Correspondence

Survey of Non-facial/Non-verbal Affective Expressions for Appearance-Constrained Robots

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***Abstract*—Non-facial and non-verbal methods of affective expression are essential for naturalistic social interaction in robots that are designed to be functional and lack expressive faces (*appearance-constrained*) such as those used in search and rescue, law enforcement, and military applications. This correspondence identifies five main methods of non-facial and non-verbal affective expression (*body movement*, *posture*, *orientation*, *color*, and *sound*), and ranks their effectiveness for *appearance-constrained* robots operating within the *intimate*, *personal*, and *social* proximity zones of a human corresponding to interagent distances of approximately 3 m or less. This distance is significant because it encompasses the most common human social interaction distances, the exception being the *public* distance zone used for formal presentations. The correspondence complements prior, broad surveys of affective expression by reviewing the psychology, computer science, and robotics literature specifically relating the impact of social interaction in non-anthropomorphic and *appearance-constrained* robots, and summarizing robotic implementations that utilize non-facial and non-verbal methods of affective expression as their primary means of expression. The literature is distilled into a set of prescriptive recommendations of the appropriate affective expression methods for each of the three proximity zones of interest. These recommendations serve as design guidelines for retroactively adding affective expression through software to a robot without physical modifications or designing a new robot.**

***Index Terms*—Affective computing, human-robot interaction, non-verbal communication, proxemics, robotics, robotic design guidelines.**

I. INTRODUCTION

The use of affective expression and social interaction is an emerging area of importance in robotics, with the focus historically on facial expressions and/or animal mimicry [1]–[6]. However, a large number of mobile robots currently in use for applications such as search and rescue, law enforcement, and military are not anthropomorphic, do not have any method of projecting facial expressions, and cannot be reengineered to explicitly support affective expression. This poses significant challenges as to how these *appearance-constrained* robots will support naturalistic human–robot interaction [6].

Appearance-constrained robots are not engineered to be anthropomorphic and do not have the ability to exhibit facial expressions or make eye contact. Appearance constraints stem from either the limitations of the application or from economics. Mobility is a major limitation; for example, uneven terrain may drive the use of tracks instead of using anthropomorphic legs. Power and platform size are two other limitations; robots such as those for operation in highly confined spaces may not have enough space or onboard power to add facial features. Extra effectors may interfere with the mission (e.g., snag on wires or overhangs) or decrease reliability (e.g., dust breaking the effectors). The environment itself may limit affect, for example, low or unconstrained lighting may prevent the viewing of avatars on screens. In terms of economics, in many cases, manufacturers and organizations have already developed and invested large amounts of money into their robot designs, and it would not be practical to alter the robot's physical appearance to produce a more naturalistic social interaction.

Fig. 1. Illustration of a victim's response from the robot's view.

While facial displays have been the most common mechanism for expressing affect for robots in general, some roboticists have used body movement [1], [7]–[11], posture [1], [5], [7], [8], [10], orientation [1], [7], [8], [12], [13], color [10], [14], and sound [7], [8], [12], [13] as either the primary method of expression or to provide affective expression redundancy. These applications were developed mostly for educational and/or entertainment purposes. Although facial expression has been shown to be quite effective in the expression of affect, some researchers feel that body movement and posture may reveal underlying emotions that might be hidden otherwise [7], [15]–[18].

The impact of spatial distances on body movement, posture, orientation, color, and sound in robotics has been acknowledged by several roboticists but has not been codified [4], [19]–[21]. In the psychology community, spatial distances between individuals socially interacting (*proxemics*) is divided into four main categories (see Fig. 2): *intimate*, *personal*, *social*, and *public*. Argyle [15] and Fast [17] describe personal space to be the area that individuals must have surrounding them to feel comfortable, safe, and protected. Based on the experiments conducted by Argyle and Fast, if an individual or object intrudes into the personal space of another, it will produce a discomfort response from the person whose personal space was invaded [15], [17].

Our research focuses on the use of affective expression in non-anthropomorphic and *appearance-constrained* robots for human–robot interactions occurring within 3 m of each other [6]. Most social interactions occur within this distance range, the exception being formal public speaking/presentations that occur in the *public* distance zone. It is particularly motivated by a study conducted by Murphy *et al.* [22] in using man-packable robots to act as a surrogate presence for doctors tending to trapped victims, but it is expected to be applicable to any close human–robot interaction [6]. The study identifies how the robot will interact with the victim as one of the four major open research issues [22]. They noted that the robots operating within 3 m of the simulated victims were perceived as "creepy" and not reassuring (see Fig. 1) [6].

In each of these cases, the robots operated in highly confined spaces and the additions of "faces" or other devices might interfere with the

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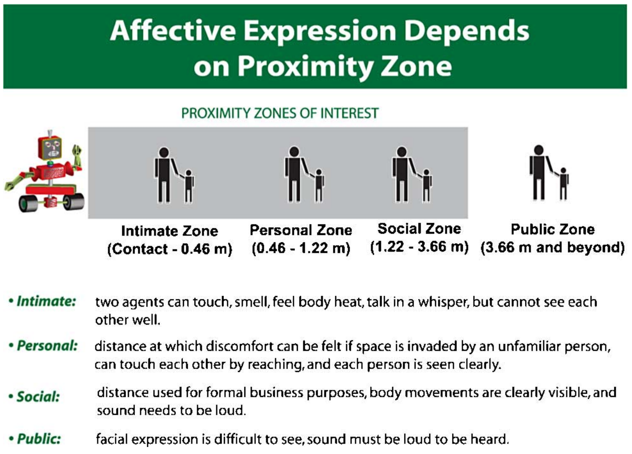


- ***Intimate:*** two agents can touch, smell, feel body heat, talk in a whisper, but cannot see each other well.
- ***Personal:*** distance at which discomfort can be felt if space is invaded by an unfamiliar person, can touch each other by reaching, and each person is seen clearly.
- ***Social:*** distance used for formal business purposes, body movements are clearly visible, and sound needs to be loud.
- ***Public:*** facial expression is difficult to see, sound must be loud to be heard.

Fig. 2. Illustration of Argyle's four primary proximity zones with the zones of interest highlighted.

critical attribute of mobility. Another source of motivation is the work of Fincannon *et al.* [21], where rescue workers working within 3 m of a small tank-like robot during breaching operations expected it to follow social conventions despite the robot's non-anthropomorphic appearance. Therefore, 3 m appear to be a reasonable, though empirical, radius for considering human–robot interaction in search and rescue, medical applications, etc.

Military applications are another robot application where the robots are appearance constrained. As part of those applications, the robots can be used to locate and interact with soldiers injured in battle. Additionally, there are applications where the military is called in to assist in natural or man-made disasters. In those situations, the robots would still need to interact with victims located in traumatized states. An in-depth discussion of military applications is beyond the scope of this particular correspondence. The focus of this correspondence is the area of search and rescue applications; however, the principles can apply to other applications also.

This correspondence synthesizes the cognitive literature on affective expression (theory) and the lessons learned from the robot implementations (practice) to date to generate a prescriptive mapping of which non-facial/non-verbal expressions are appropriate in close operation. Although non-anthropomorphic affective features are being used by roboticists, the choice of features for a particular application is *ad hoc*, and so, this mapping will contribute to the formalization of the use of affect in robotics [6]. These recommendations form a multimodal system of non-facial/non-verbal affective expression that can be useful in any type of social robotic application (anthropomorphic and non-anthropomorphic). In addition, the prescriptive mapping can guide the addition of appropriate, and economical, affective expression simply through software control, without physically changing the robot [6].

The correspondence begins with a brief overview of the issues and concepts related to emotion theory and emotional models. Although these areas are the subject of considerable research, the correspondence will focus on concepts and developments related to non-facial/non-verbal affective expressions that can be implemented independent of a particular emotional model. Section III reviews the psychology and robotics literature, which establishes five basic non-facial/non-verbal methods of expressing affect and the impact of affective cues by proximity zone. This review supplements and extends the much broader survey of social robots by Fong *et al.* [3]. Section IV reviews notable robotic implementations using non-facial and non-verbal affective expression methods either as the primary method of expression or for redundancy. Section V discusses a proposed set of prescriptive recommendations of the appropriate expression methods for each of the three proximity zones that cover the 3 m radius of interaction. An example of how the prescriptive mapping can be used for making a non-anthropomorphic robot more social is also given.

II. EMOTION THEORY AND MODELS

Although emotion theory and modeling has been the subject of significant research in fields such as psychology, neurology, computer science, and robotics, emotion theory and modeling are independent of the development of non-facial/non-verbal methods of affective expression. In the robotics community, the selection of which emotions to express has followed primarily two paths: 1) basic emotions considered fear, anger, sadness, joy, and disgust and 2) emotions as cognitive processes as seen in the model of Ortony *et al.* [23] which includes bipolar pairings such as joy–distress. Roboticists have focused primarily on the use of facial expressions for displaying emotions even though it has been shown that the use of facial expressions alone is inadequate to express distinct emotions [24]. This reinforces the need for redundant or different methods of affective expression such as non-facial/non-verbal methods of affective expression.

Emotions have been the subject of controversy and scientific investigation in a wide variety of fields such as psychology, physiology, neurology, and more recently, computer science and robotics. The controversy associated with emotion research begins at the very foundation, the terminology and definition. Researchers cannot come to any type of agreement on what an emotion is or how it is defined [25]. Russell and Lemay [24] describe five different ways to classify emotional episodes to create what he terms "basic" categories. Their classifications are as follows.

1) Classify emotional episodes based on facial expressions (which they believe is inadequate for two reasons: first, there are emotion categories that do not have a corresponding facial expression, and second, some emotion categories could share the same facial expression).
2) Emotional episodes could be classified by autonomic nervous system activity which has been shown to be effective.
3) Emotional episodes could be classified by the cognitive processes involved similar to the OCC model developed by Ortony *et al.* [23].
4) These episodes could also be classified by the action involved; however, this is more of a speculative approach.
5) Emotional episodes could be classified by the brain structures and neurotransmitters involved.

Although these classifications provide a variety of approaches that can be taken in emotion theory and modeling research, robotic implementations have focused on option 1) relying heavily on facial expressions as the primary method of conveying affect [1], [2], [5], [12], [26]–[29]. As indicated in option 1), there are potential issues with relying primarily on the use of facial expressions to classify and express emotions, which reinforces the need to develop other methods of affective expression. Although extensive research is devoted to emotion theory and emotional model development, the focus of this survey of literature is on concepts and developments in non-facial/non-verbal methods of affective expression in relation to proxemics that are independent of the emotional model supporting those expressions.

III. FACTORS IN AFFECTIVE EXPRESSION

There are two main factors related to affective expression identified in the psychology literature and supported by observations from computer science and robotics: 1) presentation methods for affective expression and 2) the importance and impact of proxemics, the relative spatial distance between agents in social interactions [6]. These factors provide a key understanding into the development of a multimodal system of affective expression that is essential for non-anthropomorphic and *appearance-constrained* robots, and provides affective expression redundancy in robots that have a more anthropomorphic appearance. The consideration of both of these key factors is important in the distillation and development of the affective expression heuristics discussed in Fig. 4. In general, researchers in the fields of psychology, computer science, and robotics have focused most of their attention on facial expression as the main method for expressing affect, and have neglected other important methods of presentation such as body movement, posture, orientation, color, and sound [2], [15], [16].

A. Presentation Methods

Non-facial and non-verbal presentation methods of affect can be separated into five different cues: *body movements*, *posture*, *orientation*, *color*, and *sound* [6]. Argyle [15] and Bartneck [30] describe some affective expressions using body movements: *depression*—slow and hesitating movements, and *elation*—fast, expansive, and emphatic movements. Robot orientation toward a person it is interacting with is indicative of its perceived attentiveness and caring for that person [3], [12], [19], [21]. Argyle [15] discusses the use of color to produce an affective response such as: *blue*—elicits pleasant, calm, secure, and tender responses; *yellow*—elicits cheerful, joyful, and jovial responses; and *red*—elicits anger, affection, and love. Norman [31] discusses that vocal patterns and tone can express affect even if the literal meaning is not understood; however, Scheeff *et al.* [5] describe situations where tones can be offensive to individuals interacting with their robot. Additionally, Bartneck [30] describes the use of music to express affect such as *tenderness* expressed with slow tempo, soft timbre, intense vibrato, and low to moderate sound levels; whereas *anger* has a fast tempo, high sound level, sharp timbre, and distorted tones. Research conducted by Balkwill *et al.* [32] indicates that listeners are sensitive to emotion expressed in both familiar and unfamiliar music based on the perception of acoustic cues and transcending cultural boundaries for affective expression.

1) Body Movement, Posture, and Orientation: The study of non-verbal communication by psychologists does not offer a complete understanding of body movement, posture, and orientation. Bull [16] notes that psychologists investigating non-verbal communication have neglected the areas of gesture and posture, instead focusing on facial expression, gaze, pupil dilation, and interpersonal distance. Spiegel and Machotka [33] offer at least two reasons for this lack of focus. First, it is difficult to separate body communication from verbal modes of communication. Second, there is no system for measuring and interpreting body movement communication that is independent of language. Despite these barriers, researchers such as Buck [34], Bull [16], Fast [17], and Spiegel/Machotka [33] opine that body movements and posture can reveal more about the actual affective state of an individual than do facial expressions or even verbal communication. Research conducted by Fast [17] suggests that body movement and posture are a human's most primitive and basic methods of conveying affect. Buck [34] argues that further investigation into the influence of bodily feedback through the use of body movement, posture, and orientation is necessary for understanding affective responses.

Movement, posture, and orientation are related to each other and are often used interchangeably. Argyle [15], Bull [16], and Fast [17] indicate that posture and orientation can indicate liking, interest, and level of comfort between individuals. Based on their qualitative and quantitative studies, interest and liking can be expressed through forward leaning, closer proximity, raised head, and direct orientation. In some situations, they discuss that orientation indicating liking can also be in a side-by-side position, especially noted in close friends. Fast [17] describes that different postures are related to different emotional states and through observation of an individual, their emotional state can be decoded by their posture. Additionally, he mentions that changing orientation away from a person can be perceived as boredom and a desire to discontinue communication and interaction.

As noted earlier, body movement dominates non-facial/non-verbal affect. Argyle, a social psychologist whose work in non-verbal affect is seminal, identified in [15] four affective expressions that can be displayed through body movement are:

1) *extreme inhibition*—withdrawing or unnecessary movements;
2) *depression*—slow and hesitating movements;
3) *elation*—fast, expansive, and emphatic movements;
4) *anxiety*—fidgeting or hiding movements.

Though this categorization is extracted primarily from the movements of the hands and feet, the movement description can clearly be applied to a robot platform or effectors on a platform. His study showed that, in some cases, body movements better reflected a subject's true emotional state even though it contradicted their facial expressions and verbal communication of their emotional state. This supports the postulations of Buck [34], Bull [16], Fast [17], and Spiegel and Machotka [33].

From the computer science and robotics perspective, motion and body movement have been used in [1], [5], [7], [12], [13], [26], and [35], and have been posited in [4], [7], [18], and [19] to be essential elements in presenting affective expression to individuals who are interacting socially with robots. There appear to be two motivations for using affective movement, posture, and orientation: *to create attraction* and *to create trust*.

Eight robot systems used either movement [4], [5], [7], [10], [13], [26], [35], posture [4], [5], [10], orientation [4], [5], [7], [10], [12], [13], [26], [35], or all three [4], [5], [10] to attract human attention and interaction. Based on a series of experiments and three robots spanning over a five-year period, Nourbakhsh *et al.* [13] state that the most successful way for a robot to attract attention is by deliberately orienting the robot toward a person and addressing them. Additionally, they describe that individuals are more likely to interact with a robot that is in motion, than with a robot that is in a fixed position. Unfortunately, in the robotic systems that have implemented these methods of affective expression, body movement, orientation, and posture were secondary and coupled to some type of facial expression either on a physical robot or an avatar connected to a robot and viewed on a monitor [4], [5], [7], [10], [12], [13], [26], [35]. Therefore, there is no quantitative measurement of the relative contributions of these different expressions of affect. There has been some discussion on the importance of postures; however, it appears that this is not as effective in presenting specific affective expressions [16], [17], [36]. According to Argyle [15], Bull [16], and Spiegel and Machotka [33], posture is indicative of overall liking, interest, and openness between individuals.

Movements, posture, and/or orientation have been identified as creating trust between the robot and human in three studies. Bickmore and Picard [19] discuss that people are more likely to trust something that they perceive cares for them. While caring is often demonstrated through verbal communication and facial expressions; they also believe that it can be expressed in a robot or avatar through close conversational distance, nodding movement of a perceived head, or through body movement and gestures [19]. Their quantitative results indicate that by applying these non-verbal behaviors, such as body and facial orientation of the robot or avatar, toward the individual increases the perception of caring for that individual [19].

Fincannon *et al.* [21] describe that rescue workers feel more comfortable in their social interaction if the search and rescue robot is oriented toward the rescue worker during all verbal and non-verbal communication. By orienting the robot toward the rescue worker, it is perceived by rescuers that they are the focus of attention of the robot and that the robot is intently listening to the rescuers' communication. Their experimental results indicate that humans interacting with a robot use the same social conventions for eye contact and *personal* distance as they would in human to human contact [21].

Dautenhahn *et al.* [37] conducted experiments in a laboratory setting to determine preferences for robot approach orientation using the PeopleBot robot. From these experiments, it was determined that subjects in both a conference and a lab setting were most comfortable with the robot approaching from the right and were most uncomfortable with a robot approaching them from the front. Subjects reported that the frontal or a more direct approach was more threatening, aggressive, and they had concerns about the robot not stopping and running into them. Therefore, it appears that subjects trusted the robots that approached from either the left or the right more so than those that approached them from the front.

2) Color: Color as an expression of affect has not been deeply researched by either the psychology or robotics communities. Within the psychology community, Argyle's work [15] shows that colors are often associated with affect, and in some cases, color can produce an affective response. The following colors are associated with these affective responses:

1) *red*—anger, affection, love;
2) *blue*—pleasant, calm, secure, tender;
3) *yellow*—cheerful, joyful, jovial;
4) *orange*—disturbed, hostile, upset;
5) *purple*—sad, depressed, dignified, stately;
6) *green*—pleasant, leisurely, in control;
7) *black*—sadness, anxiety, fear;
8) *white*—joy, lightness, neutral.

Although Argyle's work [15] discusses a color mapping for affect, the colors have multiple emotions associated with each color. The use of color will require additional investigation to develop a strong mapping of a color to a specific emotion. The blue or light blue color has been more commonly mapped to pleasant and calm energy, which could prove useful in search and rescue applications.

In the robotics community, the only known work to utilize color for affective expression is Sugano and Ogata's WAMOEBA-1R robot [14]. Their non-anthropomorphic robot has seven lamps containing the three primary colors in the head-like portion of the robot. The robot expressed fear using the color *blue*; anger was displayed by the color *red*; and *yellow* indicated expectation and pleasure. It appears that the color–affect associations were empirical rather than extracted from the psychological literature. The affective meaning associated with *red* and *yellow* are similar to Argyle's associations; however, their correspondences depart from those associations when it comes to the affect for *blue*.

3) Sound: The use of non-verbal sound as a method of affective expression has not been thoroughly investigated by the psychology or robotics communities. In the psychology community, the research related to non-verbal use of sound has been associated with the study of animal communication [15], [34] as it is a primary method of conveying affect between animals. An example would be, in primates, distress is indicated by a screeching sound, growling is used to convey anger, and soft grunts are used to keep touch with those in close proximity while traveling [15]. The work that has been conducted on non-verbal sounds related to affective expression in humans is primarily focused on vocal patterns and tone of voice [15], [34], [31]. Norman [13] indicates that vocal patterns and tone can be used to express affect, and indicates that these patterns and tones can be interpreted even if the literal meaning is not understood. He also observes that pets can interpret a person's affective state based on their vocal patterns and tone. Scherer [38] indicates that the recognition of a person's emotion in content and context-free judgment situations, vocal cues have been as indicative of some emotions as facial cues.

In the robotics community, sound has been used as a supplemental method of affective expression [1], [5], [7]. Scheeff *et al.* [5] found that when the sounds produced are not vocalized in words that are understandable by the individual interacting with the robot, there is a tendency to dislike the sounds. Kismet, the robot developed by Breazeal, uses a vocal response to reinforce its emotional display [1], [7]; however, it is not the primary mode of affective expression. El-Nasr and Skubic utilize sound to indicate the emotions of anger, fear, and pain on a mobile robot [39].

Bartneck [30] describes the use of music as a method of affective expression; however, this method is more difficult to implement because it is culturally dependent. He discusses music parameters for various affective expressions as:

1) *happiness*—fast tempo, moderate variations in timing, moderate to loud sound level, mostly staccato articulation, fast tone attacks, bright timbre, light or no vibrato;
2) *sadness*—slow tempo, low sound level, legato articulation, slow tone attacks, slow and deep vibrato, soft timbre, final ricard, flat intonation;
3) *anger*—fast tempo, high sound level, no final ricard, mostly non-legato articulation, very sharp tone attacks, sharp timbre, distorted tones;
4) *fear*—large tempo variations, large deviation in timing, very low sound level, large dynamic variation, mostly staccato articulation, fast and irregular vibrato, pauses between phrases, and soft spectrum; and
5) *tenderness*—slow tempo, low to moderate sound level, legato articulation, slow tone attacks, soft timbre, and intense vibrato.

Although his focus is on music parameters, the acoustic cues associated with each emotion are consistent with related research in [15], [32], [38], [40]–[43]. Balkwill [32] discusses that there is a strong association between music and emotions. His quantitative results indicate that it is possible to detect emotions such as joy, anger, and sadness presented through the perception of acoustic cues in familiar and unfamiliar music transcending cultural boundaries [32]. It appears that if sound and music are correctly used and implemented in robots, it could be a valuable tool for affective expression.

B. Proxemics

The underlying thesis of proxemics research is that the spatial distance between humans has a significant impact on the quality and comfort level of interactions; this has been predicted to extend to humans interactions with robots [44], and recently confirmed in [4], [19], [20], and [21]. Although there have been some differences in the division of social distances, the consensus appears to be in four primary zones (see Fig. 2): *intimate* (contact–0.46 m), *personal* (0.46–1.22 m), *social* (1.22–3.66 m), and *public* (3.66 m and beyond) [4], [15], [45], [46]. Studies have indicated that individuals are most comfortable interacting with robots in the *social* distance zone [4], [46]. It is important to determine the best method of affective expression to use in each of the social distance zones to ensure the comfort level of the individual with the robot in social interactions.

There are three competing classifications of social distance. The earliest was first defined by anthropologist Edward T. Hall [45], the creator of proxemics, as four distance zones between pairs of individuals as *intimate*, *personal*, *social*, and *public* with each zone consisting of a close and far phase. Argyle [15] eliminates the close/far subdivisions and defines boundaries on each of the four proximity zones. Spiegel and Machotka [33] posit an individual centric, rather than pair centric, partitioning of space: *internal*, *proximal*, *axial*, *distal*, and *limbic*, where *internal* literally means inside the body and *limbic* is detailed as being beyond the borders of sensory processing. Spiegel and Machotka's partitioning appears to be relatively abstract and difficult to incorporate into a human–robot interaction application.

Argyle's categories appear more relevant to the study of human–robot interaction. His four proximity zones are as follows.

1) *Intimate* (from contact to 0.15–0.46 m) zone is for individuals who are involved in an intimate relationship; they can touch, smell, feel body heat, talk in a whisper, but cannot see the other person very well.
2) *Personal* (0.46–1.22 m) zone is for individuals who are at a distance at which discomfort could be felt if that space is penetrated by someone whom the individual is not familiar with; each person can be clearly seen, and they can touch each other by reaching.
3) *Social* (1.22–3.66 m) zone is used for formal business purposes such as sitting across a desk from one another; body movements are clearly visible, and speech needs to be louder.
4) *Public* (3.66–7.62 m or more) zone is a distance used for important public figures; facial expressions are difficult to see, louder voice is needed to communicate, and body movements need to be exaggerated to be visible.

For the purposes of the search and rescue applications motivating this correspondence, only the first three zones will be discussed since they cover the 3 m distance between human and robot (see Fig. 2).

From the robotics perspective, Mizoguchi *et al.* [4] report empirical results indicating that individuals interacting with their robot were most comfortable if the robot interacted at a *social* distance (consistent with Hall's work [45]); however, this was dependent on the speed at which the robot was moving. The individuals interacting were more comfortable allowing a robot to come within a closer distance if it moved slowly. Additionally, the results specify that no difference was found in the accepted proximity distance based on whether the individual interacting was standing or sitting during the experiments with the robot [4].

Walters *et al.* [46] utilize similar proxemics zones as that presented by Argyle [15] with the exception that the *intimate* zone is broken into *close intimate* and *intimate* zones in their experiments with the PeopleBot robot. In 60% of the subjects studied, the interaction/approach distances between the robot and the human subject were consistent with human-to-human social distances falling within the *personal* and the *social* distance zones. The remaining 40% of the subjects were comfortable with the robot interacting in the *intimate* zone at a distance of 0.45 m or less. In these cases, the subjects did not treat the robot as a *social* entity, and also stated that they were not threatened or uncomfortable interacting with the robot.

IV. ROBOT IMPLEMENTATIONS

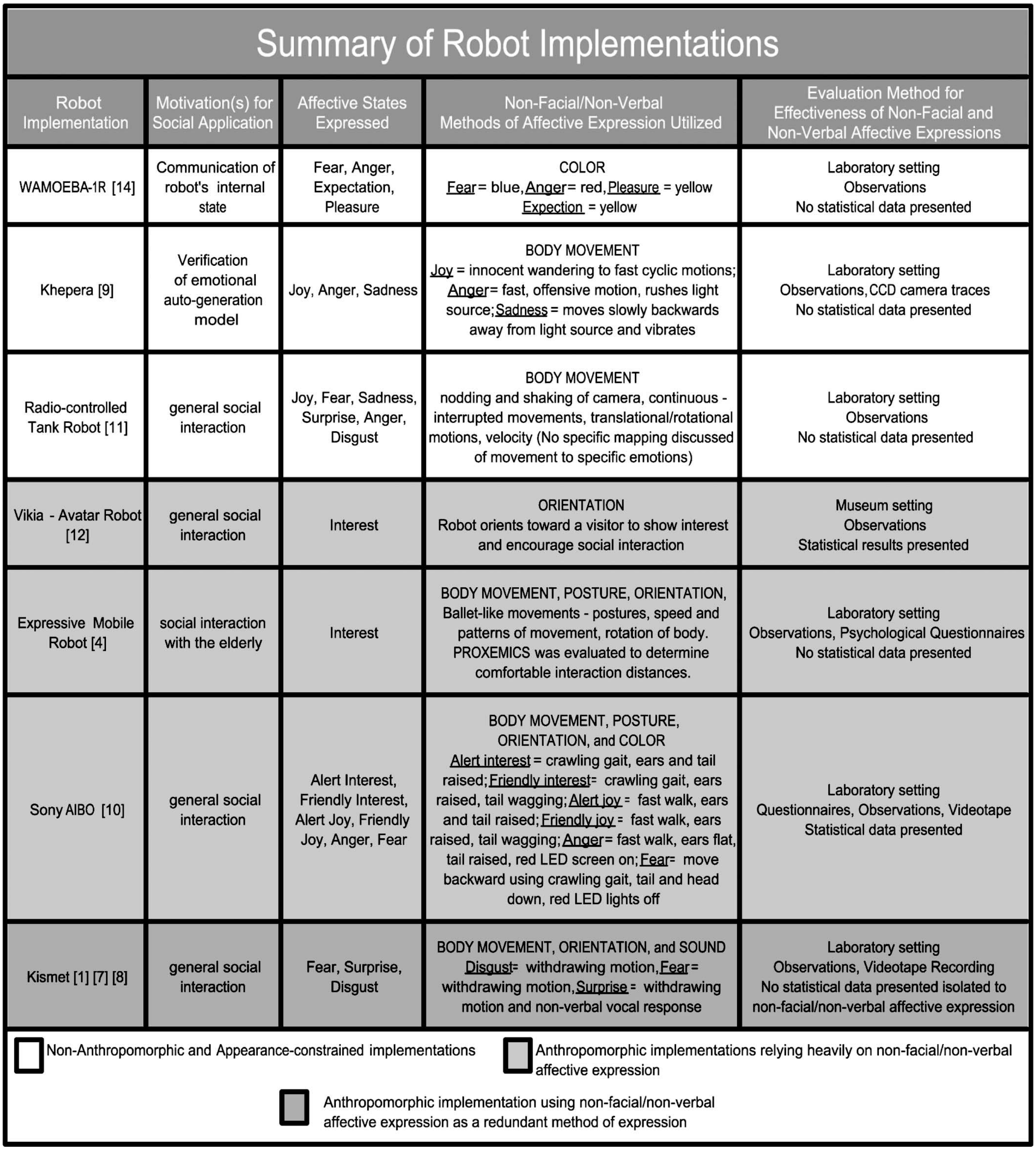
Robot implementations using affective expressions can be divided into three basic categories: 1) non-anthropomorphic/appearance-constrained using non-facial/non-verbal affective expression; 2) anthropomorphic relying heavily on non-facial/non-verbal affective expression; and 3) traditional anthropomorphic using non-facial/non-verbal affective expression as a redundant method of expression in a tightly coupled conjunction with conventional facial expressions of affect. Representative robot systems from all three categories will be discussed in this section and summarized in Fig. 3. Six of the implementations reviewed in this correspondence rely heavily on non-verbal and non-facial methods of affective expression [4], [9]–[12], [14]. Three of the six implementations discussed display affective expression using non-anthropomorphic mobile robots [9], [11], [14]. The review concentrates on determining what affective expression was used for which proximity zone, any justification for that choice, and measurement of success. Although it is possible to express the six basic emotions in addition to other emotions with the use of non-facial/non-verbal affective expressions, some applications do not require all of these emotions to be implemented.

A. Non-anthropomorphic and Appearance-Constrained Implementations

Three of the robotic implementations rely *solely* on non-facial and non-verbal modes of affective expression. As noted earlier, Sugano and Ogata [14] developed a robot called WAMOEBA-1R that displayed emotion using color. The color reflected the internal state of the robot based on battery status, location, movement, and sensor data. The WAMOEBA-1R was developed to evaluate learning behavior based on self-preservation, and expressed its inner state through the use of color [14]. The robot operated primarily in the *personal* and *social* distance zones. Color for expression was visible to humans in both the *personal* and *social* zones. Laboratory experiments were performed, they reported empirical results for the use of color as a method of affective expression to successfully convey the internal state of the robot to human observers; however, the effectiveness was not completely or objectively evaluated during these studies [14].

Maeda [9] implemented affective expression using orientation and speed of movement on a miniature Khepera robot. The purpose of this research was to evaluate the efficiency of a simulator developed to generate emotions using fuzzy logic. Emotion was expressed through reactions to a light source used in the laboratory experiment. If scaled for the size of the robot, it appeared to function in the *intimate*, *personal*, and *social* distance zones in relationship to the light source. If the robot experienced joy, then it cheerfully wandered around the light source; however, if the value for joy generated by the simulator increased, then the robot motion increased and became cyclic. For the affective expression of anger, the robot rushed toward the light source, and if the value for anger increased, then the robot moved faster and would overrun the light source and returned to it again. In the case of sadness, the robot moved away from the light source, if it was present, and went to a dark location in the laboratory; however, if the sadness value increased, the robot's motion would become slow, and if a light source was present, it would move backward and vibrated its body. Maeda conducted experiments in a laboratory environment using human observations and charge-coupled device (CCD) camera traces for evaluation; however, the outcomes were not clear, and there is no statistical data presented to support the stated successful results. The authors note from the experiments conducted that it was difficult to recognize the specific emotion when the intensity of anger was equal to the value for sadness.

Shimokawa and Sawaragi [11] developed an agent–robot system using a radio-controlled model tank with a video camera with pan, tilt, and zoom mounted on top with a head-like appearance. The camera was capable of producing a nodding or shaking appearance to users. The main method of emotion display for this system was the use of motion, velocity, and direction through the use of a throttle and rudder system. Emotions were varied using continuous and interrupted movements: forward, backward, and turning directions, and the velocity of the movements. Their experiments were conducted in the *social*



Summary of Robot Implementations

Robot Implementation	Motivation(s) for Social Application	Affective States Expressed	Non-Facial/Non-Verbal Methods of Affective Expression Utilized	Evaluation Method for Effectiveness of Non-Facial and Non-Verbal Affective Expressions
WAMOEBA-1R [14]	Communication of robot's internal state	Fear, Anger, Expectation, Pleasure	COLOR Fear = blue, Anger = red, Pleasure = yellow Expection = yellow	Laboratory setting Observations No statistical data presented
Khepera [9]	Verification of emotional auto-generation model	Joy, Anger, Sadness	BODY MOVEMENT Joy = innocent wandering to fast cyclic motions; Anger = fast, offensive motion, rushes light source; Sadness = moves slowly backwards away from light source and vibrates	Laboratory setting Observations, CCD camera traces No statistical data presented
Radio-controlled Tank Robot [11]	general social interaction	Joy, Fear, Sadness, Surprise, Anger, Disgust	BODY MOVEMENT nodding and shaking of camera, continuous - interrupted movements, translational/rotational motions, velocity (No specific mapping discussed of movement to specific emotions)	Laboratory setting Observations No statistical data presented
Vikia - Avatar Robot [12]	general social interaction	Interest	ORIENTATION Robot orients toward a visitor to show interest and encourage social interaction	Museum setting Observations Statistical results presented
Expressive Mobile Robot [4]	social interaction with the elderly	Interest	BODY MOVEMENT, POSTURE, ORIENTATION, Ballet-like movements - postures, speed and patterns of movement, rotation of body. PROXEMICS was evaluated to determine comfortable interaction distances.	Laboratory setting Observations, Psychological Questionnaires No statistical data presented
Sony AIBO [10]	general social interaction	Alert Interest, Friendly Interest, Alert Joy, Friendly Joy, Anger, Fear	BODY MOVEMENT, POSTURE, ORIENTATION, and COLOR Alert interest = crawling gait, ears and tail raised; Friendly interest = crawling gait, ears raised, tail wagging; Alert joy = fast walk, ears and tail raised; Friendly joy = fast walk, ears raised, tail wagging; Anger = fast walk, ears flat, tail raised, red LED screen on; Fear = move backward using crawling gait, tail and head down, red LED lights off	Laboratory setting Questionnaires, Observations, Videotape Statistical data presented
Kismet [1] [7] [8]	general social interaction	Fear, Surprise, Disgust	BODY MOVEMENT, ORIENTATION, and SOUND Disgust = withdrawing motion, Fear = withdrawing motion, Surprise = withdrawing motion and non-verbal vocal response	Laboratory setting Observations, Videotape Recording No statistical data presented isolated to non-facial/non-verbal affective expression

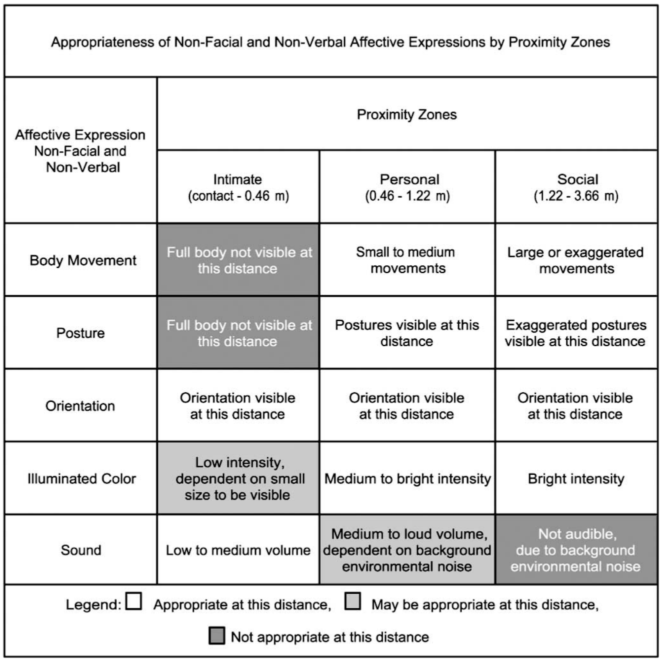
☐ Non-Anthropomorphic and Appearance-constrained implementations
▨ Anthropomorphic implementations relying heavily on non-facial/non-verbal affective expression
■ Anthropomorphic implementation using non-facial/non-verbal affective expression as a redundant method of expression

Fig. 3. Summary of robotic implementations including motivations, affective states, non-facial/non-verbal affective expressions, and evaluation methods.

distance range. They implemented the emotions of joy, fear, sadness, surprise, anger, and disgust; however, they determined that the movements for joy were the most reliably interpreted by observers [11]. The focus of this research was the development of natural and intuitive social interactions between the robot and the human(s) with which it is interacting. The robot was designed so that feedback from human observers was recorded by the software agent, and the agent would, in turn, modify the robot's affective expressions with genetic algorithms that adapted to the feedback of the observer. The paper discussed the empirical results from one observer who interacted with the robot for 163 iterations. The paper did not discuss details on how each emotion was expressed through motion, direction, and velocity.

B. Anthropomorphic Robot Implementations That Rely Heavily on Non-facial/Non-verbal Affective Expression

Generally, non-facial/non-verbal affective expression is used as a secondary method to relay affect. However, in three of the six implementations covered in this review [4], [10], [12], either body movement/postures or orientation were a significant means of affective expression to those who interacted with their robots.



Appropriateness of Non-Facial and Non-Verbal Affective Expressions by Proximity Zones

Affective Expression Non-Facial and Non-Verbal	Proximity Zones		
	Intimate (contact - 0.46 m)	Personal (0.46 - 1.22 m)	Social (1.22 - 3.66 m)
Body Movement	Full body not visible at this distance	Small to medium movements	Large or exaggerated movements
Posture	Full body not visible at this distance	Postures visible at this distance	Exaggerated postures visible at this distance
Orientation	Orientation visible at this distance	Orientation visible at this distance	Orientation visible at this distance
Illuminated Color	Low intensity, dependent on small size to be visible	Medium to bright intensity	Bright intensity
Sound	Low to medium volume	Medium to loud volume, dependent on background environmental noise	Not audible, due to background environmental noise

Legend: ☐ Appropriate at this distance, ▨ May be appropriate at this distance,

■ Not appropriate at this distance

Fig. 4. Appropriateness of non-facial/non-verbal affective expressions by proximity zones.

Vikia, a museum robot developed by Bruce *et al.* [12] was of interest because it *oriented* toward a museum visitor. It was an avatar that appeared on a monitor attached to a fixed robotic base and interacted in the *personal* and *social* distance zones. If a museum visitor was detected within the *social* zone, they were acknowledged through facial expression, verbal interaction, and orientation that indicated focus of attention. Bruce *et al.* [12] determined that adding the ability to orient the robot toward the visitor displayed robot interest in the visitor and increased the likelihood that visitors would interact with Vikia. They were able to support this claim with data collected over four days and trials performed twice daily. The results indicated that the use of orientation and no facial expression (p-value of 0.002 with 99% confidence) had a higher probability of compelling visitors to stop and interact with the robot than using no facial expression and no orientation (p-value not presented for this scenario), or just using facial expression and no orientation (p-value of 0.042 with 95% confidence). There was an additive effect if both facial expression and orientation were used to encourage visitors to interact with the robot. Although Vikia does utilize the anthropomorphic features of the avatar face, the use of orientation displayed robot interest and played a significant role in achieving the goal of attracting people for interaction, regardless of whether a face was present or not.

Mizoguchi *et al.* [4] developed an expressive mobile robot that was animal-like in appearance. The robot included a head, two moveable arms, and wheels for mobility. The head contained large round eyes that were not expressive; however, the head did have the ability to orient toward a user. The entire purpose of this robot was to interact with humans, more specifically the elderly, and to display affect using body movement, poses, orientation, and proxemics. It used gestures patterned after ballet poses to communicate with humans, mobility to express spatial distance from the individual with which it was interacting, and trajectory of motion as methods of affective expression. The robot operated in the *personal* and *social* distance zones. When the robot was in the *personal* zone, the individual with which it was interacting appeared to show greater interest in the robot. The distance of interaction was dependent on the speed of movement of the robot. If the robot was moving at a slow speed, it could interact in either zone; however, when it was moving at a high speed, it must interact in the *social* zone, or the individual with which it was interacting became uncomfortable. Expression was generated by the changing of poses (gestures), the speed of movement and posture changes, rotation of the body, and the patterns of movements. Experiments were conducted in a laboratory setting. Participants observed 11 different robot poses and completed psychological questionnaires. The participants reported their comfort with the robot and their impression that the robot took interest in them. Orientation toward a tester was crucial in the impression of robot's interest. A significant problem with this approach was that there was no association of a movement with a particular affective expression. Statistical data to support their conclusions were not presented.

Moshkina and Arkin [10] utilized the speed of body movement, tail and ear positions, and the red illumination of an LED screen to express affect on a Sony robotic dog AIBO. The motivations for this research were to determine whether the AIBO was able to display emotions, and whether the display of emotions made interactions between participants and the AIBO more enjoyable. The emotions expressed in their experiments were alert interest (crawling gait, ears and tail raised), friendly interest (crawling gait, ears raised, and tail wagging), alert joy (fast walk, ears and tail raised), friendly joy (fast walk, ears raised, tail wagging), anger (fast walk, ears flat, tail raised, and red LED screen), and fear (robot backed up using a crawling gait, tail and head down, red LED lights off). The dog reacted to commands and stimulus presented in the *personal* and *social* proximity zones. The laboratory experiments were conducted with two groups, one that interacted extensively with a standard Sony AIBO and a second group interacted extensively with the emotion-equipped Sony AIBO. Later, the groups were able to interact with the opposite type of dog and give impressions. Their research presented a detailed experimental design and was supported with a thorough statistical analysis of results. The results indicated that those participants who believed the AIBO displayed emotions and/or personality (six out of ten in each group—a total of 20 participants) found that emotion and/or personality made the interaction more enjoyable [10]. They also found that women were more likely to attribute the affect to the dog than were men (mean value for women $= 3.8$, mean value for men $= 2.5$, $F = 4.829$, $p < 0.043$) [10].

C. Anthropomorphic Using Non-facial/Non-verbal Affective Expression as a Redundant Method of Expression

In traditional social robot implementations, body movement, posture, orientation, color, and/or sound are used for affective expression redundancy as a multimodal method of expression. These robots are perceived to be "cute" in appearance and have expressive robotic faces, and are developed explicitly for social interaction [1], [2], [5]. Although they utilize non-facial/non-verbal affective expressions for redundancy, they are not the primary focus of this survey. The robots utilized in search and rescue, law enforcement, and military applications do not have an expressive face for affective expression, and must rely on other methods of expression.

The robot Kismet developed by Breazeal [1] is an example of an anthropomorphic robot that utilizes non-facial/non-verbal affective expression methods for redundancy in social interactions. When objects appear too close to Kismet, it will not only display the expression of surprise with a startled facial expression, but also rapidly withdraw by moving its head and neck away from the stimulus and produce a vocal response [7]. Kismet typically interacts with caregivers who are in the *personal* and *social* distance zones, and will produce the aforementioned reaction when a person or object invades its *intimate* and *personal* distance zones of safety. Additionally, Kismet displays a withdrawing movement for redundancy purposes for the affective expressions of disgust and fear. Experiments are performed in a laboratory setting; however, the effectiveness of Kismet's non-facial/non-verbal affective expressions are not specifically isolated and evaluated in these social interactions. Several studies have been conducted regarding the overall effectiveness of affective expressions for Kismet.

V. HEURISTICS FOR AFFECTIVE EXPRESSION SELECTION FOR THE THREE PROXIMITY ZONES

A set of recommendations for the appropriateness of the non-facial and non-verbal affective expressions by proxemity zone is needed to guide the application of affective cues for particular robots and scenarios [6]. Fig. 4 proposes such recommendations. It captures heuristics such as the use of body movements and postures that is most effective in the *personal* and *social* distance zones; however, they are difficult to interpret in the *intimate* zone because of sight constraints at such close proximity [15]. Body orientation is perceivable in any of the proximity zones. The use of color for affective expression is likely appropriate in any of the distance zones because it can be made small enough to be visible in the *intimate* zone and still be observable in the *personal* and *social* zones. In the case of sound, it is most appropriate when expressed in the *intimate* and possibly the *personal* zones; however, it is difficult to impossible to audibly perceive affective expressions in relation to sound in the *social* zone due to background noise and environmental conditions.

A. *Justification for the Heuristics*

The prescriptive affective expression recommendations described in Fig. 4 is a synthesis of the cognitive literature and robotic experience reflecting the preferred non-facial and non-verbal affective expression for the three relevant proximity zones [15], [45]. Following Argyle [15] and Hall [45], the preferred non-facial/non-verbal affective expressions in the *social* and *personal* proximity zones are body movement and posture; they also note that sound can be heard at a medium level in the *personal* zone and at a loud level in the *social* zone. Body movement and posture are visible in both of these two proximity zones, and therefore, easy to interpret whether they are constant as in posture or changing as in body movement; however, sound is dependent on the volume in each of these zones. Unless the volume can be adjusted easily to accommodate different distance ranges, it is not likely that sound will be effective in the *social* zone. Maeda [9] prefers to use body movement in the *personal* and *social* proximity zones as the primary method of affective expression on the Khepera robot. Moshkina and Arkin [10] rely heavily on body movement, posture, and orientation in the *social* and *personal* zones for expressing affect in the Sony AIBO utilized in their experiments.

Following the work of Bruce *et al.* [12] and Nourbakhsh *et al.* [13], orientation is the preferred non-facial/non-verbal method of affective expression in the *personal* and *social* proximity zones. Bruce *et al.* [12] discuss that using tracking/orientation alone was more effective than using a face alone or no face/no tracking for attracting visitor's interactions and indicating attentiveness. Fincannon *et al.* [21] discuss that orientation toward the worker was preferred in the *intimate* proximity zone especially during communication interactions. Argyle [15] and Hall [45] do not directly discuss orientation; however, based on discussions of visibility in these zones, orientation would be observable.

Based on research from Sugano and Ogata [14] and Moshkina and Arkin [10], illuminated color is visible and an effective non-facial/non-verbal affective expression in the *personal* and *social* proximity zones. Sugano and Ogata preferred the use of color in the form of illuminated lights on the WAMOEBA-1R robot to express affect in both the *personal* and *social* proximity zones; however, the WAMOEBA-1R must be oriented toward an observer for the affective expression to be visible since the lights are the only means it has for expressing affect. The Sony AIBO used by Moshkina and Arkin [10] utilizes a red illuminated LED screen to support affective expression in the *personal* and *social* zones. The literature is lacking on the use of illuminated color in the *intimate* proximity zone; however, based on Hall's [45] description of what is visible in each proximity zone, an illuminated colored light is likely visible; however, it would be dependent on being small in size as indicated with a light gray entry in Fig. 4.

Argyle [15] and Hall [45] support the effectiveness of sound in the *social* zone if it is loud; however, the effectiveness is unclear in the robotics literature. For example, Bruce *et al.* [12] uses sound effectively at the *personal* and *social* distances in Vikia, the museum robot operating in a relatively quiet environment; however, Fincannon *et al.* [21] discuss that due to external noise found in the search and rescue environment, closer proximity improves hearing. Based on the Fincannon *et al.*'s [21] example, "ear-to-robot" sound communication was most effective (*intimate* zone); however, the appropriateness of sound in the *personal* proximity zone is dependent on the background environmental noise levels, and would need to be either medium to loud in volume as indicated by a light gray entry in Fig. 4. Due the fact that sound levels would need to be adjustable to accommodate the volume needed to be effective in the *social* zone, and in most situations, environmental noises would impede sound transmission at the *social* distance, the entry in Fig. 4 for the *social* zone is marked dark gray indicating that it is not appropriate at this distance.

The preferred affective expressions in the *intimate* zone are orientation and sound because vision is constricted, preventing perception of body movement and posture as indicated with dark gray entries in Fig. 4 [15], [45]. Fincannon *et al.* [21] discuss that both orientation and sound are highly effective in the *intimate* distance; however, the effectiveness of illuminated color in this zone is not clear based on the literature.

B. *Heuristics Applied to Victim Assistance*

In order to illustrate one of the potential uses of the prescriptive affective expression recommendations in Fig. 4, it is helpful to consider how it could be applied to a search and rescue robot that locates a victim and stays with the victim until assistance can arrive (usually 4–10 h [22]). The human–robot interaction in this case would span all three of the proximity zones: *intimate*, *personal*, and *social*. The robot would first approach a *social* distance from a located victim, and in this situation, body movements must be "large enough" or exaggerated in order to be visible by the victim at the *social* distance and should be reassuring to the victim; such movements are usually slow and smooth. Abrupt and jerky movements would give the impression that the robot is angry [30]. The robot should be oriented toward the victim to indicate concern and attentiveness [3], [12], [13], [19], [21]; however, the approach would be less threatening if made from the right or left side if the environment permits [46]. The robot could also begin displaying blue illuminated light to indicate the approaching of a calm presence. Sound at this distance would not likely be audible due to environmental noise occurring in the disaster site that would drown out any sound emitted by the robot [21].

The robot would quickly move from the *social* zone into the *personal* zone in order to perform a preliminary medical assessment of the victim. At this distance, the robot should be slightly raised and oriented toward the victim to indicate interest and attention to the victim. Body movements of the robot at this distance should be slow and smooth in order to keep the victim calm. Slow and deliberate movements would not be alarming to a victim. At the *personal* distance, the use of an illuminated blue lighting feature would be more readily visible by the victim, and as described by Argyle [15], blue would express calm, secure, tender, and pleasant affect by the robot to the victim. Additionally, the use of soothing tones [31] or music [30] could be utilized to express calmness and tenderness to elicit a calming response in the victim. Tones could be used to indicate a positive or negative response to acknowledge communication received by the robot from the victim. Additionally, tones and/or music can be used by the robot to indicate understanding to the victim regarding their situation.

The robot would also operate in brief intervals in the *intimate* zone when assessing the status of the victim, and possibly to administer air and/or water [22]. Actual body movements and postures would not be visible by the victim at the *intimate* distance, and therefore, it must rely on orientation, color, and sound as methods of affective expression; however, in some situations, orientation could be impeded due to space constraints. The robot would need to continue to move slowly and should remain oriented toward the victim if at all possible to show attentiveness and caring similar to the *personal* zone. Sound would be easily audible at this distance, and would be one of the preferred methods of expression to reduce the stress levels of the victim in the *intimate* zone. It would be important for the robot to emit soothing tones or music to the victim to keep them calm during medical evaluation and robot contact. This would be the most stressful interaction between the robot and the victim; therefore, soothing sounds would be a valuable tool during this type of interaction. The use of the blue illuminated light would possibly be effective in the *intimate* zone adding to the calming effect.

The majority of the 4–10 h [22] for victim recovery, the robot would operate primarily in the *personal* proximity zone (0.46–1.22 m), giving the responders enough standoff distance to monitor the status of the victim until assistance can arrive, while not being too intrusive to the victim. Murphy *et al.* [22] surveyed 28 medical providers, and several respondents discussed the need for a search and rescue robot to be comforting to the victim. Additionally, they commented on the "creepy" appearance of the robot; therefore, the use of these non-facial/non-verbal affective expressions could prove invaluable to a victim that is experiencing high levels of stress and trauma.

VI. DISCUSSION

From the review of the psychology and robotics literature, it should be clear that much work is warranted on the use of non-facial and non-verbal affect, and how it might be applied to human–robot interaction. However, the review also identifies two open issues: 1) *Is there any difference in the proximity zones between a human and mechanical device versus that of the human–human zones?* and 2) *What is the impact of the physical environment, the context, and the size of the robot?* The first issue has been explored by Walters *et al.* [46] with the PeopleBot robot that is similar in size to a human; however, it is not clear if their results will apply to smaller sized robots. The second question has seen some investigation but is still an open area of investigation. It is surprising that non-verbal tones and/or music have not been investigated by the robotics community, since it appears that this could be a valuable, low-cost mechanism that can potentially cross cultural boundaries for affective expression [32]. In addition, a formal correspondence between non-facial affective expression and specific emotions, such as the taxonomy of facial expressions generated by Breazeal for Kismet [1], [7], [8] is needed to guide research and applications.

The impact of the ecology that the robot functions in appears to be an important factor in the expression of affect, and is worth of further discussion. In terms of physical environment, Dautenhahn *et al.* [20] mention that physical context may limit the types of interactions that are likely to occur; however, this is not an area that has received much attention in the research community. In search and rescue situations, the robot must be able to interact with a victim in such a manner that it can provide comfort and calmness until help can arrive [6]. The robot will often be operating in confined spaces such as a void in a collapsed building or crash site, as discussed in [21], but unfortunately, a significant portion of robotic research has occurred in an open and relatively unconstrained environment. As a result, the size of the robot interacting with the human may make a difference in the amount of distance for each proximity zone, and the constraints on its maneuverability may limit body movements.

VII. CONCLUSION AND FUTURE WORK

This correspondence has reviewed and summarized the psychology, computer science, and robotics literature on affective expression by *appearance-constrained* robots operating within 3 m of a person. Taken together, the theory from psychology and limited robotic implementations to date suggest that non-facial/non-verbal expressions of affect will be useful for both *appearance-constrained* and anthropomorphic robots.

In athropomorphic robots, non-facial and non-verbal affective expressions can be used to reinforce facial expressions for naturalistic social interaction. Body movements, posture, orientation, and non-verbal sounds can add richness to the affective expression conveyed by facial expressions in human–robot interaction. For example, if the robot is expressing fear with a facial expression, the communication would be stronger if the robot also used a withdrawing body movement and a non-verbal whimpering sound. Additionally, if the face is not visible for some reason, then the non-facial and non-verbal affective expression would provide an additional method of social interaction and expression.

There are three key issues that were identified in the course of this research: 1) *the development of an accurate model of emotion generation*; 2) *how to measure emotional responses to the robot*; and 3) *how the robot can accurately convey its role and intent*. The development of an accurate model of emotion generation is a very challenging problem. This will likely require an interdisciplinary approach using concepts from psychology, neurology, fuzzy logic, and computer science concepts and theories. As shown in this correspondence, emotional responses need to be approached from a psychological perspective, which has a rich body of work in this area, and verified through human–robot interaction experiments. Using psychophysiological measurements, it is possible to adjust robot responses in real time, and this should receive further investigation. Human studies and experiments will be necessary to develop an accurate method of conveying the robot's role(s) and intent to the human with which it is interacting, since task context influences perception of affect. Currently, it is difficult to determine the intent of the robot and what it is conveying to those with which it is interacting.

Current research is the development of a mapping of body movements/postures to specific emotions as part of the development of a multimodal system of non-facial/non-verbal affective expressions analogous to Breazeal's mapping of facial expressions to specific emotions [1]. The development of this mapping will be used to program robots that can interact with humans appropriately in the confined space, highly stressed environs of search and rescue.

Future work includes the development of a mapping of sounds, tones, and/or music to specific affective expressions to be utilized in the *intimate*, and possibly, the *personal* proximity zones. In the case of *appearance-constrained* robots, the sounds should not attempt to anthropomorphize the robots, but rather to assist in making a non-anthropomorphic robot more socially interactive, and to improve the comfort level of individuals interacting with these robots.

Research needs to be performed to verify the heuristics presented in this correspondence. Experiments should be conducted with human participants to determine the appropriateness of each non-facial/non-verbal method of affective expression by proximity zone. Additionally, human studies should be conducted for each non-facial/non-verbal method of affective expression individually, and in combination to determine the appropriateness of use by proximity zone and to gain understanding of which methods assist in improving interactions between the robot and participants. Future studies should be conducted to determine whether participants are more comfortable with a robot using non-facial/non-verbal affective expressions in each proximity zone compared with a standard robot interacting in each proximity zone.

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