A systematic comparison of affective robot expression modalities

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Abstract— This paper provides a survey of the different means of expression employed by robots, to convey affective state to human recipients. The paper introduces a model of affective means (MOAM) to effectively describe and compare the emphasis on specific means and applies it to the surveyed robots. The model entails viewing the effect of applied means in light of how well the robot responds to external stimuli and with attention to how aligned the robot's means of affective expressions are with the intended working scenario. The model-based survey shows that a majority (85%) of the surveyed robots contain a category with room for additional affective means, and a quarter (25.6%) of the robots use a single or two affective means of expression to convey affective states. The result of the survey indicates there is an under-researched opportunity in exploring synergies between means of affective expression to amplify the overall affective impact of a robot.

I. INTRODUCTION

To improve the way robots interact with humans, the intentions of the robots need to be easy to interpret. This means that the information they convey about their current status and intentions is easily readable and warrants no further need for formal explanations [1]. One way to reach such communicative skills is by enhancing the interaction using affective means of expression. These means could be comprised of the robots appearances, the way they move, how they gesture and pose themselves, how they sound and whether we are familiar with what they portray [2], and lastly how they respond to incoming communication [3], [4].

In contrast to robots, humans use subtle cues such as body language, tone of voice, gestures, and movement in a constant negotiation of affective status through each encounter with each other [5]. Even before the interaction is initiated our posture and general appearance sparks an initial presumption of our current mood and intentions towards the interaction [6], [7]. These affective measures emphasize the messages we want to convey and influence how well they are received.

In addition to being able to express affective status some degree of emotional understanding is also demanded from the robots to improve the interactions with them. Since affective computing and emotional intelligent systems were reintroduced by Picard in 1997, a significant amount of research on the topic has centered on how to measure human affective status [8], [9]. This has yielded successful results using facial recognition [10], electromyography [11], gesture recognition

[12], voice patterns [13], and touch measurements [3]. Although the emphasis on how to measure affective changes is relevant for realistic social interactions between humans and robots, this study aims to give an overview of the different means for robots to express affective states and to provide a model for describing and comparing affective systems. Therefore the focus will lie solely on the technological capabilities of the robots to convey emotions.
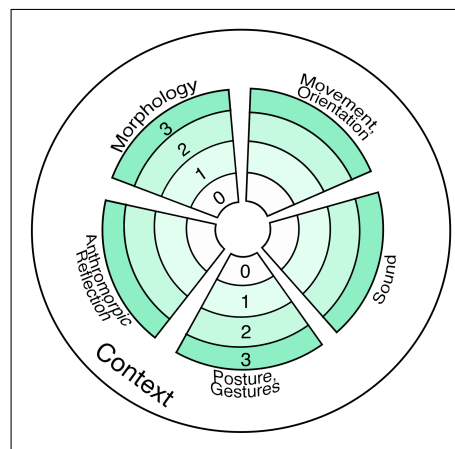

Fig. 1. The model of affective means (MOAM) and context alignment with with 0 to 3 points distributed in each of the included five categories of means. (See the Expression modalities section for further explanation of the systematic point distribution)

A majority of the robots included in this survey were created to test and improve single means of affective expression in isolation from other means. However, there are indications that means can influence each other and distort or increase the emotional impact of any emotional expression on human recipients. Eg. adding music to a scenario might alter a negative mood towards the positive [14]. By exploiting synergies between means, we can emphasize the intention of the robot beyond what is possible with one mean alone.

II. MOAM - MODEL OF AFFECTIVE MEANS

This survey proposes a simple model to facilitate a systematic comparison of affective robots. The aim is to illustrate how much emphasis is placed on specific aspects of the affective means and to work as a tool for robot engineers to employ in the design phases of robot construction. The model divides the available affective means of robots into five high-level categories. The chosen abstraction level is the result of a trade-off between the ability to depict robots in greater detail and the ability to easily compare different robots. The current model favors the last of the two. The

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TABLE I
THE SYSTEMATIC RATING SYSTEM FOR THE MOAM MODEL.

	0 Points. The mean is NOT CONSIDERED in any way.	1 Point. The mean is implemented but has NO RELATION to the overall affective expression of the robot	2 Points. The mean provides a COORDINATED effort to increase the impact of the affective expression.	3 Points. The mean provides a RESPONSE to incoming stimuli.
Morphology	The morphology has not been considered from an affective expression point of view	The morphology has been considered in the design of the robot, but is is unrelated to the affective expression.	The morphology is designed to support the overall affective reflection. Eg. colored lights express fear.	The morphology changes as a reaction to stimuli. Eg. adapts to context or reacts with lights.
Movement and Orientation	The robot does not move	The robot moves with no consideration to expessions	The robot moves to highlight emotional state	The robot moves as a response to stimuli.
Posture & Gestures	The robot has no onboard movement	The robot can move internally, but with no relation to conveying emotions.	The robot changes onboard positions or moves limbs to display emotional states.	The robot moves internally as a reaction to stimuli. Eg. it waves to other robots.
Sound	No sound or naturally occuring noise	Sound with no relation to affective expression. Eg. status messages	Coordinated sound to increase affective impact. Eg. music to set an athmosphere,	The sound is used as a mean to respond to incoming stimuli.
Anthropomorphic reflection	The robot bares no resemblance to any recognizeable character	The robot has a single or two features shared with a known character. E.g. has arms.	The robot resembles a known character and it supports an anthropomorphic interpretation	The robot's reaction to incoming stimul matches the expectation of the character.

downside to simplifying the model is that in a few cases the outcome could have similar profiles for robots that have very different real-life potentials.

A. Expression modalities

The inner parts of the model consist of the different modalities of the affective means. Through literature studies of papers from previous affective robot research projects, we have identified five categories of expression modalities. The five identified high-level modalities are "Morphology", "Movement and Orientation", "Posture and Gestures", "Sound", and "Anthropomorphic Reflection". Each part of the model corresponds to a modality and depicts the amount of effort directed towards these specific affective aspects of the robot. Further details on each of these categories will follow this overview. When depicting arbitrary robots using the model each of the categories are rated from 0 to 3, and the points are added to the corresponding section of the model to form a diagram over the different measures. When considering each part, the following criteria are used to establish a distribution of points:

- **0 Points:** The mean is **not present** in any capacity.
- **1 Point:** The mean is implemented but has **no relation** to the overall affective expression of the robot.
- **2 Points:** The mean is implemented and provides a **coordinated effort** to increase the impact of the overall affective expression.
- **3 Points:** The mean is implemented, increases the affective impact level and provides a **response** to incoming stimuli.

Table I displays the criteria for each of the identified categories. The criteria were selected from a combination of interaction theory and first-hand experience from affective robots. We emphasize the importance of responsiveness in the affective expression modalities as delays and lack of responsiveness tends to cause interaction outage [15]. It is important to stress, that the ratings of each category are neither an expression of positive or negative scores. A zero-rated robot on all accounts can be perfectly suited for certain tasks depending on the target context, and type of task it is designed to solve. This means that the role of the robot is important and can purposefully limit the amount of point distributed in specific categories. Eg. Paro the therapeutic seal robot has zero points distributed to the movement category because its main purpose is to stay still at the lap of the interacting user [16]. This is why any MOAM model of a robot is context-specific and comparing different models should be done in light of the role the robot fulfills. It is likewise important to mention that the ratings given to the robots in this survey are strictly interpreted from the information gathered in the referenced articles. This means that it has not been possible to obtain some of the details on specific mean categories. This may result in errors in the ratings stated for those categories.

B. Responsiveness and adaption

The final points in every category describe the level of responsiveness or adaptation the robot exhibits towards incoming stimuli. It depicts how well, in any of the categories, the robots respond to external context changes. E.g. the robot might make a sound every time it discovers another robot or human in the vicinity, or it might change position to orient itself towards any entities discovered in the working scenario. E.g. Limbu 2013 [4], enabled the 'CuDDler' robot to respond

to audio stimuli with both gesture and sound.

A response might be immediate but could also manifest as a longer-lasting effort from the robot to dynamically fit its means of expression to match the recipient of the interaction or as an attempt to better align with a current working context. Examples of such are Miranda 2018 [17], where a robot alters its longer-lasting personal traits such as level of disagreeableness through an interaction.

C. Context and task alignment

The outer circle of the model corresponds to the working context as every individual working context demands different kinds of expressive means. E.g. low light situations makes gestures and postures hard to decipher while lights and sounds fit well. Even small changes to the context may demand large changes to the composition of expression methods to remain effective. This makes it difficult to create multi-purpose expressive means without dynamic ad-hoc adaption to the current environment and attention to the target of the interaction. As Bennett 2014 [18] argues, the context changes influence how we recognize the affective expressions of robots. If the context supports the expressed emotions the recognition rate will increase. Aligning the means of expression with the context can potentially amplify the conveyance of emotional values.

III. USING THE MOAM MODEL

The following example is provided to give an impression of the applicability of the model. A single robot has been selected and analyzed using the model in accordance with the criteria outlined in Table I. Stiehl et al. 2006 designed a therapeutic robot companion to function alongside nurses and improve the health and well being of the patients. It features several input sensors and reacts to touch, temperature, audio input, and visual stimuli. To express emotions the robot can change its posture, move limbs or emit sounds in response to user input. Furthermore, the robot has the appearance of a teddy bear, with fabric fur covering most of the body. The MOAM point distribution of that robot is depicted in the right image of Figure 2.

The affective scores in Figure 2 represent an affective robot with an even distribution of points. Although the robot is designed for the specific purpose of being stroked and to react to user input using movements and sound, the morphology has been considered in the design phase as well. The selected materials are applied to make the robot seem nice to touch and to highlight its familiar anthropomorphic shape and appearance of a teddy bear. The Huggable robot responds well to user input, and the responsive elements consisting of gestures, sound, and posture, increase the affective interpretation of its overall behavior.

The intended task for the huggable robot is to provide therapeutic comfort to medical patients, and as such, it is important that the robot's affective impression is considered. The 2 points in morphology mean that the robot's appearance and construction have been specially designed to support the affective impression. The Huggable has no locomotion
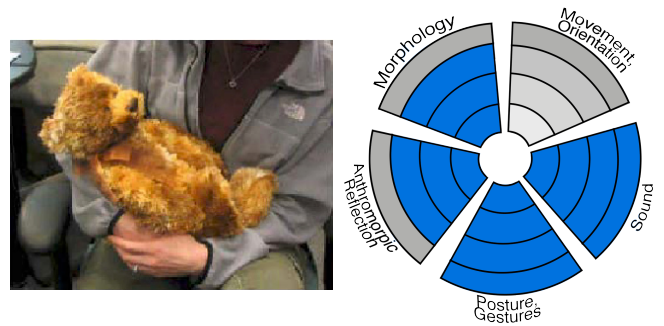

Fig. 2. Left: (Pending confirmation of image usage) The Huggable robot by Stiehl et al. 2006. Right: MOAM for Stiehl 2006 the huggable.

ability, resulting in a zero rating for the movement category. As the robot responds to outer stimuli with moving limbs and changing postures the robot is rated 3 for the onboard moving category. The same argument counts for the sound rating of 3. The robots resemble a well-known character type (a teddy bear), but the response manifestations to outer stimuli do not match the appearance of that figure, resulting in a rating of 2 for the anthropomorphic reflection.

IV. MODALITIES OF MEASURES

The following sections provide further details and illustrative examples for each category. All robots included in this survey have been rated using the MOAM model, and the resulting point distributions can be seen in Table II

A. Morphology

The morphology of a given robot describes its general appearance and depicts the level of attention given to affective expression details in the construction phase. A model with a high number of points allocated to the morphology category means, that the visual appearance or tactile sensation has been considered to a high degree from an affective expression perspective during the physical construction phase of the robot. This includes physical size and choice of colors [19], [20], type of materials used in the construction [3], [21], the sturdiness and build-quality or lack thereof [3], and the form and shape of the robot [21], [22]. Furthermore, as a mean of causing affective changes, the morphology precedes any initial contact and works at large spatial distances from the recipient, as long as there is a clear line of sight to the robot.

Some robot projects take advantage of factors that are already affiliated with certain types of signals. Eg. a red color means danger. Bethel 2009 used a blue light placed on the undercarriage of the robots to produce a calming effect [19]. Boccanfuso et al. 2015 used the 'Sphero' robot with colors, sound, and movement to simulate the expression of emotions [20].

The familiarity of certain appearances is also used by Singh et al. 2013 in the form of a dogtail attached to a small-sized robot [22]. Using the shape and size of recognizable animals was done by Sefidgar et al. 2016 in a small rat-like form factor therapeutic robot [21]. The soft materials were similarly important for the 'Huggable' robot introduced by

Stiehl et al. 2006 [3]. It made the humans that interacted with it relax when touching it and the fabric type added a teddy bear aesthetic to the robot.

B. Movement and orientation

The contents of this category are all implementations that influence how the robot moves, and how the robot reflects behavior of directing attention to something or someone in the vicinity. The specific speed [23], [24], acceleration changes [25], directional patterns [20], [24], [26], orientation [19], [27], and gait patterns employed by the robot as it moves from point A to B can convey emotional status. Yoshioka et al. 2015 and Boccanfuso et al. 2015 used simple small robots that employed movement style to successfully express emotions with changes in direction, velocity, acceleration and frequency of rotation [20], [24]. In Bethel et al. 2009 an emotive mode of the robots made them approach slowly, keep low to the ground and sustain an orientation towards the recipient to express attentiveness, caring and caution [19].

The relation between the acceleration curve and the type of interpreted delivered emotion was investigated in Saerbeck et al. 2010 [25]. The research results indicated a strong relation between motion parameters and affective recognition, such as causality between the acceleration curve and the PAD placement on arousal and valence axis. A system to retrofit existing robots was introduced in Fernandez et al. 2017 as an emotional enrichment system [26]. The aim was to enable users to describe emotions and to enrich the movements of the robot using these descriptions.

C. Posture and Gestures

As movements and orientation describe the positioning of the robot in an external or global scope, this category describe onboard or internal movements. This covers gestures [22], [28]–[36], speed of motions [32], [37], main body movements [4], [21], [38], posture [7], [28], [39], and touch [40]. With a combination of gestures, torso movement and facial expressions, Hegel et al. 2011 used a 'BarthocJr' model robot to measure and mimic live emotions from a human recipient [38]. The duplication of emotions and expressions mimicked by the robot works as a primitive form of empathy. Using solely body movements to express emotions, a faceless Nao robot in Cohen et al. 2011 successfully conveyed emotions as well as an 'iCat' robot that had a face [29], [41]. This indicated a high affective impact of solely employing body movements. Sefidgar et al. 2016 employed ears that stiffen in their therapeutic robot and a moving rib cage that simulated breathing [21]. Emotions can be expressed through touch as well. This was investigated in Chen et al. 2011, with a medical robot that touches its patients to calm them down [30]. The results indicated that the best effect was gained when people understood the intentions of the robot.

The effect of the neck, arm, and eyelid movement was researched by Limbu et al. 2013 in a study using the 'CuD-Dler' teddy bear therapeutic robot [4]. It was found that a combination of movements had a soothing effect on humans interacting with it. With a subsystem to generate emotions, Park et al. 2007 used a robot to show several emotion types including Fear, surprise, joy, anger, and sadness [36]. The robot employed motion in combination with posture and gestures and responded to user input from touch sensors whenever the users stroked it. A robotic stand-up comedian was developed in Addo et al. 2014 and it was discovered that using gestures enhanced the comedic impact on the audience [33]. Investigating affective physiology was the aim of Bianchi et al. 2016, with the development of an affective touch device built from rollers to simulate a pleasant human stroke [40]. The test persons could distinguish different kinds of emotional touch, which indicated that touch works as an effective way of expressing affect.

D. Sound

The sound aspect of an affective robot covers all audio originated from the robot. This includes both naturally occurring sounds (eg. the sound of wheels turning, limbs moving, servo buzzing), as well as artificial sounds emitted from the robot. The artificial sounds include voice [33], [42]–[45], soundscapes [46], [47], and notifications sounds [4], [20], [23], [48].

Matching the audio to the context is used by Lisetti et al. 2004 with a robot that has different voices to better match face and scenario [42]. Read and Balpaeme 2012 used non-linguistic sounds for robots to communicate with children and found that utterance rhythm is influential, while the pitch contour may have little importance in how the message is conveyed [48]. Gonsior et al. 2012 depicted emotions from the PAD space, by changing the voice with a different pitch, range, and accent [43].

To complement the behavioral traits of a pet dog robot, Yang et al. 2013 used audio as one of the expression modalities to convey both cognitive and emotional statuses [23]. Zhang et al. 2017 rated the importance of a robot's current synthetic emotional values with each other and formed the pitch, rate [47]. and volume of the robot's voice thereafter. The NAO robot platform was used by Winkle et al. 2017 to determine that the recognition of emotional values from robot voice and motion is possible in explicit validation experiments, but does not work with similar effect in socially assistive interaction situations [44]. The results suggest, that the correct interpretation of emotions relies on the human recipient to have formed an expectation of the attempted conveyed emotion. The impact of sound seems to work best when it matches the appearance of the robot, as was indicated by Becker et al. 2009 investigating laughter in robots [45]. The results were dependent on how well the synthetic laughter matched the robot appearance, and furthermore depended on the receiver's traits such as gender and nationality.

E. Anthropomorphic reflection

The anthropomorphic reflection attribute describes how much emphasis is placed on making the robot appear like a humanoid or recognizable character. Examples of humanoid

inspired robots are Sophia [49], Gemini(s) [50], [51], Barthoc Jr. [52] and Pepper [53], while robots based on familiar characters include among others Leonardo [54], Aibo [55], and Paro [16]. There is currently an emphasis on using facial features in many robot research projects, [1], [2], [28], [42], [56]–[59], under the assumption that using a face makes it easier to convey emotions as a result of human familiarity with interpreting affective status through most social interactions. Only a small number of facial features are needed to successfully express emotions, as Bennet et al. 2013 found using only lips and eye lines to convey affective status [2].

Coupling a face with other means of expressions in a consistent manner over time could improve the amount of impact. This is a concept Lisetti et al. 2004 attempted to utilize in a service robot that maintained an ongoing personality throughout a series of interactions [42]. Zecca et al. 2008 designed KOBIAN a humanoid with the ability to convey emotions using facial expressions and by using bio-inspired body language [60]. It is not necessary to employ a whole face to trigger an emotional response, as Egawa et al. 2016 discovered using a single eye pupil in combination with an artificial laughter sound [61]. The results demonstrated that the dilated pupil response with a laughing response is effective for enhancing empathy.

V. RESULTS AND DISCUSSION

The table in Table II provides an overview of MOAM point distributions of the robots included in this paper. It is a table created based on information gathered through a literature study of papers published from previous affective robot projects. To create it, the authors gathered all information available from the paper regarding each specific category and distributed points according to the rules outlined in the matrix seen in Table I. By using the point distribution rules outlined in the MOAM matrix, the authors attempted to approach an objective overview of the affective means available for each robot. In the table, the robots are sorted by the number of non zero affective mean categories. 15% of the robots have points distributed to all categories while the remaining 85% display a single or several categories that contain a zero-rating. Furthermore, the average number of categories per robot with a zero-point distribution is 1.71. As most of the robots included in this paper are built for research purposes, this could indicate that it is the norm to focus solely on a single category when testing affective means. About a quarter of the included robots (25.6%) has a zero rating in more than 3 categories. It can be argued that disregarding several categories could have a negative impact on the robot's affective expression abilities. Eg. a research project might ask participants to consider the affective facial expressions of a robot, but forget to acknowledge the loud mechanical noise the robot is emitting throughout the tests. This could subconsciously influence how the robot is perceived by the audience.

The MOAM model illustrates the affective strengths of the robots, but the model also highlights the areas which

TABLE II

THE DISTRIBUTION OF POINTS FOR ROBOTS INCLUDED IN THIS PAPER. THE INTENSITY OF COLORS INDICATE THE SCORE.

Publication / Category	Morphology	Movement	Gestures	Sound	Anthropomorphic
Xu et al. 2015 using Nao	2	2	2	2	2
Zecca et al. 2008	2	2	2	2	2
Becker et al. 2009 Robovie-II	1	1	2	2	1
Fujita et al. 2001 (AIBO)	2	2	2	1	2
Becker et al. 2009 Robovie-R2	1	1	2	2	2
Pepper (Softbank robotics)	2	1	1	1	2
Singh et al. 2013	2	1	2	0	1
Yim et al. 2009	1	1	2	1	0
Stiehl et al. 2006	2	0	3	3	2
Yang et al. 2013	1	2	2	2	0
Park et al. 2007 CuDDler	2	0	3	2	3
Cohen et al. 2011 w. NAO	2	2	2	0	2
Chen et al. 2011	1	0	2	2	1
Xu et al. 2013	2	1	2	0	2
Sophia (Hansen Robotics)	2	0	3	3	3
Gemini (By Hi. Ishiguro)	2	0	2	3	3
Breazeal et al. 2004	3	0	3	1	3
Paro (By Parorobots)	2	0	1	1	2
Breazeal et al. 2003 Kismet	1	0	3	1	1
Breemen et al. 2005	3	0	2	0	2
Hegel et al. 2006	2	0	2	0	3
Bethel et al. 2009	2	2	0	2	0
Boccanfuso et al. 2015	2	2	1	0	0
Sefidgar et al. 2016	2	0	3	0	3
Park et al. 2007	1	2	3	0	0
Fernandez et al. 2017	1	2	0	0	2
Addo et al. 2014 Zoei	2	0	2	0	2
Lisetti et al. 2004 Cherry	1	1	0	1	0
Gonsior et al. 2012	0	1	0	1	2
Yoshioka et al. 2015	1	2	0	0	0
Zhang et al. 2017	0	0	0	3	0
Benson et al. 2016	1	0	0	0	2
Egawa et al. 2016	0	0	1	0	1
Saerbeck et al. 2010	0	2	0	0	0
Fernandez et al. 2017	0	2	0	0	0
Yoshioka et al. 2015	0	2	0	0	0
Lee et al. 2013	0	0	2	0	0
Bianchi et al. 2016	0	0	2	0	0
Bennett et al. 2013	0	0	0	0	1

represent opportunities for improvements. A fully covered inner circle of the model equals a distribution of two points for each category of means. This requires each category to be manifested in some form but demands no further coordinated effort to increase the affective impact of the robot. It is possible, that by ensuring a point distribution that covers the inner circle when constructing robots, the outcome could be more efficient affective robots with lesser disregarded areas to influence how they are perceived. Even some state-of-the-art affective robots contain categories of the MOAM model with zero points allocated leaving room for further improvements. An unattended category of means could present an opportunity to add further expression means to mitigate any negative aspects of the category.

The lower entries of the table consist of robots that are constructed with an emphasis on a single category of means. This makes a lot of sense as these robots are often designed to test the validity of a single mean of affective expression. There may be practical (and economic) reasons for limiting the number of included affective design details. However, the indication that the MOAM categories could influence each other in both positive and negative ways, could be viewed as an argument for considering other means of expression when designing affective systems. The distribution of points in each MOAM model can in some cases be limited by the task intended for the robot to handle (Eg. Paro [16] which it not designed to move), making it difficult to compare robots intended for different contexts. For that reason, there might be a research opportunity in exploring how to create further specialized MOAM models containing the attributes of specific working scenarios. Such models could provide an easier method to compare robots designed to fulfil similar roles (Eg. social companion robots, therapeutic robots, robot teachers). However, the main intention of proposing the model is to provide a general overview of the technical capabilities of each robot, not to rate how well the robot performs in different working contexts. As such, the current model reflects a loss of finer details to gain a wider range of included robots to compare with. Furthermore, the model is not solely intended to provide a scoring mechanism. It has a purpose besides working as a comparison between robots, it is also intended as a quick reference to aid in the process of designing affective robots. The overview table in this paper was created solely by the authors. To generalize the result, future iterations should also include participation from a larger sentiment of people to minimize the influence of subjective evaluation. The aim of using the point distribution matrix was to avoid bias and subjectivity in the creation of MOAM models. However, some categories are less prone to subjectivity than others (Eg. the anthropomorphic reflection can be culturally dependent), but this can be mitigated by evaluating the robot in light of its intended role and working context. Doing so increases the consistency of the resulting MOAM points distributed by different people.

Some research projects build upon commercially available robots such as the NAO robot when testing affective means. Building on top of these platforms allows the research teams to emphasize on different aspects of affective means. Using a common base for affective robot research is a good idea as it works towards minimizing any negative impact from disregarded categories. However, relying on NAO and similar robot solutions could in some situations mean missing an opportunity to customize the morphology to the specific context. It is possible that some scenarios could demand an easier customizable affective robot to better align with the working context but that could be a possible topic for further research.

VI. Conclusion

To this date, essential progress has been made in affective robot research. As a result, we have substantial knowledge of how single means of expression works. In comparison, we know relatively little about how categories of means influence each other when used together or when disregarded.

The paper has identified five high abstraction level categories of expressional means and has provided examples of each to highlight their functionality. The mean categories are 'Morphology', 'Posture and Gestures', 'Sound', 'Movement' and 'Anthropomorphic reflection'. All identified categories have been summed up in a proposed model of affective means (MOAM) to capture strength and weaknesses for any robot from an affective perspective. To make the MOAM models comparable to each other, this paper has also proposed a point distribution system to allocate points to the affective mean categories. The MOAM model and its underlying point distribution system have been used to score and compare all included affective robots. The resulting MOAM scores are directly comparable and work as systematic descriptors of the affective strengths and shortcomings of the robot, but should be viewed in light of the intended role and working context of each robot. Overall we argue, that the MOAM model can sufficiently categorize and be used to compare a large plethora of different affective robot types.

Using the models to rate robots and compare with each other gave insight to the possible opportunities for improving even the already successful robots that rely on single affective means to express affective states. There are indications that the synergies between affective means could possibly change the impact of the overall impression of the robot. These indications warrant further investigation into the feasibility of testing single means of affection in isolation. Furthermore, we argue that the number of robots in this survey, that has room to add further means of expression, shows there could be an unexplored area of research in building more complete affective agents with attention to all categories.

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