

(e)motion: Exploring the Affect of Abstract Motion in Human-Robot Interaction

John Harris

Ehud Sharlin

Interactions Lab, University of Calgary
Calgary, Alberta, Canada
1-403-210-9404
{harrisjj,ehud}@ucalgary.ca

ABSTRACT

In this paper we present our exploration of the emotional impact robot motion has on humans. We argue and attempt to justify the exploration of a fundamental layer of physical motion, trying to understand how it is being interpreted by observers. We discuss our design philosophy, attempting to create an abstract robotic platform, formless and affordances-less, and to examine it in an exploratory fashion; allowing participants to reflect on the motion they experience in various open ended ways. We argue that through our observations we could be able to achieve insight into how different robotic motions map to emotion, insight that could have implications for design well beyond abstract robotic interfaces.

The paper discusses our early prototype efforts and their design critique evaluation. It then follows by presenting our final prototype and an extensive user study we performed using it; attempting to understand whether and how basic robot movements, conveyed via an abstract robotic platform, can elicit emotional reactions and engagement in users. We detail and discuss our findings and their significance to the domain of social human-robot interaction design.

ACM Classification Keywords

H.5.2 [Information Systems]: User Interfaces – Interaction Styles, Evaluations

General Terms: Human Factors

Keywords: social human-robot interaction, affective interaction, emotive motion

1. INTRODUCTION

Arguably, one of the primary differentiating features between computers and robots is a robot's ability to move. Whereas computers are typically described as "black boxes that do math really fast", robots are capable of moving through their environment, gesturing, reacting, exploring, communicating, and affecting their surroundings in a very dynamic, physical way. We share this belief that this ability to move is a key factor in how humans interpret their interaction with robots and so plays an important role in the study of Human-Robot Interaction. [1]

For thousands of years, humans have been expressing emotions through theatre, dance, and puppetry; conveying frustration, sorrow, jubilation, and an entire spectrum of other powerful emotions using only the movement of their bodies and the objects around them. Even the motions of supposedly lifeless objects, such as wind passing through forest canopies, has elicited hours of meditative, emotional reflection. While excellent research continues to be done in the fields of robot usability, synthetic facial expressions, voice synthesis, and affective computing



Figure 1 - *The Stick* engaging with a participant using emotive motion

(among others), we feel that there are powerful lessons to be learned from these low-level observations that could translate into powerful design tools for robots and the uniquely mobile realm human-robot interaction.

A seminal experiment by Heider and Simmel [2] exploring the interpretation of abstract 2D shapes served as an inspiration for our current experiment. In the 2D case, abstract geometric shapes (e.g. circles, rectangles, and triangles) were animated against a blank background and participants were asked a series of increasingly concrete questions: 1. "Write down what happened in the picture?" 2. "What kind of person is the big triangle? Why did the two triangles fight?" Etc. Heider and Simmel found that the vast majority of the participants interpreted the moving geometrical shapes as animated beings. Participants attributed emotion and intent to completely abstract, animated geometric shapes.

A different set of experiments by Reeves and Nass [5] demonstrated a similarly remarkable phenomenon wherein humans are shown to treat computers, televisions, and even photographs with many of the same social tendencies normally afforded to other humans. E.g. being polite to computers when

asked for criticism, attributing gender roles to digital devices such as extroversion and masculinity or emotionality and femininity, viewing these media mediators as teammates, and so on.

In this paper we present our efforts to replicate a Heider and Simmel-like approach to social HRI. We were hoping to find which types of emotional reactions abstract motion, applied by formless, affordances-less robotic interfaces can elicit. We were trying to demonstrate that even abstract robotic platforms can create strong emotional reaction and engagement in observers.

In the following sections, we briefly discuss related efforts, detail our design philosophy, we present our early interactive prototypes and their design critiques. We then outline our final prototype, its evaluation via a thorough set of user studies and discuss the implications our findings point to when considering how abstract robotic motion can be used to impact and engage users emotionally.

2. RELATED WORK

Several current HRI research efforts attempt to explore the emotional qualities of robot motion more directly. When teaching robots behaviours by example, Young et al. [8] use the motion paths of iRobot Roombas as an implicit means of having robots (and by proxy, their human instructors) express their intentions; conveying frustration, aggression, and affection by controlling the robot's locomotion.

Saerbeck and Bartneck directly quantify some of the relationships between the movements of two robot embodiments (a Phillip's iCat and a Roomba) and their emotional affect [7]. These results suggest a number of intriguing correlations between motion characteristics (such as acceleration and curvature) and generalized emotional responses (e.g. positive/negative affect and valence).

Notably, we are also aware of several recent efforts that while tangential to ours, and not directly related to HRI, can inform of the importance the perception of emotion through motion can play in future interaction design. For example, Park and Lee [4] approach basic questions of motion as design elements in interaction and entertainment interfaces. Roether et al. [6] investigated the type of emotions different (human) body movements and gait elicit from observers.

In our current effort to approach emotive robot motion from the same "abstract" perspective as Heider [2], we find the results for the Roomba embodiment [7,8] to be of particular interest. With the iCat [7], we think it is possible that the robot's uniquely expressive visual characteristics and purposefully cat-like form and affordances are playing a powerful role in how its motions were interpreted. In contrast, a Roomba is a much more abstract entity; a rolling white circle on the floor as opposed to a plastic pet. However, the Roomba as a moving entity is focusing attention on what we believe is a higher level of movement: locomotion. Our work is an attempt to observe the emotional impact of an even more basic layer of motion: one that is abstract and formless. Our current endeavours to push the level of abstraction even further, removing the Roomba's blinking lights, rolling wheels, whirring motors, and dynamically changing interpersonal distance to the observer in an attempt to explore the fundamental characteristics of emotive robot motion in an even more abstract way.

3. DESIGN PHILOSOPHY

In order to explore the expressiveness of abstract robot motion, we chose to take a fundamentalist approach. In attempting to address our primary design question "What can robots express using motion alone?" we chose to design an experiment that could explore this idea in its basic a form. Our somewhat naïve hope was that by exploring the emotional impact of abstract, formless robotic motion we would be able to gain a fundamental, generic insight into how robotic motion engages and influences users' emotions.

Our belief was that if these lessons would have been learned using a formless, affordances-less robot, they would provide a common ground and perhaps even apply to a variety of other robots that, while using a much more meaningful form and affordances, would still share fundamental movement capabilities with our generic, formless robot.

Visual abstraction was our central design challenge. In order to observe motion, *something* needs to be moving. However, a something would have some visual form, and visual form brings with it some degree of meaning. Seldom is the visual appearance of an object in direct opposition with its function [9]. For example, larger objects tend to be perceived as heavier or stronger, slender objects tend to be perceived as faster or sharper, and so on.

In the case of a robot platform, even vaguely anthropomorphic qualities such as a "face" area, "mouth" or "eyes", would have immediate connotations associated with those intrinsic features; such as which way those "eyes" were facing. Any motions that such a robot platform would perform would then most likely be interpreted in the context of those visual preconceptions; mixing and competing with the interpretation and perception of the platform's low-level motion.

We also considered the fundamental qualities of motion that we could interpret: speed and direction. In combination with form, these basic characteristics lead to ideas of rotation, curvature, proximity and approach, movement vs. locomotion, frequency, hesitation, and numerous other qualities that we could attempt to examine and gauge.

Determining how to attempt and measure all of these expressive properties of robot motion immediately became an enormous challenge. Eventually we decided that instead of seeking to solely gauge specific qualities or to try and isolate particular types of motion or map motion to a specific tasks, we should seek abstraction in our evaluation methodology as well.

We decided to push the common 'think aloud' user observation technique to the extreme, to isolate our participants and ask them to focus, almost to meditate, on the robotic motion. We rephrased our experimental design question and posed it directly as "What do you think or feel when you observe (a given) motion?" While responses to such a question would still be difficult to quantify or measure concretely, we felt that its open ended nature granted us an important freedom: the ability to encounter the unexpected.

On top of observing and interpreting abstract motion in isolation, we felt that there was a distinct and complimentary aspect of expressing emotions that should be explored. Whether we consciously recognize it or not, expressing emotion is typically done as a means of communicating our feelings within the context of a target audience. For example: crying, as an expression of sadness can be a means of attracting sympathy from our loved

ones, dancing can be a means of sharing joy not just with our dancing partners but with everyone around us, and so on. In this way, the audience becomes an integral component of (and a subconscious, almost instinctual motivation for) expressing emotion; particularly in how and whether or not the audience respond to those expressions.

From this perspective, expressing emotions becomes a two-way, interactive communication. We argue that, in an exploration of how emotion is expressed and interpreted in an abstract sense, interactivity will also play an important role alongside visual abstraction and purposeful movement.

With these guiding philosophies in mind, we set about designing a sufficiently abstract and expressive robot platform, as well as an evaluation scenario by which to explore that robot's emotive motions.

4. DESIGNING THE ROBOT PLATFORM

The robot platform itself was designed to be as visually abstract as possible. In this way, it could avoid referencing any visual preconceptions and functional affordances. In this section, we outline the evolution of our abstract motion robot via three prototypes: “*The Tentacle*”, “*Stick Jr.*” and “*The Stick*”.

4.1 “The Tentacle”

One of the early prototype platforms that we devised (henceforth referred to as “*The Tentacle*”) involved only four degrees of actuation. (See Figure 2) In an early attempt to explore unique modes of actuation, a long, flexible spring was affixed at one end to a stable base. From beneath that base, a set of cables was inserted through the interior of the spring and affixed to its far end in an equally spaced cross pattern. Using simple servo motors as winches to create tension in the strings, the spring could then be actuated to bend in all four cardinal directions as well as squash and stretch longitudinally. This resulted in simple worm-like motions. While this resulted in a very natural and intriguing style of motion, we have decided that such a mechanism that the visual connotations of interacting with such an entity were too specific; immediately eliciting unsettling thoughts of “creepy crawlers”. Additionally, we should note that this early prototype mechanism proved difficult to control correctly and consistently.

4.2 “Stick Jr.”

Adopting an even simpler approach, the flexible shaft of “*The Tentacle*” was replaced by rigid wooden rod. The degrees of actuation were also reduced from four to only three and were rearranged to operate in sequence instead of in tandem. Specifically, the base of *Stick Jr.*'s wooden arm was affixed to a trio of servo motors which were arranged in a “spherical joint” configuration; allowing *Stick Jr.* to roll, pitch and yaw about a central point. Unlike *The Tentacle*, *Stick Jr.* could perform these motions with much more precise control and better repeatability.

Early pilot testing of *Stick Jr.* revealed that while the functional mechanics of the platform were capable of many complex motions, the visual scale of the robot (25cm x 25cm x 20 cm) already evoked undesirable connotations. No matter how quickly or in which direction *Stick Jr.* moved, having to look down at this relatively small entity had a very detached, observational quality.

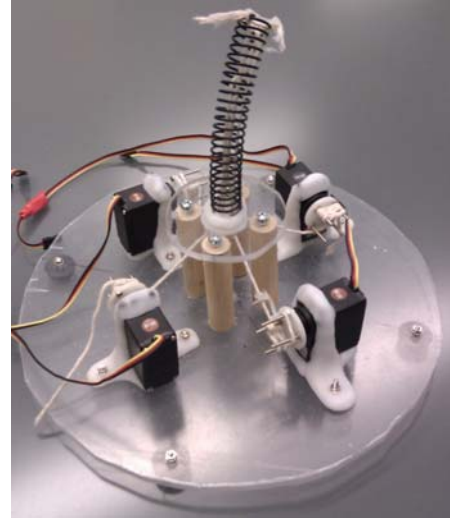


Figure 2 - *The Tentacle* Prototype

4.3 “The Stick”

Given this perceived shortcoming, a much larger scale version of the prototype robot platform, *The Stick*, was constructed using the same motor configuration. The small wooden rod was replaced by a 1m x 2.5cm x 2.5cm balsa wood shaft and the motor assembly was mounted onto a 1m x 1m cubic aluminum frame. A square sided shaft was purposefully chosen (as opposed to *Stick Jr.*'s round rod) so that as *The Stick* rotated, the various facets of the now square shaft would catch the light and shadow of the environment; allowing observers to notice the yaw rotation more easily than if they could only observe the minute wood grain patterns and monotone shadowing of a rotating cylinder.

In their standard control mode, each of the robot's motors is also capable of precise position-control along a 300 degrees arc. When combined with the length of the wooden shaft, this gives *The Stick* a significant range of motion in all three axes as well as a significant “reach” within its immediate surroundings.

Also in keeping with our goal of maximizing visual abstraction, both the motors and aluminum base frame were covered by a black cloth skirt. This obscured the inner workings of the robot platform and focused observers' attention on the *movement*, that is, on the wooden shaft alone.

Between its overall height and large base, *The Stick* was designed to have a much more substantial physical presence. Unlike smaller desktop-style robots such as the Phillip's iCat [10], or shorter mobile robots such as Robovie [11] which are designed to have unimposing appearances, *The Stick* was deliberately constructed to be viewed from eye-level and in close proximity in an attempt to maximize its physicality and the impact of whatever emotions its movements might elicit.

Regarding the physical risks of interacting with *The Stick*, while the motors that were used were capable of producing up to 16.5kg-cm of holding torque (significantly more torque than typical hobby servos), the leverage provided by the long length of the wooden shaft meant that the tip of the wooden shaft travelled with a high speed but relatively little force. At the same time, the balsa wood material was chosen for its extremely low density. For its size, the entire wooden shaft of the robot weighs less than 150

grams. Together, this meant that being struck by the shaft, a scenario that **never** occurred during our design or evaluation of the robot, would result in nothing more than a gentle bump with next to no inertia behind it. The arm itself, although seemingly long and imposing, could easily be pushed back by a young child, even when operated at full power.

5. DESIGNING THE STUDY

With a relatively abstract, but highly articulate robot platform constructed, we then focused on designing an experiment that could study how people interpreted the abstract motions of *The Stick* and whether or not they would do so in terms of living entities, emotions, and intentions. We chose to strike a middle ground between an entirely abstract experiment and one that prompted the user with questions strictly relating to emotional interpretations. Our goal was to present each participant with a moving robotic entity as devoid of visual connotations as possible and query them about their interpretations while introducing as little bias as possible.

5.1 Experiment Environment

Again, in keeping with our design philosophy of maximizing abstraction, the study environment was setup to be as devoid of distractions as possible. *The Stick* robot platform was positioned in the corner of an empty white room. The participant was seated 2 meters away from the robot with a screen placed directly behind them to block out the rest of the room. Having each participant sit not only provided them with a comfortable position to remain in for the duration of the experiment, but also ensured that they were looking at least *across* to the robot (if not *up* at it), instead of *down* on it; again emphasizing its physical presence.

A single spotlight was placed within the ceiling above the robot and all other room lights were turned off. This provided a strong focusing effect, drawing the participant's attention directly to the robot and away from the rest of the room. The spotlight was pointed straight down and positioned slightly behind the robot, creating a strong shadowing effect. Not only did this create enhanced visual contrast on the various facets of the wooden shaft (to help emphasize its yaw rotation), but it also cast a strong shadow from the moving shaft down to the floor immediately in front of the participants as well as onto the nearby walls whenever the robot tilted to the side. These cast shadows were employed as a means of further highlighting the motion of *The Stick* by providing more points of visual reference.

Besides equipping the participants with a wireless microphone so that their spoken comments could be recorded, each participant was also required to wear a set of over-ear, closed-can headphones for the duration of the experiment.

These headphones played a continuous white-noise sound meant to prevent the participants from hearing the sounds that the robot's motors would make when they moved. Much like typical hobby servo motors, the motors used in *The Stick* make a high-pitched "whirring" sound that is proportional to their speed of movement. Without blocking these sounds out, *The Stick* would make distinct noises whenever it moved which would become more intense in as the vigor of the robot's movements increased. In an anthropomorphic sense, it was thought that this would translate into a yelling or growling metaphor similar to an aggressive animal; interfering with the participant's ability to focus on the motion of *The Stick* alone.

Over the participant's shoulder was a video camera which recorded each session as well as a desk which the experimenter used to administer the experiment. The contents of the desk were obscured by a waist-height barrier; preventing the participant from seeing the contents of the desk, but still allowing the experimenter to observe both the participant and the robot platform. On the desk were a laptop computer used to control the robot's motions as well as the *Stick Jr.* prototype which was now used as a form of joystick input control for the larger robot platform during a later phase of the experiment.

In all, the participant was left in an empty, essentially silent room with just *The Stick* under a single spotlight.

The experiment procedure was broken up into several phases and two conditions. The two experiment conditions primarily altered what types of motions were being observed and interpreted. The overall structure and procedures for the experiment remained largely unchanged.

The following sections briefly detail the individual motions that were performed by *The Stick* for each experimental condition. Study participants were only told that each experiment phase would contain "a set of motions", and were never made aware of the "titles" of the motions, nor their total number of variety.

5.2 Mechanical Condition

Under the "Mechanical" condition, we chose to examine the emotional expressiveness of what might be considered "typical" robot-style motions: relatively simple, cyclical motions.

The "Mechanical" set of motions was labeled as such because they were constructed without any specific intent or dynamic intervention. Each motion consisted of a combination of simple sinusoidal motions performed by each of the three axes of motion (roll, pitch, and yaw).

While the robot's motors were capable of travelling through a range of 300 degrees, the Mechanical set of motions was limited to arcs of approximately +/- 35 degrees. This was primarily due to the inertia of the wooden shaft when it performed some of the more vigorous movements during initial testing. If the robot was commanded to tilt much farther beyond 35 degrees, the motors were not sufficiently powerful enough to affect rapid direction changes; effectively limiting the expressiveness of the robot to sweeping but lethargic motions. By limiting the motors' range of travel, sharper and quicker motions could be tested.

Following are brief descriptions of the 11 "Mechanical" motions, combined into Fast/Slow pairs where applicable:

1. and 2. - Front to Back Fast/Slow (F2B): Robot pitched toward and away from the observer to 35 degrees in either direction, repeating this pattern cyclically at either 0.5Hz (Fast) or 0.1Hz (Slow).

3. and 4. - Side to Side Fast/Slow (S2S): Identical to the Front To Back motion except rolling side to side while maintaining vertical inclination with respect to pitch.

5. and 6. - Twist Fast/Slow (T): Standing straight upwards, the robot's arm yawed about the vertical axis; twisting 35 degrees to either side at either 0.5Hz (Fast) or 0.1Hz (Slow).

7. and 8. - Circle Fast/Slow: The robot's pitch and roll motors were commanded by sinusoidal waves of identical amplitude (+/- 35 degree) but with their phases offset by 0.5 PI radians from each other. The result was the tip of the arm travelling in a complete circle at either 0.75Hz (Fast) or 0.25Hz (Slow).

9. Figure Eight: The pitch command sinusoid operated at 0.5Hz while the roll command sinusoid operated at 0.25Hz. The result was the tip of the robot's arm tracing an "infinity" symbol when viewed directly from above. Again, the amplitude of each sinusoid was +/- 35 degrees.

10. "Nodding": A rapid 0.8Hz pitch sinusoid combined with a slower 0.2Hz roll sinusoid. The resultant motion saw the robot's arm rapidly pitching forward and backward while slowly rolling from side to side.

11. Motionless: All three motors remained motionless and the robot's arm remained in a vertical position.

5.3 Organic Condition

In the "Organic" condition, we chose to explore a set of "atypical" robot motions; instead modeling this set of motions on more natural entities such as humans or animals. Rather than consisting of simple sinusoidal waves, the "Organic" set of motions were pre-recorded sequences, each designed with specific emotional intentions designed to explore the expressive limitations of *The Stick's* abstract visual form.

Unlike the "Mechanical" motions, the "Organic" motions were intended to be acyclic and complex. Each motion lasted approximately 45 seconds (the same duration as the "Mechanical" motions) and follows a particular theme; as represented by their titles. While more easily understood when seen in motion, these sequences are briefly summarized as follows:

1. Angry: Emphasis on aggressive, rapid pitching motions towards the observer, relatively little roll or twist, and maintaining constant, high energy motion.

2. "Bear Swipes": Emphasis on low, high-speed, horizontal sweeping motions separated by periods of withdrawing away from the observer. The intent is a "defensive posture" which attempts to maintain a safe distance from the observer.

3. Sad/Moping: A low-energy sequence characterized by *The Stick* leaning almost 90 degrees over to one side, moving only to occasionally slowly rise a few degrees and then fall back down slowly as if releasing a large sigh.

4. Wailing: A high-energy sequence consisting of continuous random, high-amplitude motion.

5. Working: A somewhat periodic sequence with *The Stick* leaning over to one side (the "working" side), bobbing and twisting for approximately 7 seconds and then arcing up and over to its far side (the "deposit" side). Here it performs one large bobbing motion and then arcs back over to the "working" side to repeat the sequence. The metaphor is that *The Stick* is filling an imaginary bucket and the emptying it elsewhere.

6. Conversation: Mimicking a spoken conversation, *The Stick* stands nearly vertical (with minor side to side rocking) while periodically responding "Yes" or "No"; either quickly pitching forward and backward by approximately 10 degrees or by quickly rolling/twisting side to side by 10 degrees.

7. Inspection: *The Stick* leans towards the participant and rolls to each side and staying there for short periods before switching sides; as if trying to get a better view of the participant through a magnifying glass.

8. Surprised: *The Stick* leans in random directions, sweeping an arc around its perimeter before periodically jumping back to vertical and then slowly leaning back to a new direction and

repeating the sequence. The intended expression is that *The Stick* is being frightened or surprised while looking around itself.

9. Searching: A high-energy sequence that combines quick leans in random directions followed by rapid bobbing motions before *The Stick* leans in a new direction. The metaphor is that *The Stick* is searching all around it for a lost item.

10. Happy: A high-energy sequence that emphasizes rhythmic rolling motions while avoiding any aggressive pitching motions. *The Stick* also occasionally pauses to perform a series of rapid twists before resuming its rhythmic rolls.

11. Fidgeting/Idle: Rather than remain completely motionless like the "Mechanical" Idle motion, *The Stick* remains essentially vertical while making subtle pitching and rolling motions of no greater than 10 degrees. Occasionally, *The Stick* also makes a sharper, single twisting motion. The intent is to mimic the idle fidgeting motions performed by most living creatures while stationary. (In contrast, a completely stationary animal is usually either hiding or dead.)

5.4 Phase 1: Open Interpretation

In order to allow each participant to be as reflective and open-minded as possible and to avoid biasing their responses towards a strictly "emotional" agenda, each experiment session began with a period of open reflection and meditation. During the recruitment process, participants were only informed that they would be participating in a Human-Robot Interaction experiment, with no details given as to the nature or purpose of the study.

The participants were asked to sit in front of "the robot" and were told that the robot was going to be "performing a series of motions" while they were tasked with "simply observing it and speaking aloud whatever thoughts or feelings come to mind". The specific phrasings of each instruction are emphasized here to highlight the experimenter's attempts to avoid biasing the participants. The critical component of this phase of this experiment was that, while these instructions specifically mention that the robot would be performing motions, it did not instruct the participants as to what they should be reflecting on or what the "true purpose" of the experiment was.

Additionally, the participants were told that the experimenter would be leaving them alone in the room to reflect for this first phase of the experiment. Ostensibly, the experimenter would step outside of the experiment room and would not be able to hear any of the participant's spoken comments. In reality, the experimenter would walk to a distant corner of the room, out of sight of the participant, such that could still listen to and record the participant's spoken comments, as well as intervene should something abnormal occur during the course of the experiment.

This deception was an attempt to allow the participants to feel as reflective and open minded as possible. Instead of potentially feeling guarded about sharing their inner thoughts with a stranger in an unfamiliar scenario, they could feel free to speak whatever thoughts they felt were appropriate presuming that those comments would only be reviewed via the video recording after the experiment had ended (and after they had left the experiment area).

During this phase, *The Stick* would perform a continuous series of different motions. Each motion would last approximately 45 seconds before smoothly transitioning to the next distinct movement pattern. Once the complete set of motions was

performed, the experimenter would “return” and provide instructions for the second phase of the experiment.

5.5 Phase 2: Survey

Having attempted to allow the participant’s reactions to emerge without biasing them towards an emotion-centric perspective, the second phase of the experiment was designed with a more overt directive and a more quantifiable structure. In the event that the free-form first phase yielded little insight into a participant’s interpretations of *The Stick’s* motions, the second phase of the experiment would rely on a series of qualitative survey questions..

In this phase, the participant was provided with a packet of survey pages and instructed that the robot would “perform another series of motions” (in reality, the same set of motions as the first phase, but in a randomized order) and they were asked to complete one page of the survey for each motion. On each page of the survey were a set of 7 Likert-scale style questions. Each question asked the participant to rank (on a scale of -3 to 3) how applicable a pair of adjectives was for the motion the robot was currently performing. Ranking an adjective pair as 0 was labeled as “Neutral”.

The adjective pairs included:

| | |
|------------------------|----------------------|
| Mechanical vs. Organic | Bored vs. Interested |
| Sad vs. Happy | Tired vs. Energetic |
| Dumb vs. Smart | Shy vs. Outgoing |
| Enemy vs Friend | |

As an example, if a participant felt that a particular motion was very energetic, they would rank “Tired vs Energetic” as 3. If they felt a motion was slightly mechanical, they would rank “Mechanical vs Organic” as -1. Etc.

Once the participants understood the instructions, the experimenter commanded the robot to begin performing the first motion. In order to emphasize the repetitive nature of the “Mechanical” motions, participants were given an unlimited amount of time to observe each motion and complete each survey page in the “Mechanical” condition. When they completed a page, they would say “Next” or “Finished” and the experimenter would command the robot to transition into the next motion and so on until all 11 motions had been performed and all 11 survey pages had been completed.

In the “Organic” condition, participants were only given one opportunity to observe each motion sequence. After the robot had finished a given sequence and become stationary, participants again had unlimited time to complete each survey page before saying “Next”.

5.6 Phase 3: Open Interaction

In order to explore our theories on the importance of interaction in expressing emotion, this third phase invited participants to stand up and “freely interact with the robot” for 5 minutes. As a slight deception, and to reinforce the participants sense that this phase would be different from the “strictly observational” phases 1 and 2, the experimenter would also stand behind *The Stick*, reach beneath the obscuring black cloth, and pretend to adjust some (imaginary) switches. The experimenter would then instruct the participants that “They robot’s sensors are now on. It will not be aware of you.” The details of what type or number of “sensors” had been activated were not disclosed, nor were any other

instructions given except asking the participants to remain within the general experiment area.

The experimenter would then return to the administration desk and proceed to “Wizard of Oz” *The Stick’s* behavior using the hidden *Stick Jr.* as a joystick. It was our intent that because of the barrier obscuring the front of the experimenter’s desk, if the participant would look behind them, it was appear as if the experimenter were simply observing the interaction and taking notes.

In actuality, the experimenter was puppeteering *The Stick* according to a simple “emotional state machine” based on the set of Organic motions used in phases 1 and 2. In short, *The Stick* would “wake up” (similar to Sad and Surprised) and would then transition between Happy, Scared, Angry, or Sad behaviours depending on the participant’s interaction. The “intelligence” and state transition logic of *The Stick’s* personality were modeled after a small household pet. For example, *The Stick* attempted to act as if it:

1. Enjoyed gentle, close contact
2. Became frightened by sudden, unexpected movements
3. Became bored if the participant would either repeat the same actions or did nothing for an extended period of time
4. Became angry if the participant became overly aggressive

After 5 minutes, the interaction was stopped and the participant was instructed to take a seat in preparation for phase 4.

It should be noted that this open interaction phase only occurred under the Organic condition. This is because of the contrast between how the Mechanical and Organic motion sets were constructed. The Mechanical motion set was designed to be simple and repetitive; exactly the opposite of a free-form, highly dynamic interaction session. By only performing phase 3 under the Organic condition and maintaining a between-participant study, we could form a better picture of the qualitative difference between the design goals of the Mechanical and Organic motion sets.

5.7 Phase 4: Open Interview

During this final phase, the participant was interviewed about their experiences with *The Stick* and their thoughts on the experiment. While the participant was encouraged to share any additional comments they felt appropriate, the experimenter also primed these discussions with a set of specific interview questions. Some example questions included:

1. Which way is the robot facing?
2. How would you describe this robot? What is it doing? Why is it doing that?
3. Do you have any thoughts or comments about the black base?
4. How connected do you feel to this robot? Did you feel this was an interactive experience or more strictly observational?

Having made note of observations during phases 1, 2, and 3, phase 4 was also an opportunity for the experimenter to follow up on any observations they had made during previous phases of the experiment.

6. RESULTS

In total, each participant spent an hour either observing and/or interacting with the moving robot and continuously sharing their interpretations of it through a variety of methods; including speaking aloud, survey questions, open interaction and guided interviews. In addition, each participant's session was recorded via both audio and video; allowing the experimenters to review their non-verbal expressions such as body language, facial expressions, and physical gestures throughout the experiment.

In total, 30 participants were recruited for the study. The experimental conditions were studied "between-participants", with 9M/6F in the "Mechanical" condition, and 7M/8F in the "Organic" condition. All participants were recruited from the local campus community. Their ages ranged from 19 to 56 with a median age of 23.5. Their professional/academic backgrounds also covered a variety of specializations including electrical engineering, computer science, history, languages, and psychology; with the majority coming from science and engineering backgrounds.

6.1 Survey Results

The results of the survey phase of the experiment were aggregated and compared as histograms. Some example trends are presented next.

| Tired vs. Energetic | | | | | | | |
|---------------------|----|----|----|---|---|---|---|
| | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| F2B Slow | 1 | 4 | 3 | 5 | 2 | 0 | 0 |
| F2B Fast | 0 | 2 | 4 | 0 | 3 | 1 | 5 |
| S2S Slow | 5 | 5 | 3 | 2 | 0 | 0 | 0 |
| S2S Fast | 1 | 0 | 4 | 1 | 2 | 3 | 4 |
| Angry | 0 | 1 | 0 | 0 | 1 | 6 | 6 |
| Sad | 4 | 3 | 0 | 5 | 2 | 0 | 0 |

For the "Mechanical" condition, most motions showed a marked tendency towards "Energetic" when comparing their fast and slow counter-parts. For the "Organic" condition, visibly more energetic motions (e.g. Angry, Wailing, Happy) were graded as such.

| Enemy vs. Friend | | | | | | | |
|------------------|----|----|----|---|---|---|---|
| | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| Circle Fast | 7 | 2 | 2 | 1 | 1 | 0 | 2 |
| Angry | 6 | 5 | 0 | 1 | 0 | 0 | 2 |
| S2S Fast | 0 | 0 | 3 | 4 | 1 | 2 | 5 |
| Inspection | 0 | 0 | 0 | 7 | 3 | 2 | 2 |

Motions that emphasized fast, advancing (towards the participant) motions tended to be graded as more "Enemy" than "Friend".

| Mechanical vs Organic | | | | | | | |
|-----------------------|----|----|----|---|---|---|---|
| | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| S2S Slow | 9 | 4 | 1 | 0 | 1 | 0 | 0 |
| Fidgeting | 5 | 2 | 4 | 0 | 1 | 1 | 1 |
| Circle Fast | 3 | 0 | 1 | 0 | 1 | 6 | 4 |
| Bear Swipes | 1 | 2 | 0 | 0 | 4 | 5 | 2 |

Rather than be split between the different sets of "Mechanical" and "Organic" motions, when asked to apply either the adjective "mechanical" or "organic" to their observations, motions that emphasized fast-moving, complex motions tended to be graded as more "organic" while slower, more repetitive motions were graded "mechanical".

6.2 Verbal Comments and Observations

A number of prominent themes also emerged from the "Meditation", "Open Interaction", and "Interview" phases of the experiment.

1. More than 17 out of 30 participants said that they thought some of *The Stick's* motions felt dangerous, scary, intimidating, or that it was otherwise attempting to attack them. A number of participants also visibly recoiled away from the robot when it transitioned into certain aggressive motions. (E.g. Angry, Front to Back Fast) In particular, one participant (Male, 26) withdrew his outstretched legs saying "The robot doesn't reach me, but its shadow does. Somehow I'm not even comfortable with its shadow touching me."

2. At least 10 participants, mainly from the "Organic Condition", claimed that *The Stick* was "dancing" during certain motions. These comments generally occurred as they were observing the "Happy" motion. Most participants would smile as they made this comment and many would begin to mimic *The Stick's* rhythmic bobbing.

3. When asked "Which way is the robot facing?" two thirds of the participants responded with "Towards me." When asked why they felt this, despite the symmetry of *The Stick's* appearance, most participants could not provide a specific reason.

4. A large majority of participants made at least one comment attributing an internal thought process or intentions to *The Stick*; at different times claiming the robot was "pensive... it's thinking about something" (Female, 25), "enjoying this, sort of purring like a cat" (Male, 50), hiding something (Female, 20), bowing or greeting them (6 participants), drawing or painting (3 participants), looking for/inspecting something (10 participants), and so on.

5. Only two participants described *The Stick's* motions in essentially technical terms.

4. At least 11 participants exhibited boredom when faced with slow, repetitive motions; primarily under the Mechanical condition. Each appeared interested in observing the new motion when the robot transitioned from one to the next, but their attention quickly waned once they claimed to have "figured out the programming" (Male, 28).

5. More than two thirds of all participants made some comment similar to "It looks like the robot is holding a sword or a baseball bat and is swinging it around" or that "the robot must be inside the box [the covered base platform] and is manipulating the stick"; implying that the wooden shaft itself was not the robot but merely a tool.

6. When asked if they felt their experience with the robot had been interactive or strictly observational, 12 out of 14 participants in the "Organic" condition said they felt they had been interacting with the robot. Conversely, more than half of the participants in the "Mechanical" condition felt that their experience had been strictly observational.

8. One participant (Female, 24) remained essentially stationary during the entire 5 minute period of her open interaction session with *The Stick*. Visibly intimidated by the robot, she continued to mutter comments such as "Oh no... Oh no... Stop pointing at me... Oh God..."

9. Despite individual motions appearing dangerous or intimidating, every participant claimed that they enjoyed taking



Figure 3 - A participant trying to "sneak around" *The Stick*

part in the study. Many stated they felt it a uniquely thought-provoking experience.

7. DISCUSSION

In this section, we briefly summarize our interpretation of our results and discuss their implications.

7.1 Speed and Direction

As was our original hypothesis, a number of direct correlations appeared to emerge between certain motion types and emotional characteristics. Most straightforward of these were the connections between speed- excitement and approach-aggression. That these trends tended to be common across all participants leads us to believe that there is some form of instinctual emotional interpretation at work.

7.2 Autonomy and Control

With so much of the experiment depending on presenting *The Stick's* motions in an unbiased fashion, there was some concern about the participant's implicit control over the robot during Phase 2. By allowing the participant to dictate when to move on to the next motion ("Next!", "Finished!"), the experimenters' control over the robot's motion was made transparent; rather than *The Stick* existing as an autonomous (and therefore intelligent/emotional) agent.

7.3 Physicality

Unlike on-screen, virtual representations of objects (e.g. computer graphics or 2D animation), we feel *The Stick* is quite viscerally "real" and present with its human observers; able to directly affect its environment through motion and physical interaction in more powerful (as well as more subtle) ways than strictly virtual displays. *The Stick's* physicality allows it to exploit our senses of depth perception, personal space, vibration, and even subtle air currents using its mass and rapid movement. We feel that the instinctual fear of being physically struck by *The Stick* itself is an important component of this experiment and a characteristic unique to Human-Robot Interaction in general.

7.4 Purpose and Context

The "purpose" of the robot played a large role in how participants thought to interpret its motions. When asked to openly reflect on the experience of observing the moving robot, many participants repeatedly asked what the robot was meant to be doing or why it was moving. That is, before describing their thoughts on their interpretations, they wanted to place their ideas in a more concrete context.

We feel that it was almost guaranteed that, had participants been pre-biased by introducing *The Stick* as (for example) "a security robot on patrol", participants would be more likely to interpret certain motions as more aggressive than if they were to enter the experiment with a more open mindset.

Alternatively, the entirely freeform nature of the experiment's meditative and open interaction phases may have left participants so bereft of official context that their reported interpretations of the robot, instead of being accurate reflections of their internal thoughts, were instead their best attempts to brainstorm *any* "appropriate" answer they could think of in order to follow the experimenter's instructions.

What is clearer is our participants' apparent reflex to draw upon any and all of their applicable experiences in order to understand and explain the behavior of a novel entity that they do not initially understand; whether that is living with household pets or formal engineering training.

7.5 Personal Space

As suspected, many participants responded to the rapid approaching motions (e.g. Front to Back Fast, Nodding, etc.) by expressing concern for their own personal safety; withdrawing into their seats and drawing their arms into their torsos.

During the open interaction phase, some participants made their own aggressive approaches towards the robot (e.g. suddenly jumping towards it and raising their arms above their head), saying they were "trying to see if I could scare it." As per the experimenter's protocol for controlling *The Stick* during this phase, the robot would in turn recoil from these motions, attempting to maintain a safe distance from the participant. Noting this, one participant remarked "Ah... I see it doesn't like that."

8. CONCLUSION AND FUTURE WORK

In this paper we presented our exploration of some of the associations between robotic motion and its coupled elicited human emotion. We argued for the validity of our basic, low level approach to the problem, looking at abstract robotic motions, avoiding form and affordances as much as possible, requiring the user to focus on the motion, rather than on a task.

We detailed our design philosophy and efforts, and presented the prototypes we developed in order to reach a robotic platform we can use in a full user study. We discuss our evaluation approach, a reflective meditation-like think aloud observation session as well as an interactive session allowing the users to relate directly, through action, to the robotic motion.

We discussed our extensive user study and its results. While some of the mapping we observed between set of motions to the emotions they elicited were, we believe, quite obvious, we were also pleasantly surprised to see a strong level of user engagement emerging from our observations. Many of our participants

engaged in seemingly emotional and unexpected ways with our very simple, almost purely abstract robot.

We see promise in these findings: users ability (or is it need?) to be deeply engaged with an abstract robotic motion is, we believe, powerful. We are wondering if and how far can this insight scale to non-abstract robots? We see form as a continuum and are wondering if and how the level of emotion engagement would be affected by enhanced form? How far can this engagement be carried on when the user is dealing with a valid task, supported with a progressive interaction flow? Would users still pay so much attention to the robotic motion when they need to perform a task, or perhaps the motion will move to the backburner, providing a sort of ambient interaction trait?

Our coming efforts are dedicated to including more form in our methodology, to allow for somewhat less abstract robots to attempt and engage users emotionally in a somewhat less abstract and more task-oriented interaction scenarios. We are also hoping to investigate the emotional reactions to different robotic motion expression in a more valid, robot-in-the-wild-type task.

9. REFERENCES

- [1] Harris, J. and Sharlin, E. 2010. Exploring emotive actuation and its role in human-robot interaction, Late-breaking abstract in HRI 2010, Osaka, Japan
- [2] Heider, F. and Simmel, M. 1944. An experimental study of apparent behaviour" American Journal of Psychology, vol. 57, pp. 243—259
- [3] iRobot Corporation. *iRobot*. <http://www.irobot.com>, 2010
- [4] Park, D. and Lee, JH. 2010 Investigating the Affective Quality of Motion in User Interfaces to Improve User Experience, *In Proceedings of ICEC 2010*, Seoul, Korea.
- [5] Reeves, B. and Nass, C. 1996. The Media Equation.
- [6] Roether, C., Omlor, L., Christensen, A. and Giese M. A. 2009, Critical features for the perception of emotion from gait, *Journal of Vision*, 9(6):15, 1–32.
- [7] Saerbeck, M. and Bartneck, C. 2010 Perception of affect elicited by robot Motion, *In Proceedings of HRI 2010*, Osaka, Japan
- [8] Young J. E., Ishii, K., Igarashi, T. and Sharlin, E. 2010 Showing robots how to follow people using a broomstick interface, Late-breaking abstract in HRI 2010, Osaka, Japan
- [9] Gibson, J. J. 1979 *The Ecological Approach to Visual Perception*, Psychology Press.
- [10] van Breemen, A., Yan, X. and Meerbeek, B. 2005 iCat: an animated user-interface robot with personality, extended abstract at AAMAS 2005, The Netherlands
- [11] Ishiguro, H., Ono, T., Imai, M., Maeda, T., Kanda, T. and Nakatsu, R. 2001 Robovie: an interactive humanoid robot, *Industrial Robot*, Volume 28, Number 6, 2001 , pp. 498-504(7)