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Research article

An android architecture for bio-inspired honest signalling in Human-Humanoid Interaction

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ABSTRACT

This paper outlines an augmented robotic architecture to study the conditions of successful Human-Humanoid Interaction (HHI). The architecture is designed as a testable model generator for interaction centred on the ability to emit, display and detect honest signals. First we overview the biological theory in which the concept of honest signals has been put forward in order to assess its explanatory power. We reconstruct the application of the concept of honest signalling in accounting for interaction in strategic contexts and in laying bare the foundation for an automated social metrics. We describe the modules of the architecture, which is intended to implement the concept of honest signalling in connection with a refinement provided by delivering the sense of co-presence in a shared environment. Finally, an analysis of Honest Signals, in term of body postures, exhibited by participants during the preliminary experiment with the Geminoid Hi-1 is provided.

1. Introduction

Robots are going to be integrated into everyday life for cooperative, welfare and education aims due to technological innovation. Accordingly the interdisciplinary research into social robotics, Human-Robot (HRI) and Human-Humanoid Interaction (HHI) has been devoted to discovering under which conditions such integration may be successful (Kanda & Ishiguro, 2012; Lin, Abney, & Bekey, 2011; Mohammad & Nishida, 2015). This research spans in fact a wide field of features or ability that are candidates for playing a functional role in those conditions: the outward look of the robot, the implementation of cognitive and affective capacities, the display of behavioural clues that in ordinary experience display cognitive abilities (Adam, Johal, Pellier, Fiorino, & Pesty, 2016; Breazeal, 2003; Komatsu & Yamada, 2007; Sorbello et al., 2014; Walters, Koay, Syrdal, Dautenhahn, & Te Boekhorst, 2009). The variety of research lines is extended also to the designing principles that are likely to allow robots embodying the social intelligence, that is the capacities and abilities required to understand, predict and cope with other agents behaviour (Dautenhahn, 2007). One strategy is to select the set of skills, heuristics, routines, cognitive modules, which have been developed by humans and animals to solve the problems that arise living in groups whose members are tied by social bonds. That set is used to model the requirements robots have to meet to interact with humans in a common environment. An alternative option is claiming that robots, in particular humanoids, learn the required abilities by means of scaffolding (Brooks, Breazeal, Marjanović, Scassellati, & Williamson, 1999). As parents shape and guide infants acquisition of behavioural abilities and rules, so human subjects act as a scaffold that foster the required abilities in robots endowed with a motivational system as the interaction goes along (Gu & Hu, 2004). Another strategy is to build robots that are able to undergo a process akin to epigenetic development of human individuals through which they acquire intentionality, empathy and mind-reading (Kozima & Yano, 2001). In this paper we focus on the research into the minimal conditions that are reasonably the core of as successful and natural-like an interaction as possible: the mechanisms underlying the attribution of intentionality, agency and trust. As regards the theoretical and design strategy, we draw the model of such mechanisms from the biological theory of honest signalling. As Chella, Lebiere, Noelle, and Samsonovich (2011) hold it is likely that the conditions under which human and robotic agents successfully interact and pursue common goals are biologically inspired. Such conditions meet those that enable

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humans and animals to sense what is salient and act accordingly in a shared environment. Besides the theory of honest signalling has been already extended to human interaction laying the basis of sociometrics (Pentland, 2007). The paper is organized as follows. In the first section we reconstruct the biological meaning of the concept of honest signals. We emphasize the advantage of signalling intended as an automatic and perceivable communication that induces animals to choose stable strategies in competitive contexts. In the second section we present the extension of honest signalling to social human interactions and the project of social metrics. In the third section we describe the architecture that embeds the insight of sociometrics based on honest signalling and allows bringing in and controlling further conditions for a conceptual refinement.

2. Bio-inspired honest signalling theory

2.1. Honest signalling in biology: insights and stable state model

Zahavi (1975, 1977) and Zahavi and Zahavi (1999) brought the concept of honest signals in theoretical biology to account for cases in which individuals that compete with one another or have conflicting interests opt for a strategy that benefit them all rather than deceiving one another. Suppose that members of group A, which for instance belong to a prey species or are nestlings begging for food, and of group B, which belong to a predator species or are the feeding mother birds, have different access to information. Instead of following the incentive to cheat, A and B members shift to sharing information as the strategy that benefit both groups. To warrant the reliability of that communication they issue signals that cannot but being taken as honest because they are cost-added signals. Consider that gazelles and cheetahs are A and B members respectively. In the presence of cheetahs, gazelles make high up and down jumps instead of fleeing as if they wanted the predator to spot them. Thus gazelles show cheetahs to be able to flee by investing in a display of fitness, which is costly in terms of energy and time badly needed to run away. On the other hand, cheetahs learn that they cannot take the preys by surprise and may choose not to waste energy and time to hunt instead other preys. Furthermore, the gazelle that is able to jump that way shows cheetahs to have such strength that the predators will have to spend much more resources to try to catch her than those needed to chase another gazelle that is not able to display the same signal. Accordingly cheetahs use the added cost of this display as an observable gauge of signal reliability, because the cost of that jumping is much greater than the gain gazelles would get were it a phony signal. Therefore cheetahs can take the signal as honest communication that reduces uncertainty, because they come to know a quality that is possessed by some gazelles rather than others. In the case of nestlings and feeding mother birds, each nestling has an incentive to cheat and show it is hungrier than the other ones to receive food, while the mother bird has interest in knowing how much each nestling is hungry to feed the hungriest. Honest signals solve the problem of parent-offspring conflicting interest. Loud and harsh cries display hunger so that the louder and the harsher they are, the hungrier is the nestling that emits them. Those squawks have the further added cost that they may call the attention of predators. Therefore the risk of being caught outweighs the gain of cheating. If starving the nestling will bet against this risk and mother birds will get honest information about whether and how much each nestling is hungry. Signals of this kind are honest in a statistical sense. On average they show the receivers correctly the existence of an otherwise unobservable quality. They bear a cost that is added to that which the signallers undertake just to make sure that the signal is emitted with the physical properties needed to convey the information unambiguously. This is instead a strategic cost that means a reduction of fitness under some respects by which cheating or deceiving are constrained (Smith & Harper, 1995). In the case of prey-predator interaction, this signalling allows high fitness preys being distinguished from the other ones and deterring predation, thus serving predators to discriminate two subset in the preys group. Low fitness preys can't pretend to be otherwise because of the added cost that makes the signal unattainable for them. Honest signalling affects the behaviour of individuals by sharing and modifying the information to which they have access so that it increases their fitness. It leads to a state that has been qualified as stable by Grafen (1990) and Smith (1991).

We can summarize this result by letting:

1. A and B be any members of two competing or conflicting groups such that A has a two states quality, for instance hungry/satiated or strong/feeble, and B has a resource, be it food or deterred predation;
2. p be the probability that A is needy or strong and $(1-p)$ the inverse probability (for B these values have a uniform distribution);
3. r be a "coefficient of relatedness" such that a maximizing process of survival chance may pay B if it delivers the resource to A but if A is p (this measures the inclusive fitness for A and B being genetically related but it can be generalized to any case in which As and Bs pay offs are mutually dependent);
4. $(1-t)$ be the reduction factor in As survival chance due to the cost t of signalling that p.
5. $(1-d)$ be the reduction factor in Bs survival chance due to the cost d of delivering. A survival chance depends on his state and Bs delivering: if A is p and B delivers the chance is 1, if A is p and B does not deliver the chance is 0, if A is $(1-p)$ and B delivers the chance is 1, if A is $(1-p)$ and B does not deliver the chance is X with $0 < X < 1$. B survival chance is 1 if it does not deliver and $(1-c)$ otherwise. Given A and B are somehow related, the choice of each one benefits the other one r times. It can be shown that the equilibrium strategy occurs if the loss that reduces As survival chance, because B does not deliver while A is p, is greater or equal to the signalling cost t and the cost d, which reduces Bs survival chance, once weighted for r is greater or equal to the loss for A because B does not deliver while A is $(1-p)$. In such a case A will signal if p and B will deliver according to signalling. Instead if $(1-t)$ and $(1-d)$ weighted for r are not greater than the relatedness of A and B,A will never signal; if X and the relatedness of A and B are not greater than $(1-t)$ and $(1-d)$ weighted for r, A will always signal. On the other hand, if Bs survival and X weighted for r are not greater than $(1-d)$ and the relatedness of A and B,B will always deliver; if $(1-d)$ and $(1-t)$ weighted for r is greater than B survival, B will never deliver. Therefore given an appropriate cost $t > 0$ honest signalling is a stable strategy in the sense that neither A nor B benefits from switching to another behaviour. Cheating and deceiving are still possible, rather they actually occur but this strategy is not optimal because it undermines the communication system that reduces uncertainty by sharing information and promotes the inclusive fitness of all parties.

2.2. From biology to sociometrics

Pentland (2008) has extended the theory of honest signalling to strategic contexts in which humans are engaged in face-to-face or group interactions. Speed dating and salary negotiations are examples of face-to-face interactions, while tactical decision making and coalition membership shifting within and across groups are examples of social aggregates interactions when conflicting or competing interests hold. Like in biology honest signals are unconscious, in the sense that they do not involve conscious reasoning, normative or linguistic judgments, mandatory and costly in terms of cognitive resources. Pentland (2008) describes four types of honest signals by which agents tune, synchronize or change cognitive features that are socially salient like attention, understanding, interest, focus and openness. The first type collects signals of the influence that agents have in the interaction, which is displayed by the distribution of attention to control and orienteer the communication and the behaviour. The second type collects mimicry signals that display the tuning of agents to each other, like nodding or leaning towards or away, providing feedback for mutual understanding and cooperation. The third type collects signals of the activity by which agents maintain the interaction, which is displayed by the increase of the energy devoted to making gestures and sustaining the conversation. The fourth type collects signals of the consistency of motivation and of determination of agents in pursuing some goals in the interaction. Those signals consist in modulating the energy applied to gestures and words and its distribution in time. Discontinuous or smooth modulation and regular or irregular distribution are signal of the emphasis and the openness of agents as well as of the straightforwardness or conflicting interests of agents. Honest signals are traded back and forth by individuals face-to-face, within and across groups, hence they build social circuits or networks in which the trust and reliability needed by successful interaction are unconsciously settled. On this account honest signalling serves as a machine whose function is drawing decisions and actions out of agents in such a way to solve coordination problems, when the information is not fully available to all of them. Because signalling is mandatory (Pentland, 2007; Olguin, Paradiso, & Pentland, 2006; Olguín et al., 2009) have submitted that technological socioscopes can track honest signals accurately and continuously by means of an automated and computer-aided process of extraction of associated physical variables. For instance, wearable tools have been built with an integrated sensory package to measure the honest signals in speech, localization and actions that build the interactive networks within organizations. This kind of automated detection, extraction and analysis of social honest signals lies at the core of the project of the sociometrics, that is the science that aims to map the structure and the dynamics of interactive networks.

3. Material and methods

3.1. The Geminoid robot

Geminoid HI-1 is a tele-operated humanoid robot with the external appearance of its inventor, Prof. Hiroshi Ishiguro and it is thought to be indistinguishable from real humans at first sight (Ishiguro, 2007).

Geminoid HI-1 android has fifty degrees of freedom that allow Geminoid HI-1 behave like actual humans. This android has been used to answer questions like “What is a human presence?” or “Can human presence transfer to a remote place?”, (Kanda, Ishiguro, Ono, Imai, & Nakatsu, 2002; Shimada, Minato, Itakura, & Ishiguro, 2006).

3.2. The proposed architecture: conceptual refinement and modules of a signalling machine

We have developed a robotic architecture in connection with the nature of honest signals as pieces of observable behaviour. The architecture is restricted to mimicry signals, which support successful face-to-face interactions with clues of reliability and trust among agents. The aim of the architecture is twofold: to serve as an signalling machine that employs specifiable honest signals as testable parameters to bring about a natural like HRI; to model the efficacy of the specified honest signals and to test their generalization to every kind of agent. For that to be the case, the architecture embeds the insights of sociometrics but also a refinement. Honest signals are unconscious but one should not neglect their connection with what it is observable for agents and what they become aware of on the grounds of what they come to share through signalling. The prey avoids being chased by making it apparent to predator that the latter has been detected and displaying its strength in escaping it. The predator sees which prey bears the risk of wasting resources and which ones instead are in so poor condition that they cannot afford signalling. Therefore, the architecture involves humanoids in order to implement the conditions of co-presence and the specification of coordinate systems for various honest signals, which amount to the cognitive frame of reference of signalling. The co-presence is the condition under which agents sense one another as accessible, available and subject to each other (Goffman, 1963). It provides interaction with the features of instantaneity and of bi-directionality. Instantaneity is grounded on the co-localization of agents in space and in time by which the interaction is distinguished from diachronically mediated communication like that which is obtained through postal systems. Bi-directionality is grounded on the mutual acquaintance of the agents by which the interaction is distinguished from unilateral exchanges, like getting information from mass media, and from those in which the bi-directionality may be scattered over time like in interacting by means of social media applications. The co-presence can be extended to virtual cases in which a distance that is beyond the scope of sensory co-localization or acquaintance is turned in one that is perceived as proximate through technological devices (Zhao, 2003). As a consequence the humanoids of our architecture have the function of a robotic model of the co-presence in which it is easier to identify, manipulate and control the parameters underlying instantaneity and co-presence. Besides the use of humanoids have another experimental advantage. The control of the humanoids behaviour allowed by their Dof make the coordinate systems in which mimicry signals are carried out specifiable. The stable state of honest signalling is indeed brought about by the back and forth acting and mirroring gestures and postures of agents. However the manifest contributions of agents to building those patterns make sense in connection with the system of possible actions allowed by ones body parts and their change of standpoint and appearance. The shared environment in which the co-presence underlying interaction occurs is scaled at various coordinate systems. The architecture of the system, as shown in Fig. 1, consists of two macro modules: *SKE* and *GES*. The *SKE* module is used to track the skeletal of the users during their interaction with the Geminoid Robot. It is composed by a skeletal tracking and a skeletal reconstruction block. The first block tracks users movements over time through the location of their body’s joints. The second one, builds the so-called *skeleton* based on the joints obtained from the first one. The *GES* module is composed by a gesture prediction and a gesture recognition block. In the *Gesture*

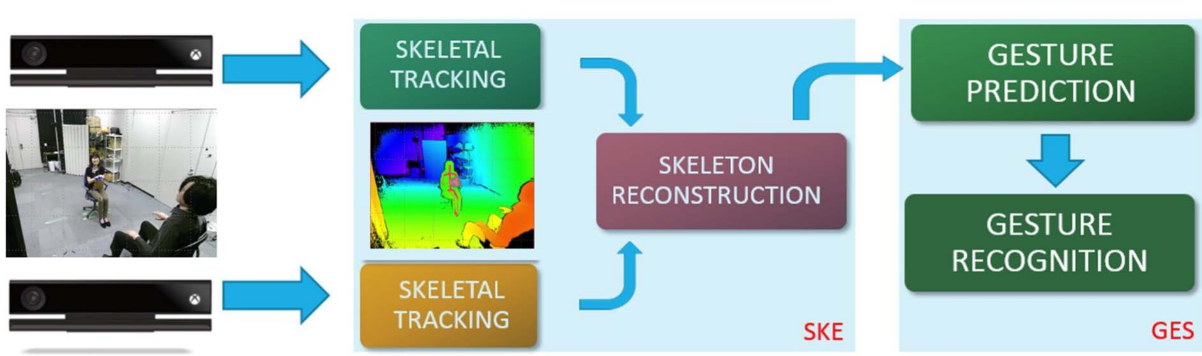

Fig. 1. The architectural schema.

Prediction the stream of features extracted by SKE modules as skeleton joints are aggregated in a non-overlapping temporal window of 1.5 s blocks.The size of the window has been chosen empirically. In the *Gesture Recognition* block a support vector machines (*SVMs*) (Suykens & Vandewalle, 1999) classifier has been trained and used to recognize of a set of eleven honest signals gestures. For instance *changing position over the chair*, *rising the folder*, *lowering the folder*, *touching the head*, *bending down*, *writing*, *approaching the robot*, *getting away*, *standing still*,*gesticulating* and *touching the robot*. Two Microsoft Kinect have been used in this architecture, to use the skeletal data coming out from all sensors. A single shared reference system is a requirement that has been considered mandatory to have consistent and usable information.

4. The experimental results

We defined a pilot experimental setup to test the architecture in a controlled environment in which the people could exhibit a rich repertoire of honest signals, taking into consideration the research done by Mehrabian (1968). This study has noticed a significant relationship between mimicry signals, intended as body orientation, and the attitude to interact.

4.1. The experimental setup

A controlled environment called *Geminoid room* (shown in Fig. 2) was set up for the session test. The Geminoid robot has been sitting in a chair located on the right-hand side of the Geminoid room and another one has been positioned in the opposite way for the people involved in the experiment. Two Kinect cameras and one HD camera, also, have been disposed behind the Geminoid to catch the interactions and to record all the useful data for the whole experiment.

The chairs were located in the room following a prefixed marker based schema in according to the position of the kinect camera and HD camera. Moreover, it has been chosen a room with neutral color of floor and walls and with basic furniture. Furthermore, the position of lights and spots was designed for making comfortable the environment as much as possible. Twelve paid participants (¥3000 each) have been getting involved in the experiment and a questionnaire for the robot assessment acceptance has been given to fill before the starting of the session test. The participants' details and the questionnaire results are reported in Table 1. In Fig. 3 is showed a typical moment of a face to face interaction during the session test and the markers on the floor for the right positioning of the chairs in the environment.

Table 1
The statistics related to participants involved in the main experiment.

Subjects:	
-Number of participants	12
-Male	**7** (58.33%)
-Female	**5** (41.67%)
-Average age	31.33
Previous knowledge or general acquaintance and robotics issue:	
Personal attitude to robotics	
-Real interest	**4** (33.33%)
-Significant knowledge	**2** (16.67%)
-Curiosity	**9** (75%)
-Suspicious	**1** (8.33%)
-Indifference	**1** (8.33%)
Degree of agreement on the Acceptance of Robots in the near Future	
-Accept as useful tools in jobs	**7** (58.33%)
-Accept in all aspects of daily life	**1** (8.33%)
-Accept with suspicion	**1** (8.33%)
-Accept with nuisance	**1** (8.33%)

4.2. The description of the experiment

A total of six experimental sessions of *face to face* interaction with the Geminoid robot have been conducted. Before starting the experimental session, each participant has been informed of the session test aims and of its terms and conditions that had been approved by signing. Moreover, have been provided informative documents paper in original language. The experimental session is started when the people take a seat in the chair placed in front to the Geminoid robot and have an interaction with the Geminoid robot, trying to execute a provided task.

4.3. The body postures evaluation

The body posture evaluation is demanded to a classifier that is designed and implemented in the *Gesture Recognition block* as shown in Fig. 1. The classifier has been trained with the 25% of cameras data as training set. From the data analysis, eight gestures associated with the corresponding honest signals have been found and good recognized. We report in Fig. 4 the list of all the gestures classified: *gesticulating, changing position over the chair, raising folder, lowering folder, touching the head, bending down, writing and holding the folder with one hand*.

The evaluation of the postures in terms of hidden emotions and gestures assumed by people during a interaction is widely described in literature. Argyle (2013) and Corraze (1992) have stated that, facial expressions and postures are the best way to communicate and transmit

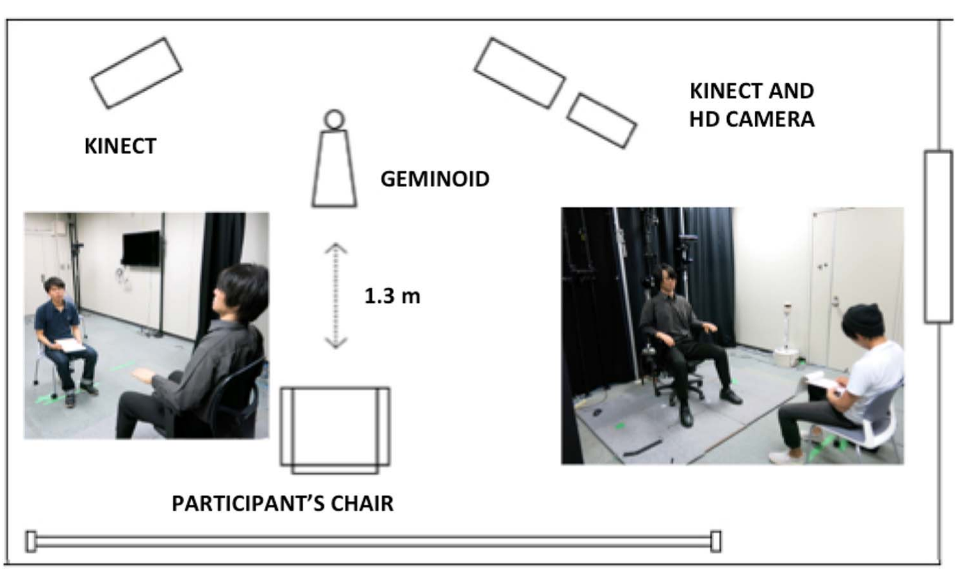

Fig. 2. The experimental setup.

Fig. 3. Some of the participants involved in the main experiment.

Fig. 4. The list of all gestures recognized by the system.

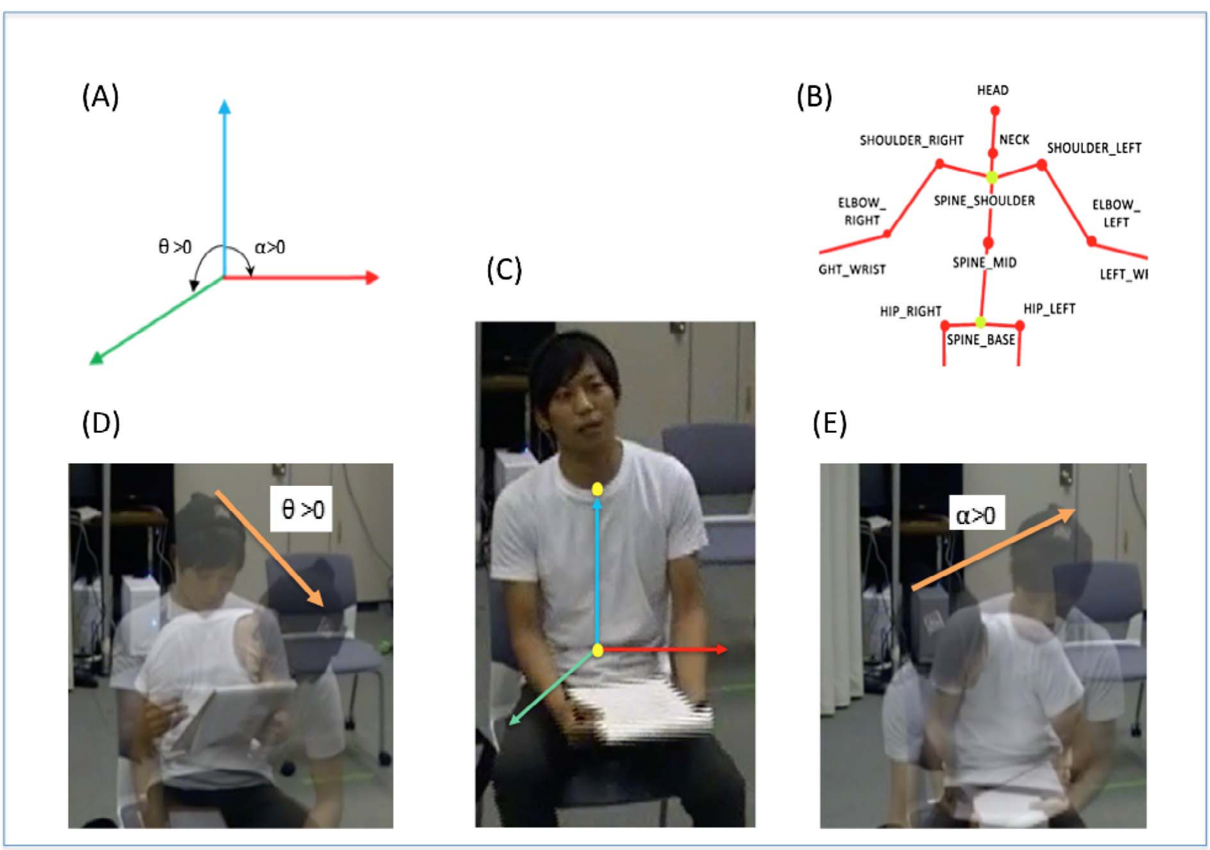

Fig. 5. Body markers and reference system.

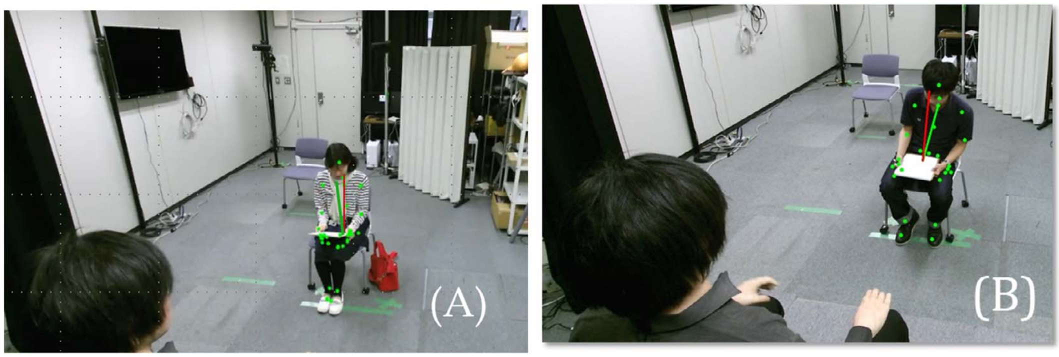

Fig. 6. Two examples of forward (A) and backward (B) inclination: the reference axis, as *red segment*, and the axis relative to the participant during the movement, as *green segment*, are highlighted. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

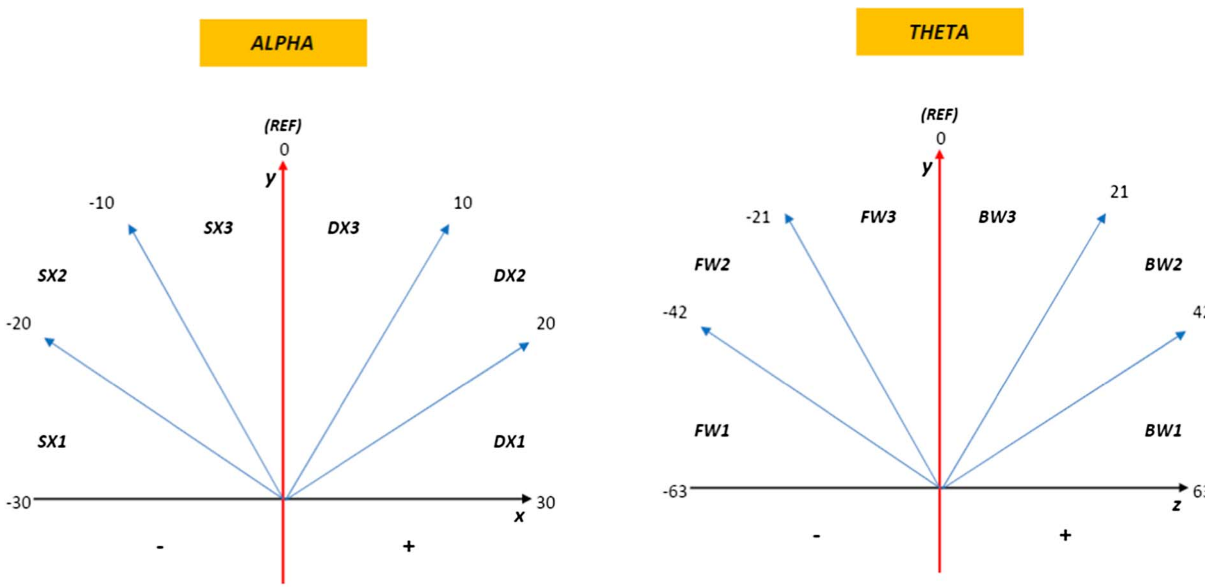

Fig. 7. The symmetric intervals for alpha and theta considered.

Table 2
The average values of the total number of left, right, forward and backward variations and their standard deviation in a range time of 30 min.

	FW		BW		DX		SX	
	Mean	Dev	Mean	Dev	Mean	Dev	Mean	Dev
Human - Geminoid interaction	76.50	41.39	63.00	41.72	50.60	61.06	50.60	61.16

the emotions and the states of mind. As reported in Guye-Vuillème, Capin, Pandzic, Thalmann, and Thalmann (1999) a posture is defined as a precise position of the body referring to a reference system (Mehrabian, 1968; Scheflen, 1964). Basing on these findings we studied the postures of the participants taking into consideration the angle formed between a reference system and the position of the torso; in particular we focused on the left-right and forward-backward movements.

Some virtual markers have been assigned to prefixed parts of the body (Fig. 5B), in order to create for each part a unique point of reference to be related with the reference system (Fig. 5A). Furthermore, has been chosen the origin of the reference system with the *spine_base* that basically is the origin of user body (Fig. 5C) when a user is in the seated position. Lastly, we reported, as illustrative purpose, an example of positive variation during *forward body movement* (Fig. 5D) and during *left body inclination* (Fig. 5E).

The body posture has been evaluated as follows; for each variation of the torso from left to right an α angle is calculated and for the ones from forward to backward a θ angle is measured.

Two examples of an angle variation are shown in Fig. 6. All the measurement are expressed as *long sequences*. The term *longest sequences* is referred to the longest movement in the same direction until the subject changes the direction of his movement. In order to make this definition clearer lets suppose the subject is moving in the forward direction; when he or she changes direction and he or she starts moving along the backward, left or right direction then the sequence ends. The analysis of the users posture data during the interaction led to the definition of a maximum and minimum angle of variation. Between the latter, a symmetric range of angle values has been fixed. The range goes from $-30°$ to $30°$ for the α angle and from $-63°$ to $63°$ for the θ angle. As shown in Fig. 7, these intervals have been subdivided into six symmetric sub-intervals in order to compare the relative inclinations detected during the experiments.

This was done by counting the number of the forward-backward and left-right inclination of each user during the face-to-face interaction (*FFI*) and the human-humanoid interaction (*HHI*). The average values of the total number of left (*LT*), right (*RT*), forward (*FW*) and backward (*BW*) variations for each participant involved in both the experimental sessions are summarized in Table 2.

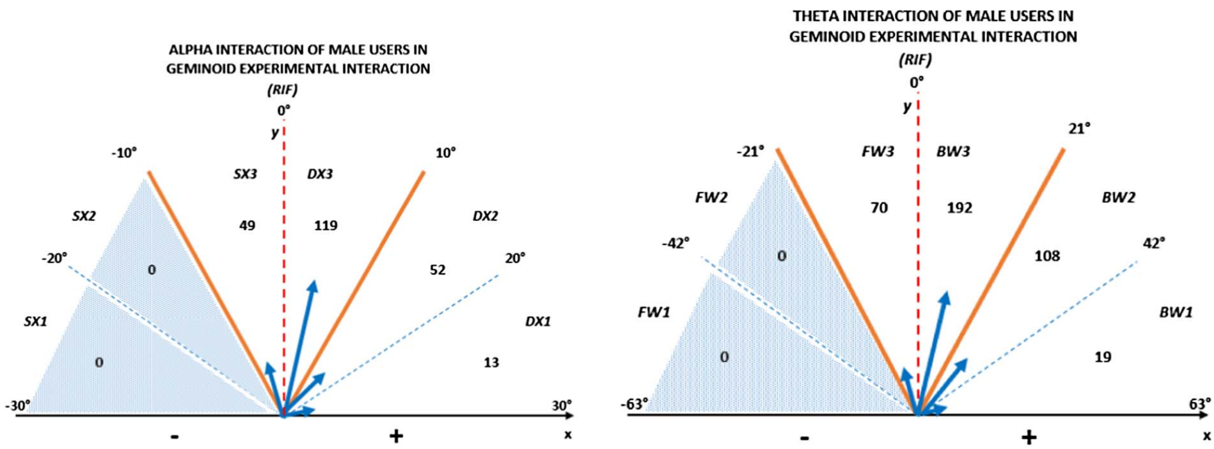

Fig. 8. The occurrences of body postures of male participants in terms of alpha and theta angles.

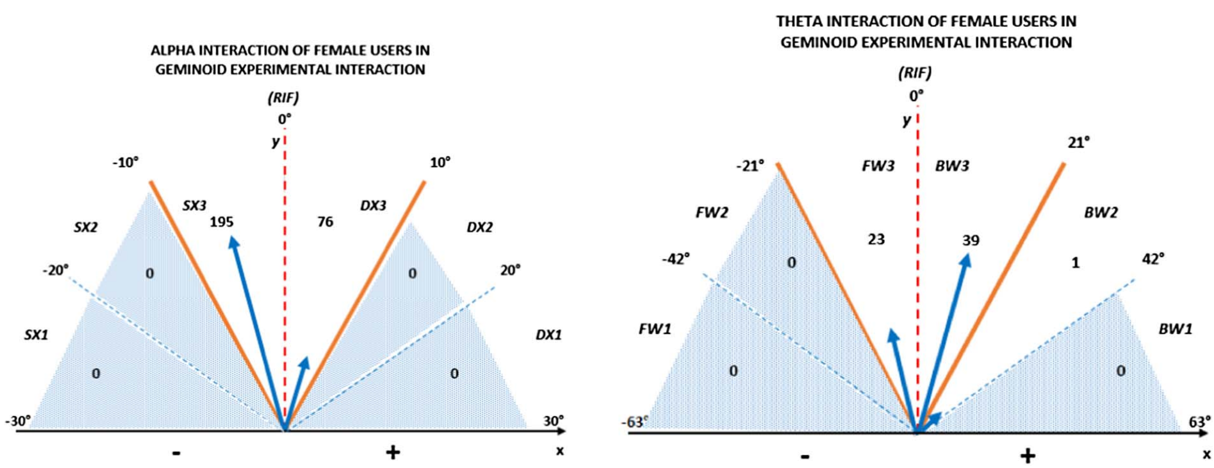

Fig. 9. The results in terms of alpha and theta angles regarding female participants.

5. Discussion

The results are reported in Figs. 8 and 9 and take into consideration the gender of the participants. In the charts, the most significant values, to take into consideration are those referred to the intervals, labelled as *normal*, which start from -10 to 10 in the case of α angles and from -21 to 21 for the θ angles. The fact that the values lie in an interval is justified by the impossibility for the subjects to remain absolutely static without moving at all. In the charts the label *unusual* is referred to the intervals between -63 to -21 and 21 to 63 for θ angles and from -30 to -10 and 10 to 30 for α angles. In the intervals that don't show occurrences, were labeled as label *absent*. As the data plotted in the Figs. 8 and 9 show, there is a greater number of forward inclinations during the interaction with the Geminoid for the group of male subjects in comparison with the group of female subjects. That points out that female subjects are less inclined to maintain the back and forth pattern of posture signalling than male subjects are. In particular, being more likely to bend ones own body toward another subject is a signal of ones commitment to cooperation (see also Guye-Vuillème et al. (1999), D'Mello & Graesser (2010) and Richmond, McCroskey, & Payne (1991) for an interpretation of such a behaviour as conveying attentiveness in the connection with the study of non verbal communication). Therefore the reduction of this kind of mimicry signalling in the group of female subjects may mean that they are less willing to understand the other subject or to tune their behaviour to it or, at least, to provide it with a feedback. Further research is needed to confirm that difference across the groups, to measure it properly and to assess what interpretation is actually the case. From the inspection of the video recordings of the experimental sessions, the Authors have noticed that some female participants showed to feel like uncomfortable at the beginning of the session. If this may be a cue of unease, it remains to be seen whether it depends on interacting with the robot or in an apparent strange situation with an unknown agent. Nonetheless, Fig. 9 shows that female subjects realized most of the movements required by the face-to-face interaction. That suggests to drop the hypothesis that they were unease about the robot itself.

6. Conclusions

Honest signalling is the subset of observable behaviour selected by a stable and equilibrium state of sharing information as the solution to coordination problems in competitive or conflicting interest contexts. HHI and HRI provide the interdisciplinary field in which to study honest signalling as the cognitive means to set the conditions for successful interaction between human and artificial agents and to test them to provide a simulation of human behaviour. We have outlined the architecture to study the mimicry type of honest signalling in face-to-face interactions, which allows controlling the sense of co-presence and the coordinate systems of the shared environment. A preliminary experiment has been conducted and it has been measured the forward-backward and left-right inclination of the users involved in the human-humanoid interaction.

The experimental results evaluation have confirmed that bending ones body toward, as an instance of the leaning towards or backwards signalling pattern, conveys cooperation. Subjects provide a visual feedback to the robot signalling that they are inclined to tune their behaviour to it, thus showing to be committed to the interaction. Future work will be devoted to specify the conditions of meaningfulness, consistency and congruence of definite kinds of honest signalling and in particular to study the tuning of agents to one another by means of dynamic behaviour like kinesics. The difference across male and female subjects groups, if confirmed, will suggest carrying out further studies to see whether the cost and the benefit of displaying particular honest signals of a defined class can be modulated by factors like gender or culture and, if so, at which level of specialization. Since the Geminoid is able to generate movements which are almost human-like, designing long term interactions will let us (i) study which honest signals allow humanoid robots and human subjects to adapt their behaviour for a successful interaction, (ii) specify which honest signals can be selected to gauge users confidence and familiarity with the robot.

Compliance with ethical standards

The authors declare that they have no conflict of interest. This study was carried out in accordance with the approval of ethical committee of Advanced Telecommunications Research Institute International, as No. 15-601-1, with written informed consent from all subjects.

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