Beyond anthropomorphising robot motion and towards robot-specific motion: consideration of the potential of artist—dancers in research on robotic motion

Naoko Abe

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Abstract
The design of robot motion is one of the most important questions in social robotics as it underpins successful human–robot interaction. Human-inspired motion design based on anthropomorphic models, through which human motion features are identified and implemented in a robot, is dominant in social robotics. The article considers perceptual, communicational and social dimensions of motion and suggests going beyond anthropomorphising robot motion and towards the quest of robot-specific motion. Robot-specific motion, as opposed to motion designed using an anthropomorphic model, can be characterised as motion that is designed and generated by robot features drawn through its mobility, materiality, and electro-mechanical ability. Through research on robot-specificity in motion it is possible to consider expressive and communicative features of motion independently of an anthropomorphic model. With this aim, the article stresses the importance of the artistic approach, especially in collaboration with dancers who are expert in motion, pointing out two specificities in art: non-efficiency centred approach and experiences. The article argues for renewing the traditional robotics approach by illustrating some artistic work and research which explore robot-specific motion.

Keyword Human–robot interaction · Social robot · Motion · Non-verbal communication · Anthropomorphism · Robot-specific motion

1 Introduction
The design of robot motion is one of the most important questions for human–robot interaction (HRI) studies. A robot should move predictably to ensure the legibility of its motion and the safety of its users, and expressively to enhance communication with those users. From industrial robots to companion robots, the question of how a robot should move is central to both scientific and practical purposes.

Generating human-like motion in a humanoid or other form of robot is a key aim of many roboticists. Such roboticists have a strong motivation to understand and synthesise some aspects of human function, reproducing them by the use of sensors, actuators, mechanisms and computers [1]. They analyse and design algorithms to generate and control robot motion which should be safe and legible for human users. As social robots are supposed to share space with humans, it is natural for a roboticist to aim at generating anthropomorphic motion or creating a humanoid robot [2] so that the robot is directly applicable to an unmodified human environment.

Motion plays an important role in making human–robot interaction successful because motion has meaning and transmits information as a mode of communication. One objective in social robotics is to make machines that can behave socially in human-inhabited environments. Such machines are expected to perceive and/or express emotions, communicate with high-level dialogue, recognise or learn models of other agents, establish and/or maintain social relationships, use natural cues such as eye gaze and gestures, exhibit distinctive personality and character; and learn or otherwise develop social competencies [3]. The expressiveness of robot motion, beyond its utilitarian characteristics of speed, accuracy and repeatability, becomes very important in conveying information on the robot’s purported ‘internal
states’ during communication or interaction with humans [4].

The principal aim of this article is to argue for going beyond anthropomorphising robot motion and moving towards robot-specific motion. Current social robotics studies deal with the design of robot motion which relies on anthropomorphic models. By “anthropomorphic models” I mean that the designed motion of a robot—regardless of the form of the robot—is based on human motion patterns: human motion features are extracted and implemented in a robot. Human-inspired motion design is dominant in social robotics. This dominance is supported by studies that demonstrate that human-like behaviour of a robot has a positive impact on human–robot relationships [5–7] as well as on the introduction of robots into society [8–10].

Considering the current dominance of anthropomorphic motion models in social robotics, the present article emphasises the importance of seeking novel models for designing idiosyncratic motion of robots to expand the possibility of meaningful interaction occurring between a human and a machine. Idiosyncratic motion of a robot refers to robot-specific motion which I define as motion that is designed and generated by the distinctive features of a robot: its mobility (capacity to move) which is conditioned by the robot’s kinematic degrees of freedom, materiality, and electro-mechanical ability; features that are not shared with human beings. Focusing on robot-specific motion, expressive or communicative features in motion can be considered independently of anthropomorphic models and generated by these specificities of the robot.

Can social robotics go beyond anthropomorphising robot motion? What could idiosyncratic robot motion be? How can roboticists find robot-specific motion cues? To discuss such questions, the article argues for the contributions of artists, particularly dancers or choreographers, to the field of social robotics as a source of inspiration in the design of robot-specific motion. I stress an artistic approach as a meaningful resource for understanding motion in a novel and different way from the classical approach that is dominant in social robotics. Collaboration with artists could allow social roboticists to explore a range of robot-specific motions that are designed to communicate with humans. To concentrate on the dominant approach of anthropomorphic models in social robotics, consideration of zoomorphic motion of animal-like robots is excluded from consideration in this article.

The remainder of the article is structured as follows. Section 2 discusses the perceptual, communicational and social dimensions of motion and the dominance of robot motion based on anthropomorphic models in social robotics. Section 3 introduces some research on non-anthropomorphic robot motion, human–robot dance performances and interdisciplinary research between robotics and dance. The potential contribution of an artistic approach or collaboration in the design of robot-specific motion is then discussed. To conclude, the article argues that the quest for robot-specific motion can allow us to reconfigure human–robot interaction through a process of designing novel modes of communication between human and machine.

2 Anthropomorphising robot motion

2.1 The power of motion

Motion attracts the attention of humans. The detection of moving entities in a human’s visual field is indeed crucial for survival. Psychological studies [10] show that a moving object captures more attention than unanimated objects do, even unanimated coloured objects [11]. The psychology of perception deepens the study of the motion of an object and its relation to the animacy perceived by humans. It investigates questions such as “How is a moving object perceived as animate or inanimate?” and “What features or motion cues can contribute to the judgement of animacy?” The classic study of Heider and Simmel [12] on the psychology of perception employs an animated film where geometrical figures (a large and a small triangle and a circle) move in various directions and at various speeds. On viewing the film, experiment participants spontaneously attributed personality, and even gender, to the geometric figures. The study concludes that the motion of these geometrical shapes gained the significance of acts such as motivation and intentions [12]. Blythe et al. [13] shows that seven trajectory cues in the motion of an agent—in their research, a bug-like object on the computer screen—are sufficient to distinguish between six intentions of two interacting agents such as pursing, evading, courting, being courted, fighting and playing. In a 10-min animated film The Dot and the Line: A Romance in Lower Mathematics [14] the personality and emotional state of simple geometric characters, a dot and a line, are meticulously drawn by their simple and expressive movements. Observers can easily attribute human-like attributes to the objects and assimilate the love story between the dot and the line. Thus, motion has a strong power to capture the attention of viewers and convey information. In turn, the human viewer can infer, imagine and speculate on possible attributions such as personality to moving objects, even those with abstract shapes.

2.2 Motion is a tool of communication and interaction

Motion contains meaning and transmits information to others. Non-verbal communication, that is, communication without using spoken words [15], investigates kinematic
aspects such as motion and gestures as a communicational mode.

Non-verbal action and behaviour is idiosyncratic, while also containing shared meaning between a set of people [16]. Non-verbal actions can therefore be informative to, and communicative with, others [17]. For instance, research demonstrates that identification of a person’s sex is possible by observing their way of walking [18] because of sex differences in walking gait [19–21]. Body actions can provide information regarding one’s emotional state and its intensity according to Dittmann [21], and Ekman and Friesen [22]. Body positioning offers information about the attitude, status, interpersonal roles, motives, and personality characteristics of the emitter. Motion and body positions also provide clues that assist in the interpretation of more subtle emotions emitted by facial expression, or vocally [17].

Certain motion patterns are also understood differently in different societies and cultures. Birdwhistell [23] investigates human motion within social context and states that movements can be coded and patterned differently in different cultures. Interpersonal positioning in space, known as “proxemics”, can vary across different types of cultures [24]. Gesture and behavioural manners are also investigated in traditional sociology in terms of the social process of embodiment of motion. Motion is certainly shaped by biological (e.g. physiological state) and psychological (e.g. perception, emotion) factors [25], but also by environment, social context and through tradition [26]. Bourdieu [27], like Mauss [26], raised the question of social influences on motion. According to his concept of “habitus”, an individual acquires a manner to behave in a society where they belong and learns how to interpret situations in ways that are convenient for them and that are common to the members of the social categories to which they belong.

Thus, the motion of a person contains rich and diverse information concerning the individual’s characteristics, psychological states, and cultural and social background.

2.3 Applying anthropomorphic models to robot motion

Studies of non-verbal communication play a major role in designing robot social motion when building communicative motion into a robot. According to the work of Saunderson and Nejat [28], which examined the social robotics literature on the application of non-verbal communication, most of the literature states that a robot’s non-verbal behaviour, including movement, considerably influences a human’s perception of the robot. For example, their article reports that “robot arm movements” can be an effective way for robots to influence people’s recognition, reaction and performance in human–robot collaborative tasks while “robot body and head movements” can influence human cognitive framing of robot; for example, whether a robot is perceived as empathetic, likeable, dominant, intelligent, trustful, and so on [28].

The contemporary method used to design robot motion depends largely on the application of studies of human non-verbal communication to robotics; that is, an anthropomorphic model is used, and human motion patterns are implemented in the robot. For example, human gestures, which are semantic action patterns, are directly replicated in humanoid robots. Human hand gestures, such as indicating an object, handing something to a person, and handshaking, are regarded as elements to be transferred to a social robot that is designed to operate in a collaborative work situation [27–30]. When generating “emotional expression” in a robot, the principal method used to design robot motion is to call upon professional actors [6, 8, 31]. The latter are often asked to move in a way that expresses different emotions while wearing a motion capture suit so that their motion data can be recorded and subsequently used to synthesize motion corresponding to emotions such as happy, angry, and sad. This method is not limited to reliance on professional actors in the case where researchers seek to extract key motion pattern data in a more natural context. In this case, roboticists observe human interaction between colleagues, family members, friends and members of the public in everyday contexts [32, 33]. To generate human-like behaviour through proxemics, human models are also applied to robot behaviour and to examine human preferences in the direction of robot approach [34, 35].

It is undoubtedly natural to employ human behavioural or motion models to humanoid robots because their human-like shape leads to an expectation that they will behave and move in an anthropomorphic way. However, human motion patterns have also been applied to non-human shaped robots, such as quadcopters, for the purpose of designing motion that expresses emotion [5, 36, 37]. Ende et al. [33] creates a postural lexicon from human posture and implements static postural features on an industrial arm robot for the purpose of increasing a user’s understanding of the robot’s static state (e.g. “Sleep Mode”, “Standby”) as well as its active gestures expressing its intentions (e.g. “Yes”, “No”, “This One!”). Similarly, Moon et al. [38] capture arm gestures expressing “hesitation” between two people doing a simple task in order to reproduce the hesitating gesture in an arm-shaped robot.

The anthropomorphic model is also supported by the argument that a robot with human-like shape and performance would be directly adaptable to human environments [39]. Indeed, the environments that we inhabit are built to be suitable for our way of living and working, for our physical conditions and capacities. An anthropomorphic shape and motion are therefore of use for making robots that are functional in the workplace or at home. These ideas guide a strategy for designing social robots and shape the direction
of research in social robotics towards further application of anthropomorphic models to robots.

3 Towards robot-specific motion through artistic collaboration

3.1 Robot motion for non-anthropomorphic robots

Although an anthropomorphic model has been applied to non-anthropomorphic robots, there are researchers who are exploring the design of expressive and communicative motion for non-anthropomorphic robots. Hoffman and Ju [40] explores interactive motion of non-anthropomorphic robots using a design-research approach. The authors emphasize that the process of motion design should be practiced in parallel with the design of the robot shape because the expressiveness of the robot is strongly related to the morphology of the robot and its degrees of freedom. The authors propose different techniques for prototyping motion design that are applicable to a non-anthropomorphic robot. These techniques include free-hand sketching to define the robot form, 3-D animation studies to explore the robot’s degrees of freedom and find expressive motion, and scale studies to adjust the robot to a proper size according to the context of the robot use or performance. The authors also state that the process of finding the “right movement” for a non-anthropomorphic robot relies more on artistic creativity than on scientific principles. They suggest greatly increased participation of experts and professionals from movement-related fields such as actors, dancers, choreographers, and animators, and by lay people or end users who can offer specific insights or intuitions on how a robot should move.

Bianchini et al. explores expressive movement in non-anthropomorphic robots [41] and propose a conceptual framework for the design of motion. First, they provide a model of the human attribution of perceptive skills and abilities of a robotic object to adjust to environmental and social constraints. This model includes three levels of interpretation that describe behavioural patterns according to the psychological attribution given to a non-anthropomorphic robot by an observer: animacy, agency and social agency levels. These three levels correspond to the following factors: the object looks alive, the object acts with intention, and the object appears to interact socially with other agents. Second, this model is combined with a schema of the affective state of the robot as perceived by an observer: state of comfort, state of discomfort and state of distress. The authors argue that the object’s empathy can be perceived through the three affective states and the three levels of psychological attribution. For example, motion of a robot that is perceived to be at the animacy level and with the stage of comfort can express “indifference” (Fig. 1). The models are conceived to allow designers of robot motion and human–robot interaction to elaborate general objectives regarding robot expressiveness through the technique of psychological prototyping [41]. Their approach to the design of motion in non-anthropomorphic robots is noteworthy, although their research remains conceptual.

In research into interactive devices/objects of non-anthropomorphic form, Hobye and Ranten [42] propose five strategies to make a non-humanlike device’s behaviour complex and expressive. The five strategies are (1) “reactiveness”, (2) “multiple modes” in the communicational and interactional system, (3) “non-linearity”, which is a logic of behaviour without a straightforward cause-effect reaction, (4) “multiple layers” which are composed by multiple non-linear parameters in a multidimensional interaction space, and (5) “alive connotations” which are computational patterns with anthropomorphic or zoomorphic expression. Although their research does not focus particularly on motion, it demonstrates the possibility of rich interaction between human and non-anthropomorphic objects combining their five strategies which render the object expressive and lifelike.

3.2 Robot-specific motion

While the research of Hoffman and Ju [40] and Bianchini et al. [41] seeks to define appropriate motion for robots of non-humanlike shape, the specificity of a robot’s motion could be designed independently of its anthropomorphic or non-anthropomorphic shape. Robot-specific motion, as defined in Sect. 1, refers to the motion to be designed and generated by the features of a robot, that is, its capacity to move with its limitation of the degree of freedom, materiality, and electro-mechanical capability; features that are not shared with human beings. This approach is inclusive of any
type of robot to be designed to interact to some extent with humans, including non-anthropomorphic robots.

There is some research where roboticists attempt to design robot-specific social cues using modes of expression, particularly colour and lighting, that humans do not have. For example, the use of a robot’s eye colour [42–44] and body colour [45] to convey emotional meaning are investigated as robot-specific social cues [39]. Wang et al. [46] demonstrates an experience where users may prefer exaggerated, caricatured behaviour in a robot to the robot merely mimicking human behaviour. Such work is still rare in contemporary social robotics and it remains unknown what robot-specificity in motion or behaviour might be.

Aiming at the design of robot-specific motion means finding communicational modes specific to the robot without relying on human-inspired communication or interaction models. Appropriate robot motion should be designed in relation to the robot’s motion capacity, materiality, shape and appearance. The salient questions leading the design of such specificity are “How could the non-verbal communication mode(s) performed by a robot be completely specific to the robot?”; “What cues are necessary to define and design robot-specific motion?”; and “How can humans infer and understand the robot’s intention from its motion?”.

### 3.3 Artistic works and interdisciplinary collaboration between robotics and dance

Moving towards an understanding of robot-specificity I stress the importance of collaboration with artists, especially dancers who are expert in motion and bodily interaction, as highlighted in Hoffman et Ju [40]. Such collaboration, as a possible method of exploring robot-specificity, allows exploration of a range of robot-specific motions to be designed to communicate with humans. The artistic lens can be a meaningful resource and tool for designing motion and interaction though bodily expression in a novel way, apart from and parallel to the classical approaches currently employed in social robotics.

In contemporary dance, there are multiple artworks involving human–robot dance performances where dancers and robots (or other autonomous devices) dance together. These artworks deal with human–robot interaction and relationship from a different angle in comparison with current methods in social robotics. Instead of the efficient communication mode usually sought in social robotics, the primary aim of human–robot performance is to explore new kinds of motion and experiences between organic body and machine in a non-work environment and unconstrained to specific tasks [47]. Though these performances, artists also aim to redefine and redesign human–machine interaction.

For example, some human–robot performances stress the specificity of robot motion as precise or augmented motion in their works. Väroffer [48] conceived by Swedish choreographer and ABB engineer Frederic “Benke” Rydman comprises a duet with a two-metre tall, 900 kg IRB 6620 industrial robot arm from ABB. It used ABB SafeMove2 software to allow the robot to sense where the dancer was at all times. The concept of this artwork focuses on “machinelike” motion, which can be characterized by qualities specific to machines such as moving at a precise speed, under strict control. The choreography here is meticulous and motion performed is characterised as superhuman, or rather super-machinic. The work explores gentle movement governed by temporal precision. It is intended and perceived as an impressive feat in machinic motion, especially in such close proximity to its human dance partner.

The theatrical installation I/II/III/IV by Kris Verdonck and Kim Awankwa [49] explores augmented motion by utilizing a robotic device to suspend and spin dancers in space. Inspired by a Russian play about the evolution of ballet in the aristocratic courts of Louis XIV of France, this piece involves a quartet of dancers, similar to the four swans in the quintessential quartet from Swan Lake. The four female dancers are literally picked up in harnesses by a robotic machine hidden in the loft above the stage that suspends the dancers on wires and manipulates their movement in space. These human–robot partnerships replace the traditional female-male courtships of classical ballet whereby male dancers would lift their female counterparts, apparently freeing them from the confines of gravity. The work complements and extends the ideal of classical ballet which is to be weightless and explores the possible augmented motion for dancers. This work allows us to think of the interaction and relationship with a robot that aids human movement and augments his/her motion capacity.

There are also artworks with concepts that focus on the responsiveness of two parties resulting in a feedback loop or some form of communicative network on stage. These works aim particularly to explore new types of interaction through different channels of communication, or new ways of interacting. For example, Personal Space, conceived by media and dance artist Margie Medlin in collaboration with motion capture engineer Gerald Thompson, is a real-time duet between a robotic arm with a camera for an eye and a dancer [50]. The robot uses data from camera to respond to the dancer’s movement in real time. In Co(ai)xistence [51] by Justine Emard and Mirai Moriyama with Ikegami Lab and Ishiguro Lab, a dancer physically converses with a robot head animated by a form of primitive intelligence based on a neuronal system. The piece expresses a dialogic interaction though movement and bodily expression.

Another type of interaction is drawn though body connection where the human body and machine body are connected. In the choreography Alia: Zú tài [52] by Marco Donnarumma and Nunu Kong, a dancer attaches to her
body a robotic spine which performs sinuous movement, wagging its body and moving as an eerie, alive piece of metal. A similar approach to amplifying the living body is Devolution [53], where dancers likewise move connected to robotic prostheses.

William Forsyth’s artwork Black Flags [54], from his Choreographic Objects series—laying at the intersection of dance and visual arts—shows and teaches us the specificity of robot motion which cannot be performed by a human. Black Flags is a 28-min dance of two industrial robot arms, each waging a large black flag. Although the artwork does not deal with human–robot interaction, it showcases a robot’s motion specificity through its controlled, weightless, and measured gestures.

Interdisciplinary research collaboration between robotics and dance demonstrates the potential contribution of a dancer to the design of robot-specific motion. For example, the research project “Performative Body Mapping”, which seeks to design expressive and unique motion for a non-humanlike robot, led by Petra Gemeinboek and Rob Saunders [55] well illustrates a fruitful collaboration with dancers, taking fully advantage of their expertise in the design of robot motion. The authors attach importance to the dancer’s kinaesthetic experiences and capabilities, and awareness and sensibility of body and movement which allows exploration and creation of motion fitting the robot’s form. Their research demonstrated not only that collaboration with dancers allowed them to design a “boxiness” in the motion of a box-form/cube-like robot, but also that this “boxiness” in motion can be perceived as affective agency by human observers.

Dance notations with potential utility are cited by Bianchini et al. [41] and provide a useful tool to bring an analytic framework to motion, and conceptualise and design robot-specific motion. Dance notations have been developed and employed in the field of dance as a tool of pedagogy, and for creation and storage of dance techniques. Several interesting collaborations between roboticists and experts in dance notations have been undertaken in research of motion in robotics [56]. Interdisciplinary work on motion generation systems using dance notation is not new in robotics. Several projects have attempted to automate dance notations such as Kinetography Laban or Benesh Movement Notation, creating computational systems to generate motion from dance scores [57]. Such research has developed mainly in computer science and the domain of animation. The difficulty of developing robot motion generation systems inspired by dance notation is that robot motion generation needs more complex computation than does animation, together with a well-designed and tuned motion control system. A robot has a material body, but an avatar is only a visual image and does not have a body. Motion generation in a robot needs therefore to consider acceleration and gravity which are often excluded from the domain of animation.

3.4 Discussion on the potential contribution of artistic collaboration to the design of robot-specific motion

What can an artistic approach bring to the development of the creation of robot-specific motion? I emphasise two factors which an artistic collaboration can bring to the exploration of robot-specificity in motion. First, in artistic work it is unnecessary for the interaction to be efficient or optimal in any way, in comparison to engineering- or science-based approaches where the robot motion is conceived only to be effective and practical in terms of a robot’s function. The robot’s efficient, perfect, and meticulously precise motions are certainly demanded in the industrial field, whereas in social robotics perfection in robot motion or behaviour does not always ensure a successful relationship between a human and a robot. Salem et al. [7] demonstrates that people who interacted with a robot that occasionally performed an incorrect gesture to indicate the location of an object was regarded more favourably than a robot that always gestured correctly. From this research, the authors speculate that a certain level of unpredictability or imperfection in a robot may lead to a more positive human experience. The concept of ambiguity is frequently exploited in the arts. Ambiguity of information, context and relationship is also explored as a design strategy to arouse the curiosity of people and to create “intriguing, mysterious, and delightful” interactions between users and artefacts [58]. Thus, although the potential of robot motion is unlimited, this limitlessness is often negatively considered as redundant in terms of efficient computation, task completion and practical communication. An artistic approach impels us to explore the possibilities of motion beyond the question of efficiency.

Second, the artistic approach can contribute to producing novel experiences for interactants and viewers. Analysing and understanding these experiences beyond goal-oriented interaction allows us to redefine the interaction in a novel way. Admittedly, the examples of human–robot dance performance cited here are intended to be presented as public performances and are not scientific research in human–robot interaction. Information and data on the perceptions of the human dance partners and audience are absent in these performances. It is therefore important for researchers and robot designers to collaborate with artists to gain access to such information on people’s perceived experiences. In this sense, the research of Gemeinboek and Saunders [55] shows an interesting example of robot-specific motion and the perception of viewers. Such examples teach us that models of interaction or communication between a human and a robot are not limited to convention but are diverse. The creativity and
imagination in an artistic approach can lead to a paradigm shift in the design of robot motion from the predominant anthropomorphic model to the quest for robot specificity. This can redirect research focused solely on technical feasibility and provide a complementary view and approach to social robotics [59].

One concrete example of dance-robotics/HRI collaboration is the utilization of human–robot dance performances to understand an audience’s perception of robots, and also to transform their perception through performance. This initiative has been undertaken by Cuan et al. [60], demonstrating the power of performance to modify an audience’s perception of robots. Their study shows that watching a human–robot interactive performance can positively change an audience’s perceptions of robot power, valence, and acceptance.

Certainly, much work remains to be done before understandings from artworks can be applied directly to social robotics. However, artistic initiatives will provide insights to the design of robot-specific motion and new kinds of interaction. Human–robot dance performances ultimately provide a provocation for the field of social robotics, and an invitation to redefine motion and interaction in everyday contexts, furthering theoretical and practical enquiries in social robotics.

4 Conclusion

The question of how a robot moves is an important consideration in designing positive and successful human–robot interactions. Contemporary social roboticists therefore investigate how humans move, extract key information from human motion, and implement these features in a robot. The design of robot motion based on anthropomorphic models remains dominant.

The potential of robot motion is currently neglected and limited by the strong motivation to replicate human motion in a robot. The article therefore argues for moving beyond this limitation to give robots more possibilities to move in various ways and stresses the importance of collaboration with artists, especially dancers or choreographers, as a source of inspiration for designing robot-specific motion. Such collaboration will help to design robot motion in a non-conventional way and to think of new possibilities for exploration of robot motion. Existing human–robot dance performances seek a novel way of interaction between dancer and robot and explore novel experiences resulting from motion performed between them beyond the requirement for efficiency or optimality in robot motion. The quest for robot-specific motion allows us to reconfigure human–robot interaction and rethink novel modes of communication between humans and machines. An artistic approach in collaboration with dancers would contribute to breaking down the current dominant anthropomorphic approach in social robotics and stimulate a novel way of thinking towards the design of interaction motion based on robot specificity. More interdisciplinary research and collaboration will be needed to establish a strong connection and deepen mutual understanding between artistic fields and robotics. This endeavour will enable robot motion to be more varied and expressive, therefore enriching interactions between a robot and a human.

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