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Exploring the Interaction Kinesics of a Soft Social Robot

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Abstract. In this pilot study, we explore the kinesics of a non-humanoid pneumatically actuated soft robot developed for social human-robot interaction (HRI). The robot uses motion and gesture to communicate: it can tilt; expand; and perform movements reminiscent of breathing. To explore the robot's kinesics, we hand-coded 8 movement presets intended to represent a specific action, internal state/emotion, or pattern of motion: greeting; avoid; breathless; joyful; alarming; jellyfish; frighten; sigh. We then conducted an online survey where participants (N=59) chose words to describe their perception of each preset behavior. Semantic analysis of word choices indicates that the intended meaning was conveyed to users for most of the presets. Analysis of the general comments with text mining techniques showed that the robot was perceived as resembling an animal-like sea creature or a human body part (lungs, belly, or heart) and as communicating distinct emotional states. The results indicate that it is possible to communicate with a user solely through soft robotic movement, and suggest that soft robotics has applications within the design of affective interfaces and social robotics.

Keywords: Soft robotics · Nonverbal communication · Kinesics · Zoomorphic · Human-robot interaction · Emotions

1 Introduction

Nonverbal communication (NVC) plays a significant role in human-human interaction and research has shown that up to 93% of human communication can be nonverbal [1]. Humans unintentionally emit nonverbal cues related to their emotional state that help others understand the their actions and verbal utterances. Kinesics is defined as nonverbal communication through facial expressions, gestures, body movements and positioning [2]. Kinesics are intuitively and routinely used in human interaction and compared to other forms of NVC, kinesics is highly informative and even on level with verbal communication [3], and may convey

rich information pertaining to both context and social interaction dynamics [4]. As humans have the innate psychological trait of anthropomorphism, robotic behaviors can be made more understandable by utilizing kinesics from human communication even in cases of non-humanoid social human-robot interaction (HRI). Kinesics-based robotics research has focused on arm gestures, body and head movements, eye gaze, and facial expressions [5]. Body kinesics encompass both static postures and dynamic movement. Body posture has been shown to define the steps and order in human interaction [6], while head movements are used to communicate a referent in narration through e.g., nodding or indexing [7, 8].

In this pilot study, we explore a soft silicone-based robot's potential for kinesics. We developed a custom-made pneumatically actuated soft robot specifically for social HRI. Research on soft robotics usually consider the tactile dimension of HRI, which is critical considering the increasing need for assistive robots [9]. However, prior work has shown that motion and shape-change in soft robots can be interpreted as socially communicative [10–13]. Hence, our robot solely relies on bodily motion and posture to communicate with a human interaction partner: it is able to tilt and expand its upper and lower parts and can perform movements reminiscent of breathing.

2 Materials and Methods

2.1 Robot

We chose an abstract zoomorphic design, as we did not want the robot to resemble nor a human neither a familiar pet, yet it should be perceived as endowed with the qualities of a living organism. The morphology has a rounded, organic shape that somewhat resembles a jellyfish (Fig. 1). The bottom part of the robot is split into three individually controllable separate air chambers. They allow the robot to tilt towards every direction within a full circle of 360 degrees, and also enable upward movement if inflated simultaneously. The top part houses a single chamber that when inflated makes the robot expand upwards, and increase in width. Small indentations in the silicone material were added to the top's surface to give it a textured skin-like appearance. The robot is 12 cm in diameter, and has a height of 6.2 cm. It was manufactured from Ecoflex 00-30 silicone through a multi-step casting process using 3D printed molds [14]. An Arduino UNO R3 with a custom 8 channel motor shield was used to control 4 electrical pumps and 4 solenoid valves for actuation using pneumatic supply tubing with 1.5/3mm ID/OD.

2.2 Movement Presets

To explore the robot's kinesics, 8 expressive movement presets were hand-coded. The first 3 were adapted from existing socially communicative movements described in the literature. The first two were based on the "*approach*" and the

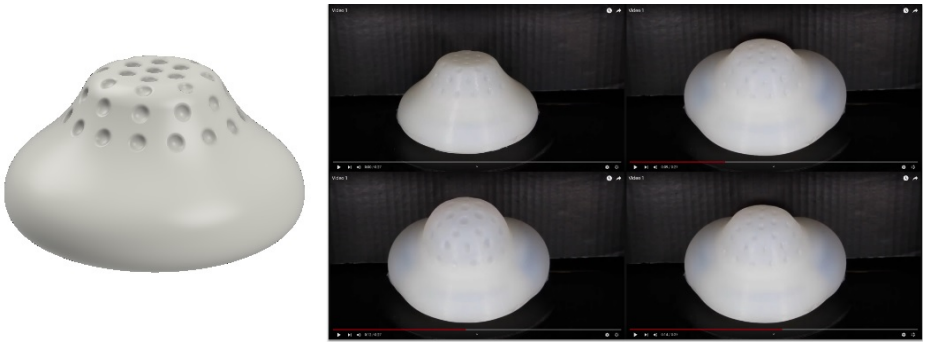

Fig. 1. CAD rendering of the soft robot morphology (left), and screenshots from Video 1 showing the physical robot (right).

"*avoid*" gesture used by the abstract robotic object the "Greeting Machine" [15]. In prior work these were found to respectively be perceived as signaling that the robot was and was not available for social interaction (i.e., a positive and negative opening cue). The third preset was based on a study finding that observing breath-holding in another person induces the effect of *"breathless"* (the feeling of not being able to breathe enough) in the observer [16]. The remaining 5 presets (*joyful, alarming, jellyfish, frighten, sigh*) were exploratory non-validated movements that we designed ourselves. An overview of the presets and hyperlinks for each video stimulus are provided in Table 1.

Table 1. Overview of expressive movement presets used in the study.

Preset name	Description	Source/inspiration	Video link
1. Greeting	*Tilts toward the observer; pause; top chamber performs slow breathing*	[15]	Video 1
2. Avoid	*Tilts toward the observer; tipping movement away from the observer; fast breathing performed with top chamber*	[15]	Video 2
3. Breathless	*Slow breathing with all chambers; no movement; small inflation; no movement; rapid breathing with all chambers*	[16]	Video 3
4. Joyful	*Circular motion of the top of the robot while top chamber breathes at medium rate*	Joyful dance	Video 4
5. Alarming	*Two bottom chambers inflate and tip the robot forward; top chamber breathes rapidly (repeats this sequence 3 times facing different directions*	Bird warning gestures	Video 5
6. Jellyfish	*Slow breathing performed with slight delay between top chamber and bottom chambers*	Motions of a jellyfish	Video 6
7. Frighten	*Bottom chambers filled with air; slow breathing going to fast breathing on top chamber*	Pufferfish defense	Video 7
8. Sigh	*Inflation of all chambers; no movement; full deflation*	Sighing	Video 8

2.3 Experiment procedure and stimuli

Due to Covid-19 restrictions, we conducted an online survey. Video recordings were made of each preset with the robot in front of a black background and used as stimuli (see Fig.1 - right). First, participants watched a demonstration video of the robot [4]. Participants were allowed to watch each video of a preset multiple times before answering. For all videos, participants were asked "After watching the video, how did you perceive the robot?". For the first 3 movement presets, we asked participants to choose words from a predefined list, including the words matching their intended meanings. Participants could choose multiple words for each preset. For the remaining 5 exploratory presets, participants were asked to respond with single words freely chosen. The data collection approach was inspired by prior work using word associations. Word associations have been used as a means to evaluate conceptual structures and changes in attitude or belief within psychology and social science research [17]. We adapt the method by using short expressive movement sequences, intended to convey a concept, state, or feeling, as stimuli, rather than a single word to gain access to spontaneous mental representations of what each preset signified. The questionnaire ended with four open-ended questions: "After having watched all the different videos of the robot, is there anything you would like to add?", "Did you compare the robot to something?", "Did the robot make you think of something?", and "How did the robot make you feel?".

3 Results and Discussion

3.1 Existing socially communicative movement presets

The distributions of words chosen by participants is shown in Fig. 2-Bottom. For all three presets, the word "Breathing" was the word most frequently chosen. We attribute this to the inflation used to actuate the robot.

The word choices for each of the 3 existing socially communicative movement presets were to some extent overlapping with the intended meanings, however not unambiguous (see Fig. 2). To identify characteristic words for each preset, one may compare how many times a word was chosen for the specific preset in relation to the other presets, and for each preset to list the words that had a higher prevalence than for both of the other presets.

The only word that was chosen more frequently for the *Breathless* preset was "Breathless". Yet, this was not the word that was chosen the most for this preset, indicating that the movement was not predominantly understood as expressing breathlessness.

Compared to the two other presets, the *Avoid* preset scored higher for the words "Alarming", "Impulsive", "Dominating", "Frightening", "Aggressive", "Irritated", "Aroused", "Angry", "Excited", and "Afraid". These words all refer

[4] The demonstration video of the robot is available at: https://youtu.be/xI2RGWL6cXI.

to being in an intense, alert, and outgoing state, which is consistent with emotions felt when trying to avoid a person, or a situation. However, the valence of this state seems to have been ambiguous to participants, as both negative words (e.g., "Frightening" and "Afraid") as well as positive words ("Excited") were scored higher.

The *Greeting* preset scored higher for "Breathing", "Organic", "Alive", "Calm", "Submissive", "Depressed", and "Happy". Here again the valence of the emotional state seems to have been ambiguous as both "Depressed" and "Happy" were scored higher. The remaining words that were scored higher describe a nonthreatening, living being in a tranquil state, which is compatible with the dominant interpretation of the *Greeting* motion as signalling openness to social interaction found in prior work [15].

3.2 Exploratory movement presets

Word association distributions for the 5 exploratory presets are visualized as a stacked bar graph in Fig. 2-Top. The graph includes all words that were mentioned 4 times, or more for one of the presets. Using the same strategy to identify characteristic words for each preset as above, we note that the *Frighten* preset was largely perceived as intended namely "Stressed", "Dominant" and "Aroused", *Alarming* was associated with activities that require higher breathing rates and intense emotions like "Working", "Heartbeat","Dancing", "Communicating" and "Searching", *Joyful* mostly triggered positive reactions like "Playful", "Joyful", "Dancing", and "Curious", while *Sigh* was confused with yawn (another paralinguistic respiration) and *Jellyfish* was associated to a relaxed, and calm breathing being.

3.3 General commments

We received 44 general comments. 11 were translated from Danish to English by a native speaker. To prepare the text corpus for analysis with the Voyant Tools open text mining environment [18] we removed common word endings like "-ing", "-ed","-s" to make our results more accurate. We chose to analyze the comments via text mining in order to have a quantitative and more objective approach to a completely subjective input. Figure 5 shows the collocates -directed network-graph of higher frequency keywords and terms that appear in proximity.

The collocates graph of the combined general comments indicate that the robot was perceived either as a jellyfish or animal-like sea creature, or as a human body part (specifically lungs, belly, or heart) and as communicating certain distinct emotional states.

4 Future work

As future work, we plan to develop more refined motion presets for the robot based on insights gained from this pilot study. In addition, we will integrate physical

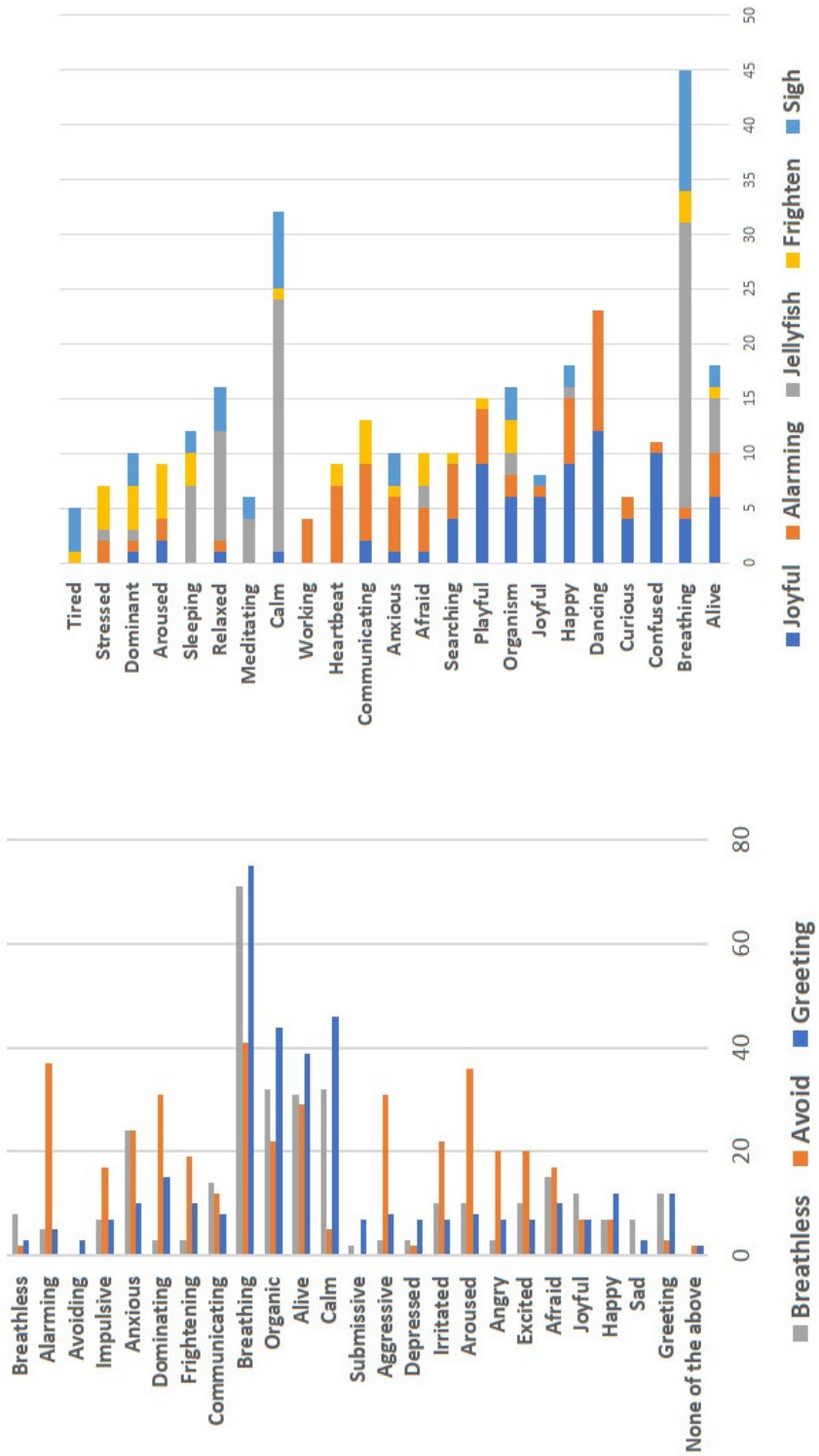

Fig. 2. Clustered (bottom) and stacked (top) bar charts showing the distribution of the words chosen for the presets. Bottom: Existing socially communicative movement presets. Top: Words with higher frequency for exploratory movement presets.

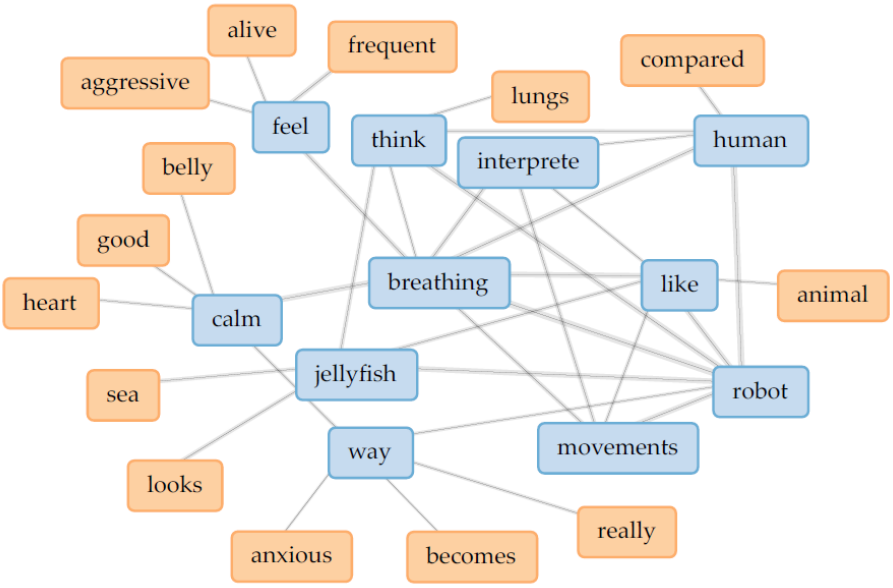

Fig. 3. Collocates graph of the general comments representing the main keywords in blue and their main collocates (up to 7 words in proximity) in orange.

sensors and computer vision to make the robot interactive, and explore adding additional NVC modalities including sound and light, to obtain both clearer and more complex communication, and plan to test whether they may contribute to e.g. communicating valence more clearly. Additional physical experiments are also required to elucidate the soft robot's potential for haptic interaction.

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