Human Perception of Swarm Robot Motion

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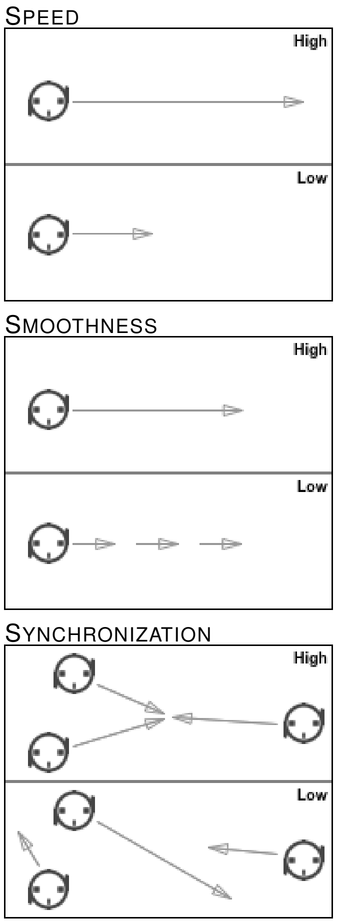

Figure 1: Participants observe robots executing 8 motion patterns varying speed, smoothness and synchronization. Diagrams show how the 3 motion elements vary in each condition (either high/low).

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Abstract
As robots become ubiquitous in our everyday environment, we start seeing them used in groups, rather than individually, to complete tasks. We present a study aimed at understanding how different movement patterns impact humans' perceptions of groups of small tabletop robots. To understand this, we focus on the effects of changing the robots' speed, smoothness, and synchronization on perceived valence, arousal, and dominance. We find that speed had the strongest correlation to these factors. With regard to human emotional response to the robots, we align with and build on prior work dealing with individual robots that correlates speed to valence and smoothness to arousal. In addition, participants noted an increase in positive affect in response to synchronized motion, though synchronization had no significant impact on measured perception. Based on our quantitative and qualitative results, we suggest design implications for swarm robot motion.

Author Keywords
Human-robot interaction (HRI); perception; affect; robot swarms; swarm user interfaces; tangible user interfaces

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User interfaces; User-centered design

Introduction

As robots become more intelligent and pervasive within society, we need to understand the emotional effect they have. The most common interaction currently discussed in literature is between a human and a single robot. Existing literature shows that a human's perception of a single robot can be changed based on the robot's motion, and that that perception can alter how the human feels about the robot (as a social partner, employee, work assistant, etc.) and perceives its demeanor [6].

However, swarm robots present an emerging technology with numerous potential applications. Human-robot interaction (HRI) researchers have designed a taxonomy classifying the collective behavior of groups of robots [5], and are exploring the design space of swarm robotics in various domains including: underwater [9], mine detection [11] path-finding [14] , fire-fighting [17], and communication [19].

As technology for swarm robots becomes increasingly popular, it is important to know if our understanding of perception of single robots extends to, or is magnified by, a group of robots. For example, a single mini-robot might be cute, but when many robots are involved, do they become intimidating? How does a human's perception change as the robots' synchronization increases? It is important to answer these questions if we hope to encourage the public's acceptance and adoption of robot technologies.

Small tabletop robots in particular are interesting because they may be used to perform tasks such as cleaning, moving objects, and displaying information. Le Goc et al. have created Zooids, a platform for developing tabletop swarm interfaces made of independent, programmable, self-propelled elements [12]. In this paper, we contribute a study of human perceptions of various tabletop robot motions using these Zooids.

We vary the robots' speed (high speed vs. low speed) and smoothness (smooth vs. jittery), which have been shown to have effects on emotion in prior literature [13]. Additionally, we vary synchronization (all robots moving toward the same goal vs. each robot moving toward its own goal), which is a dimension of motion that is only possible with multiple robots, and is, to our knowledge, previously unstudied. We measure the user's perception via the Self-Assessment Manikin (SAM) scale [2], which measures valence, arousal, and dominance as elements of emotion. These elements of emotion are commonly used in HRI literature to measure a user's affect towards robots, for example by Lee et al. [13]. Using these variables and measurements, we find that differences in motion patterns do impact human perceptions of groups of small tabletop robots.

Related Work

Single Robot Perception

Extensive literature exists regarding human perception of a single robot, including human response to proactivity and expressivity [15], how humanlike-ness and demeanor influence perceived cooperability [6], and understanding intention of colocated robots [4, 22]. In terms of the relationship between emotions and the motion of a single non-humanoid robot, Lee et al. found that people link higher speed to increased arousal (energy), and smoother motion to increased valence (pleasure) [13].

Swarm Robots

With recent developments in swarm robot technology, we see that human-swarm interaction may differ from interaction with individual robots [10]. Appropriately designed swarm user interfaces can help a swarm of robots achieve its goals more efficiently [1]. Harriott et al. survey the space of human-swarm interfaces, describing nine categories for evaluation, such as human attributes, task performance,

Figure 2: Experimental setup. Study participants observe the Zooids, which are placed in front of them on a table. The study administrator sets the motion of the Zooids on a computer nearby.

leadership, etc. [7]. In our study, we focus on human attributes.

Looking at biological swarms, as they grow in size, human perception of them benefits from coherent organization [20]. However, when a biological swarm gets too large, we cannot keep track of the whole swarm at once; we must develop ways to visualize it as a whole from our view of a part [24, 3]. This extends to our interaction with robots as well; as we interact with more robots at any given time, mechanisms to control them must change [16].

As such, in order to develop effective interfaces, we must understand how human perception of robots changes as the number of bots increases. Podevijn et al. looked at physiological metrics, as well as valence and arousal, for 1, 3, and 24 robots [18]. They found that even in passive interactions, the number of robots affected participants' psychological responses.

Motion & Animacy

In looking at perception of multiple robots, we are specifically interested in looking at differences in varied motion patterns. It has long been known that motion affords animacy in two dimensional shapes [8, 23]. Further, participants ascribe different intents to shapes with different motions [8]. In robots, too, motion alone is sufficient to convey intent, even without typical anthropomorphic cues, such as face or voice [21].

With differing mechanisms of interaction between humans and individual robots, and humans and swarms, it is important to explore how human perception changes with various swarm motion patterns, especially in the realm of affect.

Methods

To better understand how people's perceptions vary with different robot motion qualities, we designed and conducted an in-lab user study.

Participants

We recruited 14 volunteer participants (8 female, 6 male) from our institution. 7 participants majored in Computer Science, 1 in another engineering field, 3 in the natural sciences, 1 in Political Science, 1 was undecided, and 1 declined to answer. The protocol was approved by the University's Institutional Review Board, and subjects gave informed consent before the experiment.

Apparatus

We used a set of 10 Zooids [12] to illustrate the different motion patterns. Zooids measure around 2.6 cm in diameter and are programmed to individually follow the specified motion patterns (speed, smoothness, synchronization of goals). Because of the hardware requirements of the robots, the study is run in a dimly lit room. The user is seated in front of a table on which the robots are placed, and a projector mounted above the table projects a bright 0.8m x 0.5m rectangle within which the robots are able to move. See [12] for more details on hardware specifications and requirements.

The experimental setup involves a human study administrator who controls the motion of the Zooids. The administrator's computer is connected to a receiver which communicates to the Zooids in real-time. The study participants observe the Zooids, which are placed on a table in front of them.

Procedure

The robots were configured to follow a set of 8 randomly-ordered motion patterns varying 3 parameters: speed (high or low), smoothness (smooth or jittery), and synchronization of goals (shared goals or individual goals). The robots were programmed to move towards a particular moving target. When a single robot reached its current goal, all robots' goals were updated to randomly selected positions. These goals were unknown and not visible to the participants. The robots moved at an average speed of 40 cm/s in the high speed condition and 9 cm/s in the low speed condition. To create jittery motion, the speed would alternate between their normal speed (high/low) and 2 cm/s to produce a fast-slow-fast-slow motion (40% of the time at normal speed, 60% of the time at 2 cm/s). Speeds were chosen for these conditions based on what appeared most differentiable and they were verified during piloting.

The participants were first shown the motion patterns, in random order, with a single robot varying speed and smoothness (synchronization is ignored as it is not applicable) to better prime them to recognize the differences between motion patterns. Once these were completed, the participant was then shown the multiple robots portraying all 8 motion patterns, again in random order. Only the data from the trials with multiple robots was used in analysis.

Each of the 8 patterns was shown for 15 seconds and then participants completed a brief survey. Participants were shown 7-point visual and numerical SAM scales for valence (1: negative to 7: positive), arousal (1: calm to 7: excited) and dominance (1: dominated to 7: dominant), and were asked to rate each of these as conveyed by the robots and as felt by the participant himself. After all patterns were presented, participants also filled out a qualitative post-study survey. This survey asked them several open-ended questions, including:

- Which motion stood out to you the most? Why?
- Which motion did you enjoy the most? Why?
- Do you believe the robots behave as individuals or as a cohesive whole? Why?

Analysis
To examine the effect of speed, smoothness, and synchronization of robots on the different emotional scales, we used an ordinal logistic regression. A standard linear regression assumes that the outcome is ratio or interval. However, we did not believe that this was a valid assumption in our case as users' psychological distances between values of valence, arousal, and dominance are not guaranteed to be equivalent. Thus, we used an ordinal logistic regression, which does not make this same assumption.

To examine if a correlation exists between different emotional scales, we used a Kendall correlation test. Kendall tests also do not make the assumption of ratio or interval data, so we were able to use it on this ordinal data. It also allows for the possibilities of ties in data; that is, for a given data point, the two numbers we are comparing can have the same value. This is not the case for other correlation tests.

Results

How does motion affect the perceived robot emotion?
As seen in the upper half of Table 1, speed and smoothness both had significant effects on the valence, arousal, and dominance of the swarm's perceived emotion, while the effect of synchronization on those robots' emotion had a lesser, non-significant effect. With high speed, valence of the robots was 3.38 times more likely to increase ($z = 3.45$, $p < 0.001$), arousal was 3.83 times more likely to increase ($z = 3.80$, $p < 0.001$) and dominance was 4.14 times more likely to increase ($z = 3.99$, $p < 0.001$) when compared to low speed. With smoother motion, valence of the robots' emotion was 2.54 times more likely to increase ($z = 2.69$, $p = 0.0071$), arousal was 2.85 times more likely to increase ($z = 2.99$, $p = 0.0028$), and dominance was 2.67 times more

Emotional Response		
Predictor	*Odds ratio*	*z value*
ROBOT		
Valence		
Speed	3.38	$3.45^{\ddagger}$
Smoothness	2.54	$2.69^{\dagger}$
Synchronization	1.12	0.34
Arousal		
Speed	3.83	$3.80^{\ddagger}$
Smoothness	2.85	$2.99^{\dagger}$
Synchronization	0.68	-1.11
Dominance		
Speed	4.14	$3.99^{\ddagger}$
Smoothness	2.67	$2.86^{\dagger}$
Synchronization	0.84	-0.52
PARTICIPANT		
Valence		
Speed	1.86	1.81
Smoothness	1.96	1.97^{*}
Synchronization	1.05	0.15
Arousal		
Speed	2.94	$3.08^{\dagger}$
Smoothness	1.61	1.39
Synchronization	0.74	-0.88
Dominance		
Speed	0.73	-0.93
Smoothness	0.52	-1.88
Synchronization	1.74	1.64

Table 1: Odds ratios of the ordinal logistic regression on valence, arousal, and dominance of the perceived robot emotion and participant's emotional response. *p<0.05, †p<0.01, ‡p<0.001

likely to increase (z = 2.86, p = 0.0043) when compared to jittery motion.

How does motion affect the user's emotional response?
As seen in the lower half of Table 1, smoothness had a significant effect on the participants' emotional response only for valence, whereas speed had a significant effect on the participants' emotional response for arousal. With smoother robot motion, the participants' own valence response was 1.96 times more likely to increase (z = 1.97, p = 0.049) when compared to the jittery motion. With high robot speed, the participants' own arousal response was 2.94 times more likely to increase (z = 3.08, p = 0.0021) when compared to low robot speed.

How do emotional response values correlate to each other?
Our results also show that higher valence values for the robots were more likely to occur with higher valence values for the participants' emotion responses (r_τ = 0.64, p < 0.001). Similarly, higher arousal values for the robots were more likely to occur with higher arousal values for the participants' emotion response (r_τ = 0.62, p < 0.001). We saw a trend toward an inverse relationship between perceived robot dominance and participant dominance, but did not find statistically significant results (r_τ = -0.14, p = 0.06).

Discussion & Design Implications

In addition to our quantitative results, our qualitative survey shows that participants indeed were able to distinguish between different motion patterns. While in our SAM scale ratings, speed had the most significant impact on emotional response, participants actually noted synchronization of targets most often in the post-study survey as being enjoyable or having stood out. Participants also often mentioned smoothness of motion, specifically noting a discomfort with jittery movement. Based on the above results and the qualitative data we collected, we present suggestions for general design implications for swarms of multiple small robots.

Speed
Among the three attributes we varied, speed mattered the most – having a significant impact on human's perception of the swarm's valence, arousal and dominance. Based on these results, we would recommend that designers of swarms pay particular attention to designing the speed of robotic swarms in order to achieve a desired affect.

Synchronization
In designing swarm motion for small robots, consider leveraging synchronization. In the post-study survey, 11 of the 14 participants mentioned liking the grouped, collective movement (synchronization) of the robots. Many described this motion as the robots "finding friends" [P5, P9] or "cooperating" [P3, P5, P6]. In many cases, participants attributed this type of motion to human-like intention around "trust and teamwork" [P7], describing it as "moving in a pack (like they were hunting or foraging)" [P9]. In fact, 11 participants attributed life-like characteristics such as intention to the swarm robots.

Smoothness
Qualitative results suggested that swarms of robots should move smoothly whenever possible. For both robot and participant emotion, smoothness correlated with higher valence, implying that jitter correlated with negative affect. In our qualitative survey, participants characterized this non-smooth motion as expressing fear and frustration [P3, P6, P7, P12].

Varying Emotion
Designers can attempt to evoke certain positive/negative and high/low energy emotions by varying speed and smoothness of the robots. In particular, higher speeds may evoke

higher energy (arousal) in human observers and greater smoothness may result in more positive (valence) emotions.

Limitations & Future Work

One limitation of the study is the lack of intervals in motions: our three independent variables (speed, smoothness, and synchronization) were all binary. Finer-grained movement controls would allow for a deeper exploration of motions, but pilot testing showed us that hardware limitations on these early robots prevented small interval changes from being as detectable and differentiable as the binary changes were. Additionally, because the jittery effect was created by a period of very low speed within the high or low speed setting, the average speed of the smooth and jittery versions of a given speed are not the same, creating a correlation between speed and smoothness. The proximity of the experimenter may also have slightly influenced the participants' trust in the robots.

Another limitation of our current study design is that the users are passively watching the swarm motion rather than actively interacting. We are interested in studying tasks where the user assists the robots or the robots assist the user to see if this impacts human perception. How would a participant understand if the robots need help? Would participants be more inclined to help robots moving in a certain manner?

Additionally, in this study, all of the motions were random. In the future, it would be interesting to study the human perception of predetermined choreographed movement. For instance, robot movement can serve as a method of information display [12]. We are interested in exploring the potential for swarms of robots to provide information to the user based on their movement. The Zooids also allow for user interaction in real-time, and it may therefore be fruitful to explore task efficiency and effectiveness with the Zooids for various types of tasks.

Finally, we ran this study on very small robots, so we cannot guarantee our findings extend to larger robots. In the future, it would be interesting to explore if robot size or form factor affects the perception of motion.

Conclusion

We foresee a future where swarms of robots, regardless of size and form factor, become ubiquitous and pervasive. For these swarms to be effective, we need humans to feel comfortable around the robots. Thus, in our study we aim to understand how humans perceive swarms of robots by looking at what emotions are associated with different motion patterns. We found that varying speed and smoothness does indeed have an impact on some elements of perceived emotion and emotional response, while synchronization had no significant quantitative impact. With these preliminary results, we can further investigate how designers might be able to have some influence on these perceptions through the design of appropriate movement qualities. Imagine interacting with the robots to accomplish a task. How quickly do they move? Do they work together? We hope that this study will present design insights for future developers and researchers of swarm robotics for various applications.

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