A Dog Tail Interface for Communicating Affective States of Utility Robots

by

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Abstract

As robots continue to enter people's spaces and environments, it will be increasingly important to have effective interfaces for interaction and communication. One such aspect of this communication is people's awareness of the robot's actions and state. We believe that using high-level state representations, as a peripheral awareness channel, will help people to be aware of the robotic states in an easy to understand way. For example, when a robot is boxed in a small area, it can suggest a negative robot state (e.g., not willing to work in a small area as it cannot clean the entire room) by appearing unhappy to people. To investigate this, we built a robotic dog tail prototype and conducted a study to investigate how different tail motions (based on several motion parameters, e.g., speed) influence peoples perceptions of the robot. The results from this study formed design guidelines that Human-Robot Interaction (HRI) designers can leverage to convey robotic states.

Further, we evaluated our overall approach and tested these guidelines by conducting a design workshop with interaction designers where we asked them to use the guidelines to design tail behaviors for various robotic states (e.g., looking for dirt) for robots working in different environments (e.g., domestic service). Results from this workshop helped in improving the confusing parts in our guidelines and making them easy to use by the designers. In conclusion, this thesis presents a set of solidified design guidelines that can be leveraged by HRI designers to convey the states of robots in a way that people can readily understand when and how to interact with them.

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Publications

Some ideas and figures in this thesis have appeared previously in the following publications by the author:

Ashish Singh and James E. Young. Animal-Inspired Peripheral Interaction: Evaluating a Dog-Tail Interface for Communicating Robotic States. In *proceedings of the Workshop on Peripheral Interaction: Embedding HCI in Everyday Life at the IFIP TC13 international conference on Human-Computer Interaction-INTERACT*, 2013.

Ashish Singh and James E. Young. A Dog Tail for Utility Robots: Exploring Affective Properties of Tail Movement. In *proceedings of the IFIP TC13 international conference on Human-Computer Interaction-INTERACT*, 2013.

Ashish Singh and James E. Young. A Robotic Tail for Communicating States. In *adjunct proceedings (video abstracts) of the ACM/IEEE international conference on Human-Robot Interaction-HRI*, 2013.

Ashish Singh and James E. Young. Exploring Animal-Inspired Human-Robot Interaction: A Robotic Tail for Communicating States. In *adjunct proceedings (late-breaking reports) of the ACM/IEEE international conference on Human-Robot Interaction-HRI*, 2012.

Chapter 1

Introduction

In this relatively young field of Human-Robot Interaction (HRI), many robotic interfaces, designs and prototypes are built to help people in their homes and workplaces (e.g., the iRobot Roomba vacuum cleaner robot cleans the floor). We expect robots to continue to enter peoples' lives in many ways. For example, from robotic vacuum cleaners to various other service robots such as autonomous lawnmowers, pool cleaners, floor washers, etc., to help people throughout the world. Interaction with such utility robots might be challenging if people are not aware of the present state of the robot, such as low-battery, etc. In addition, it is also important for robots not to bother people too intrusively by giving them status updates, but maintain an appliance-like presence to let people know when and how they should interact with the robot. For example, a dishwasher gives an indicator light to show it is working and you can hear the sound it makes while cleaning - it provides peripheral awareness.

One common technique for providing peripheral awareness in human-robot interaction is to incorporate human or animal-like affect and emotion directly into interfaces [32, 33]. For example, a humanoid robot which uses walking style to communicate its mood to people, where walking with its head lifted up represents a "proud" state [12]. Such impressions of robotic affect can be used to help users gain high-level state information without requiring them to read complex sensory information [6, 33]. For example, if a robot appears surprised, it can suggest that it is not sure how to proceed further and a person can help by taking control of the situation.

We propose to create an affective interface to leverage peoples' passing knowledge of dog behaviour [19]. Zoological research tells us that dogs can convey affective states through their tails [40], for example, suggesting a happy state by wagging, high arousal or self-confidence by raising their tails, or fear by lowering their tails [10, 17]. In our research, we leverage peoples' passing knowledge of dog tail motions (e.g., tail lowered means scared) [19] to help them understand the underlying present state of the robot. Because affective states can be easily understood, these can be effective in communicating the robotic states and letting people know when and how to interact with the robot. For example, when a robot is wagging its tail, it might be considered as happy, i.e., it is successfully doing its task and does not need attention.

Existing robotic pets such as the AIBO only use simple tail wagging, and it is still unclear how a wide range of tail behaviors and motions can be integrated into robotic interfaces. Therefore, in this thesis, we explored and unpacked a robotic tail vocabulary and investigated: how people interpret different kinds of tail-motions (based on various motion parameters, e.g., speed) and how can such a tail vocabulary be mapped to a utility robot's states. We built a robotic tail prototype to fit on a small utility robot (Figure 1.1) and investigated peoples' perceived affect by showing them a full range of robotic tail configurations and motions. From our results, we developed a set of guidelines that can be used by designers in the field of HRI for conveying different robotic states using a dog tail interface.

We validated these resulting design guidelines by conducting a design workshop where we asked people working in the field of interaction-design to design tail motions for a robot to convey its states in a particular scenario (e.g., urban search and rescue operation). The premise of this workshop was to investigate and improve the usability of our design guidelines for HRI interaction-designers. For example, polishing the parts that people find difficult to understand and improving the overall clarity of our guidelines.

In this thesis, we explored how a dog tail interface can be used by robots to

Figure 1.1: Our dog tail prototype

communicate zoomorphic affective states to people and help them understand when and how to interact with the robot.

1.1 Methodology

In our investigation, to physically show robotic tail motions to people, we built a dog tail prototype and mounted it on a robot. Next, we conducted a formal exploratory study where we showed a range of tail motions to the participants and asked them to rate each motion in terms of perceived robotic affect. Results from this study were used to form design guidelines for conveying desired affective robotic states via a dog tail interface. Finally, to evaluate our overall approach and validate our design guidelines, we conducted an informal design workshop.

In this section, we briefly describe how we designed our prototype (subsection 1.1.1), a user study we conducted (subsection 1.1.2) and how we evaluated our overall approach (subsection 1.1.3).

1.1.1 Designing the Dog Tail Prototype

We required a real working prototype in order to conduct a user study to determine how people perceive the robotic dog tail motions. Our prototype design was based on the following goals: tail should be able to move smoothly in the left-right (e.g., horizontal wagging) and up-down (e.g., tail raised and tail lowered gestures) directions and the entire prototype should look like a part of the robot. For example, the tail itself should have an appropriate length, relative to the size of the robot.

Therefore, in order to design a prototype that looks like a part of the robot, we took an iterative construction approach and conducted informal design workshops and pilot studies. Chapter 3 describes the construction of our prototype and participant suggestions that we recorded from our design pilots.

1.1.2 Mapping Affective Robotic Dog Tail Vocabulary

We developed our design guidelines by conducting a formal exploratory user study (fully controlled) where we varied the tail motions based on motion parameters such as speed, wag-size and height, to investigate how these parameters influence peoples' perception of robotic affect (e.g., which tail motions can make a robot appear more happy or more sad). To measure peoples' perceived robotic affect, we used a standard psychological instrument called Self-Assessment Manikin (subsection 4.1.2, page: 30) which allowed our participants to rate how they perceived the robot was feeling while communicating via tail motions. Chapter 4 of this thesis details our study design and the results obtained.

1.1.3 Evaluation

To evaluate our overall approach and to test our design guidelines, we conducted an informal design workshop with people working as HRI interaction-designers. In this workshop, designers used our guidelines for designing tail motions to convey the states of various robots that might work in different scenarios (e.g., search and rescue). Through informal discussions, designers helped us in identifying the parts in our guidelines that were difficult-to-understand and further suggested improvements to solidify them for future use. Chapter 5 details how we conducted our workshop and solidified our guidelines.

1.2 Contributions

Contributions of our research include:

- A Unique Robotic Dog Tail Interface Design and Implementation — We provide the design and implementation details of our novel dog tail interface.
- A Set of Design Guidelines for Communicating Affective Robotic States — We present a set of tested design guidelines that can be leveraged by HRI designers for developing dog tail behaviors for specific affective response.

We organized this thesis as follows: chapter 2 details the related work that has been done in the past, and chapter 3 describes how we designed and implemented our prototype. Chapter 4 describes our formal exploratory study to investigate how people perceived robotic dog tail motions in terms of affect. Finally, we present the evaluation of our method in chapter 5 and with some open questions for future research, we conclude our thesis in chapter 6.

Chapter 2

Related Work

> "Human-Robot Interaction (HRI) is a field of study dedicated to understanding, designing, and evaluating robotic systems for use by or with humans."
>
> — Goodrich and Schultz, 2007 [18]

Over the past several years, robotics has advanced dramatically and many utility robots have been developed. For example, robots with manipulator arms to assist people in nuclear plants [44], robotic guides giving directions to people in malls and museums [28, 52] to friendly robot companions to individuals [35]. These robots are designed to assist people, and it is therefore important to explore how people perceive these robots and how they interact with them. For this purpose, Human-Robot Interaction (HRI) has emerged as a field from Robotics, Human-Computer Interaction (HCI), Psychology, etc., where researchers design and study robots and their interfaces while keeping both humans and robots in the same interaction loop.

In HRI, researchers have been working on robots that can interact with people as social partners [27]. Many of these robots use abstract, nonverbal ways to communicate affective states to people in a way that they can be easily understood, such as using human body language, facial expressions, gaze, etc. For example, Keepon [24] uses its body language, iCat [48] uses speech and Kismet [6] uses its facial expressions to interact with people.

Affective states can also be communicated using animal body language. For example, Sony AIBO [16] was designed as a puppy, and was able to communicate using puppy voices, simplistic tail wagging and a cluster of LEDs that formed its eyes. However, it is still not clear if tails can communicate more robotic states other than happy (tail-wagging). For example, by lowering its tail a robot can suggest that it is stuck (scared – cannot move) and ask people for assistance, similar to a dog's tail [17]. Therefore, to investigate this, we built a dog tail interface for a robot to communicate its states such as "excited," "depressed," etc., using a variety of tail motions (e.g., tail-raised, tail-lowered, etc.).

In this chapter, we begin with discussing the social aspect of HRI (section 2.1). Next, we describe the nonverbal communication practices used in the past and how affect can be used for communicating abstract states (section 2.2). Finally, we end this chapter by describing a previous simplistic tail exploration and how we leveraged the related work to move further (section 2.3).

2.1 Social Human-Robot Interaction

One of the important research aspects in HRI is Social Human-Robot Interaction. Social HRI refers to the interaction of people with socially interactive robots, also known as social robots [6, 38]. Some have defined social robots as:

> "A social robot is an autonomous or semi-autonomous robot that interacts and communicates with humans by following the behavioral norms expected by the people with whom the robot is intended to interact."
>
> — Bartneck and Forlizzi, 2004 [3]

People are experts in interacting socially with others and find social interaction enjoyable and engaging [34] which can be leveraged by robots as an additional communication channel. Researchers have suggested that people perceive robots as living, for example, human-like (known as anthropomorphism) or animal-like (zoomorphism) based on how a robot looks and behaves [50]. Therefore by appearing human-like (e.g., having arms, face, legs, etc.) or animal-like (e.g., having dog ears, cat paws, etc.), and using social cues such as facial expressions, a robot can interact socially with a person and communicate its state in a way that people can readily understand them [15]. In our research, we leverage this by building a dog tail interface to enable a utility robot to communicate its zoomorphic states to people.

2.2 Robots and Nonverbal Communication

Nonverbal communication plays a significant role in interaction among people (e.g., waving their hands to say hello, smiling to convey a happy mood, etc.) [2, 29]. Some suggest that nonverbal behavior can be used to communicate easy to understand high-level states of robots [9]. For example, a humanoid robot that nods its head to suggest that it agrees with a person [7] and AIBO uses LEDs on its face to communicate happy and sad states [4]. Our proposal of using a dog tail to communicate robotic states likewise uses this zoomorphic nonverbal way of communicating the robotic states (e.g., happy, sad, etc.) that can be readily understood by people.

2.2.1 Affect as a Means of Communication

One way of incorporating nonverbal communication into robotic interfaces is to allow the robots to convey their state information via affect to help people readily understand when and how to interact with a robot. For example, researchers in HCI have explored that people attribute affect to movement of geometric figures like triangles, rectangles, and circles on a display [20], ambient color displays [11, 16], and sound [16, 42] by either anthropomorphizing or zoomorphizing them. Some have even suggested the use of human-like facial expressions and gestures for robots, where examples include mechanized faces with eyebrows, mouths [6, 8, 48, 53], human-like gestures with arms [8], animated faces on screens [26, 30], using mixed reality to superimpose graphics faces on robots [51], etc. In our work, we leverage the zoomorphic affect to communicate the affective states of our robot, using a dog tail.

Animals have commonly been used as a robotic interface inspiration for communicating affective states that can be readily understood by people. Leonardo, for example, was designed as a fantastical mammalian creature that communicates its states using hand gestures, facial expressions and body movements (Figure 2.1b [9]). Paro was designed as a baby harp seal, was covered with soft white fur to look cute and friendly and interacted with people using seal sounds (Figure 2.1a [49]). Several

(a) Paro (b) Leonardo

Figure 2.1: Some robots that are inspired from animals and can communicate their states via affect (source: creative commons [13, 21])

robots have also used tails in concert with other features to entertain people, as part of their animal persona or design [16, 39]. Therefore, in our research, we further investigate how a dog tail interface can be made useful and can communicate robotic states using animal-like affect, on top of being cute and fun.

2.3 Dog tail exploration

We are only familiar with one previous piece of work that made an attempt to explore peoples perceptions of a robotic dog tail [43]. In their work, researchers built a 1 Degree-of-Freedom (DOF) tail that moved horizontally and attached it to a picture of a dog in a way that the dog itself seemed to be sitting on a table while its tail moved. They conducted an informal study where they showed different tail motions by varying the horizontal wag speeds to their participants and asked them to report the emotions they perceived from the wagging tail. The results of their study suggested that the participants were able to associate the tail motions with emotions such as “interesting,” “sad,” “natural,” etc., and that interpretations vary with wag speed in one dimension. However, the researchers did not find consistent results across people.

Although this was an initial, informal study, it still provided some promising results. Therefore, in our work we take a step further and investigate this formally and in more depth. We enhanced the motion capability of the tail by adding another degree-of-freedom to allow the tail to move in left-right as well as up-down directions to include more tail motions in our exploration (e.g., tail-raised and tail-lowered gestures). In addition, we mounted our tail prototype on a real robot to explore peoples interpretations of robotic states communicated via a dog tail. We further expanded the scope of investigation by identifying two more tail motion parameters (wag-size and height) and varied them in 3 different levels.

In the next chapters we detail how we designed the dog tail prototype, how we investigated peoples’ perception of a range of robotic dog tail motions and our observations.

Chapter 3

Designing the Dog Tail Prototype

To help us investigate how people perceive robotic dog tail motions, we first designed a dog tail prototype. Our prototyping included exploration of various methods of tail construction, including servo motors with joints or a skeletal mechanism and various tail design aspects including tail size to robot ratio, tail appearance, etc. Moving further, we conducted several design pilots where we showed our prototype to interaction designers and informally discussed how we can improve it. We constructed our final prototype by implementing the suggestions we obtained from the designers.

In the sections below, we describe the robot prototyping platform (section 3.1), early prototypes we designed, and the design pilots we conducted (sections 3.2 and 3.3). Finally, we end this chapter by describing our final prototype that we used in our formal investigation (section 3.4).

3.1 Robot Prototype Platform

We selected the iRobot Create [54] robot for our research. The Create is a programmable prototyping version of a commercial off the shelf iRobot Roomba [47] vacuum cleaner robot that autonomously vacuums peoples' homes and workplaces. The Create resembles Roomba except that it does not have a vacuum which makes it easier to prototype with (less noisy, moves faster). We selected this robot for developing our prototype since it resembles a commercial robot that works closely with people (e.g., domestic service) and provides an additional space to install the dog tail. Sections 3.2, 3.3 and 3.4 detail how we designed our dog tail prototypes.

3.2 Initial Servo Prototype

Our initial attempt was to design a tail prototype entirely using servo motors (motors with rotary actuators that provide precise control of speed and position), as shown in Figure 3.1. An advantage of using servo motors is that we can control each motor individually to make various curves (Figure 3.2b). To construct our dog tail prototype, we used 4 Bioloid AX12+ servo motors from a consumer level robotics kit (ROBOTIS Bioloid Premium kit). Several plastic connectors were used to connect the servo motors together, including a plastic piece at the tip to make it pointed, similar to a dog's tail.

For initial testing, we simply chose several common dog tail motions including: wagging, raising and lowering the tail, and a tail straight posture (Figure 3.2). The four servo motors that we used provided us with four degrees-of-freedom for our tail.

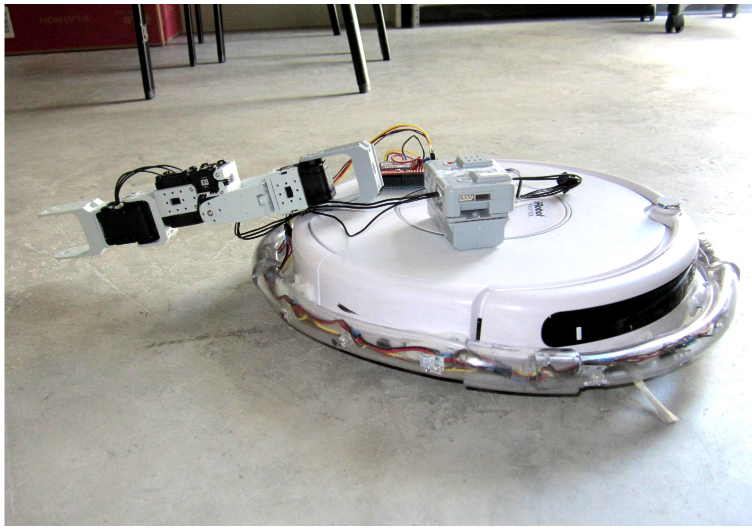
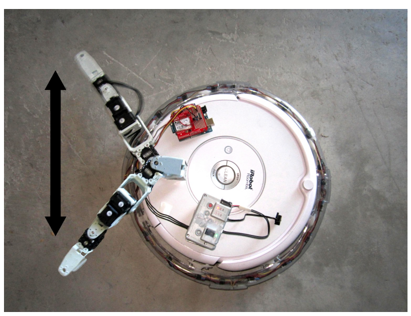
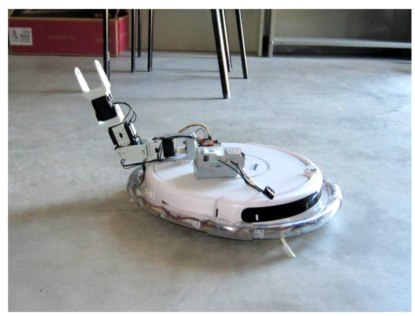


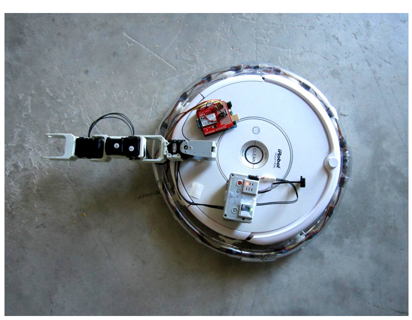
Figure 3.1: Our initial servo prototype.



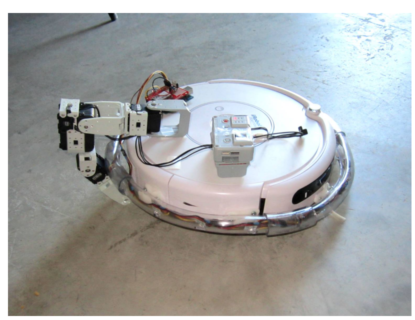
(a) Horizontal wagging



(b) Tail raised



(c) Tail straight



(d) Tail lowered

Figure 3.2: Our initial servo prototype showing various tail motions.

These degrees were: wagging (horizontal movement) and raising and lowering the tail (vertical movement), as shown in Figure 3.2a and 3.2b. However, tail lowered gesture was a bit complex for this prototype as we wanted the tail to go under the robot (e.g., forming a U-shape). Therefore, we used two more degrees-of-freedom by using two more servo motors: one to rotate the plastic piece at the tip (which prevented the tail from going under the robot) by 90 degrees (Figure 3.2d) and one more motor to lift this piece upwards by 45 degrees so that it can go under the robot. Lastly, we implemented the tail straight posture by keeping all the servos at 0 degrees position (Figure 3.2c).

After installing this prototype on the robot, we showed the tail motions to our lab members and informally asked them if our mechanical tail resembled a dog tail and how it could be improved further. To demonstrate the tail-motions on a moving robot, we used components from the Bioloid kit: servo controller (CM-510), an infra-red (IR) receiver and an IR remote controller (RC 100A). For showing each motion, we pressed a specific button on the IR remote controller.

Our lab members mentioned that the tail itself was too long for the size of the robot and the thickness of the tail made some members mention that it looked more like an arm than a tail. The curvature of the tail was also poor because it was segmented and not an actual curve. Some of our participants even complained that it looked too mechanical and suggested to cover it. In addition, the tail was heavy (difficult to mount on the robot) and started off with a jerk every time we moved it (a servo motor property). To overcome the weight and length issue we first explored smaller and lighter heavy duty servos. Smaller servo motors did reduce the length, however the tail still started off with a noticeable jerk. Therefore, we investigated other means for designing our prototype that would let us have a thinner and more light-weight tail, better curvature, and smoother movement. Eventually, we decided to investigate cable-pully mechanism for the tail. Section 3.3 describes our cable-pulley prototype.

3.3 Cable-Pulley Prototype

We constructed a second version of our dog tail prototype using a cable-pulley mechanism (Figure 3.3). To design the tail spine we used a modified common construction toy kit (Klixx): the interlocking pieces were sanded to achieve smooth movement and to increase range of motion, and paper-clips were inserted through

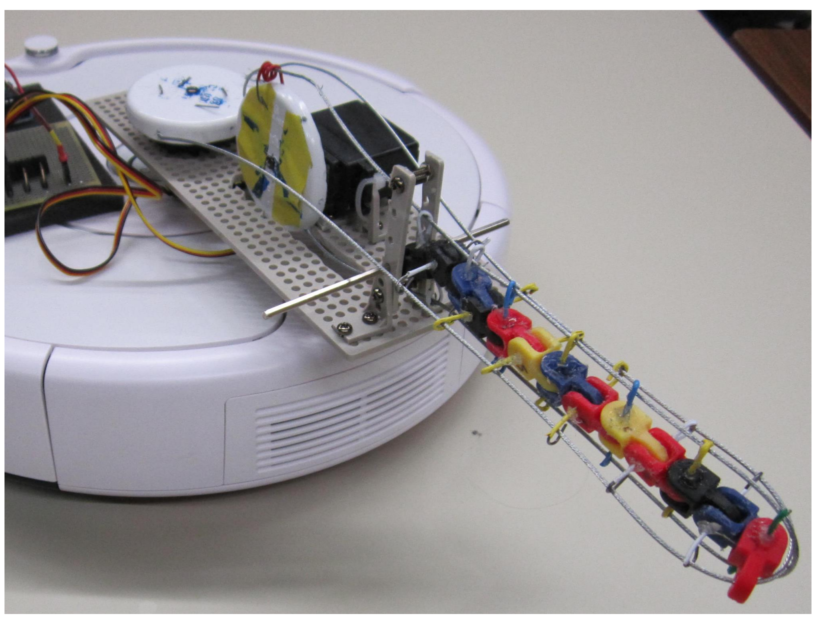


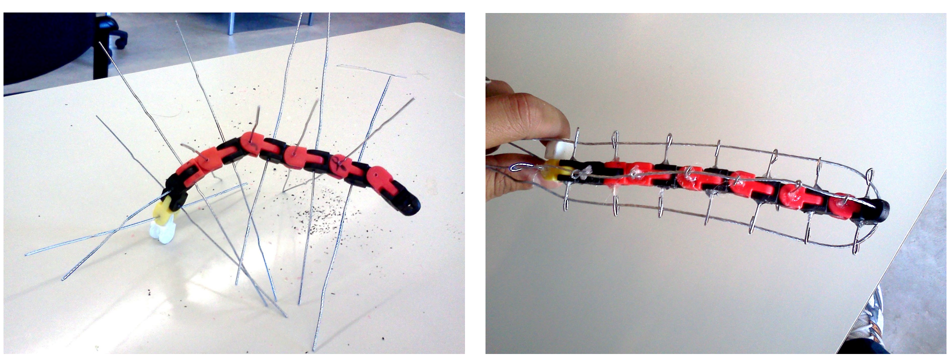
Figure 3.3: Our cable pulley prototype.

drilled holes to strengthen the joints (Figure 3.4a). This approach was inspired and was based on a technique used in hobbyist animatronics [1, 46]. Tail deformation was achieved using two cables (one for left-right and the other for up-down movement) and heavy-duty servo pulley mechanism attached to a wooden board. The cables were attached to the tail by being threaded through the paper clips (Figure 3.4b).

A challenge that we faced while designing the cable-pulley interface was that we had difficulty with the tail curving straight – when the cables moved, the tail would often go off-axis (e.g., instead of a horizontal wag, it would do roughly 45 degrees tilt). Due to this, we readjusted the cables each time the tail went off-axis.

For controlling the tail movement, we used an Arduino prototyping platform. We controlled the tail motions from a simple serial interface running on a laptop via USB tethering. To perform specific tail motions (e.g., wagging) we sent commands from the laptop.

In comparison to the prior servo prototype, our cable-pulley prototype had a

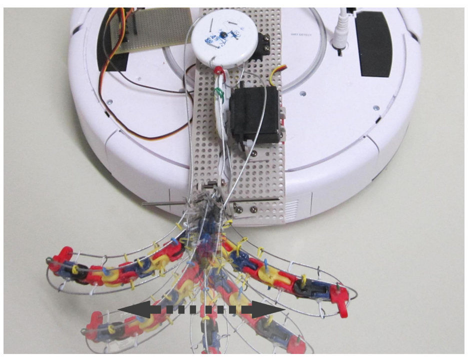


(a) Drilled and sanded with paper-clips inserted

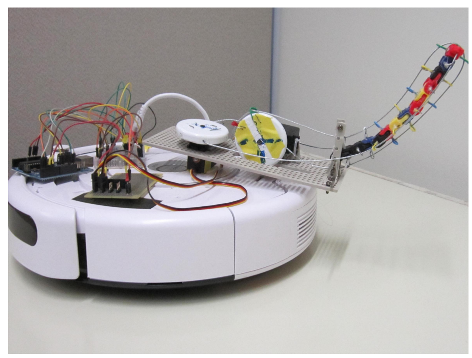
(b) Bent paper-clips ends holding the cable

Figure 3.4: Construction of our cable-pulley prototype

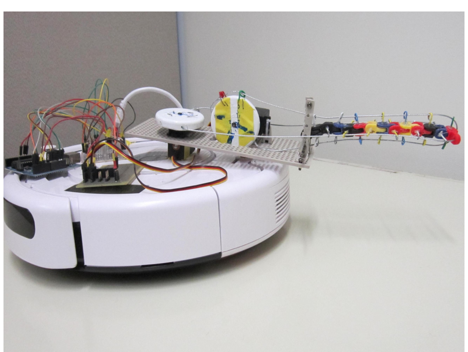
uniformly shaped tail-spine because of the interlocking identical klixx pieces (Figure 3.4). These interlocking pieces also helped in shortening the tail length as we simply reduced the number of pieces used. In addition, the cable-pulley mechanism resulted in smooth motion of the tail as the tail-spine itself was very light and cables provided a fluid pull and push, for example, to turn the tail left, the servo pulled the cable from the left side but pushed it from the right side using pulleys (Figure 3.5). This also provided control over the curvature of the tail as we could turn the servo more to allow the tail to curve more. However, there were several other



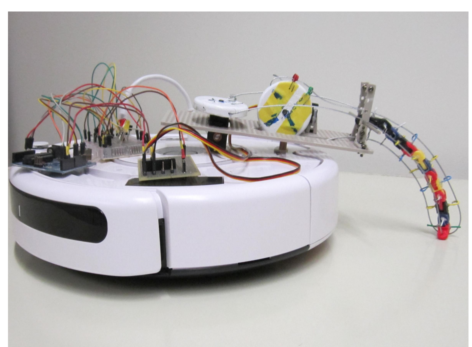
(a) Horizontal wagging



(b) Tail raised



(c) Tail straight



(d) Tail lowered

Figure 3.5: Our cable-pulley prototype showing various tail motions.

questions that still remained unanswered. For example, how long should the tail be? To explore these questions, we conducted several design pilots where we invited researchers working in the field of Human-Robot Interaction (HRI). The following section describes the design pilots we conducted and the results we obtained.

3.3.1 Design Pilots

We conducted several design pilots with interaction designers and HRI researchers and informally discussed various design related questions (e.g., whether or not the tail should be covered?). The results from these design pilots were helpful in further improving our dog tail prototype. We present the questions that we asked during the design pilots (Figure 3.6) and the results obtained, in the subsections below.

Figure 3.6: Designers participating in our design pilots and the informal study setup.

What should be an appropriate tail-length for our disc-shaped robot?

We showed 3 tail versions with different lengths to our participants. These tail versions were: short (10 cm), medium (15 cm), and long (32 cm), as shown in Figure 3.6 (leftmost picture in the bottom row – white, uncovered and black tail versions).

Most of the participants preferred the medium tail length for our disc-shaped robot. Participants also mentioned that short version was too small to observe from a distance and the long version was too long for our robot (e.g., one participant felt it like an alligator's tail). Medium tail length was favored strongly and some reported that it looked like a part of the robot.

Whether or not the tail should be covered?

We were not sure if people prefer seeing the robotic tail uncovered or covered. Therefore, in our design pilots we showed our participants various different tail versions including an uncovered tail (mechanical appearance) and several other versions covered with spandex stockings (semi-transparent), fur covering (soft to touch, opaque) and children socks (opaque). Also, we used both black and white colors as we were uncertain if people would prefer it to look mechanical, black or white that matches the color of the robot. Some of these coverings are shown in Figure 3.6 (leftmost picture in the bottom row, covering the 3 tail versions we built with different lengths).

Our Participants mentioned that they prefer seeing the tail covered because the robot itself is covered in white plastic. They also reported that no covering was too mechanical or unpleasant and a white spandex (hose) cover was seen as somewhat reptilian and left a negative impression. White fur covering for our tail was seen as cute and fun.

Do people understand basic robotic dog tail language?

In addition to the tail appearance, we informally asked our participants if they understand the basic dog tail language such as wagging means happy and whether they felt our robot to be happy when it wagged its tail. It was an initial proof of concept to test if people can understand basic robotic tail language so as to move forward with our investigation. We first showed pictures of both dogs and our robot with their tails in the same posture to the participants for example, both pictures showed the tail lowered posture (second and third pictures from the left in top row of the Figure 3.6). Next, we informally asked them if they do understand the robots' moods being conveyed through the tail motions.

Our participants mentioned that they were able to understand the basic robotic tail motions in terms of affect and did perceive the robotic tail as a dog's tail. Interestingly, some reported that: straight tail (parallel to the floor) was "neutral" on the robot while it appeared to be confusing for dogs.

Based on the results of our design pilots, we modified our cable-pulley prototype (e.g., covered the tail with fur) and constructed our current prototype. Section 3.4 details our modified cable-pulley prototype.

3.4 Modified Cable-Pulley Prototype

We modified our cable-pulley prototype by improving its overall design in terms of its functionality and appearance (Figure 3.7). We first identified why the tail went off-axis: this happened because the servos were not aligned directly in line with the central tail axis, both in terms of height above the platform and lateral offset. Furthermore, after adjusting servo positions, we observed that larger deviations in servo alignment can even cause the cables to collapse, stalling the movement of the tail. Figure 3.8 shows how servos and the tail spine should be aligned to avoid this tilt. This on-axis placement improved how the two axis could work together simultaneously and yielded circular tail motions.

To further improve the functionality of our prototype, we re-adjusted the spots where we connected the brake wires to the pulley, by aligning them directly in a line. This increased the size of each wag (the tail could go further left and right, and up and down) such that it allowed the tail to even perform full circular motions.

Figure 3.7: Modified cable-pulley prototype

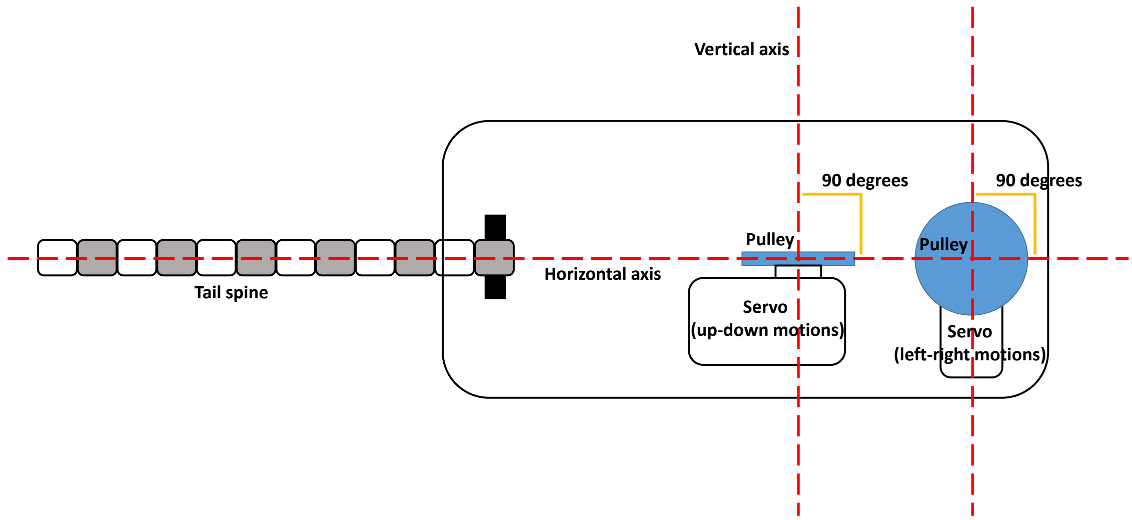


Figure 3.8: Layout of our prototype showing correct alignment of servos and the tail-spine.

Also, the servo that controlled the up-down motions (Figure 3.8) was in the way of the cables used by servo that controlled left-right tail motions, making it difficult for the tail to curve left, therefore we increased the lengths of the paperclip-loops to 1.5 centimeters each side from 1 centimeter to increase the space between the pulley and the cables. To further enhance how the tail looks and make it appear as a part of the robot itself, we covered the entire tail mechanism with a wooden box to hide the internal workings, covered the tail spine with white furry fleece (taken from a stuffed animal toy) and kept the tail length at 15 centimeters (medium tail length, as observed from design pilots).

The electronic implementation for this prototype was achieved by using two Arduino Uno prototyping platforms, one to control tail motions and one to drive the robot around a space. We also added a WiFly wireless internet module for remote control of both the tail and the robot.

3.5 Prototype Conclusion

Our final prototype is a modified version of the cable-pulley prototype that moves in up-down and left-right directions smoothly and looks like a part of our disc shaped robot. This prototype was useful for conducting a user study in order to investigate if peoples' basic understanding of dog tail communication (e.g., horizontal wagging communicates a positive and playful state) transfers to interacting with a robot with a dog tail. Also, if it did transfer, is there a dog tail vocabulary that can be unpacked based on how a tail moves (e.g., is faster wagging different from slower wagging)? In the next chapter, we detail an exploratory user study we conducted using our final prototype and the results we obtained.

Chapter 4

Investigating Peoples' Perceptions of Tail Motions

Previously in this thesis, we described how we designed a dog tail prototype and mounted it on a disc-shaped robot. This prototype design is a part of our research that focuses on investigating how people perceive a broad range of robotic dog tail motions, in terms of affect. Therefore, in our investigation, we conducted an exploratory user-study where we asked participants to rate the tail motions on an instrument based on a standard psychological model known as Russell's Circumplex Model of Affect [36] that maps the perceived emotions on a two-dimensional scale which includes valence (unpleasant to pleasant) and arousal (low energy to high energy) scales. Through this tail exploration, we developed a set of design guidelines that can be used by HRI designers to convey the affective states of their robots in way that they can be easily understood by people and help them understand when and how to interact with them. In this chapter, we begin with detailing our exploratory methodology and the user-study design. Next, we present our results and discuss them. Finally, we conclude this chapter by presenting a preliminary set of design guidelines that we developed from the results of our study.

4.1 Exploratory Methodology

From previous zoological research, we are aware of how dogs use their tails to communicate [10, 17]. Also, people have some basic understanding of dog tail communication (from our initial pilot study and [19]). However, we still did not know if this knowledge actually transfers to peoples' perception of robotic dog tail motions and to what extent they can be perceived by people. To explore this, we designed and implemented a broad range of possible robotic dog tail motions and asked people to rate them. This exploration was aimed at investigating how people perceive various tail motions in terms of a robot's affective state.

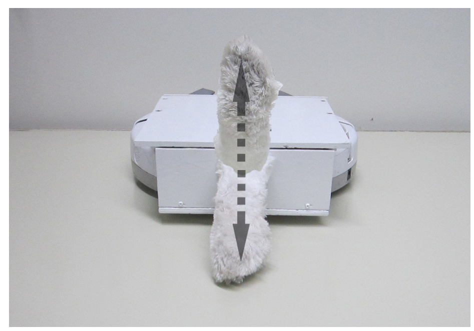
4.1.1 Tail Motions Involved In Our Study

In developing a broader range of robotic tail motions that we can investigate, we used both existing dog tail vocabulary (how real dogs act, e.g., they wag their tails when they are happy) and other mechanically possible motions which do not exist in nature (e.g., circular wagging). These motions were combined and further grouped into three categories: continuous motions (tail keeps moving), static postures (tail keeps a pose) and action gestures (tail performs a gesture such as lowering the tail).

Continuous Tail Motions

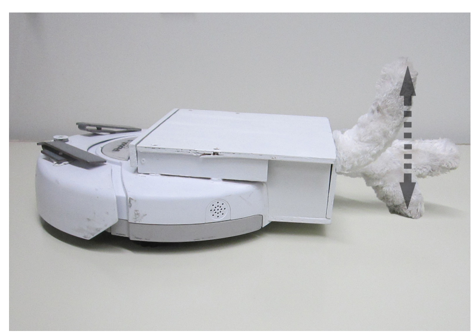
Continuous tail motions include those motions in which the tail is always moving. We designed three different kinds of continuous tail motions: horizontal, vertical and circular wagging. For horizontal wagging, the tail moved from left to right on a plane roughly parallel to the floor similar to as in nature [10, 17] (Figure 4.1c). In case of vertical wagging, the tail moved up and down perpendicular to the floor (Figure 4.1b) and for circular wagging, the tail moved in a complete circle (Figure 4.1a), where both of them are not present in nature.

(a) Circular wagging



(b) Vertical wagging

(c) Horizontal wagging



(d) Side-view of vertical wagging

Figure 4.1: The three continuous motions used in our study.

Static Postures

In the case of static tail postures, the tail is kept at a tail-straight posture having a given constant offset from the floor. We used three different offsets for the static postures: higher offset (tail held at a larger distance from the floor), medium offset (tail held parallel to the floor) and lower offset (tail held closer to the ground).

Action Gestures

In addition to the continuous motions and static postures that do not change, we developed two tail gestures, a raising and a lowering action. To mimic how dogs act in nature: the tail was kept at a non-moving neutral state slightly below center (as with a real dog) except when it moved to complete a gesture. We created low, medium, and high speed versions of the gestures, referring to the time taken to change from neutral to target state (raised or lowered), and a low and high offset version of each, representing how far the gesture moved from neutral. To make the gestures noticeable, we added a pause such that the tail would hold the gesture for 0.5 seconds before returning to the neutral state.

We were also interested in investigating how low-level motion parameters (e.g., speed) impact the perception of people. For example, how differently a faster wagging tail is perceived as compared to a slower moving tail. We explored three low-level parameters in our study: speed (how fast or slow the tail moves), wag-size (how wide or narrow each wag is) and height (offset from the ground – how far or close the tail is to the ground). All of these parameters were explored for continuous motions, however, for action gestures wag-size and for static postures both speed or wag-size were not used. Additionally, the speeds for action gestures represented the time taken to change from neutral to target state (raised or lowered) and a low and high offset version of each, representing how far the gesture moved from neutral.

Table 4.1 presents an overview of our 31 motions deriving from the above configurations. Note that attributes are manipulated independently of others and thus some entries of the table are identical. For example, for the three wag sizes of horizontal wag, the other two attributes (speed, height) were kept fixed; for horizontal wag, the medium speed and the medium height settings were effectively identical. This reduction yielded 26 unique behaviors that were shown to participants.

4.1.2 Measuring Perceived Affect

To investigate how people perceive the tail motions, we used a standard Psychological model of affective and emotional states, Russell's Circumplex Model of

Table 4.1: Paramteterized tail motions

category	sub-type	attributes
continuous wagging	horizontal	speed: low, medium, high wag-size: small, medium, large height: low, parallel to floor, high
	vertical	speed: low, medium, high wag-size: small, medium, large
	circular	speed: low, medium, high
action gestures	raising	speed: low, medium, high height: low, high
	lowering	speed: low, medium, high height: low, high
static postures		height: low, medium, high

Affect [36]. This model is largely used to represent and explain affective states by breaking them in two dimensions: valence and arousal. Valence indicates how pleasant an emotion is (from unpleasant to pleasant) and arousal indicates how intense an emotion is in terms of energy (from low to high energy) (Figure 4.2). For example, "sad" is represented as being unpleasant and low energy while "delighted" is represented as being pleasant and high energy. Some suggest that there can be a third dimension of affect: dominance (control over one's emotions) [5] that further breaks down affect into the feeling of being controlled to completely in control. For simplicity, we did not use dominance dimension in our investigation.

Russell's model of affect provides a framing for affect but it does not provide a way

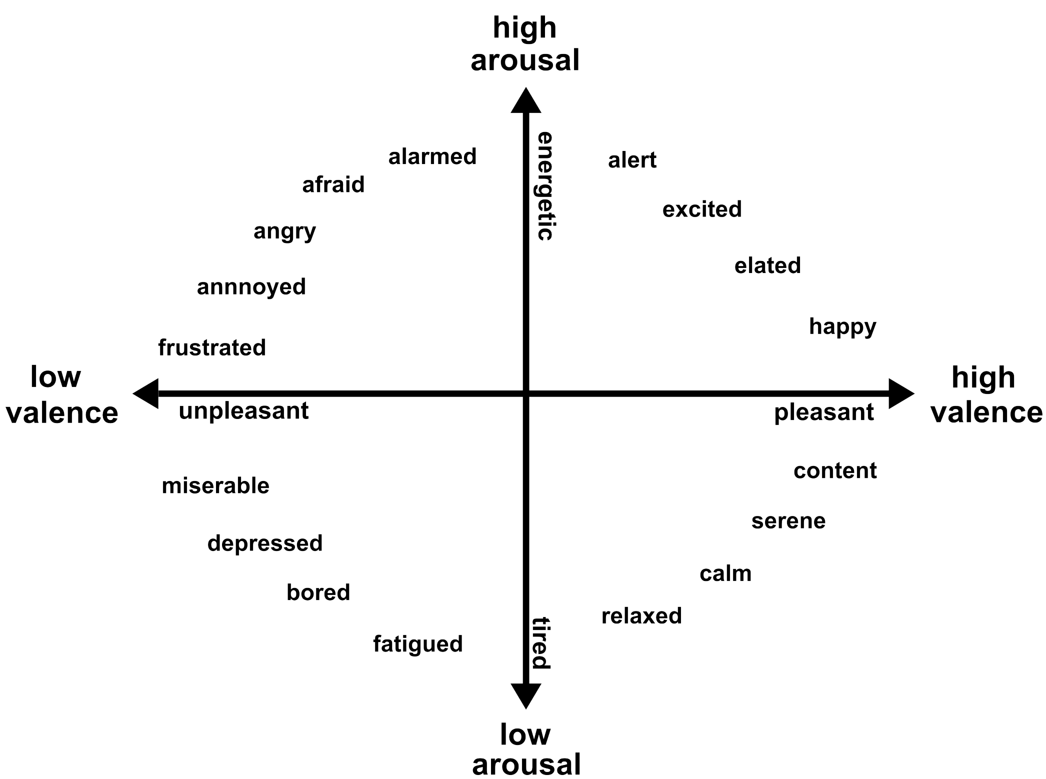
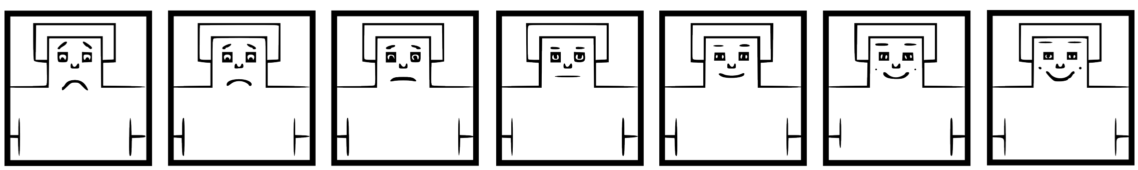
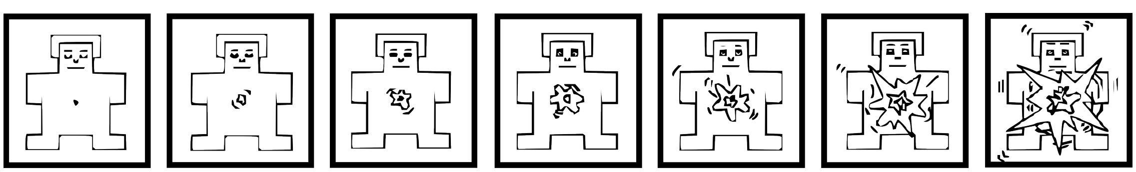


Figure 4.2: Russell's Circumplex Model of Affect. (see [36])

to assess these. Therefore, in order to measure peoples' perceptions of the robot's affect, we employed the Self-Assessment Manikin (SAM) [31]. SAM (Figure 4.3) is a standard psychological instrument for rating affective states on the above affect model, where valence and arousal are represented by a series of easy to understand comic-like pictorial representations: from a very unhappy to a very happy character on the valence dimension, and from a sleepy low-energy to a high-energy awake character on the arousal dimension. People can rate an affective state simply by selecting the most appropriate picture on each dimension; in our case we used seven-point scales. Although generally used for a person to rate their own feelings [25], this method can be used to rate the perceived affective state of other people [37, 41].



(a) Valence scale



(b) Arousal scale

Figure 4.3: SAM rating scales used in our study

4.2 A Formal User Study

In our exploratory study (published in [45]), we asked participants to rate each motion in terms of the perceived valence and arousal where valence indicates how pleasant the perceived affect is and arousal indicates the intensity and energy, using SAM [25]. We recruited 20 participants from our local university population to participate in our study: 12 men / 8 women, aged 18–47 ($M = 24.25$, $SD = 6.79$). Our study was reviewed and approved by our university research ethics board, and all participants received $10 for their participation in the 60 minute study.

Participants were brought to our lab environment, and after a brief introduction, signed an informed consent form and received their compensation. We introduced the robot and the tail, the concept of the robot using the tail to communicate mood, and introduced the SAM scales based on the recommended text from the instruction manual [25]. Participants proceeded to view the tail behaviors. The order of appearance of tail behaviors was counterbalanced across participants using a incomplete Latin Squares design [22]. We counterbalanced the order that the groups were shown in: continuous motions, static postures and action gestures. Further, within each group we counterbalanced the tail behaviors, such as for continuous motions: horizontal, vertical and circular wagging and the tail parameters (e.g., for speed: high, medium and low). Therefore, participants would see a counterbalanced set of tail motions within a group before moving on to the others. Participants were given 15 seconds post-demonstration of each tail behavior to rate the configuration on the SAM scales. Finally, we conducted a semi-structured interview, to investigate general views on the tail interaction, and debriefed the participants before ending the study. All studies and interviews were videotaped.

The layout of the study environment is shown in Figure 4.4, where the participant was seated at a desk positioned to easily view the robot's motion, as it followed the path indicated. We designed this path to provide views of the tail from the front, sides and behind. The robot used the same path for all tail configurations, where the tail action was the only thing that changed. Blue ellipses on the robot path represent the spots where the robot showed the action gestures such as "raising the

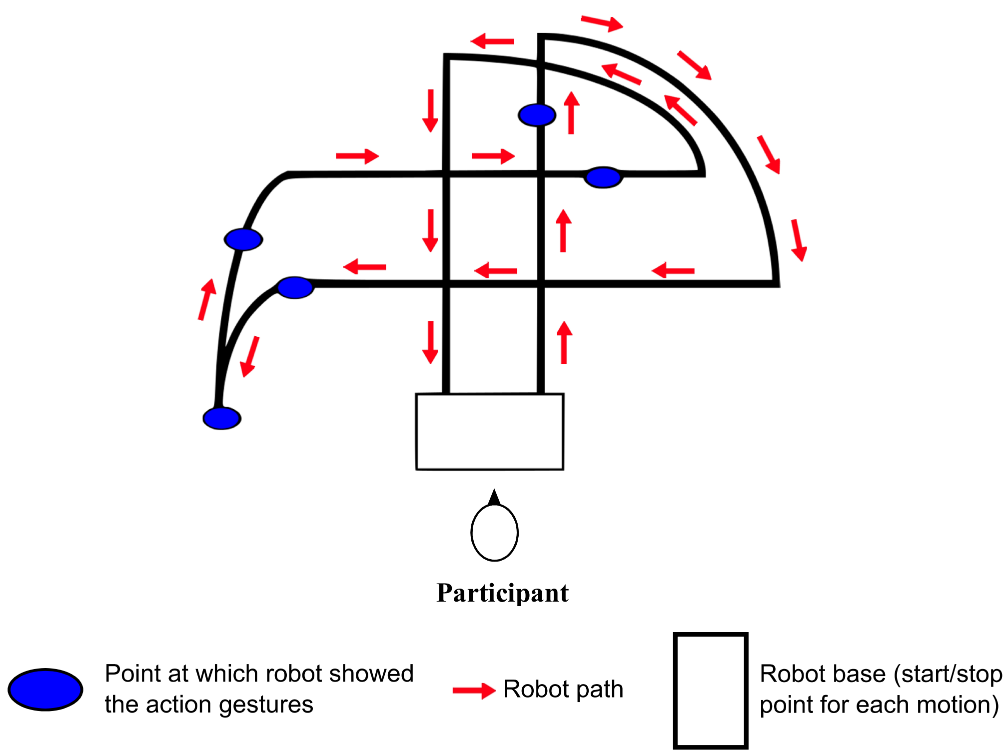


Figure 4.4: Robot motion plan, blue ellipses define the points where robot showed action gestures in those cases. Participants were seated at a desk.

tail" which can only happen at certain points (e.g., a dog lowers its tail only when its scared). We used side and back views of the robot for showing action gestures so as to provide a clear view of the tail to the participants; we did not have a view from the robot's front as the robot might have occluded the tail. Other than action gestures, all tail motions were programmed to initiate when the robot started to move and moved continuously until the robot came to a halt. The path took 35 seconds to complete, after which the experimenter returned the robot to its original position to minimize drift over the cases.

4.2.1 Software Setup

To show various tail behaviors to our participants, we implemented a remote control software using C++, on a windows 7 laptop. This software offered a simple GUI with labeled buttons to choose the desired tail behavior (e.g. horizontal wagging, raised gesture, etc.) and the tail parameters (e.g., speed: high, medium and low). Once the researcher chose the desired tail behavior, the software printed the selected combination of tail behavior and the parameter (e.g., HW3S for horizontal wagging with high speed) on the screen for the researcher to confirm and send it over a wireless 802.11 n network to the robot by clicking the send button. Figure 4.5 shows our software implementation.

The robot received this information using a WiFly wireless internet module (section 3.4) that triggered the tail microcontroller to move the tail according to the information received and prompted the robot microcontroller to move the robot. The wireless module and both of the microcontrollers were programmed using C++. In

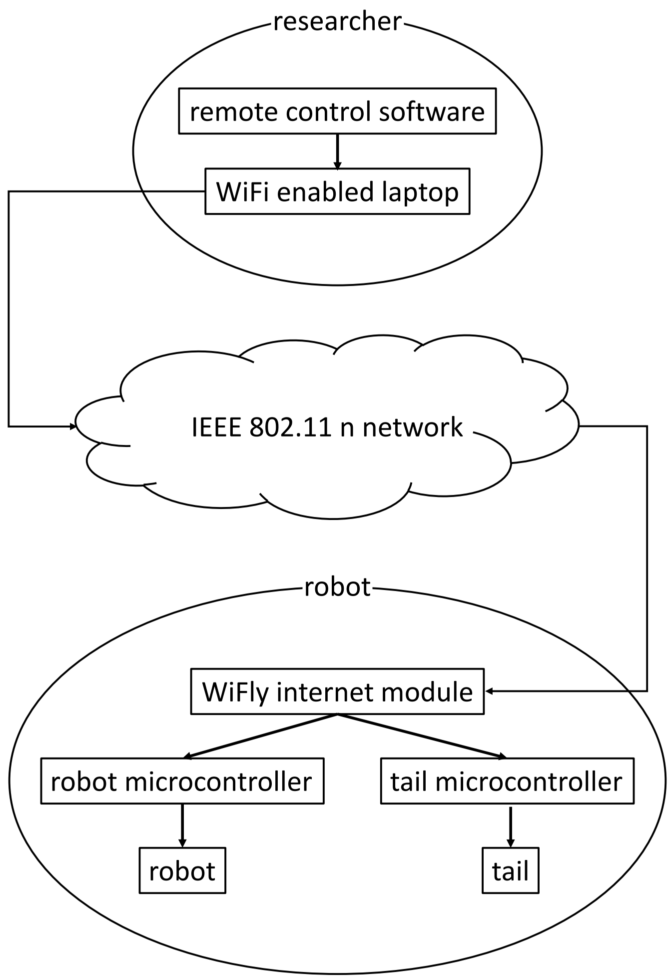


Figure 4.5: Our software setup

this process, our robot did not communicate back to the researcher.

4.2.2 Anticipated Interpretations

In general, we assumed that high tail height will have high valence, and that valence values will decrease when the height is decreased, as this is naturally how dogs communicate with their tails [17, 23]. Additionally, it was seen in previous work that higher speeds will have higher arousal [37]. We expected this to happen for wagging, gestures, and postures. We did not look further into the dog tail specifics as we believe that people do understand the basic tail behavior such as wagging but they may not understand more intricate motions, for example, wagging on the left versus on the right.

4.3 Results

We converted participant ratings under SAM scales to numbers by mapping the scales from 1 to 7, for both valence and arousal. These numbers were used as scale data for statistical analysis. We performed six primary analyses using a standard statistical tool: Analysis of Variance (ANOVA). ANOVA is used to test significant differences between the means of groups of independent variables [14]. Based on our configurations highlighted in Figure 4.1 and our anticipated interpretations; our dependent variables were the participant ratings of affect on the valence and arousal dimensions.

4.3.1 Statistical Analysis and Inference

Speed Vs. Wag Type

We conducted a 2 way ANOVA on wag type (horizontal, vertical, circular) versus speed (low, medium, high). As the assumption of sphericity was violated for the main effect of speed on valence (Mauchly's test, $X_{22} = 14.93$, $p <.05$), degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (e =.631).

All effects are reported as significant at p<.05. There was a significant main effect of the wag speed on both valence $F_{1.26,24.30} = 9.79$, $\eta^2 = 0.35$ and arousal $F_{2,36} = 71.38$, $\eta^2 = 0.80$. Planned contrasts (we predicted that more speed would express more energy and more positive valence) revealed that, on both the valence and arousal dimensions, high speeds were rated significantly higher than medium speeds $F_{1,18} = 18.53$, $\eta^2 = 0.50$ valence, $F_{1,18} = 42.92$, $\eta^2 = 0.70$ arousal, and low speeds $F_{1,18} = 11.79$, $\eta^2 = 0.40$, valence, $F_{1,18} = 99.42$, $\eta^2 = 0.85$, arousal.

There was also a significant main effect of wag type on both valence $F_{2,36} = 15.52$, $\eta^2 = 0.46$ and arousal $F_{2,36} = 39.63$, $\eta^2 = 0.69$. Post-hoc tests (with Bonferroni correction) reveal that vertical wagging ($M = -0.56$, $SD = 1.49$) was rated as lower valence than both horizontal ($M = 1.44$, $SD = 0.98$) and circular ($M = 0.98$, $SD = 1.83$), although there was no difference found between horizontal and circular. For arousal, all differences were significant: horizontal wagging ($M = 0.63$, $SD = 1.3$), vertical ($M = -0.56$, $SD = 1.45$), and circular ($M = 1.61$, $SD = 0.97$). These relationships are shown in Figure 4.6.

There was a significant interaction effect between the wag type and speed on valence $F_{4,72} = 3.74$, $\eta^2 = 0.17$ and arousal $F_{4,72} = 3.02$, $\eta^2 = 0.14$, indicating that speed's effects on perceptions of valence and arousal depends on the wag type. For valence, post-hoc tests (with Bonferroni correction) revealed that all three speeds yielded different results for horizontal wag, but no significant effects were found for vertical or circular wags, as suggested by Figure 4.6. For arousal, post-hoc tests (with Bonferroni correction) revealed that speed is a significant predictor of measured arousal for horizontal and vertical wagging, but for circular wagging, low

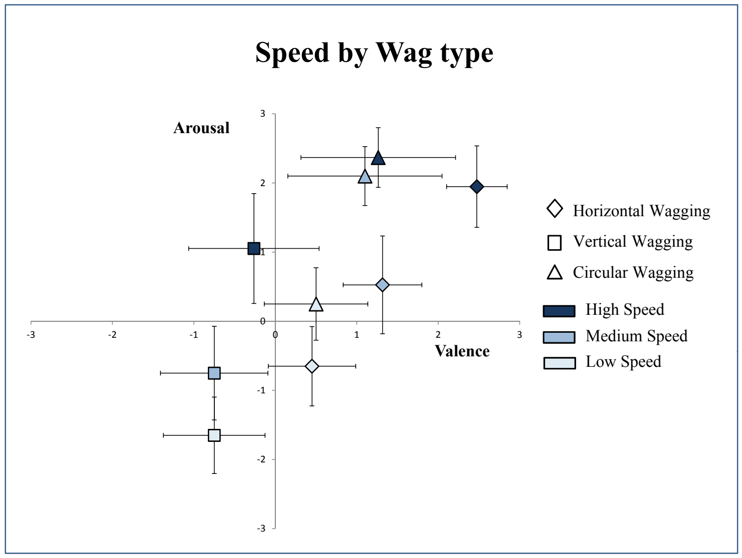


Figure 4.6: Speed by Wag-type, error bars show 95% confidence interval.

speed is significantly different from medium and high, which themselves are not different.

Wag-Size Vs. Wag Type

We conducted a 2-way ANOVA on wag-size (small, medium and large) versus wag type (horizontal, vertical); all effects reported significant at $p<.05$. There was a significant main effect of wag-size on both valence $F_{1,17} = 7.77,\ \eta^2 = 0.31$ and arousal $F_{1,17} = 48.39,\ \eta^2 = 0.74$, showing that smaller wag-size increases perception of both valence and arousal (Figure 4.7). A significant interaction effect was found between the wag type and wag size on arousal ($F_{1,17} = 6.037,\ \eta^2 = 0.43$) indicating that effect of wag size on levels of arousal for horizontal wagging and vertical wagging are not the same. The interaction plot below suggests that when wag size is reduced, arousal value of vertical wagging increases dramatically as compared to horizontal

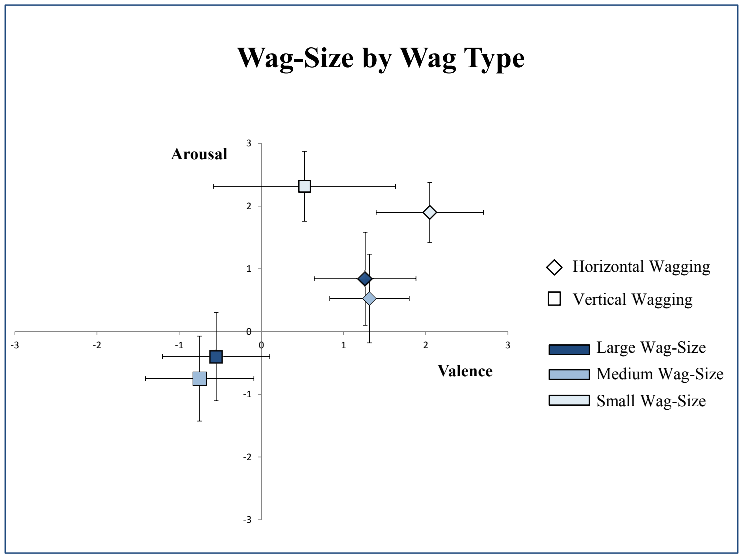


Figure 4.7: Wag-Size by Wag-type, error bars show 95% confidence interval.

wagging. Figure 4.8 represents the interaction graph we obtained.

Height of Horizontal Wagging

We conducted a 1-way ANOVA on height (low, parallel to floor, high) with horizontal wag type; all effects reported significant at $p<.05$. There was a significant main effect of height on valence $F_{2,32} = 6.601$, $\eta^2 = 0.29$, with planned contrasts highlighting that both medium $F_{1,16} = 4.69$, $\eta^2 = 0.23$ and high height $F_{1,16} = 12.48$, $\eta^2 = 0.44$ were higher valence than low height (Figure 4.9). There was no effect on perceived arousal.

Height of Static Postures

We conducted a 1-way ANOVA on height (low, parallel to floor, high) with static postures; all effects are reported significant at $p<.05$. There was a significant main

Figure 4.8: Interaction between wag size versus wag type on arousal score

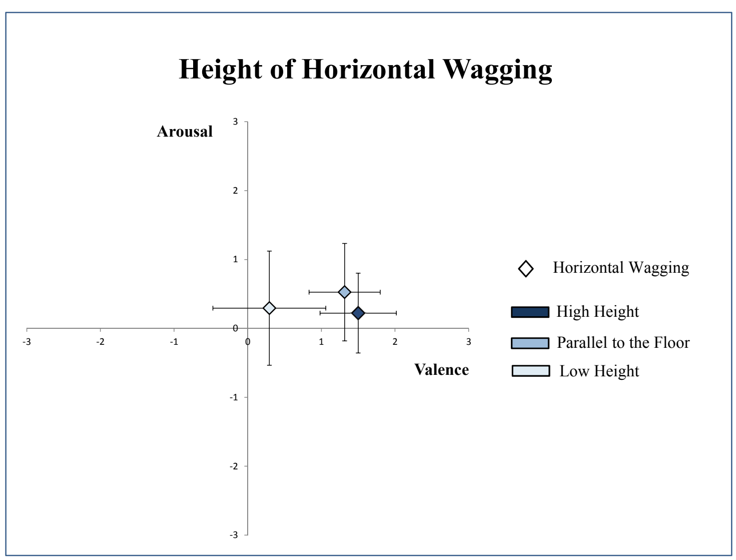


Figure 4.9: Height of horizontal wagging, error bars show 95% confidence interval.

effect of the height on perceived valence $F_{2,38} = 21.4$, $\eta^2 = 0.530$ and arousal $F_{2,38} = 6.36$, $\eta^2 = 0.251$. Planned contrasts for valence showed that low height ($M = -2.35$, $SD = 1.04$) was lower rated than both medium ($M = -1.1$, $SD = 1.59$) and high ($M = -0.1$, $SD = 1.41$), and for arousal low height ($M = -2.00$, $SD = 1.59$) was lower rated than high ($M = -0.65$, $SD = 1.46$) (other contrasts non-significant). This explains that high height had more arousal and more valence as compared to low height (Figure 4.10).

Non-Significant Tests

No significant effects were found using ANOVAs on speed (low, medium, high) by action gestures (Figure 4.11), or height (low, parallel to the floor, high) by action gestures (Figure 4.12).

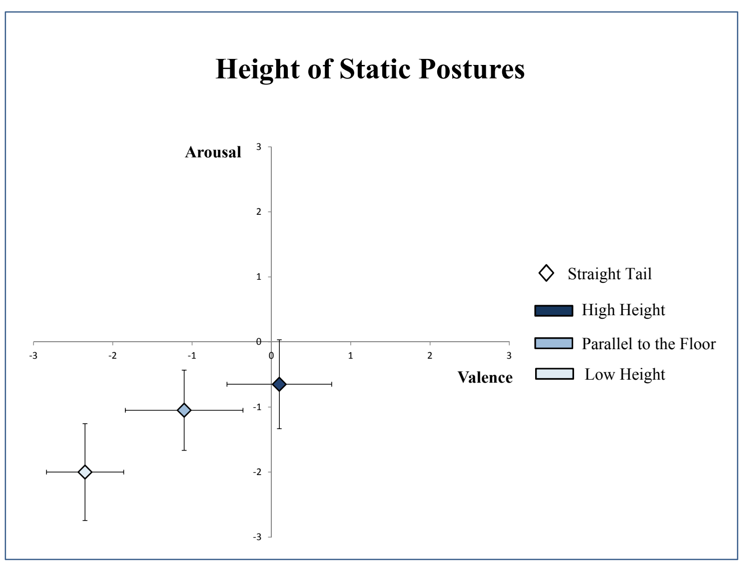


Figure 4.10: Height of static postures, error bars show 95% confidence interval.

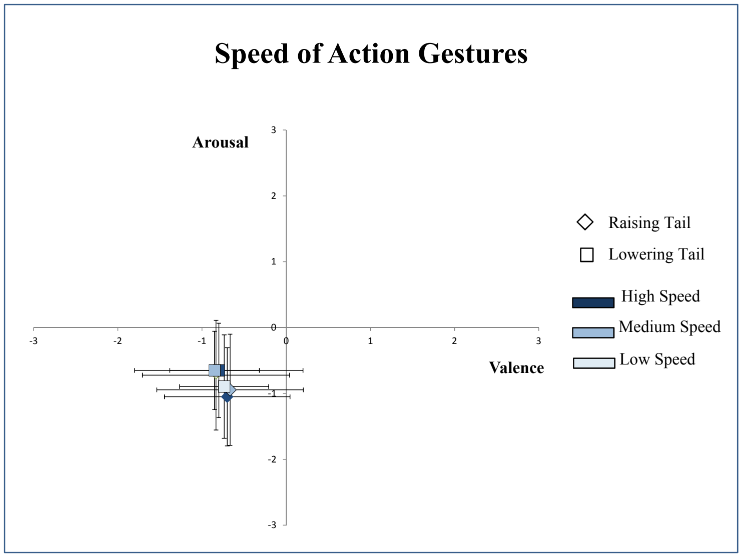


Figure 4.11: Speed of action gestures, error bars show 95% confidence interval

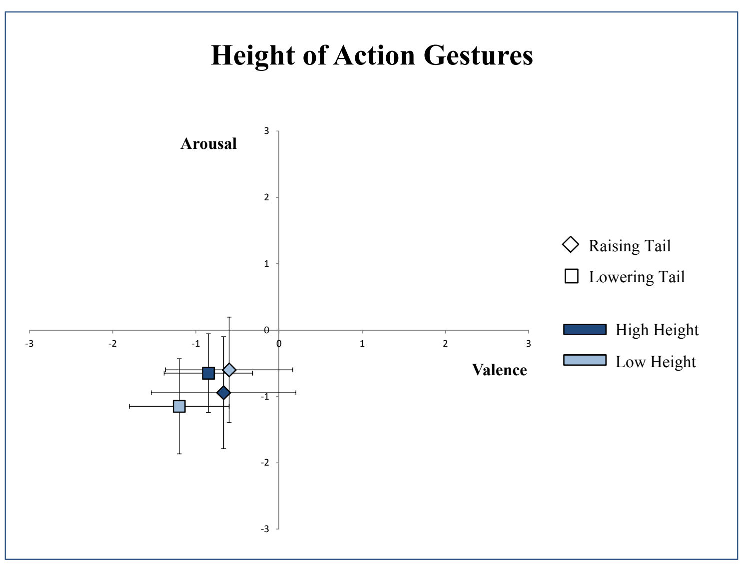


Figure 4.12: Height of action gestures, error bars show 95% confidence interval

4.4 Semi-Structured Interview

From the post-study semi-structured interview, we found that: 17 participants (85%) zoomorphised the robot, for example, saying "it looks like an animal, it felt like a dog." Additionally 2 female participants (25% of females) asked the name and gender of the robot and 6 of them discussed its "cuteness," while 6 male participants (50% of males) talked about it being "helpful and useful" and 2 of them mentioned that they felt "happier" when the robot wagged its tail with high speed.

19 participants (95%) responded positively when asked if they found the dog tail interface easy to understand and read, saying such things as "I am able to perceive its feelings," "it was easy to understand feelings of the robot."(here feelings refer to the perceived abstract affective state of the robot as represented by the tail). Some, however, suggested that we add other dog elements, such as puppy sounds to improve the communication clarity. Many mentioned that they were also interested in seeing the dog tail interface on other utility robots, and some (2 participants) were interested in seeing a cat-tail version.

4.5 Study limitations

Though being a formal exploration, our study design had some limitations. We primed our participants in the beginning of our study that our prototype is a dog tail interface since the tail motions were inspired from the dog tail motions. We believe that this may have created a bias such that people might have perceived it differently if it was introduced as a robotic tail instead of a dog tail. Further, during our study people were fixed at a seat and did not move. This is different from a real world interaction where people can move around and interact with the robot. This means that our tail should be tested in a real world environment.

4.6 Discussion

We observed that people readily accepted a dog tail interface on a utility robot and easily understood the concept of the robot communicating through the tail. Further, we found that the tail interface has a broad vocabulary and that it can be used as a communication medium. We observed that basic dog tail language such as higher tail height is understood, and also that higher tail wagging speeds result in perceptions of higher arousal, and in general, also result in more positive perceived valence. This was also echoed in the static tail postures, although with no movement, results were all generally less aroused and less positive than their moving counterparts.

We further found consistent differences in wagging types. While horizontal wagging was generally perceived as positive valence, vertical wagging was seen as being more negative - even with faster wags - and circular was somewhere in between with less clear results on valence. Thus, different wag types can be used depending on what a robot is trying to communicate. We feel that this inclusion of non-natural motions did not hinder our results as designers are free to stick to natural ones, and our statistically-significant results (including non-natural motions) indicate that there is a base-line common interpretation between people that can be used in design. Upon consideration of our lack of consistent findings for our action gestures, we realized that the robotic motion itself and the neutral tail state held when a gesture was not being performed was a likely confound, where people perhaps rated those constant elements instead of the periodic gesture. This is supported by the fact that the perceived valence and arousal of all the action gesture movements were tightly grouped.

One perhaps unexpected result was that smaller wag-sizes result in perceptions of higher valence and arousal; we expected these motions to have lower results given their lower movement profiles. Upon consideration, however, we realized that smaller wag-sizes at the same tail speed will result in more wags per second, perhaps increasing the perception of speed.

Overall, our results show that people were able to understand affective robotic states as conveyed using a tail, and as such this technique could be used as a peripheral-awareness channel for conveying high-level robotic state to people. For example, energetic versus fatigued tail motions could be used to show battery level (e.g., fast or slow tail wagging), or a robot could appear depressed (low-arousal or low-valence, e.g., slow-moving low tail posture) to show navigational confusion such as being lost. By communicating these abstract states, a utility robot can indicate its present state using peoples' existing knowledge of dog tail movement and help them understand when and how they should interact with the robot.

4.7 Preliminary Design Guidelines

From our results we formed a set of guidelines to help designers to convey the affective states of their robots, using a dog tail interface. In this section, we present our guidelines on the basis of: motion parameters (e.g., speed), wag-type (e.g., horizontal wagging) and postures (e.g., straight tail - high offset from the ground). In addition, we present the results from an exercise where we correlated our average ratings to a related work that provided rough informative keywords for the perceived affective states, based on the valence and arousal dimensions of affect.

4.7.1 Dog Tail Motion Parameters

- **Speed.** A higher speed projects a higher valence and arousal (e.g., elated) and a lower speed projects a lower valence and a lower arousal (e.g., uninterested).
- **Wag-Size**. A smaller wag-size projects more arousal (e.g., energetic) and a larger wag-size projects lesser arousal (e.g., lazier).
- **Height.** A higher tail projects a more positive valence (e.g., happier), and lower tail a more negative valence (e.g., sadder).

4.7.2 Dog Tail Wag Types

- **Horizontal Wagging.** This is the natural form of wagging, as found in dogs. This type of wagging can convey a range of valence and arousal values (linked together), starting from medium to high. For example, a tail wagging with higher height projects a more positive valence and a more positive arousal.

- **Circular Wagging.** A tail wagging in circular motion may be able to project a more positive arousal as compared to horizontal and vertical wagging at the same speeds.

- **Vertical Wagging.** A tail wagging in vertical motion generally projects a more negative valence and a slightly more negative arousal as compared to horizontal and circular wagging, although medium high arousal states can be achieved with high speeds or small wag sizes.

4.7.3 Static Tail Postures

Static dog tail postures provide more subdued impressions of affect and valence than the moving counterparts. A low, static tail projects a very low valence and arousal, while a higher tail makes this impression more moderate.

4.7.4 Correlated Perceived Affect and Emotional Adjectives

From our results, we observed several data points on the valence-arousal map (e.g., Figure 4.10, page: 42) that might be difficult for designers to understand what they mean and how they can be used. Therefore, in order to make these easier to use, we explored an existing work from psychology that maps data points on the valence-arousal space to affective adjectives [31]. We took the average rating for each tail motion and correlated it with the closest point on the previous work, as a means of generating loose-yet-informative keywords to roughly describe how various tail configurations may be perceived. A summary is given in Table 4.2.

Although we developed a preliminary set of design guidelines from our results, we did not yet know if these were easy to understand, and whether they can be further improved in terms of clarity. In future chapters, we will describe how we conducted an informal workshop by inviting people working as interaction designers, and how the results from this workshop were used to improve our design guidelines.

Table 4.2: Adjectives matching participant ratings of tail motion

category	sub-type	parameter	attributes and descriptive keywords
continuous wagging	horizontal	speed	low - modest medium - wondering high - joyful and elated
		wag-size	small - strong, mighty and powerful medium - awed large - interested
		height	low - contempt parallel to floor - awed high - wonder
	vertical	speed	low - solemn medium - shy and disdainful high - aggressive
		wag-size	small - aggressive medium - timid large - selfish and quietly indignant
	circular	speed	low - reverent medium - aggressive and astonished high - overwhelmed
static postures		height	height: low - lonely parallel to floor - fatigued high - concentrating

Chapter 5

Evaluation

Through our investigation we learned about how people perceive dog tail motions in terms of low-level parameters such as speed and developed a set of design guidelines, however, we were not sure how designers will interpret and use our guidelines. We targeted designers and not, for example, end users, as these are the people that will actually use our design guidelines. Also, we did not know if our guidelines had some difficult to understand or confusing parts that might make them hard to use. Therefore, to investigate this and to solidify our guidelines, we conducted an informal design workshop where interaction designers used our guidelines to design tail behaviors for the possible states a robot might communicate in a given scenario (e.g., search and rescue). The sections below describe how we conducted our design workshop and the results obtained.

5.1 An Informal Design Workshop

The objective of organizing this workshop was to investigate how interaction-designers and HRI researchers interpret and use our guidelines to design tail behaviors for communicating the states of a robot. Further, this workshop allowed us to test our overall approach for designing tail behaviors to communicate affective robotic states.

We conducted our informal design workshop by inviting 6 people working as interaction-designers in the field of Human-Computer Interaction. This workshop took an hour and fifteen minutes to complete. During the workshop we provided snacks and drinks to compensate the participants for their time.

The workshop began with bringing the participants to our lab and briefly explaining the purpose of this workshop and their involvement. Next, each of the participants were given a cue-card, containing details of robots working in a particular scenario (e.g., domestic environment), and some of the possible states they can communicate (e.g., looking for dirt in case of a domestic utility robot). There were a total of six different cue-cards: search and rescue robot, game playing robot, learning robot, robotic teacher, security guard robot and domestic robot. We gave them 5 minutes to read the cue-cards and ask questions in case they needed more information.

To explore which states may not be easily communicated using our dog tail interface, we handed over a sheet to our participants and asked them to list some more states a robot might want to communicate in addition to those listed (Figure 5.1).

Figure 5.1: Interaction-designers participating in our design workshop

Participants informally discussed the possible states in their scenario and suggested additional states to each other.

Before outlining the design guidelines in detail, we showed a video comprising of the tail motions and showed a few slides in which we presented our design guidelines in a simplified way to our participants so that they will not feel overwhelmed with the great deal of information being presented (e.g., Table 4.2, page: 49). At this point, we asked our participants if they had any doubts or if anything was unclear from our explanation. After all participants finished reading the design guidelines, we asked them to design the tail behaviors for the states listed. While designing, the designers informally discussed their own preferred ways of communicating those states via tail behaviors. We did not limit the participants by forcing them to use only the tail behaviors but instead asked them to freely use other existing communication channels (e.g., LEDs) should they so desire.

Finally, we asked them to fill a post-study questionnaire to ask them about their overall experience, some positive and negative comments about the guidelines and our overall approach, and their suggestions for further improving them. Through this process, we were hoping to evaluate our approach and solidify our design guidelines so that designers can readily use them to communicate affective states of their robots.

5.1.1 Results

Overall, our design guidelines were found to be simple and easy to use for communicating the affective states of a robot. Participants were able to design the tail behaviors for most of the listed states using the guidelines we developed and stated them as: "very useful," "thorough," "easy to follow," and "helpful." However, they did indicate several parts in our guidelines that could be further simplified (e.g., making it easier for designers to find which tail behavior can communicate a fatigued state). In the following subsections, we describe the positive and negative comments we received from our participants and the improvements they suggested.

Making It Easier to Find the Tail Behavior for a Desired Affective State

Since our design guidelines were organized in a way that they were grouped by tail motions (continuous motions, action gestures and static postures) and each tail motion was associated with one or more keywords, it was difficult for designers to find a specific desired keyword. For example, if a designer wants to communicate a lonely state, they might have to go through all the keywords in the table (Table 4.2, page: 49) to find what they are looking for. To make this easier, one participant suggested that we "develop a reverse-index for searching by keyword to narrow down the choices [P3]." We added an index (lookup index, Table 5.1) to our guidelines by assigning a number to each row in Table 4.2), sorting the descriptive keywords alphabetically and placing the appropriate index value next to them (Table 5.2). This improvement is aimed at making the process of designing a tail behavior for a specific affective state quicker and easy to use.

Using Action Gestures for Events Instead of States

Action gestures, unlike continuous and static motions, cannot happen continuously but instead take place at a certain time. One of our participants mentioned that:

> "Action gestures should be applicable to events not states, this is because they are not continuous or static like wagging or postures, they can be repeated periodically but still might be preferred for an event such as bumped into something while working."
>
> — [P2]

This is interesting because we did not find any significant differences for action gestures in our exploratory study (chapter 4) which perhaps, could be because participants found it hard to connect the continuous and non-continuous tail behaviors. One way to fix this in the future would be to come up with a new, distinct way of showing the action gestures and asking people to rate them individually (e.g., the tail goes down when the robot hits an obstacle). Despite the fact that we did not

Table 5.1: Design Guidelines

category	sub-type	parameter	attributes	results: happiness	results: energy	descriptive keywords	lookup index
			low	medium	medium	modest	1
		speed	medium	slightly more	slightly more	wondering	2
			high	more	more	joyful or elated	3
			small	–	more	strong, mighty or powerful	4
	horizontal	wag-size	medium	–	less	awed	5
			large	–	lesser	interested	6
			low	less	–	contempt	7
		height	parallel to floor	medium	–	awed	8
continuous wagging			high	more	–	wonder	9
			low	lesser	lesser	solemn	10
		speed	medium	lesser	medium	shy or disdainful	11
	vertical		high	lesser	more	aggressive	12
			small	–	more	aggressive	13
		wag-size	medium	–	less	timid	14
			large	–	lesser	selfish or quietly indignant	15
			low	medium	medium	reverent	16
	circular	speed	medium	slightly more	more	aggressive or astonished	17
			high	more	even more	overwhelmed	18
	raising	speed	low, medium and high	–	–	shy, selfish, disdainful or weary	19
action gestures		height	low and high	–	–	shy, selfish, disdainful, weary timid or fatigued	19
	lowering	speed	low, medium and high	–	–	shy, selfish, disdainful or weary	19
		height	low and high	–	–	shy, selfish, disdainful, weary timid or fatigued	19
			low	very less	very less	lonely	20
static postures		height	parallel to floor	less	less	fatigued	21
			high	medium	slightly less	concentrating	22

Table 5.2: An additional table we designed, lookup index here points to the index shown on Table 5.1

descriptive keywords	lookup index
aggressive or astonished	12,13,17
awed	5,8
concentrating	22
contempt	7
fatigued	19,21
interested	6
joyful or elated	3
lonely	20
modest	1
overwhelmed	18
reverent	16
selfish or quietly indignant	15
shy, selfish, disdainful, weary timid or fatigued	11,19
solemn	10
strong, mighty or powerful	4
wonder	2,9
wondering	2,9

have significant results, participants formed their own interpretation of gestures and used them in the design process; only one mentioned that they were not clear and she had a difficult time choosing them.

Tail Motions Can Be Used With Other Communication Channels

There exist several other communication channels that are being used by robots such as LEDs, sound, etc. Participants suggested that by incorporating these other channels along with our method, robots will be able to communicate affect more effectively. For example, one suggested that:

"The design guidelines were good and helpful to describe robot behaviors,

> incorporating other interaction components such as gestures using arms, head on a humanoid, sound and light using speakers and LEDs in compliance with our tail interface can be beneficial for communicating robotic states more effectively."
>
> — [P4]

For example, when a cleaning robot is working under a table or a couch, it can make sounds to suggest its states, "a robotic teacher can use red LEDs to indicate that it is being harassed [P4]" and "a humanoid robot can also use its face and hands while a tail is being used to communicate [P6]." We believe this will be helpful when the tail is occluded by the robot itself or other objects, or even when there's an emergency situation for a robot and it needs human assistance urgently. For example, for a humanoid full-size robot, his knee or ankle servo is broken and its about to fall to the ground which can result in further damage to the robot itself or people and other objects at a close proximity.

More Tail Motions Can Be Explored

In our tail exploration, we did not yet investigate how people interpret several other tail motions such as wag-size and height (offset from the ground) for circular wagging. One of our participants, P5, suggested that we explore other tail motions that are currently not present in our vocabulary, such as tail moving in cross-motion and wobbling in horizontal wagging. Interestingly, P6 suggested that these tail motions can be used to convey error messages as this will not be a part of dog tail language and the robot might appear confused or erroneous.

Tail Parameters May Be Combined to Work Together

We explored three low-level parameters in our study to form design guidelines. One participant suggested that it might be possible to further expand the scope of our guidelines by investigating how the tail parameters may interact with each other. He mentioned that:

> "It could be possible to develop a language where certain combinations of these parameters have specific meanings and that it would be more useful if the tail motion types can be linked together."
>
> — [P2]

For example, how wag-size may work with speed to give unique results [P2]. However, we did not find significant interaction effects between the three parameters in our statistical results, except for wag-type Vs. wag-size that exists between tail motions (e.g., horizontal wagging) and parameters (chapter 4). This indicates that these tail parameters themselves may not work together.

5.2 Summary

This workshop turned out to be very engaging for participants as they got involved in several informal discussions where they talked about the robots in their (given) scenarios and the states for which they are going to design tail motions. Participants even discussed their preferred ways of communicating a particular state and sometimes were found thinking aloud while designing the tail behaviors.

Overall, we found that our participants were comfortable with our methodology and were able to use our guidelines (explained in chapter 4) to design tail behaviors for specific affective response. Observations from this workshop helped us in testing and solidifying our design guidelines by highlighting the parts that can be simplified and provided us with further insights into how they can be further improved. We believe that our guidelines will serve as a useful design toolkit for HRI designers to communicate the affective states of their robots to help people understand when and how to interact with a robot.

Chapter 6

Conclusion

In this thesis, we formally investigated how a dog tail interface can be used for communicating affective robotic states. We showed a range of tail motions to our participants based on various tail parameters (e.g., speed) and observed that people do perceive the affect conveyed by the robotic dog tail motions in consistent terms. Using the results from our investigation, we developed a set of design guidelines that can be used by designers to convey the affective states of their robots to people in an easy to understand way. Further, to evaluate our overall approach, we conducted a design workshop where interaction designers used our design guidelines to convey various robotic states and suggested improvements to make them easy to use. We conclude this thesis by discussing the limitations of our work, suggesting some directions for future research and presenting a set of solidified design guidelines.

6.1 Limitations and Future Work

Our work is an initial step toward exploring how a robot can broadcast its affective state to people via robotic tail motions in a way that these can be easily understood. It raises many new questions that may need to be addressed in the future, as briefly discussed below:

One of the restrictions of our work is that it is limited to giving a dog tail to a robot for conveying its states. In contrast, a real dog uses its face, eyes, voice, body language, etc., to accompany its tail motions to create more complex expressions for communicating its states. Therefore, it may be important to investigate what other aspects of dog communication can also be used by robots in similar ways or even which other animals can serve as inspiration for developing this type of interface.

While the aim of our investigation was to develop an understanding of how a robot may communicate using a dog tail, and how people may perceive the communication, moving forward it will be important to further develop our guidelines to provide researchers with more concrete tools for tail-interface design. For example, although our results and guidelines can help designers decide how to communicate a desired affective state, we did not yet address how to map low-level robotic state (e.g., battery level, malfunction, etc.) to affective ones. While this is a broad question for HRI in general, we believe that we can follow the dog metaphor as one promising direction for developing this kind of mapping.

In our investigation, we used both non-natural (e.g., circular wagging) and natural tail motions (e.g., horizontal wagging). Although, people rated both natural and non-natural motions consistently, there still remain several mechanically possible non-natural motions that we did not explore. For example, tail moving in cross-motion and "wobbling" in horizontal wagging. In the future, these motions can be further explored in terms of how people perceive them, to broaden the scope of our design guidelines.

Currently, we have only placed our dog tail on a small robot that sits close to the ground (similar to a small dog). It is still unclear how our tail will translate to other morphologies such as a humanoid robot or a flying robot, and other domains such as toy robotics. Part of this question will be to explore the limits of use. For example, while we focused on utility robots, it will be important to explore other less obvious applications such as inanimate objects (e.g., a printer) to help convey the devices' state, and consider where the tail interface may not be applicable. For instance, for remote control robotics or industrial machines where the tail may not be monitored.

Further, we developed an understanding of how robots can communicate their states using a dog tail interface, however, we did not yet formally investigate how people would interact with a robot when it conveys a particular state. For example, how a person will interact with a robot that has its tail lowered. In addition, it would be worthwhile to explore how differently a person interacts with a robot that is scared as compared to a robot that appears tired, since both suggest that a robot might need assistance from its users. Moving forward, it might also be important to consider proxemics, where a robot can inform a user that it acknowledges and appreciates their help when they get close to the robot.

Through our research, we provide an insight into how dog tails can be used by robots to communicate their states in a way that people can readily understand them and uncovered several questions to investigate in the future. We hope that this will be helpful to the HRI researchers in communicating affective states of their robots as well in moving forward and exploring how animal-inspired interfaces can be used for robotic state communication.

6.2 Contributions

In this thesis, we presented an original dog tail interface and conducted a formal evaluation to investigate how people perceived the affective states of a robot equipped with a dog tail, across a full range of tail motions and behaviors. We found that the robotic dog tail was able to convey a broad range of affective states and that people reliably interpreted the tail motions in a consistent fashion. From this, we summarized our results into design guidelines for creating dog tail interfaces. Further, to evaluate our methodology, we conducted a design workshop with interaction designers that helped in identifying the strengths and weakness of our guidelines and also in solidifying them by making the confusing parts easy to read.

Based on our results, we present our research contributions to the field of HRI:

- A Unique Robotic Dog Tail Interface Design and Implementation — We designed and implemented an original robotic dog tail interface that can be used to communicate affective robotic states to people.

- A Set of Design Guidelines for Communicating Affective Robotic States — We developed a set of solidified design guidelines that can be leveraged by HRI designers for developing dog tail behaviors for communicating affective robotic states in a way they can be readily understood by people.

Overall, we anticipate that our contribution of exploring and mapping how robots can use dog tails to communicate affect will be of use to HRI designers, providing them with a new paradigm for robotic communication. For example, if a designer wants their robot to convey a tired state in case of a low battery, they can use a tail straight posture from our design guidelines. Further, designers can also use our design guidelines to communicate a broader range of states where they can increase and decrease the amount of valence and arousal being conveyed, for example, increasing wagging speed to make the robot appear more happy and decreasing the speed to make the robot appear more sad.

We believe that our work will be an important contribution to the field of HRI, such that robots using this kind of periphery communication will help people in understanding their state and help in deciding when and how they should interact with the robot.

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Appendix A

Materials Used in our Study

- Ethics approval certificate
- Study advertisement poster
- Informed consent form
- Demographic pre-study questionnaire
- Self-Assessment Manikin (SAM) introduction document
- SAM per-test condition questionnaire
- Post-study semi-structured interview questions

Human Ethics
208 - 194 Dafoe Road
Winnipeg, MB
Canada R3T 2N2
Fax 204-269-7173

UNIVERSITY OF MANITOBA | Office of the Vice-President (Research and International)
Research Ethics and Compliance

APPROVAL CERTIFICATE

July 5, 2012

NSERC DG

TO: **James E. Young**
Principal Investigator

FROM: **Wayne Taylor, Chair**
Joint-Faculty Research Ethics Board (JFREB)

Re: **Protocol #J2012:099**
"Exploring People's Anthropomorphic Perceptions of Robotic Movement"

Please be advised that your above-referenced protocol has received human ethics approval by the **Joint-Faculty Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement (2). **This approval is valid for one year only**.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **If you have funds pending human ethics approval, the auditor requires that you submit a copy of this Approval Certificate to the Office of Research Services, fax 261-0325 - please include the name of the funding agency and your UM Project number. This must be faxed before your account can be accessed.**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Quality Management Office may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans*.

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/orec/ethics/human_ethics_REB_forms_guidelines.html**) in order to be in compliance with Tri-Council Guidelines.**

UNIVERSITY OF MANITOBA

Department of Computer Science, University of Manitoba
Winnipeg, MB, Canada R3T 2N2

Participants needed for research in the field of Human-Robot Interaction

An Opportunity To Earn $10!!

If you are interested, please contact:

Ashish Singh: [redacted]
or visit **hri2012.co.cc** to choose from the available time slots.

For further questions regarding the study, please contact:
Dr. Young: [redacted]

This research experiment was approved by the Joint-Faculty Research Ethics Board, University of Manitoba

Human-Computer Interaction Robot Lab

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Informed Consent Form

Research Project Title: Exploring people's anthropomorphic perceptions of robotic movement

Researchers: Dr. James E. Young, [redacted], Ashish Singh [redacted]

Please take the time to read this carefully and to ensure you understand all the information.

You are invited to participate in a research study on the topic of exploring people's perceptions of robotic movement, and how people may attribute emotions to them. You will be asked to fill-in a simple demographic questionnaire before starting the study, and during the study you will observe several robotic motions and complete a rating sheet for each one. After the experiment is finished you will complete an interview related to your experience with the robots during the study. If you have any questions or concerns at this time or any time during the study please feel free to ask the on-site researcher for clarification.

Participation in this study is completely voluntary: you may choose to withdraw from this study at any point of time. Further, you will not be subject to any risk of harm or injury. The entire study, including the questionnaires and interview will take approximately one hour of your time. You will receive a cash incentive of $10 for your participation. Any information you choose to disclose is completely confidential and will be used for anonymized research analysis. We may use anonymized quotes or (only with permission, detailed below) video data for purposes of dissemination; your name will not be included or in any other way associated with the data presented in the results of this study. We intend to submit results of this study for publication in peer-reviewed conferences and journals. Once published, all publications will be made available to the public for free at http://home.cs.umanitoba.ca/~young/.

Data collected during this study will be retained for a period of maximum five years in a locked cabinet in a locked office in the EITC building, University of Manitoba, to which only researchers associated with this study have access. The University of Manitoba may look at our research records see that the research is being done in a safe and proper way. Again, no personal information about your involvement will be included.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research experiment project and agree to participate as a subject. By doing this you also confirm that you are of the age of majority in Canada (18 years or more). In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. You may withdraw at any time throughout the experiment and you will still receive your full compensation of $10 unconditionally.

This research has been approved by the University of Manitoba Joint Faculty Research Ethics Board. If you have any concerns or complaints about this project you may contact Dr. James Young at [redacted] or the Human Ethics Secretariat at [redacted]. A copy of this consent form has been given to you to keep for your records and reference.

For purposes of research analysis the experiment will be videotaped. By signing this consent form, you agree that you understand this and that we may use the video for data analysis purposes.

Do you agree that any video footage taken may also be used for dissemination of research, for example, through research videos or images taken from your video?

No ___ Yes___ but only if you blur my face___ AND/OR if you muffle my voice ___

Participant's Signature ___________________________

Date ________________

Researcher's Signature _________________________

Date ________________

Participant ID:

Demographic Questionnaire

1. What is your age?

______

2. What is your sex?

Male ______ Female ______

3. Do you have previous experience with robots, such as interacting with one at a school or museum, owning one, or building one?
(If yes, please briefly explain what kind of experience you have had in rectangular box below)

Yes, I do ______ No, I don’t have ______

Tell us about your experience with robots:

4. What is the highest level of education you have received?

High School or less ______ College Diploma ______ Professional Trade Certificate ______

Undergraduate Degree ______ Graduate Degree ______ Other, please specify ______

SAM Introduction Document

We appreciate your participation in our experiment. We are interested in studying how people respond to robots expressing their feelings through motions. In this experiment, you will be looking at the robots i.e. iRobot Roomba (vacuum cleaner robot) and Parrot AR.Drone (flying quadcopter robot) and rating each in terms of how you think the robot might be feeling while expressing each motion. There are no right or wrong answers, so please feel free to be as honest as possible.

If you look at the figures 1 and 2 below, you will see 2 sets of 7 figures, each arranged along a continuum. We call this set of figures SAM[3] and you will be using these to rate "**how robot felt**" while viewing robots performing each motion. You will make 2 ratings for each motion you observe. SAM shows two different kinds of feelings: Unhappy vs. Happy and Calm vs. Excited. You can see that each SAM figure varies along each scale.

In Figure 1, SAM scale is the unhappy-happy scale, which ranges from a frown to a smile. The left extreme of the scale is used when you think that the robot felt completely unhappy, annoyed, unsatisfied, melancholic, despaired, or bored. You can indicate this by selecting the figure at the left (see figure 3a). The other end of the scale is used when you think that the robot felt completely happy, pleased, satisfied, contended, or hopeful. You can indicate this by selecting the figure at the right (see figure 3b).

These figures also allow you to describe intermediate feelings of the robot, for example, if you think the robot was neither happy nor unhappy i.e. completely neutral, you can select the figure in the middle of the row (see figure 3c). If you wish to make a more finely tuned rating of how unhappy or happy the robot is, select the intermediate figures.

In Figure 2, SAM scale is the calm-excited scale, which ranges from low energy to high energy. The left extreme of the scale is used when you think that the robot felt completely relaxed, calm, sluggish, dull, or sleepy. You can indicate this by selecting the figure at the left (see figure 4a). The other end of the scale is used when you think that the robot felt stimulated, excited, frenzied, jittery, wide-awake, or aroused. You can indicate this by selecting the figure at the right (see figure 4b).

The figures also allow you to describe intermediate feelings of the robot, for example, if you think the robot was not at all calm nor at all excited i.e. completely neutral, you can select the figure in the middle of the row(see figure 4c). Again, if you wish to make a more finely tuned rating of how calm or excited the robot is, select the intermediate figures.

[3] Lang, P.J., Bradley, M.M., and Cuthbert, B.N. (1999). International Affective Picture Rating System (IAPS): Instruction Manual and Affective Ratings. Technical Report A-4 (University of Florida).

Figure 1

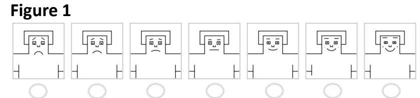


Figure 2

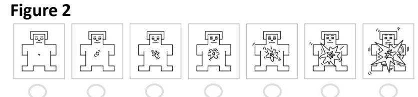


Figure 3

a
b
c

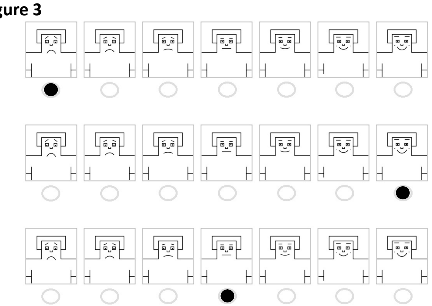
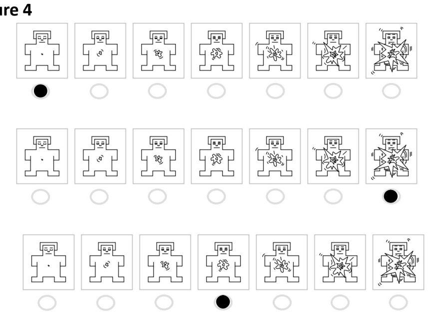


Figure 4

a
b
c

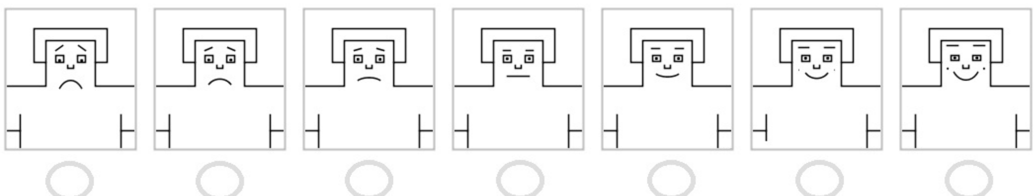


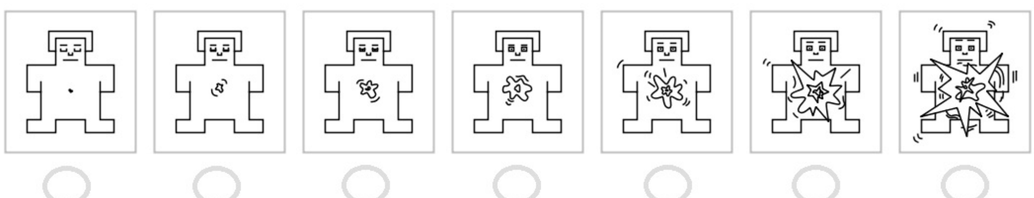
Participant ID _______________

Per-Test Condition Questionnaire Sheet

Trial __ of __

Please ***rate the robot*** *by selecting one picture from each of the two sets of pictures below.*





Post-Study Semi-Structured Interview

The semi-structured interview will use the following guiding questions, but we may ask related or slightly altered questions based on the participants responses. These questions highlight the kind of information we are looking for.

1. What do you think about the overall idea of robots using their motions for communication?

2. If you had a robot in your home or at your office, do you think it would be useful for the robot to use its motion to try and communicate? Or, for example, should it stick to other methods such as voice, text, or lights?

3. In general, did you find it easy to understand what the SAM characters/figures represented?

4. In general, did you find it easy to rate the robotic motions on SAM, or, was it often confusing? Can you discuss this?

5. Do you have any positive / negative comments on the technique of the robots communicating via motion?

6. Do you have any comments (room for improvement, problems etc.) on the robots?

7. Overall, do you have any final positive / negative comments on the experiment and your experience?

8. Do you have any additional comments, ideas or suggestions?