Affective Animation of a Simulated Robot: A Formative Study

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Introduction & Background

Motion can be a powerful communicative device, even for inanimate objects. In previous studies, when people observed a silent film of abstract, animated shapes moving around, the subjects attributed emotional state and intention to these drawings. People invented back stories for triangles and squares as if these shapes had agency. As the drawings moved around the screen, the subjects also invented a narrative for these shapes, giving meaning to abstract movement of abstract objects. [1] [2] Qualities of movement and animation in computer user interfaces have communicative affordances that designers exploit to make human computer interaction more effective. [3], [4]

Robots are increasingly finding their way into our workspaces, homes, and schools. Human beings tend to rationalize robots' behaviors by projecting intention, intelligence, and even emotion onto these machines. Researchers engaging in Human-Robot Interaction (HRI) can exploit the natural anthropomorphizing of robots to improve the quality of social interaction among robots and people [5].

For example, social robots create expressive movement by taking advantage of social cues to generate gestures and body language [6] that encourage humans to achieve a certain affective state.

Recent studies that have used expressive movement with abstract robots like quadcopters [7] or even an actuated wooden stick [8] show that robots can create convincing communication of affect despite having a non-humanoid form.

Robots have used their expressive movement on stage to communicate affect as they interacted with each other and human actors; these movements must be interpreted by audiences as believable reflections of the robot characters' affect if the robot is to be a successful, convincing character on stage. [9] Examples of performing from Media Lab alumni and faculty include Cynthia Breazeal's interactive robot theater [10], Guy Hoffman's inquisitor lamp [11], Tod Machover's many robots in his Opera of the Future [12], Heather Knight's work with robot theater and stand-up comedy [13], and my own (work-in-progress) project involving a magician-robot interaction. [14]

Magician Robot Interaction

Researchers are trying to parse the complex attributes of social robots to attempt to identify features and qualities of movement that lend most to perceived animacy in the robot [15]. The Laban Motion Analysis is a methodology for describing and notating features of human movement.[16] The method describes motion along axes of body, shape, space and effort. Effort, in particular, refers to the qualities of movement that reflect an entities inner intentions and can be further refined through axes of Space (indirect-direct), weight (strong-light), time (quick-sustained), and flow (bound-free with respect to waypoints in space).

The field of motion planning in robotics attempts to address the problem of robots moving around the real world; robots must adjust their movement to unknown and moving obstacles (including people). [17]However, it is my belief that current motion planning algorithms tend to generate "robotic" movement that doesn't often seem natural nor very expressive.

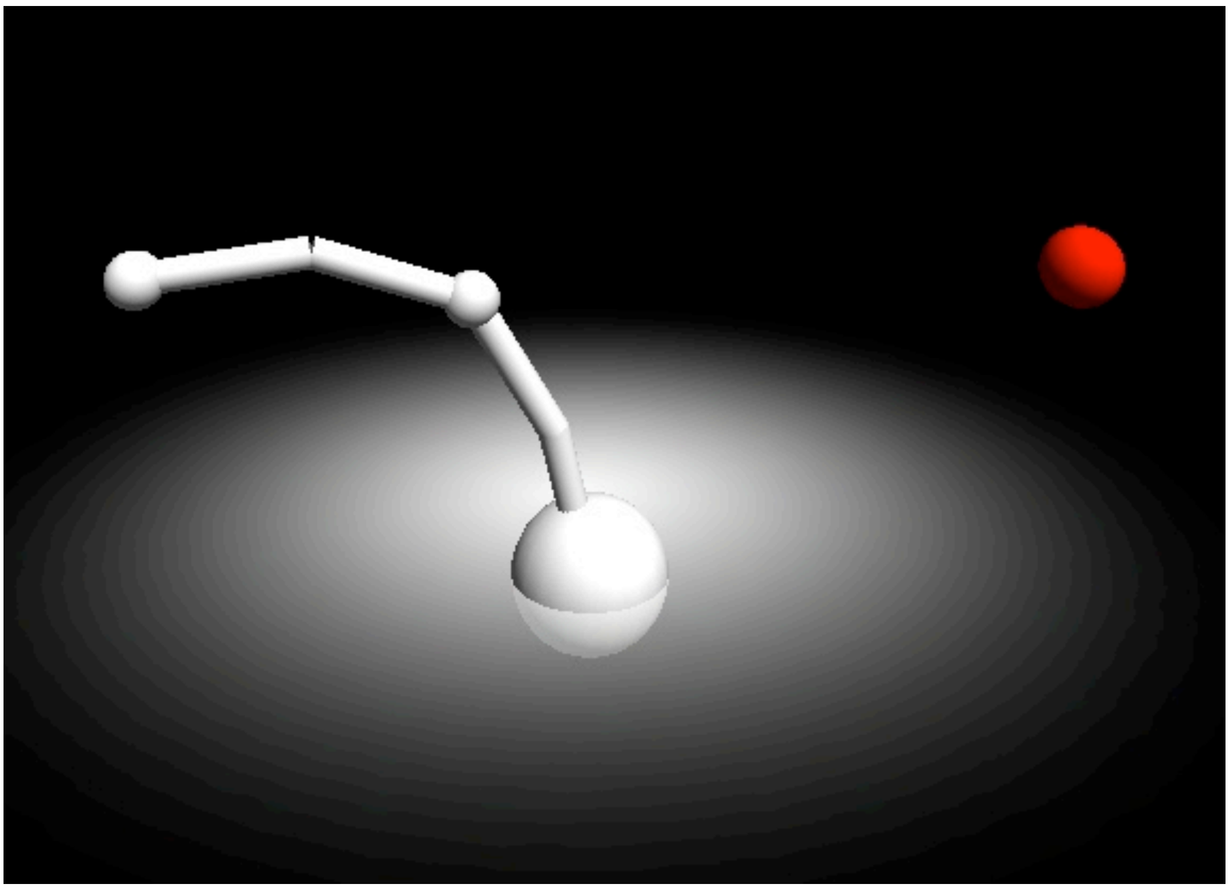
Much current related work in social robotics relies on pre-rendered and crafted animatronic movement and teleoperation to control the robot. This is not "pure" motion planning as the robot is, at best, only semi-autonomous and is a projection of the human operator's own social interaction. Recent approaches for modulating parameters in generated motion paths to create more organic movement have been successful.[18]

So work in affective actuation and motion planning might reduce our reliance on external animators' prescribed movement, and it might inform the field of motion planning by encouraging techniques that create unexpected (ex. non-optimal) plans that are otherwise HRI-friendly.

This project represents a first, formative step in a long series of work that attempts to generate a set of heuristics and tools that can be applied to traditional motion planning techniques, borrowed from animation (ex. pseudo-obstacles in configuration spaces to nudge plans into organic arcs, choosing paths with distances that factor in natural ramping/easing speeds {Penner, "Robert Penner's Programming Macromedia Flash MX", n.d.}, etc) or dance methodology on virtual or real robots.

For this study, I developed a software simulation of a robot that could modulate features of its movement while executing a simple motion plan. Study participants observed multiple instances of the movement and ranked how they thought the robot was "feeling" while executing the movement using the Self Assessment Manikin (SAM) [19] to describe observed valence, pleasure, and dominance.

Simulated Robot



The simulated robot consisted of 5 ball joints connecting a linear chain of links. Inverse kinematics was implemented using a simple Jacobian inverse technique [20] with no joint constraints. The end effector was made to move from a starting position to a target using a naive interpolation over waypoints in 3d space.

Since there are no obstacles in this configuration space, and the robot is rather flexible (albeit probably impossible to build), no other motion planning is used.

Acceleration

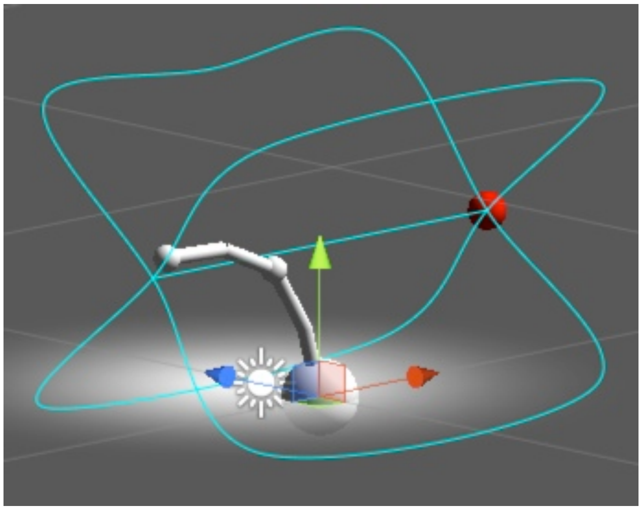
Acceleration is related to Laban's time axis of energy. The robot can express two accelerations from start to target waypoints. In one condition, the robot moved with a linear speed throughout the movement. In the easing condition, it moved with an In/Out Quartic acceleration.

Smoothing

Smoothing is related to Laban's flow aspect of energy (I.e. How tightly a path fits to waypoints). In one condition, the robot moved directly from waypoint to waypoint. In the second condition, a bezier interpolation was used to smooth the global path; the robot end effector might not hit every waypoint, but it flows in one continuous curve.

Path

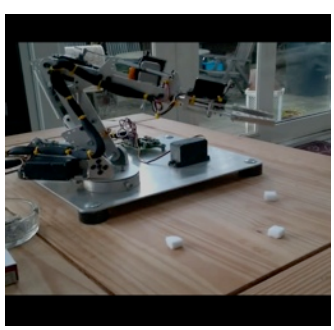
The robot expressed 7 paths by preferring waypoints that were forward (towards the viewer), backward (away from the viewer), upwards, downwards, and "neutral".



Procedure and Methodology

I recruited participants through email and signage announcements to members of the MIT Media Lab community. Participants included nine healthy adult participants aged 20-37 and one over 50 who declined to give an actual age. 1 male and 9 female subjects were included in the study. Participants were reimbursed with a $10.00 Amazon gift certificate for approximately 20 minutes of time. The experiment was approved by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES) review board.

Subjects were seated at a desk in front of a laptop running the simulation software. After providing informed consent, the users interacted only with the simulation software on the screen and the researcher sat near them, but facing away. The software first displayed 30 seconds of a dancer's arms movement and then 30 seconds of a robotic arm movement in an attempt to normalize context for arm movement. Then, each subject observed approximately 16-18 simulated robot movements with varying motion features in a random order (I was blind to the order of animations). After each movement, the users were instructed to rank the movement along 3 axes of the SAM. When they were done, the researcher conducted a semi-structured interview. Audio and face video was captured via the laptop throughout the entire experiment.



Normalizing Video Stills

Results & Discussion

With such a low number of participants, I present these results with the caveat that additional study will be required to validate the outcomes. However, approaching this project as a formative study is useful and points to some potential areas of deeper exploration and crisper formulation of hypotheses. First, using an unranked T-Test, I found no statistical significance between the smoothing variable and any of the three axes of the SAM. Easing, however, seems to correlate with higher values in both the dominance and valence axes compared to linear motion paths. Using ranked ANOVA (low n), path seemed to have a nuanced effect on dominance. In particular the forward-up paths seemed to demonstrate a statistically significant correlation with dominance compared to the backward-down or backward-up movements. No other statically significant findings could be shown regarding path.

Smoothing and Easing

	Smoothing			Easing		
	Valence	Arousal	Dominance	Valence	Arousal	Dominance
Statistical Significance (P-Value)	0.589430562	0.496301872	0.800670466	0.000039195	0.219326537	0.000407126
Effect Size (Cohen's d)	0.088401715	0.111258037	0.041109618	0.695510674	0.203082048	0.590873894
Difference Between Averages (FALSE – TRUE)	0.15634622	-0.191583989	-0.080910024	1.163561077	0.236542443	1.115942029
Confidence Interval of Difference	-0.415 to 0.728	-0.631 to 0.248	-0.713 to 0.551	0.619 to 1.71	-0.211 to 0.684	0.505 to 1.73

Path

ANOVA tables					
Ranked ANOVA					
P-Value	0.00259				
Effect Size (Cohen's f)	0.360317101				
Summary					
Group	Average	Median	Sample Size	Confidence Interval of Average	Standard Deviation
bd	3.6	3	35	2.9 to 4.2	1.9
fu	5.1	5.5	34	4.5 to 5.8	1.9
fd	3.5	3	33	2.8 to 4.3	2
bu	4.6	5	31	4.0 to 5.3	1.9
nn	3.8	4	20	3.0 to 4.6	1.7
Total	4.2	5	153	3.8 to 4.5	2
Pairwise Tests					
Group 1	Group 2	Difference in Averages (1-2)	Confidence Interval of Difference	P-Value	Effect Size (Cohen's d)
bd	fu	-1.6	-2.8 to -0.3	0.00734	0.854
bd	fd	0	-1.3 to 1.3	0.9	0.0137
bd	nn	-0.2	-1.6 to 1.2	0.9	0.129
fu	nn	1.3	-0.1 to 2.8	0.072	0.752
fd	fu	-1.6	-2.9 to -0.3	0.011	0.835
fd	nn	-0.3	-1.7 to 1.2	0.9	0.137

The qualitative discussions with the subjects proved to be valuable. I asked each participant to estimate how large they thought the simulated robot was. Most said "arm sized" to about "table size". None assumed the robot was an industrial sized robot. When asked if the robot was learning between each trial, most said that the robot was either not learning or, in one case, was getting worse.

Subjects used keywords like "sneaky" and "slithering" to describe movements along the downward paths. One subject described this movement as like a "cheetah" stalking prey. One subject talked about the joint configuration as emotionally significant (I.e. "Crumpled" poses vs "straight" arm links bearing some indication of "confidence"). Indeed, Laban talks about shape of a body as communicative.

A couple of subjects talked about how the end effector approached the target as most communicative of dominance (I.e. Touching it from above was more dominant than coming up from below). This might help explain the similar quantitative result derived from the SAM.

However, an almost universal comment among the subjects was that the SAM measurements were difficult to use to assess the robot's movement. People wanted different axes. One subject kept saying "these are the wrong words!"

Future Work

I believe recreating this experiment with an actual robot will prove valuable as there is much research that suggest embodied animation could be more potent.

Most importantly, a more relatable measurement (ex. Semantic differentials based on Russell's circumplex model of affect) might generate more useful results from subjects; particularly, if I could tie individual motion features to hypotheses about how they might influence a person's estimation of a robot's affect, I could start building to some generalized ideas about computation motion.

Furthermore, in addition to using established animation techniques to derive heuristics, expert puppeteers could work with a scaled-down and instrumented model of the robot (i.e. "sympathetic interface") to develop a gesture vocabulary for that particular robot's morphology. They might receive instructions like "make the robot puppet pick up an object with glee." Machine learning techniques could be used to extract features from these motion captured sessions in an attempt to identify what makes for a particular expressive motion. These could be used to inform more directed hypotheses about movement.

It would be interesting, as well, to see how different qualities of movement related to trust and confidence in a robot. Could a robot project how tentative it "feels" about an action just be altering its movement? Furthermore, could this be used to simulate growth and learning in a robot?

All in all, this has been an invigorating opportunity to open up many questions for much deeper research in the upcoming months.

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