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# Identifying Values to Express Emotions with a Non-Anthropomorphic Platform

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**Abstract** Although anthropomorphic embodiment may support robot acceptance in interactive tasks, there are robots that cannot have a humanoid shape, and still have to be accepted by humans. As a consequence other characteristics should be exploited to support robot acceptance. This paper presents an experiment made to understand the contribution of angular and linear velocity of a non-anthropomorphic robot, its body orientation, and movement direction on humans' perception of emotion. A top 10 table was created for each enlisted emotion using alpha agreement for the whole treatment and for the desired emotion. These results suggest values that could guide implementation of the studied emotions in this experiment in other social robots.

**Keywords** Robot-Human Interaction · Emotion Projection

## 1 Introduction

Emotions and mental states are not just expressed through facial expression but also by body through postures and other features [15]. However many psychological studies have been mostly focused on understanding the role of human face in emotion projection [13], [18] and mental states. This trend has been followed by the robotics community, where anthropomorphic faces

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(e.g., [14], [5]) and bodies (e.g., [3], [16], [10]) have been used to convey emotions. Nevertheless in many situations the presence of anthropomorphic elements would be out of place and not justified by the main robot's functionalities. Most of the current and future robotics platforms on the market will not require anthropomorphic faces [5] or limbs [24] , in some cases like, for instance, in floor cleaning robots, anthropomorphic characteristics could even be detrimental to robot's task accomplishment. This generates the necessity to study other mechanisms that could help to project emotions, which could give people an idea about the robots' state, and engage the user in long term relations.

The amount of works studying non-anthropomorphic features in robotics (e.g., [32, 21, 34, 28]) remains still small in comparison to those that exploit anthropomorphic features. Moreover, these works do not give specific range of values for the characteristics used to expressed the emotions implemented by them. For example Suk and collaborators [27] in their study gives specific values for acceleration, curvature, and but their connection to specific emotions is not given. Rather, they gave a relationship between their features and values in terms of pleasure/arousal dimensions. This could lead to select features to convey certain emotions but it would be even better to know specific range of values for those features to convey certain emotions or to know the values that could be misinterpreted with negative emotions.

In order to get a better understanding of other features and values that could be used to convey specific emotions, this paper presents an experiment that was designed to identify specific values for some movement features that could be used to express the following emotions, selected among the ones suggested by Ekman as basic [13]: happiness, anger, fear and sadness. The considered features are oscillation angle, linear and angular velocity, direction and orientation, identified as independent variables. The perceived emotions and their intensities were considered as dependent variables. It is to be observed that it was given the possibility to the subjects to provide their evaluation of emotional intensity for more than one emotion for each experience. The experiment took place in Politecnico di Milano during June and July of 2015, where students from diverse departments were asked to participate without any economical retribution. Krippendorff's alpha agreement [19] ($\alpha$) was used to evaluate the agreement among the participants for each treatment. For each of the four emotions was generated a top 10 list based on alpha agreement and perceived intensity. The results suggest that fear is perceived when the robot is looking at them and moving far from them fast. Sadness is attributed to slow velocities with slow angular velocity and small oscillation angle. Anger is attributed to fast velocities, both angular and linear, small angle of oscillation and the robot facing the person when it is approaching them.

This paper is organized as follows. The next section introduces previous studies done in human emotion and robot emotions projection. Section 3 introduces the robotic platform and the software used in the experiment. The experiment's design is explained in section 4. Finally sections 5 and 6 presents the study done and the obtained results.

## 2 Related Work

Although it is not possible to apply a direct mapping from human studies to robots [33, 3], human studies provide guidelines about possible features and values that could be used to generate emotional motion.

### 2.1 Human Studies

Emotion plays an important role in human-human interaction, and can be expressed through diverse channels such as body gestures and poses, body movements, face expressions. Given the complex structure of human face, where more than 43 muscles act, face configurations are considered as a primary channel to express emotion. As a consequence, many works have focused on facial expression, mainly, but not only, influenced by the work done by Ekman [13]. Fortunately, the role that body plays in emotions projection has been recognized and has started to be studied [15, 36]. Nevertheless, the amount of works related to body expression of emotions is still small compared to studies on facial expression.

Analysing some of the few works that have studied human body expressiveness, it is possible to recognize two different methodologies to create the data base of movements to be assessed during the experiments. Applying a first methodology, human actors (either professionals, or amateurs) are asked to walk straight from point A to point B conveying specific emotions [9, 25, 36]. Each trial is recorded and later shown to each subject, who evaluates all the sequences. The second methodology uses virtual agents [31, 35] to generate the very same set up for the experiments; the agent's movements are generated from the data recorded from human actors.

The work done by Wallboot [36] has been used as a referenced by others. His work addressed the question: *Are specific body postures indicative of emotion or are they only used to indicate the intensity of the emotion?* To answer this question, he recorded 224 videos for joy, happiness, sadness, despair, fear, terror, coldness anger, hot anger, disgust, contempt, shame, guilt, pride, and boredom, and showed them to the subjects. His results reaffirm that movement and body postures are indicative of intensity for some emotions, while, for other emotions, these two characteristics seem to be enough to identify them.

Complementary studies using virtual agents have been performed by Kluwer and collaborators [8], who studied the contribution of postures and angle view in the interpretation of emotions. They generated 176 static positions for happiness, anger, disgust, fear, sadness and surprise. Each image was later rendered from three different angles (front, left, and above and behind left shoulder) producing a total of 528 images. All the participants were exposed to all 528 images and were asked to label the image with the emotions that best represent it. Their results show that five out of six emotions were quite weel recognized independently from the angle of view. However, disgust was in some postures confused with fear.

The main drawback of all these projects is the use of video recorded sequences, which misses the impact related to a complete physical experience.

### 2.2 Robotic Studies

The direct consequence of the abundance of works in face elicitation in humans is the amount of works done in Human-Robot Interaction (HRI) focused also on faces. One of the most well-known expressive robots is Kismet [5], a robotic face able to interact with people and to show emotions. The face had enough degrees of freedom to portray the basic emotions suggested by Ekman [13] (*happiness*, *surprise*, *anger*, *disgust*, *fear*, and *sadness*) plus *interest*. The face's physical design was done so to invite humans to treat it as if it was a social creature. The interaction studies done with this platform were conceived to consider a person as a caregiver and the robot as the receiver; it seems that the system was capable to engage people in a long term interaction. To achieve this goal, the system had six sub-systems: vision, hearing, motivational, behavioral, speaking, and emotion selection system. Despite the complex system behind Kismet, the emotion's projection evaluation was done using videos with a very limited number of participants. In this experiment, each participant was asked to look at seven videos, one for each implemented emotion. After a video was projected, each participant selected the emotion from a list containing the seven implemented emotions, only. The results showed a percentage of recognition over 57%.

Saerbeck and Christoph [32] analyzed the relationship between robots' motion characteristics and perceived affect. They first did a literature review to select characteristics that could be used to show affection. From their literature review, they decided to use acceleration and curvature on robot's trajectory. Using these two characteristics, they did an experiment with eighteen participants. For the experiment they used two different platforms (iCat and Roomba) to verify if the embodiment had any impact on affection determination. For the Roomba researchers decided to use a circular trajectory in the room. While for the iCat two objects were place in front of it. It starts in a central position to then move to the left right and back to center. To reduce variables' possibilities, they picked three definite values for each variable. Each participant was exposed to both embodiments and all possible variable combinations. To assess participants' perception, they used PANAS [37] and Self-Assessment Manikin (SAM) [22]. Their results show that there was no significant difference between the two embodiments used and that participants were able to assign different emotions to the movement patterns shown to them. More importantly, they found out that acceleration is correlated with the perceived arousal but not with valence.

As part of their work on detecting emotions in humans, with a case of use in robot games, Lourens and Barakova [2] implemented a set of behaviors to determine the emotion perceived from movement. The behavior parameters were selected based on the work done by Camurri et al. [7]. To focus participants' attention on movement, they used the e-puck platform [26]. Their experiment is not fully described, but authors highlighted that the subjects were not given any list with possible emotions, rather they asked participants how they think that the robot was feeling. The results showed a very high recognition rate for the implementations of sadness, nervousness, and fear. The implementations for anger and happiness were confused.

Barakova and collaborators used a closet robot [17], which does not show any anthropomorphic resemblance, to study new possibilities in social interaction. This closet robot can perceive human presence and react to show behaviours that could be perceived as emotions or mental states. The closet robot had several sensors to detect human state and several lights to convey its behaviours. The robot's behaviours were defined using the Interpersonal Behaviour Circle (ICB) [23], which is based on two dimensions (dominance-submission and hate-love). A pilot to test the five implemented behaviours was made. The five behaviours correspond to two implementations of dominance, two of submission, and a neutral behaviour. These behaviours differ from each other in the way that the light is turned on and its intensity. From pilot's results, they selected two most convincing behaviours, one dominant and one submissive. Using these two behaviours, they did an experiment with three different scenarios, in which all the participants were exposed. To measure participants' appreciations, they used the Social Dominance Orientation (SDO) [?] questionnaire and SAM. Their results suggest that people prefer systems that display submissive behaviors. More importantly, their findings suggest that electronic systems can elicit a type of reactions different from the one expected on theories of interpersonal communication.

Using a humanoid platform NAO [30], Cañamero and collaborators [3, 4] studied the perception of key body poses designed to show emotions. They suggested that the techniques used to convey emotions in virtual characters could not be used in robots, due to the fact that virtual characters have no physical constraints, while robots are constrained by their physical capabilities [33, 3]. They proposed a set of poses that could be used to express emotions with NAO, paying a particular attention to the contribution of the head. They did two experiments in which they show the participants different poses and each participant had to pick one emotion from the list given to them. The list presented to the subjects included six emotions: pride, happiness, excitement, fear, sadness and anger. Their results showed a recognition rate of 88%, 85%, 92%, 88%, 73%, and 73% for anger, sadness, fear, pride, happiness and excitement respectively. The major finding from their experiments is that moving the head up improved the identification of pride, happiness, and excitement. While moving the head down improved the identification of anger and sadness. However, these key poses are taken statically, without any displacement of the robot in the environment.

Li and Chignell [24] used a teddy bear robot capable to move its arms and head to study their contribution on emotion projection. To achieve this, they did a total of four studies. In the first one, four participants were asked to create a gesture that the robot would do in one of the twelve scenarios presented to them. These gestures were recorded and used in the second study. The experiment consisted of two parts: one just showing the gestures, and the second one describing a scenario were the gestures were generated. The participants had to select from a list the emotion that they thought the robot was conveying. The list included basic emotions and mental states, which were selected from the comments obtained during the first study. The results showed that giving a context increased the recognition rate. In the third experiment, they asked five novices and five puppeteers to create gestures for each of the six Ekman's basic emotions. The gestures generated were recorded and used as input in their last test, where the subjects had to select an emotion from a list including the names of the six basic Ekman's emotions. Their results showed that it is possible to convey emotions just using movements in the head and arms. Also they found out that the gestures made by the puppeteers had a better recognition for disgust and fear. Although they presented numerical information about their findings, this information is shown in a way that is not possible to discern the recognition rate of each emotion for each experiment.

Daryl [14] is an anthropomorphic robot, without facial expression, nor limbs, but with mobility capabilities. This platform was used to test whether it is possible to project emotions without using cues used in a human-like platform (e.g., tail, ears and head). This robot has head, ears, ability to generate colors in a RGB-LED set positioned in its chest, and a speaker system. The head had no capabilities to show facial expressions, but its movements and robot translations were used to show emotions. The emotions implemented were: happiness, sadness, fear, curiosity, disappointment, and embarrassment. During the experiments done by the researchers, special attention was put to the final distance between the robot and the subject, but the approaching velocity and the followed trajectory were not taken into consideration. The subjects were exposed to a sequence of movements. For each sequence the subject was asked to rate the intensity of each emotion enlisted in a five-point Likert scale questionnaire. The enlisted emotions were the six implemented plus anger, disgust and surprise. Their results showed that participants gave a higher intensity to the desired emotion, also similar ones, such as sadness and disappointment.

Using the platform WABIAN-2R, Destephe and collaborators [11] studied the attribution of emotion to a robot's gait. To obtain the robot's movements, the researchers asked two professional actors to walk in a room conveying anger, happiness, sadness, and fear with different intensities (low, regular, normal, high, and exaggerated). All the actors' walking were recorded using a Cortex motion capture system. These data were later reported to robot's embodiment. To verify their data, the researchers first did a pilot study with just two emotions (happiness and sadness) and thirteen subjects [10]. Each subject was exposed to a series of videos. After each video, the subject was asked to select one emotion from a list (happiness, neutral, or sadness) and to state the intensity of the selected emotion. The videos showed were not made with the real robot, but with a virtual model of the robot. From the results obtained, they decided not to use the low intensity because it had a very low recognition rate. During the experiment they adopted the same procedure, emotion and its intensity, but this time showing all the emotions and intensities, excluding low, to the participants. Their results showed that sadness was recognized 73.81% (average) of the times with an intensity of 21.43%, happiness was recognized 66.67% (average) of the times with an intensity of 30.95%, anger was recognized 61.9% of the times with an intensity of 26.19%, and fear was recognized 83.33% (average) of the times with an intensity of 28.58%. These results show that people could reasonably well recognize emotions from the robot's gait.

Lakatos and Collaborators [21] take inspiration from human-animal interaction to create behaviours that could enrich human-robot interaction. They conducted an experiment to analyse the recognition rate of emotion expression, using as inspiration the movements done by dogs to convey emotions. The experiment was done using a Wizard-of-Oz scene and its goal was to determine if people could distinguish two emotions (happiness and fear). They use a game approach to determine participant's appraisal of the robot emotion. This was done in order to avoid asking the participants the emotion they believe the robot is eliciting. Therefore, in the experiment, each participant had two balls (yellow and black) and they could play with the robot using one of this balls at a time. However, one of the balls triggers robot's happiness and the other fear. The dog's favourite ball was changed from participant to participant to avoid any bias for the balls' color. The results of this experiment showed that the participants decided to use more dog's favourite ball to play with the dog, which is consistent with the idea that the participants could discern which ball produced "happiness" in the robot.

Brown and Howard focused their interest on head and arm movements using the DARwIn-OP platform [6]. Their hypothesis was that using some principles, that they evaluated as important, it is possible to express happiness and sadness in a way that people could recognize. These principles establish that to show happiness is necessary to quiclkly move robot's head up and arms up. While to express sadness the head goes down, arms down, both slowly. To test their hypothesis they conducted an experiment with thirteen participants. Each participant was exposed to fifteen sequences of poses and he/she had to answer for each sequence a five-point Likert scale (very-sad to very happy, with neutral in the middle). They obtained a 95%, 59%, and 94% of accuracy for happiness, neutral and sadness respectively. Although their results show that their key features are determinant to convey happiness and sadness.

Sharma and collaborators [34] used a quadrotor to study how different Laban's effort [20] parameters could impact on the perception of affection. A professional Laban certified actor was asked to generate 16 different paths, for each one changing one of the four Laban's parameters (space, weight, time, and flow). Each generated path was recorded using the Vicon motion-tracking system. Then, they did an experiment were people were asked to assess each path using the Self-assessment Manikin (SAM) [22]. In order to analyse the results, they mapped them on the circumplex model of emotion, and evaluated the contribution of each Laban's parameter in the 2-D circumplex model (arousal and valence). The results show that it is possible to increase both valence and arousal by using a more indirect space, or by performing the motion more quickly, and to decrease valence or arousal by a more direct use of space, or a more sustained motion. Although they suggest the use of Laban's model as a tool to specify affection movements in Human-Robot Interaction, how to use these parameters in the actual implementation remains an open question, since Laban defined them qualitatively, with reference to human people, and they leave very open questions about the most appropriate numerical values to be used with robots.

Suk and collaborators studied the human emotional interpretation for speed, smoothness, granularity and volume of a non-human or animal like object [27]. Two experiments were designed to determine the relationship among these features and the emotional interpretation. To assess participants' emotional response they used SAM. The first experiment was focused on speed and smoothness movement features, selecting five different values for each one of these two features. Each participant was exposed to twenty five movements. After a participant observed a movement, the participant marked the two SAM graphic figures (pleasure and arousal). The results from this first experiment show that the arousal increases as speed increases, but that there is not any clear tendency for smoothness. In the second experiment they evaluated the other two features (granularity and volume) using the same procedure followed in the first experiment. Their results show that granularity is positively correlated with pleasure and arousal, while volume is negatively correlated with pleasure and positively correlated with arousal. As overall result, they found a major contribution of speed on arousal and minor contribution of granularity and volume.

To improve the coordination between humans and robots Novikova and Watss [28] proposed the use of emotion. They did studies using a own built platform called E4 to verify whether people could detect emotions from a non-human like platform. The E4 platform was constructed using a Lego Mindstorms NTX and it was based on a Phobot robot's design. In all their experiments they used six emotional expressions (scared, surprised, excited, angry, happy, sad) and neutral. The emotion list used in their experiments was balanced using the 2-D circumplex model (arousal and valence), selecting three from each quadrant for a total of twelve emotions, plus the options of "other" and "don't know". They obtained a recognition rate of 52%, 42%, 41%, 36% and 15% for surprise, fear, sadness, happiness, and anger respectively.

These works presented in this section provide guidance about features that could be exploited to project certain emotions. However, range of values to convey specific emotions will guide other researchers in what values could be used to convey their desire emotion or what values not to use because they could be misinterpreted as negative emotions.

## 3 The System

The system used in the experiment is composed by a non-anthropomorphic platform and software architecture that enrich robot's movements with emotion. The robotic platform was envisioned to be as simpler as possible to let the study of the desired characteristics.

### 3.1 Hardware and Mechanical

A holonomic platform was built to be used in the experiment. This type of platforms are characterized by the possibility to move in any direction without the necessity to have a specific orientation, i.e., they are free to move taking any desired orientation. Therefore, it was possible to imitate movements that are done by humans. For example, people move straight even if they turn their whole body a bit. The platform has a diameter of 25 cm and height of 25 cm. Figure 1 shows the platform's blue prints and the real platform. Robot's frame of reference, in which all the velocities are going to be calculated, are depicted by the two black arrows. So, as it could be observed, to make the robot move forward it must be send a velocity in $y$ axis.

### 3.2 Software

To ensure robot's velocity it was implemented a PID controller for each motor. PID's set point is established by a controller that could receive two different types of commands. The first commands is robot's velocities ($< V_x, V_y, \omega >$), which are given in robot's frame of reference. The second command is a point ($< x, Y, \theta >$), which is given in the general frame of reference. This frame of reference is set every time the system is reset or boot. For example, if the robot finishes a trajectory and then it is reset, the new frame is going to be in the robot's current position.

Additional to this low level control, it was created a graphical interface 2 to reduce the possibility on introducing wrong values for a desired sequence. This interface loads the sequences from a .txt file and displays sequences' numbers on it. Every time that a new sequence should be presented to a participant, the sequence's number is selected in the interface, which will display sequence's values. Once the robot has been positioned to the correct position, the execution could be started by clicking on send button. Here two commands are send, one resetting the controller and the second the desire position. In case that the sequence's execution should be aborted, it should be clicked the button stop.

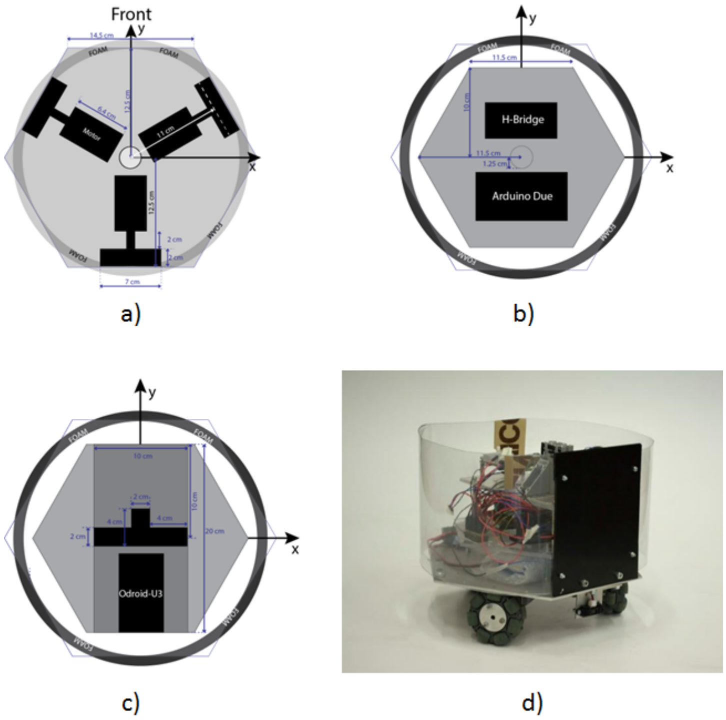


**Fig. 1** Design of the platform. a) Base platform, this layer is used to carry the batteries. The two black arrows represent robot's frame of reference. b) First layer, which includes the Arduino and the H-Bridges to control the motors. c) Second layer with the Odroid-U3 and the mechanical structure to support the upper part. d) Lateral view of the version.

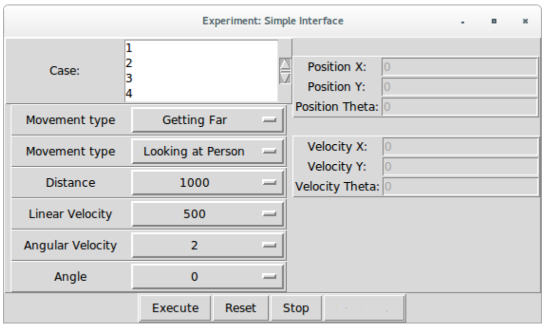


**Fig. 2** Interface used in the experiment. Once a sequence is selected, the interface shows sequence's values. Also, the interface give information about the current position of the robot and its velocity.

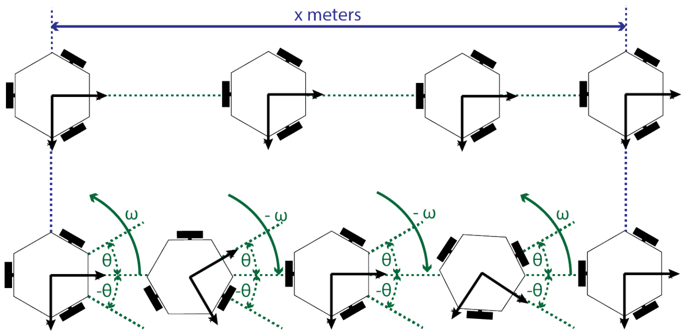


**Fig. 3** Example of the features used in the experiment. $x$ represents the displacement in meters, $\omega$ is the angular velocity ($rad/s$) and $\theta$ the oscillation of the body around its center ($rad$). The upper sequence depicts a movement based only on linear velocity, while the bottom one shows a sequence with angular and linear movement. The two black arrows in the robot's middle depict robot's frame of reference.

## 4 Experiment's Design

The experiment was designed to get a better understanding about the contribution linear and angular velocity, oscillation angle, direction, and orientation to express happiness, anger, sadness and fear, which are four out of six emotions considered by Ekman [13] as basic emotions.

### 4.1 Independent Variables

The definitions of the selected independent variables are reported here below.

- **Angular velocity** is the rotational speed ($\omega$) of the robot with respect to its center.
- **Oscillation angle** is the maximum extension in which the robot will rotate around its center in the oscillating movement ($\theta$).
- **Linear velocity** is the rate of change of the position of the robot ($V$).
- **Direction with respect to participant's perspective** is the angle generated from the participant's point of view with respect to the robots trajectory ($D$).
- **Orientation of the body with respect to participant's perspective** is the robot's body orientation with respect to the robot's trajectory ($\phi$).

The three first variables are shown in Figure 3. As it could be observed, robot's frame of reference is draw to show that it could move straight while is rotating.

### 4.2 Dependent Variables

- **Emotion:** is the feeling perceived by the participants from the robot's movement. From previous experiences , it was decided to ask the participants to select an emotion name in a list including the four emotions intended to be expressed, two mental states that could be misinterpreted from these emotions, and the option of "other", where participants could write their own interpretation. The two states of mind included as confounding terms are tenderness and excitement, which correspond to low and high arousal states.

– **Emotion's intensity:** indicate the emotion intensity as perceived by the subject. This variable is measured on a ten point scale rate, ranging from 0 to 10, where 0 means that the corresponding emotion is not perceived by the subject and 10 that the emotion is highly perceived by the subject.

### 4.3 Independents' Variables Values

It was decided to select specific for all independents variables, discrete values to make the experiment feasible. First, a simple test to evaluate when significant changes could be perceived was performed on a small sample of independent subjects. Base on this test specific values for oscillation angle, and angular and linear velocities were selected. For the remaining two variables were selected the cases that could be beneficial for the experiment. The chosen values are shown in Table 1.

**Table 1** Possible values for each of the independent variables.

| Variable \ Possibilities | First | Second | Third | Fourth |
|---|---|---|---|---|
| Angular Velocity ($rad/sec$) | 0 | 1 | 2 | 3 |
| Oscillation Angle ($rad$) | 0 | 0.087 | 0.175 | 0.349 |
| Linear Velocity ($mm/sec$) | 0 | 200 | 500 | 900 |
| Direction ($rad$) | 0 | $\pi$ | $\frac{-\pi}{2}$ | |
| Orientation ($rad$) | 0 | $\pi$ | | |

To get a better idea about the Direction and Orientation values, in Figure 4 are reported all the possibilities for these two variables.

The experiences, meant as desired procedures to compare [29], were generated from the combination of independent variables' values for a total of 384 combinations. All the experiences that would not add any significant information to the experiment were deleted, such as experiences with $\theta = 0$ and $\omega \neq 0$, which reduced the total amount of treatments to 195.

### 4.4 Participants' Sequence

It was decided that each subject will be just exposed to twenty over one hundred and ninety five possible experiences, which lasted from 10 to 15 minutes. This was decided because each subject was a volunteer and would not perceive

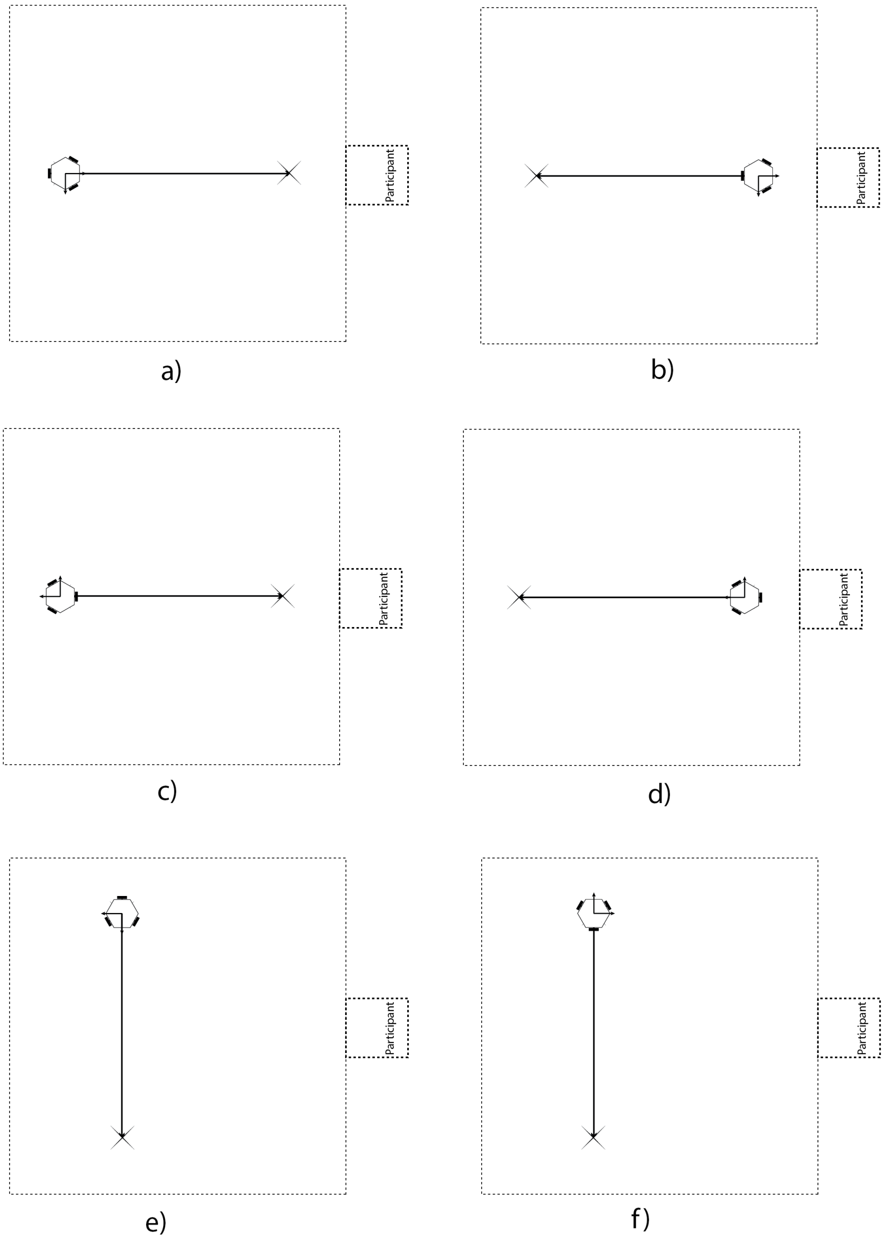


**Fig. 4** Combination of direction and orientation. The crosses symbolize the final position. The robot represents the initial position with its orientation, which is represented through the robot's frame of reference. The dash big square represents robot's movement zone, while the small represents participant's zone. a) Direction = 0 and Orientation = 0. b) Direction = 0 and Orientation = $\pi$. c) Direction = $\pi$ and Orientation = $\pi$. d) Direction = $\pi$ and Orientation = 0. e) Direction = $\frac{-\pi}{2}$ and Orientation = 0. f) Direction = $\frac{-\pi}{2}$ and Orientation = $\pi$

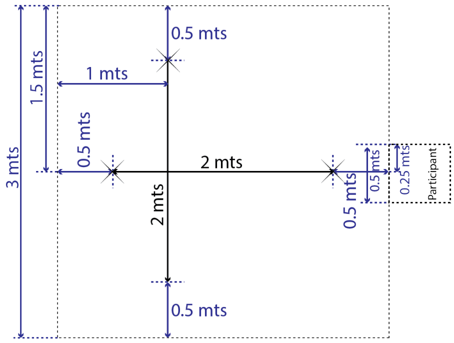


**Fig. 5** Setup for the experiment. The crosses symbolize the possible starting points.

any monetary remuneration, so the time dedicated to the experiment had to be kept limited. The twenty treatments were selected picking a number without replacement from 1 to 195.

### 4.5 Setup

The experiment's setup and dimensions are shown in the Figure 5. The crosses symbolize possible starting points, which were selected depending on the direction's value, as it is showed in Figure 4.

## 5 Study

The information about all the subjects was collected using a Google form. To maintain participants anonymity, not personal information that could be used to trace them back was collected. The procedure used with each subject is described here below.

1. The subject was asked to fill out the following information:
   – Sex
   – Career
   – Age
   – Country of origin.
2. The robot was shown to the participant and the experiment procedure is explained.
3. An example of the questionnaire was presented and a sample movement of the robot shown.
4. The subject is exposed to a specific movement sequence according to the following steps:
   (a) The subject is exposed to the movement generated by a configuration of values.

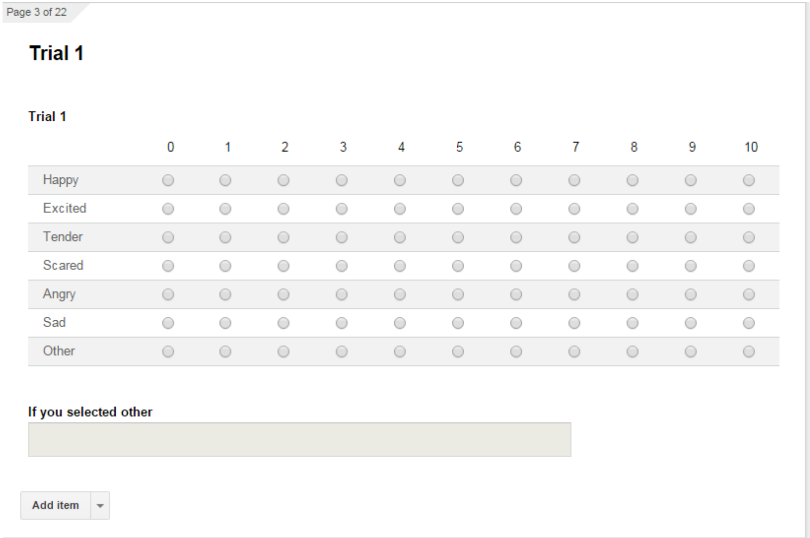


**Fig. 6** Example of the questionnaire used in the experiment.

(b) The subject could use as much time as needed to select values for intensity of the different terms in the questionnaire.
(c) After the subject had completed his/her selection about the current movement, the sequence is repeated for the rest of movements.

The order of the options enlisted in the questionnaire changed for each question to prevent any kind of bias. Figure 6 shows an example of the questionnaire used. The experiment was performed at Politecnico di Milano, involving subjects with different backgrounds. A total of 49 volunteers were involved: 12 females and 37 males. The average age of the subjects was 25.28, with standard deviation of 2.8, with a minimum age of 20 and maximum of 32. The subjects' country of origin and their backgrounds are shown in the Table 2 and Table 3, respectively.

**Table 2** Subjects' Country of origin.

| Country | Counting |
|---|---|
| Albania | 1 |
| Bosnia | 1 |
| Brazil | 2 |
| Colombia | 4 |
| Germany | 1 |
| Greece | 1 |
| Iran | 5 |
| Italy | 33 |
| Moldova | 1 |

**Table 3** Subjects' Background.

| Career | Counting |
|---|---|
| Aeronautical Engineering | 1 |
| Architecture | 1 |
| Social assistance | 1 |
| Automation | 1 |
| Bio-medical Engineering | 5 |
| Computer Science | 33 |
| Electronic Engineering | 2 |
| Mechanical Engineering | 2 |
| Nursery | 1 |
| Pedagogical Science | 1 |
| Tourism | 1 |

**Table 4** Example of the table generated for each movement. This table corresponds to the treatment with $ID = 1$.

| Sex | Background | Age | Country of Origin | Happy | Excited | Tender | Scared | Angry | Sad | Other | Explain |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Masculine | electronic engineering | 29 | Iran | 0 | 2 | 8 | 0 | 0 | 0 | 0 | |
| Feminine | Computer science | 25 | Italy | 0 | 0 | 6 | 0 | 0 | 8 | 0 | |
| Masculine | Computer science | 24 | Italy | 0 | 0 | 0 | 8 | 0 | 7 | 0 | |
| Feminine | Science pedagogiche | 26 | Italy | 0 | 0 | 0 | 0 | 0 | 0 | 7 | Dubbioso |
| Masculine | Computer science | 24 | Italy | 4 | 8 | 0 | 0 | 0 | 0 | 0 | |

## 6 Results

A total of 980 answers were collected, and a minimum of 5 trials for each motion type. A table with participants' answers was generated for each treatment. Table 4 is an example of the generated tables.

For each table, mean, standard deviation, and median were calculated. It was not possible to use ANOVA test over the data because the assumption of normality is not achieved in the collected data. This was checked using the Shapiro-Wilk Test. Additionally, a contingency table for each emotion was generated in each treatment as it is depicted in Table 9, where the intensity for the rest of emotions is calculated as their mean, including the option of other. For all tables, including the contingency, the Krippendorff's alpha agreement [19] ($\alpha$) was calculated: it is a reliability coefficient to measure the agreement among different participants. Unlike other coefficients (e.g., $Kappa$), $\alpha$ is a generalization of several known reliability indices, and it applies to: any number of observers, any number of categories, any type of data, incomplete or missing data, large and small sample sizes.

This calculation was done using the R's package *irr*. To improve the table interpretation, it was decided to just register the emotions' alpha values that had a mean greater than zero. The $\alpha$ for each treatment is shown in Figure 7. Additionally, for each emotion was generated a table with a top ten ranking treatments that considers the following items:(i) the mean intensity of the respective emotions, (ii) the alpha agreement for the respective emotion, and (iii) the alpha agreement for the specific treatment. To generate these tables, were first organized by the mean, then by the emotion's agreement and finally by the general agreement. The decision to give more importance to emotion's alpha was taken based on the situation that the participants could be agreed about the precise emotion but not for the rest of the words enlisted. From the resulting tables 5, 6, 8, and 7, it is possible to notice:

- Fear was the only emotion that had six over ten movements obtaining both general and specific alpha agreement over 0.41, which is the lower bound for moderate agreement [1]. Also, it was mostly selected (eight over ten) when $direction = \pi$ and $orientation = \pi$. The angle and the angular velocity attributed six over ten times were 0.087 and 2, respectively. So it seems that people perceive as fear when the robot is looking at them and moving far from them fast.
- Sadness was mostly attributed to linear velocities of $0mm/s$ (two over ten) and $200mm/s$ (eight over ten), and angular velocities of $0rad/s$ and $1rad/s$, with higher predilection of the second (eight over ten). It seems that people attribute sadness to slow velocities with slow angular velocity and small oscillation angle. Regarding the other two features, there is not a concrete pattern that could lead to make a generalization.
- Happiness is attributed to different values of the independent variables. But it is the only emotion that is highly perceived when the linear velocity is 0 with four over ten. However the oscillation angle for these four cases is equally divided between the values 0.174 and 3.49. So it seems that happiness is mainly attributed to fast angular velocities and big oscillations angles. However specific agreement among the other features is not present.
- Anger is highly perceived with an angle of 0.087 (seven over ten) and with linear velocities over $200mm/s$. It seems that people attribute anger to fast velocities, both angular and linear, small angle of oscillation and the robot facing the person when it is approaching them.

**Table 5** Top 10 attributions for Happiness. This tops table was generated by ordering the results from highest to lowest first by Happy mean, then by Happy alpha, and finally by Movement alpha.

| Features | | | | | Alpha | | | | | | | | Mean | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Direction (rad)** | **Orientation (rad)** | **Linear V. (mm/sec)** | **Angular V. (rad/sec)** | **Angle (rad)** | **General** | **Happiness** | **Excitement** | **Tenderness** | **Fear** | **Anger** | **Sadness** | **Other** | **Happiness** | **Excitement** | **Tenderness** | **Fear** | **Anger** | **Sadness** | **Other** |
| 0 | 0 | 500 | 3 | 0.349 | 0.38 | 0.71 | 0 | 0 | 0 | 0.13 | 0 | 0.13 | 6.8 | 3 | 2.6 | 0 | 1.4 | 0 | 1.4 |
| $-\frac{\pi}{2}$ | 0 | 0 | 2 | 0.174 | 0.53 | 0.71 | 0 | 0 | 0 | 0 | 0 | 0 | 6.8 | 3.8 | 2 | 0 | 0 | 0 | 0 |
| 0 | 0 | 900 | 3 | 0.174 | 0.33 | 0.22 | 0 | 0.13 | 0 | 0 | 0 | 0 | 6.6 | 2.6 | 0.6 | 0 | 1.6 | 0 | 0 |
| $\pi$ | $\pi$ | 0 | 3 | 0.349 | 0.21 | 0.21 | 0 | 0.13 | 0 | 0.23 | 0.34 | 0 | 6.6 | 3.6 | 1.4 | 2 | 0.8 | 0.4 | 0 |
| $\pi$ | 0 | 900 | 3 | 0.349 | 0.48 | 0.11 | 0.72 | 0.12 | 0 | 0.76 | 0 | 0 | 6.4 | 6.8 | 1.2 | 4 | 0.2 | 0 | 0 |
| 0 | $\pi$ | 0 | 2 | 0.349 | 0.34 | 0.71 | 0 | 0 | 0.13 | 0.47 | 0.23 | 0 | 6 | 1.4 | 3.2 | 1.6 | 0.4 | 0.6 | 0 |
| $\pi$ | $\pi$ | 0 | 2 | 0.174 | 0.31 | 0.12 | 0 | 0 | 0.61 | 0 | 0 | 0.13 | 6 | 4.8 | 4.8 | 0.4 | 0 | 0 | 2 |
| $\pi$ | 0 | 500 | 2 | 0.349 | 0.43 | 0.11 | 0 | 0 | 0 | 0.13 | 0 | 0 | 6 | 0 | 3.4 | 0 | 0.6 | 0 | 2 |
| 0 | 0 | 500 | 1 | 0.174 | 0.24 | 0.11 | 0 | 0 | 0 | 0 | 0 | 0.13 | 6 | 4 | 4.2 | 0 | 2.2 | 0 | 1.2 |
| $\pi$ | 0 | 200 | 3 | 0.349 | 0.28 | 0.22 | 0 | 0 | 0 | 0 | 0 | 0 | 5.8 | 0.8 | 3 | 0 | 0 | 0 | 1.4 |

**Table 6** Top 10 attributions for Anger. This tops table was generated by ordering from highest to lowest first by Angry mean, then by Angry alpha, and finally by Movement alpha.

| Features | | | | | Alpha | | | | | | | | Mean | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Direction (rad)** | **Orientation (rad)** | **Linear V. (mm/sec)** | **Angular V. (rad/sec)** | **Angle (rad)** | **General** | **Happiness** | **Excitement** | **Tenderness** | **Fear** | **Anger** | **Sadness** | **Other** | **Happiness** | **Excitement** | **Tenderness** | **Fear** | **Anger** | **Sadness** | **Other** |
| 0 | 0 | 0 | 2 | 0.087 | 0.19 | 0 | 0.13 | 0.13 | 0.13 | 0.22 | 0 | 0 | 3.2 | 1.4 | 1.2 | 1.8 | 6.4 | 0 | 0 |
| 0 | 0 | 900 | 2 | 0.087 | 0.29 | 0.13 | 0 | 0.76 | 0.13 | 0.21 | 0 | 0 | 1.6 | 3.8 | 0.2 | 1 | 6.4 | 0 | 0 |
| $-\frac{\pi}{2}$ | 0 | 900 | 0 | 0 | 0.60 | 0 | 0 | 0 | 0.13 | 0.73 | 0 | 0 | 0 | 1.6 | 0 | 1.4 | 6.2 | 0 | 0 |
| 0 | 0 | 900 | 3 | 0.349 | 0.44 | 0 | 0 | 0 | 0 | 0.12 | 0 | 0 | 3 | 5 | 0 | 2.8 | 6.2 | 0 | 0 |
| $-\frac{\pi}{2}$ | 0 | 200 | 3 | 0.087 | 0.41 | 0 | 0 | 0 | 0 | 0.11 | 0.47 | 0 | 0 | 4.8 | 2.6 | 0 | 5.8 | 0.4 | 0 |
| $\pi$ | 0 | 500 | 3 | 0.087 | 0.44 | 0.13 | 0 | 0 | 0 | 0.43 | 0 | 0 | 0.8 | 2.6 | 0 | 1.4 | 5.2 | 0 | 0 |
| 0 | 0 | 200 | 3 | 0.087 | 0.13 | 0.13 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2.4 | 5.2 | 0 | 1.8 |
| 0 | 0 | 900 | 1 | 0.087 | 0.54 | 0 | 0.16 | 0 | 0 | 0.16 | 0 | 0 | 2.4 | 6.4 | 0 | 0 | 5 | 0 | 0 |
| 0 | 0 | 900 | 0 | 0 | 0 | 0.13 | 0 | 0.13 | 0.13 | 0 | 0 | 0.13 | 1.6 | 3 | 1 | 1.6 | 5 | 0 | 1.8 |
| $\pi$ | 0 | 500 | 2 | 0.087 | 0.30 | 0.13 | 0 | 0 | 0 | 0.21 | 0 | 0 | 1 | 1.8 | 0 | 3.4 | 4.8 | 0 | 0 |

**Table 7** Top 10 attributions for Fear. This tops table was generated by ordering from highest to lowest first by Fear mean, then by Fear alpha, and finally by Movement alpha.

| Features | | | | | Alpha | | | | | | | | Mean | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Direction (rad)** | **Orientation (rad)** | **Linear V. (mm/sec)** | **Angular V. (rad/sec)** | **Angle (rad)** | **General** | **Happiness** | **Excitement** | **Tenderness** | **Fear** | **Anger** | **Sadness** | **Other** | **Happiness** | **Excitement** | **Tenderness** | **Fear** | **Anger** | **Sadness** | **Other** |
| $\pi$ | $\pi$ | 900 | 2 | 0.174 | 0.85 | 0 | 0 | 0.15 | 0.83 | 0 | 0 | 0 | 0 | 0 | 1.2 | 9.6 | 0 | 0 | 0 |
| $\pi$ | $\pi$ | 900 | 1 | 0.087 | 0.73 | 0 | 0 | 0.15 | 0.79 | 0 | 0.79 | 0 | 0 | 0 | 0.6 | 9.6 | 0 | 0.2 | 0 |
| $\pi$ | $\pi$ | 500 | 3 | 0.087 | 0.41 | 0.13 | 0 | 0 | 0.75 | 0 | 0 | 0 | 2 | 3.4 | 0 | 9 | 3.6 | 0 | 0 |
| $\pi$ | $\pi$ | 500 | 2 | 0.174 | 0.33 | 0.24 | 0.24 | 0 | 0.34 | 0.24 | 0 | 0.25 | 1.33 | 1.5 | 0 | 7.83 | 0.66 | 0 | 1.66 |
| $\pi$ | $\pi$ | 500 | 2 | 0.087 | 0.68 | 0 | 0 | 0 | 0.72 | 0.13 | 0 | 0 | 0 | 0 | 0 | 7.8 | 0.6 | 2.20 | 0 |
| $\pi$ | $\pi$ | 200 | 2 | 0.087 | 0.44 | 0.13 | 0.13 | 0 | 0.66 | 0 | 0 | 0 | 1 | 1 | 1.2 | 7.6 | 1.6 | 0 | 0 |
| $-\frac{\pi}{2}$ | 0 | 0 | 2 | 0.087 | 0.35 | 0.35 | 0.13 | 0 | 0.22 | 0 | 0 | 0 | 0.4 | 1.2 | 0 | 7.4 | 3 | 0 | 0 |
| 0 | $\pi$ | 900 | 3 | 0.087 | 0.53 | 0 | 0 | 0 | 0.30 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 2.20 | 0 | 0 |
| $\pi$ | $\pi$ | 500 | 3 | 0.349 | 0.20 | 0.13 | 0.13 | 0 | 0.16 | 0.34 | 0 | 0 | 1.8 | 1.6 | 0 | 6.8 | 0.4 | 2.4 | 0 |
| $\pi$ | $\pi$ | 200 | 2 | 0.174 | 0.53 | 0 | 0 | 0.13 | 0.71 | 0.13 | 0.13 | 0 | 0 | 0 | 1 | 6.6 | 0.8 | 1.2 | 0 |

**Table 8** Top 10 attributions for Sadness. This tops table was generated by ordering from highest to lowest first by Sadness mean, then by Sadness alpha, and finally by Movement alpha.

| Features | | | | | Alpha | | | | | | | | Mean | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Direction (rad)** | **Orientation (rad)** | **Linear V. (mm/sec)** | **Angular V. (rad/sec)** | **Angle (rad)** | **General** | **Happiness** | **Excitement** | **Tenderness** | **Fear** | **Anger** | **Sadness** | **Other** | **Happiness** | **Excitement** | **Tenderness** | **Fear** | **Anger** | **Sadness** | **Other** |
| $\pi$ | 0 | 200 | 1 | 0.349 | 0.64 | 0 | 0 | 0 | 0 | 0.13 | 0.73 | 0.13 | 0 | 0 | 0 | 0 | 1.2 | 7.4 | 1.6 |
| 0 | $\pi$ | 0 | 1 | 0.349 | 0.39 | 0 | 0 | 0.13 | 0 | 0 | 0.22 | 0 | 0 | 0 | 1.8 | 0 | 0 | 7.2 | 3.2 |
| 0 | 0 | 200 | 1 | 0.349 | 0.18 | 0.13 | 0 | 0 | 0 | 0.13 | 0.11 | 0 | 1.6 | 2 | 5.4 | 2.6 | 1.6 | 6 | 0 |
| $-\frac{\pi}{2}$ | 0 | 200 | 0 | 0 | 0.10 | 0.13 | 0.29 | 0 | 0 | 0 | 0 | 0 | 0.8 | 0.4 | 1.8 | 0 | 0 | 6 | 3.2 |
| $\pi$ | $\pi$ | 200 | 1 | 0.349 | 0 | 0 | 0 | 0.13 | 0.13 | 0.14 | 0 | 0 | 0 | 0 | 0.6 | 1.4 | 1.2 | 6 | 2.4 |
| 0 | $\pi$ | 200 | 0 | 0 | 0.27 | 0.13 | 0 | 0 | 0 | 0 | 0.21 | 0 | 1.2 | 0 | 3.4 | 1.8 | 0 | 5.8 | 0 |
| $-\frac{\pi}{2}$ | 0 | 0 | 1 | 0.087 | 0.14 | 0 | 0.13 | 0.13 | 0.13 | 0 | 0.21 | 0.13 | 0 | 2 | 2 | 1.2 | 0 | 5.8 | 1.6 |
| 0 | $\pi$ | 200 | 1 | 0.349 | 0.40 | 0 | 0.13 | 0 | 0 | 0 | 0.57 | 0.13 | 0 | 0.8 | 3 | 3 | 0 | 5.6 | 0.6 |
| $\pi$ | $\pi$ | 200 | 0 | 0 | 0.32 | 0.69 | 0.69 | 0 | 0 | 0 | 0.16 | 0 | 0.2 | 0.2 | 1.2 | 3.2 | 0 | 5.4 | 0 |
| 0 | $\pi$ | 200 | 1 | 0.087 | 0.36 | 0 | 0 | 0 | 0 | 0 | 0.16 | 0 | 0 | 0 | 3.6 | 3.6 | 0 | 5.4 | 0 |

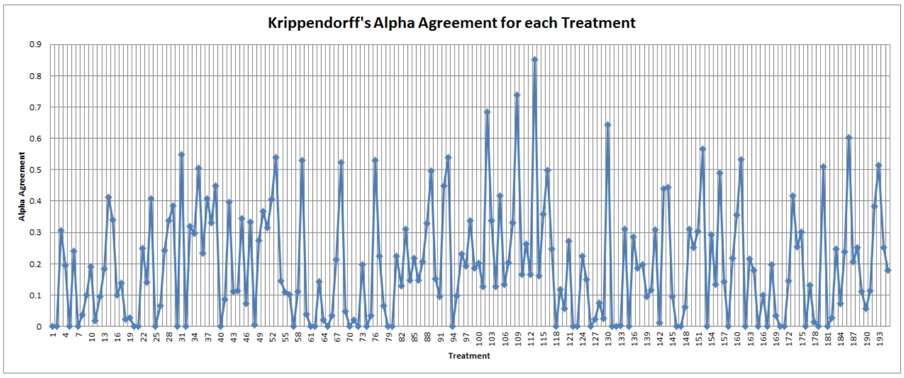


**Fig. 7** Alpha values for each movement.

**Table 9** Contingency table formula used for each emotion and treatment. Where $k$ is the kth treatment, $j$ is jth emotion for the kth treatment, $n$ is the total number of participants, and $Value$ is the intensity given by a participant.

| Participant | Desire Emotion | Other Emotions |
|---|---|---|
| 1 | $Value^1_{k,j}$ | $\frac{\sum_{i=1}^{i<=7\wedge i\neq j}(Value^1_{k,i})}{\sum_{i=1}^{i<=6\wedge i\neq j}(1)}$ |
| 2 | $Value^2_{k,j}$ | $\frac{\sum_{i=1}^{i<=7\wedge i\neq j}(Value^2_{k,i})}{\sum_{i=1}^{i<=6\wedge i\neq j}(1)}$ |
| ... | ... | ... |
| $n$ | $Value^n_{k,j}$ | $\frac{\sum_{i=1}^{i<=7\wedge i\neq j}(Value^2_{k,i})}{\sum_{i=1}^{i<=6\wedge i\neq j}(1)}$ |

## 7 Conclusions and Further Work

This paper presented an experiment made to understand the contribution of angular and linear velocity, body's orientation, and movement direction on humans' perception of emotion expression by a non-anthropomorphic platform. The emotions covered in this experiment correspond to four of those enlisted by Ekman [12] as basic emotions: anger, happiness, fear and sadness. To study the contribution of the desired features, a non-anthropomorphic, holonomic platform was used. The experiment was conducted at Politecnico di Milano, and involved 49 participants, each exposed to 20 over 195 movements, selected randomly for each participant. The Krippendorff's alpha agreement [19] was used to calculate the consensus about the interpretation of each treatment. Using alpha and the average emotion intensity attributed to each movement a top 10 movement table for each of the emotions was created.

The values obtained in this experiment could be used to express emotions in non-anthropomorphic platforms. It is still needed to cross validate the values and to determine what values from the top ten could be used more "accurately" to express the desired emotion. It is important to mention that is not expected to have a 100% of correct emotion recognition by the participants. As it has been observed in previous work in humans and robots, it is not possible to get a 100% of correct recognition. This cross validation would help to reduce the number of feature combinations to the ones with higher possibility of identification. Moreover, additional experiments should be done to obtain analogous values for changes in shape and in different platform's size.

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