Vehicles: Crossing the Boundaries between a Drive and a Ride" workshop in conjunction with CHI2015*, 2015.
[29] M. Risto, C. Emmenegger, E. Vinkhuyzen, M. Cefkin, and J. Hollan, "Human-vehicle interfaces: The power of vehicle movement gestures in human road user coordination," in *Proceedings of the Ninth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, 2017, pp. 186-192.
[30] S. Schmidt and B. Faerber, "Pedestrians at the kerb–Recognising the action intentions of humans," *Transportation research part F: traffic psychology and behaviour,* vol. 12, no. 4, pp. 300-310, 2009.
[31] R. T. Chadalavada, H. Andreasson, R. Krug, and A. J. Lilienthal, "That's on my mind! robot to human intention communication through on-board projection on shared floor space," in *2015 European Conference on Mobile Robots (ECMR)*, 2015: IEEE, pp. 1-6.
[32] J. Lindblom, *Embodied Social Cognition*. Berlin: Springer Verlag, 2015.
[33] P. Hemeren and Y. Rybarczyk, "The Visual Perception of Biological Motion in Adults," in *Modelling Human Motion*: Springer, 2020, pp. 53-71.
[34] P. Hemeren *et al.*, "Similarity judgments of hand-based actions: From human perception to a computational model," in *42nd European Conference on Visual Perception (ECVP) Leuven, Belgium, August 25-29, 2019*, 2019, vol. 48: Sage Publications, pp. 79-79.
[35] J. Kilner, A. F. d. C. Hamilton, and S.-J. Blakemore, "Interference effect of observed human movement on action is due to velocity profile of biological motion," *Social Neuroscience,* vol. 2, no. 3-4, pp. 158-166, 2007.
[36] Y. P. Rybarczyk and D. Mestre, "Effect of temporal organization of the visuo-locomotor coupling on the predictive steering," *Frontiers in Psychology,* vol. 3, p. 239, 2012.
[37] A. Dragan and S. Srinivasa, "Familiarization to robot motion," in *Proceedings of the 2014 ACM/IEEE international conference on Human-robot interaction*, 2014, pp. 366-373.
[38] A. Arntz, S. C. Eimler, and H. U. Hoppe, ""the robot-arm talks back to me"-human perception of augmented human-robot collaboration in virtual reality," in *2020 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*, 2020: IEEE, pp. 307-312.
[39] S. Crowe. "Inside the Rethink Robotics shutdown." The Robot Report. (accessed March 28, 2022).
[40] C. Fitzgerald, "Developing Baxter," in *2013 IEEE Conference on Technologies for Practical Robot Applications (TePRA)*, 2013: IEEE, pp. 1-6.
[41] G. Lemasurier *et al.*, "Methods for expressing robot intent for human–robot collaboration in shared workspaces," *ACM Transactions on Human-Robot Interaction (THRI),* vol. 10, no. 4, pp. 1-27, 2021.
[42] A. D. Dragan, S. Bauman, J. Forlizzi, and S. S. Srinivasa, "Effects of robot motion on human-robot collaboration," in *2015 10th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 2015: IEEE, pp. 51-58.
[43] A. Dragan and S. Srinivasa, "Generating legible motion," in *Proceedings of Robotics: Science and Systems (RSS '13)*, 2013.