Intention Sensing and the role of danger in physical human-robot interaction

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Abstract - This paper presents an overview about the role of intention sensing in physical human-robot interaction. Robots become more and more active agents in human environments. Applications range from caretaking and rehabilitation to autonomous vehicles that collaborate with a human user towards a common goal. By sensing human activities and deriving the intentions of the human, a better prediction of human behaviour can be made. Based on that, safety mechanisms have a higher chance of actively avoid collisions with humans and therefore support a friendly collaboration. Furthermore, a robot that can express its intentions itself is understandable to humans in the same physical space. All in all, intention sensing and expression can enhance human-robot interaction and reduce danger.

Keywords Physical human-robot interaction, autonomous robot, intention sensing, intention expression, user safety, service robot.

1 Introduction

In the past years, physical human-robot interaction (pHRI) has attracted great attention in the field of robotics. Using robots to “overcome human physical limits” [4] is not only helpful in industry settings, but also in service situations like care-taking or entertainment. Robots can take over actions to compensate for physical or mental limitations in interaction with humans while working towards a common goal.

However, direct contact with humans causes a high risk for injuries and accidents. Therefore, mechanisms need to be in place to prevent any damage. The notion of “critical systems” can also be applied to physical human-robot interaction [1] in order to measure and assess the risk associated with a certain system. An important characteristic of pHRI is the environment in which it takes place. Unlike traditional robot environments, robots are placed in a human environment in pHRI [4]. Equipped with autonomous behaviour and complex problem solving ability, the robots are introduced in an environment without a predefined structure. Events happening in these unstructured domains and the appropriate response cannot be predicted during the design of the robot - a spontaneous reaction based on cues from the environment is crucial.

In unstructured anthropic domains, thus environments, where humans and autonomous robots act together, the risk of physical collisions is relatively high compared to robot-only environments. Even though it is not the only cause for injuries, it is reported to be the greatest source of harm. The impact force of a collision poses the “major cause of injuries during unplanned interaction” [24]. This brings out several problems to the robot:

1. The robot must detect that the upcoming situation is dangerous (pre-collision safety) [24].

2. An appropriate response needs to be selected. This could either mean that the robot alters its route in order to avoid an obstacle or stops its action.

3. If a collision cannot be avoided, appropriate provisions need to be in place in order to reduce the injury severity...

When working with humans, collision avoidance has a high priority in ensuring safety. In order to predict a human’s behaviour and subsequently alter the robot’s action, it is important to understand human intentions. Collision cannot only occur if the trajectory of a human and a robot collide, but also in collectively executed tasks. A concept that is closely tied with intentions and collision avoidance is danger [24]. Being able to recognise a fearful face and therefore detect potential danger [10] can help robots to judge the level of safety in a specific situation.
This paper discusses the role of intention sensing for improving safety in a physical human-robot interaction situation. The focus lies on robots that move autonomously. The importance of efficient obstacle avoidance will be studied as well as the technological possibilities for sensing human intentions in a robot. Finally, giving a response that is understandable and clear to the human collaborator is also part of safe HRI and will be examined in a last section. The research paper aims to answer the following research questions:

1. “Which role does intention sensing play in pHCI safety for autonomous robots?”
2. “To what extent does identifying danger help to ensure safety in pHCI?”

2 Theory

The following section discusses the theoretical background underlying the need for sensing and predicting human intentions in physical HRI.

In traditional settings of robotics, machines were kept out of human’s reach [24]. Big machines that operate autonomously have been used in industrial applications but were not intended for the interaction with a human. The basic safety provision was to ensure that humans do not cooperate with the machines. If they did, the machines were kept small in size and light in weight so that the severity of possible injuries was held relatively small. Furthermore, for the same reason, the machines were less powerful than technically possible [24]. Some applications that gained importance during the past years require close interaction with humans while sharing the same physical domain. Examples include rehabilitation robots or robotic care takers. From these settings a major challenge arose for developers: ensuring a high level of safety while keeping great performance [24].

In general, safety provisions can be divided into two types:

1. passive “safety through design” [24]
2. active “safety through planning and control” [24]

While passive safety includes techniques such as shielding the robot’s mechanical parts with tissues to absorb collision force during a collision[3], active safety tries to prevent collisions [18]. In passive safety, a lot of attention has been paid to compliant systems that yield under pressure - in case of a collision, the robot reduces stiffness and therefore diminishes injury severity [11]. However, [3] describes the need for active safety in physical human-robot interaction. In a collaborative setting, robots must actively react on their human partner and other obstacles that are in the surroundings. Therefore, implementing only passive safety is not enough to ensure a friendly collaboration.

Predicting human actions and movements can help the robot to avoid collisions in a dynamic environment. However, stopping the current movement or taking a devious trajectory once a potentially dangerous situation is predicted is a highly time inefficient reaction [18], [4]. Real-time motion planning that takes into account the robot’s motion with respect to the human’s position can solve the efficiency problem while guaranteeing safety for the user. In order to find the right parameter values for altering the trajectory, “cognitive information could be used for dynamically setting the parameters” [4], meaning that the knowledge about a human’s intention can help to maximise the efficiency of the collision avoidance.

3 Research Methodology

The following research is based on a literature research approach described by Timmins and McCabe [29]. In a first step, the topic and keywords connected to the topic are identified. Based on these keywords, 20 to 30 related articles are found that can be scanned and evaluated on their validity and importance. Sources that are confirmed to be relevant to the topic in question are then organised according to subtopics.

For this research paper, the initial topic was safety in physical human-robot interaction and was during the literature review phase narrowed down to the role of intention sensing in safety for physical human-robot interaction. Based on the relevant articles it becomes clear that intention sensing is an emerging topic for pHRI and includes the study of intention models, sensing technologies, and sensing expression. Additionally, two interesting projects that show the application of intention sensing in pHRI have been found and will be presented.

4 Intention Sensing

Intentions are conceptions that describe “future states of affairs that some agent wants to achieve” [16]. They form the base of mutual understanding between agents (e.g. human-human, human-robot). The detection of intentions is made difficult...
by the fact that humans tend to shield their intentions or goals behind actions. According to Kröll and Strohmaier [16], people rather explicitly state the action of converting to a religion and express their goal of achieving salvation. Furthermore, Kim et al. [15] state that two different kinds of intention communication is observable in humans:

1. explicit intention statements through verbal communication
2. implicit intention expressions such as gestures, voice pitch, or facial expressions

This research will only be concerned with the latter kind of intentions, as explicitly stated intentions require speech recognition which could be a research topic for itself.

In order to be able to achieve a fruitful collaboration, agents need to understand the intention of their partners. Humans apply a technique of inference based on their observations - according to the Theory of Mind [25], we put ourself in our partner’s position and conclude about his intentions. This means that by observing the actions of another individual, we are able to derive intentions.

However, for intention sensing robots, two different approaches can be noted:

1. haptic communication approach
2. observation approach

The details of both approaches will be explained in the following.

4.1 Haptic communication approach

The first approach was introduced by Evrard et al. [7], describing the distinctive factor of physical human robot interaction as the exchange of mechanical energy. Exchanging through direct contact (human-robot) transfers the same information as indirect via an object of mutual interest (human-object-robot). In collaborative tasks, a proactive synergy of both agents is aimed in which the intensity of the applied mechanical force is based on each other’s intentions. By sensing the force applied by the partner, an intention can be derived. Evrard et al. base their intention derivations on negotiations [7]. In a collaborative task, an agent can take the role of either the leader, or a follower - or any mixture of both. Eventually, the role division determines the mixed execution plan for the collaborative action. By negotiating about roles, both collaborators reach an agreement about the mutual plan of execution, the plan that determines the task synergy.

Evrard et al. succeed in provoking a successful collaboration solely by sensing mechanical forces and based on the sensory information deducting the partner’s intentions [7].

4.2 Observation approach

A different approach is the sensing of non-haptic cues in order to understand the partner’s actions. Kelley et al. [14] propose a method that is solely based on visual cues, which are recorded by the robot with a camera. Besides a colour camera, other sensors can be implemented as well to help the robot “see”. In the observational approach, different variables are defined upfront that are important to identify the current action [14]. Using image processing and other techniques to interpret the sensor data, the robot can identify what is happening in the environment.

Other than the haptic communication approach, the robot can identify and interpret actions not only from a collaborative partner, but also from other agents in the shared physical domain. There is no physical connection (robot-human or robot-object-human) needed to observe the action.

4.3 Intention derivation models

Regardless of which approach to sensing actions is used, the actions subsequently have to be matched to a goal or intention. Only identifying the current action is not enough knowledge for predicting behaviour. Consider a person and a cleaning robot in a cinema hall. At the end of the film, the person gets up and starts walking. The action of walking itself does not help in predicting the walking route of the person, but the knowing about the intention of leaving the room does. In order to avoid a collision and thus protecting the human’s safety, the robot could drive to a different part of the hall that is not in between the person and the door.

The mapping between actions and goals is a crucial point in the development of an autonomous robot in pHRI. In the following, three techniques are presented.

4.3.1 Machine learning

A machine learning approach for a haptic communication approach is discussed by Ikemoto et al. [13]. Because real-time analysis requires a lot of computational power, an computational efficient learning algorithm is needed. Machine learning does not ask for a programmer that understands the human behaviour and codes an action-reaction behaviour. It rather includes a judging function that enforces good behaviour and reduces unwanted behaviour. Ikemoto et al. state that the judging is made in a
training phase where the human collaborator indicates after each task round if the interaction was successful [13]. The robot then maps the feedback to a behaviour pattern and adjusts its response. Even though the task in [13] was very basic (the human helping the robot to stand up from a sitting position), the technique could be extended to other physical collaboration tasks and implement multiple behaviour models for different tasks.

4.3.2 Four-step-model with fuzzy logic
A more narrow area of machine learning is soft computing which includes disciplines such as genetic algorithms and fuzzy logic. Soft computing resembles biological processes and therefore suggests itself for solving intention sensing problems. In [15], Kim et al. suggest a four-step model: sensing, transforming, perceiving, and recognising. As a result, sensory information is translated into intentions. For the last two steps, perceiving and recognising, fuzzy logic is used to introduce the uncertainty of implicitely stated human intentions. Fuzzy logic algorithms work with fuzzy sets: Whereas in traditional logic, an element either belong to a set or does not, elements have a degree of belonging to a set in fuzzy logic. Just as elements in fuzzy logic, actions can be connected to multiple intentions with different degrees of belonging. This makes the four-step-model applicable to “vague and uncertain situations” such as implicit intention statements [15].

4.3.3 Cause-effect model
Another soft computing approach using fuzzy logic implements an algorithm based on a hierarchical model of knowledge, emotion, and intention of an agent. On the knowledge level, “gestures of the human [are recognised] from the characteristic information” [31]. Emotions are based on the knowledge, and intentions arise from emotions. After putting all three layers in relation to each other and giving fuzzy values to each relationship, the values can be combined. The result is a cause-effect network from which the level of belonging to a certain intention can be read.

All three models can be used to interpret actions for identifying the underlying intentions. A fuzzy logic approach seems reasonable, since a human can have multiple intentions at the same time and some intentions can be more distinct than others. In contrast to binary values, fuzzy logic gives a numerical value that can express different levels, for example being “a little” sad or “very” happy. This characteristic seems appropriate when modelling intentions.

5 Intention Sensing Projects
Over the past decades, intelligent products sensing intentions have gained industrial interest. Especially in the development of intelligent cars and rehabilitation, intention sensing are a useful extension to increase safety and comfort. This chapter presents two projects that make use of intention sensing to extract knowledge from their human user.

5.1 Save driving assistance
Umemura [30] developed an active safety car system that aims to support beginners in difficult traffic situations. It was found that in 90% of 300 examined road accidents, cognitive errors and judgement errors were the reason for human failure [30]. By supporting the human driver in situations that require judgements about traffic situations and checking on the cognitive state of the driver (attention), road safety can be improved.

Umemura suggests a sensory system that corresponds to the cognitive functions of a human driver. Additionally, sensors that enhance the cognitive abilities of the driver could be implemented as well, such as a nighttime augmentation system. For enhancing the judgemental ability of the user, a judgement unit, hence an intelligent reasoning system, is added.

The most distinctive factor of the suggested system is the system’s invisibility if the driver is cognitively and judgementally able to drive safely. That is, it is “assumed that the driver’s cognition, judgement, and actions are sufficient to assure safety” [30]. The driver support system not only senses the environment, but also observes the driver himself through face monitoring and eye-gazing monitoring. If a high risk of a fatigue for example is detected, or the driver is not watching the road, the system can send a warning to the driver. In more urgent situations, the system can even activate functionalities of the car, such as enabling the brakes.

It is also interesting to note that studies presented in [30] have shown that drivers tend to rely on such systems, and might become unattentive. An intelligent assistive system needs to take this behaviour of humans into account.

However, Umemura does not provide an implementation model for his system. I would suggest to approach Umemura’s driving assistance project with a fuzzy logic approach that determines the level of fatigue, the level of attention, etc. A machine learning approach is not suitable, since it requires a training phase that cannot be realised in this case.
5.2 Rehabilitation robotics

Another application of intention sensing robots are rehabilitation and caretaking. Huo et al. [12] designed an exoskeleton for the upper limb. It is meant for people with strength problems in their arm which disables them from using their arm normally. Possible users are people who are recovering from a stroke, or elderly people that lost their muscle force. Contrary to the observational approach from Umemura, Huo et al. use mechanical force as means of communication; it is therefore a haptic communication approach.

The robot needs to react on different movements and perform it smoothly in collaboration with the user. The difficulty that presents itself in this project is the motion intenion of the user. According to the action that the user intents, for example drinking from a cup while sitting, or lifting an object from the ground in an upright position, the robot applies different forces. Huo et al. describe that “there are many possible motion mode when a person moves his/her upper limb” [12], meaning that all those different modes need to be distinguished and reacted upon differently.

The user’s motion intention is sensed with low-level force resistors that are positioned around the arm. Because of the noise resulting from muscle movements in the arm and other factors that disturb the sensor values, a filtering unit is implemented as well. Using the filtered values, a simple map from sensor values to intentions is used.

Huo et al. mention several times that the user should feel comfortable while using the system. the goal of enabling the patient to “move easily and [...] relax in every position” [12] becomes apparent. Therefore, great attention was paid to the control unit that chooses the appropriate force of the implemented motors. Especially in rehabilitation, the users can be scared of using a system they fear to be unpredictable and harmful.

In this case, implementing a sensing unit that determines the degree of fear could be helpful. The system would not only get input from the motion sensors, but could directly react on the user’s feelings. If the robot detects for example an increasing level of fear, it could decrease the force of the motors so that the overall impact of the robot on the user reduces. A behaviour like this could help to reduce fear, and increase safety and comfort.

6 Sensing Technologies

For sensing implicitly stated intentions, appropriate sensor data needs to be gathered. First, a distinction needs to be made between global and local sensory systems. Global sensor units are intelligent environments where the sensors are placed across the whole physical space. The advantage of global systems is on the one hand the possibility to “receive information from any desired direction” [27], and on the other hand to have multiple robots sharing the same sensors. However, DeSantis et al. [4] describe sensorised environments as difficult to set up. Local sensor units are robot-specific built-in sensors that move along with the autonomous robot. Other than a global system, the obtained information are unidirectional but not limited to a fixed physical space [4].

The selection of sensors for robots in pHRI should be based on four key characteristics [4]:

- complete
- robust
- active
- selective

Only a complete set of sensors enables the robot to correctly sense all key variables that are important for intention recognition. Furthermore, as the robot is operating in a dynamic environment, its sensors need to be robust with respect to changing environmental conditions. But not only the environment changes, also the present agents and collaborators change. The robot should be actively sensing the environment and should also be able to track certain objects. A moving human for example can only be interpreted if it can be extracted from the environment as an independent object - the sensors therefore need to include selectivity.

In the previous chapters, the sensing was described as a black box. In the following, common technologies that can be used to identify important variables serving as an input to the robot are presented.

6.1 Visual cues sensing

As described earlier, some systems make use of observational data to sense intentions from humans in the same physical space. A recent study by Chen et al. from 2015 [2] describes a local system combining different visual cues in order to judge about a person’s public speaking performance quality. Even though their study does not explicitly point at human intentions, it can still be seen as an intention sensing system: Intentions are goals, such as the goal of being a good presenter or giving a good speech. The bigger goal behind these intention could be to maintain or establish a certain reputation. According to Chen et al., using only basic visual sensors (Microsoft Kinect and Visages SDK FaceTrack), it is possible to rate the quality of a
The following visual features were measured:

- facial expressions
- gesture
- energy
- symmetry
- posture
- eye-gazing

Another research by Essa proposes a global sensor system using video processing to isolate human action: Knowledge about actions “could be used for determining what a user wants at a specific moment” [6]. Furthermore, tracking eye movements, recognising gestures and facial expressions helps to give a more complete image of the user’s actions. Kim et al. have also claimed that intentions can be read from visual cues “by various means such as facial expressions, [...] gestures, [...] eye-gazing, and so on” [15]. However, it needs to be noted that in Chen et al.’s project, the speaker was standing relatively still and directed at the sensors. The difficulties of deducting for example facial expressions from a moving body have been discussed by Pantic and Rothkrantz [23]. As soon as the face is partially hidden (e.g. behind glasses) or the face is turned, meaning that it is not plane towards the sensor, face recognition can become inaccurate.

6.2 Biomedical cues sensing

Besides observable variables, other, more subtle information channels can be used to sense a person’s intentions. However, Firoozabadi, Oskoei and Hu mention that compared to observable measures, biomedical signals measured with an electrocardiogram (ECG), electromyography (EMG), or electroencephalogram (EEG) “show quite complicated characteristics” [8]. Our body and brain are controlled by electrical signals that are in the range of hundreds of pico ampere - a small signal that can easily be disturbed by noise. Usually, biomedical signals are measured with non-intrusive methods, for example surface electrodes as used by Firoozabadi, Oskoi, and Hu [8]. Between the actual signal and the electrode are multiple layers that attenuate the signal, which makes the signals even more vulnerable to disturbances.

The following information can be extracted from a human body using the methods suggested by Firoozabadi, Oskoei and Hu:

- heart beat rate
- brain activity

Firoozabadi, Oskoei and Hu conducted an experiment that aimed to develop a brain controller for an electric wheelchair. By measuring muscle activity with an EMG, determining head movement, the patient is able to control the direction of the wheelchair [8]. The LifeHand project by Rossini et al. also shows the possibilities of sensing and manipulating biomedical cues [26] to move an object, in this case an upper limb prosthetic. In both projects, the user’s intention for a specific movement gets translated into a real, mechanic action. Even though the electrodes only sense electric potential, it is possible to derive a motion intention from it and transfer it to the robotic prosthetic, or the wheelchair.

6.3 Haptic cues sensing

As explained in the haptic communication approach, mechanical force can in some cases also transmit important information between robot and human. Force during interactions can be measured through force sensors (such as in [12]) or indirectly by sensing the current position of the robot joints (see [13]). The mechanical force that is applied by the human can describe for example in which direction a certain action is performed, how strong the movement is, or how far it goes. As described before in section 4.1, there have been successful projects using the input information from force sensors to derive human intentions and appropriately react on them [7].

Using those technologies, a robot can effectively sense and model the intentions of a human collaborator or bypasser in the same physical space. By identifying the intentions of other agents, a good and accurate prediction of their future behaviour can be given. Based on the forecast, a robot can adapt its movements and behaviour to avoid collisions and increase comfort.

We can conclude that intention sensing can be a strong tool to improve safety in pHRI settings.

7 Danger

Besides happiness, surprise, sadness, anger, and disgust, fear is one of the basic emotions of human beings. Scientists have agreed that at least five of them (excluding disgust) have universal facial expressions connected to them [5]. Before examining in how far the recognition of fear can help improving safety in pHRI, it is important...
to understand why we feel fear and how it has developed.

Fear is an emotional reaction on a potentially dangerous situation. According to Öhman et al. [21], fear was of great importance for the evolution of any kind of organism. As a response to constant danger, they developed new skills to overcome situations that triggered fear. Subsequently, their opponents were faced with the danger of extinction due to starvation and also developed and refined further skills to ensure survival. For primates, describes Öhman, fear fulfills in addition to the survival in a predator-and-prey situation also a social function. Early primates established a hierarchical role division in their horde. Fear was used as a sign for inferiority among horde members. Therefore, nowadays, humans do not only read fear from potentially dangerous objects, but also from other human’s faces [21].

Based on the six basic emotions with at least five of them having unique expression patterns [5], Ortony and Turner examined how the identification of these emotions through physiological cues is possible [22]. They propose to identify several independent subcomponents of a facial expression or physiologic response. Rather than giving a static view of an angry face, they suggest subcomponents like a specific mouth shape or the widening of eyes. Each subcomponent can exist in several emotions, and each emotion can have multiple subcomponents. However, an emotion has a unique composition of subcomponents which makes it easy to identify.

Furthermore, it has been proven that danger stimuli such as through fearful faces or dangerous objects can be processed faster than other stimuli. It is enough for a stimuli to be present, not even attended by the person, to trigger a fearful reaction [10].

Detecting fear can help robots in pHRI to improve safety in two ways.

First, by sensing the fear of a human in the same physical space can alert the robot about a potentially dangerous situation. If a certain danger was not foreseen by the robot but instead by the human collaborator, sensing his fear can give information about a source of danger (be it another human or object in the same space).

Secondly, the robot might scare the human collaborator and trigger an unforeseen reaction. By detecting the human’s fear, the robot is given the chance to adapt its behaviour. It has been reported by DeSantis et al. [4] that unnatural movements of machines can trigger fear in humans. Here, fear recognition and an adaptation of behaviour could improve safety.

8 Intention Expression

Implementing the concept of intention modeling in robots for pHRI can help interpreting the actions of a human collaborator. Collaboration is a bidirectional information flow, a task conducted by two or more agents. Therefore, not only the robot needs to understand its collaborators, but the humans also need to get information about the robot.

It has been observed in the past that people tend to anthropomorphise computers and robots, mostly humans that are not familiar with the inner functioning of such systems [4]. The innate curiosity of humans however lead to the tendency of people to try to understand their collaborators. Since no other system architecture is known, it is assumed that robots performing human actions also have a human inner functioning. By attributing “human-like qualities and capabilities” [4] to robots, humans also try to anticipate robot behaviour by putting themselves in the position of their collaborator [25].

Therefore, it is essential for a robot in human-robot interaction to express verbally and/or non-verbally information consistent with its inner state. Shindev et al. show that intention expression increases trust in the robot [28] which reduces fear and hence improves the quality of collaboration. While some non-verbal cues are performed intentionally, others occur unconsciously. The latter are called “nonverbal leakage” cues [19].

There exists a great variety of possibilities how a robot could express intentions and emotions. Fong, Nourbakhsh, and Dautenhahn suggest the use of artificial emotions exhibited by “expression, body and pointer gesturing, and vocalisation (both speech and sound)” [9]. On average, 90% of all gestures are being made during verbal communication [9], supporting and elaborating the information conveyed during speech. The importance of gestures and body movements in pHRI has also been stressed by Nakata et al. [20]. Furthermore, facial expressions can non-verbally convey intentions - in case the robot contains a face or face-like part [9].

Mutlu et al. [9] propose a robot that can produce facial expressions. In their research, the quality of information conveyed via non-verbal cues, more specifically non-verbal leakage, is examined. Participants had to play a guessing game with robots: The robot chose one item from a variety of items exhibited on a table between robot and participant. The participant had to ask questions about the item, narrowing down the possible items until they figured out which item
the robot had picked. During the experiment, the robot glanced at the item of choice, delivering a non-verbal cue to the participant. Mutlu et al. reported that based on simple eye-gazing movements, participants “attributed mental states and intentionality” [9] to their artificial counterparts, helping them to find the selected item faster than in conditions without the non-verbal cues.

9 Conclusion

In this research, it has been shown that safety and especially collision avoidance is of high priority in physical human-robot interaction. It can be concluded that intentions can play an important role in pHRI for avoiding collisions and improve safety in general. It can be achieved with two main concepts: by implementing intention sensing and interpreting in robots as well as by giving the robot the means to express its intentions to the collaborator.

For sensing human intentions, different technologies can be used to capture non-verbal cues. With machine learning techniques, intentions can be identified based on the captured stimuli. Several projects have already implemented intention sensing in intelligent agents in multiple domains such as car driving assistants or rehabilitation.

Additionally, letting the robot express its intentions can help collaborators to understand the robot’s behaviour. Important for a successful and comfortable interaction is behavioural consistency, meaning that the robot’s movement and behaviour needs to be in line with its intentions. It has been shown that consistent intention expression can improve the reliability, trustworthiness and transparency of a robot.

Furthermore, it has been suggested to use intention recognition for detecting fear in collaborators to react accordingly. In some cases, the robot would rationally classify a situation as safe, but a human reacts fearfully due to personal reasons for example. By detecting fear, the robot could react and alter its reaction to reduce potential danger.

All in all, it can be stated that intention sensing and expression are important concepts in pHRI. In physical spaces where humans cooperate or coexist with robots, it is essential to guarantee their safety and comfort. Having a better understanding of intentions from all agents in the physical space helps to predict future actions and behaviour which can in consequence be taken into account to avoid collisions and misunderstandings.

References


