From Motions to Emotions: Exploring the Emotional Expressiveness of Robot Swarms

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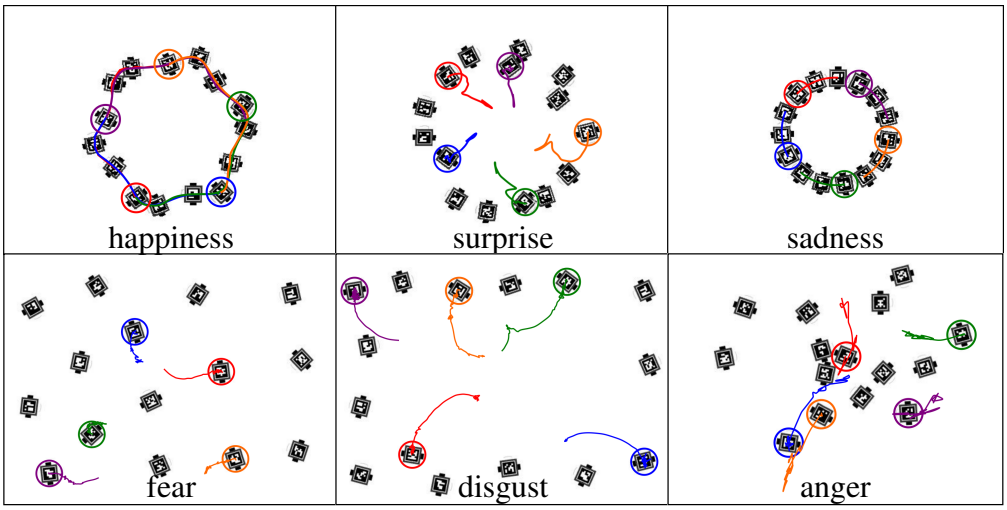

***Abstract*— This work explores the expressive capabilities of a swarm of mobile robots within the context of inter-robot interactions and their mapping to the so-called fundamental emotions. Using motion and shape descriptors from social psychology, we create a set of swarm behaviors, each corresponding to a fundamental emotion, and evaluate their effectiveness in a user study. The results show that most participants assigned to each video the emotion intended to be portrayed by design, thus confirming that abstract descriptors from social psychology can be effectively transformed into expressive swarm behaviors.**

I. Expressive Swarm Behaviors

As robots get progressively intertwined with different forms of performing arts, there is a need for them to convey artistic expression and emotion to the audience. While expressive human-robot interactions have been studied in the context of artistic expositions, the focus has been primarily on anthropomorphic robots. In this paper, we are interested in exploring the expressive capabilities of swarms of robots, for which the study of expressive interactions remains sparse [1], [2]. In particular, we study how motion and shape descriptors associated with the so-called *fundamental emotions* [3]—i.e. happiness, surprise, anger, fear, disgust and sadness—can be incorporated into the movement of a swarm to represent different emotions. An extended version of this work has been submitted for possible publication [4].

A summary of attributes related to the fundamental emotions and emotion valences is presented in Table I. Among these attributes, it seems natural for those related to *shape* and *size* to be depicted by the collective behavior of the swarm. Thus, the *roundness* feature is incorporated into the happiness, surprise and sadness behaviors, all based on the robots following circular contours, similarly to cyclic pursuit. In the case of happiness, a sinusoid is superimposed to the circle to embody the *curvilinearity* feature. The *very big* attribute for the surprise emotion is embodied through a contour of increasing radius and the circle dimensions are reduced (*small* feature) for sadness.

The scarcity of *shape* characterizations for fear, disgust and anger motivates an alternative approach, where we specify which areas of the domain the robots should concentrate around, as in coverage control. For fear, a uniform density across the domain makes the robots scatter. The density makes the swarm move towards the boundaries for disgust, giving the sensation of animosity between robots. For anger, the robots are made to stay closer to the center of the domain, which, combined with an aggressive individual control, is intended to give the sensation of a heated environment.

The control commands produced by these collective behaviors are converted into linear and angular velocities executable by differential drive robots using a transformation where we get to tune how *fast* a robot travels when executing a control command and how *smooth* the resulting movement trace is. This transformation thus provides a natural way to introduce the *movement* features in Table I through the individual robot control. The *smoothness* and *roundness* attributes are incorporated into the happiness, surprise and sadness behaviors; while for fear, disgust and anger, an angular movement trace is chosen.

A more detailed discussion of how these swarm behaviors are implemented is included in [4]. The URL links for the videos of each behavior can be accessed by pressing the

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TABLE I

MOVEMENT AND SHAPE ATTRIBUTES ASSOCIATED WITH DIFFERENT EMOTIONS AND EMOTION VALENCES

		Shape Features	Movement Features	Size
Emotion	Happiness	roundness, curvilinearity [5]	smoothness [6]	big [7]
	Surprise	roundness [5]		very big [7]
	Anger		large, fast, angular [8]	
	Fear	downward pointing triangles [9]	small, slow [8]	
	Sadness	roundness [5]	small, slow [8]	small [7]
Valence	Positive	roundness [5], [9]	rounded movement trace [5], [9]	
	Negative	angularity [5], [9]	angular movement trace [5], [9]	

YouTube symbol next to corresponding emotion in Table II.

II. USER STUDY

The expressiveness of the swarm behaviors was evaluated in a survey where each participant was asked, for each video, to select the emotion that *best described the movement of the robots*. The survey's procedure is explained in detail in [4].

The results of the survey are summarized in Table II. Each column contains the responses given to the corresponding video (link available pressing ▶). The emotions are ordered counterclockwise from positive to negative valence according to the model in Fig. 1. The diagonal terms correspond to the percentage of responses that identified the emotion in the video as the one intended by design. For all the diagonal values, the percentage is much higher that the one given by chance (16.67%), and, in most cases, it surpasses 50%. For fear and disgust, while the relative majority of the responses identified the emotion according to our hypothesis, the values are slightly lower (40%). This can be potentially caused by the proximity of such emotions in terms of their valence and arousal, as illustrated in Fig. 1. A more detailed discussion of the survey results is included in [4].

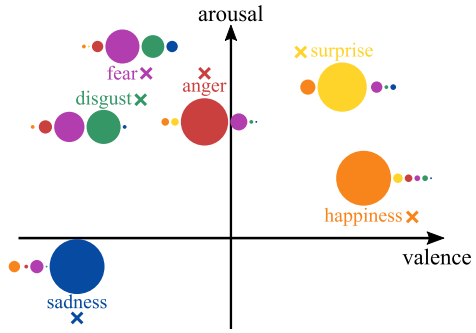

Fig. 1. Survey responses in the valence-arousal plane [10]. Next to each emotion (located by an ×) a sequence of color-coded circles represent the amount of responses given to the corresponding emotion. In general, users label the behavior according to the proposed emotion, with most variations occurring between the emotions closest in the plane, i.e. disgust and fear.

In conclusion, the data collected in the user study supports that the swarm behaviors design in this paper effectively depict each of the fundamental emotions, therefore providing a collection of motion primitives for robotic swarms to effectually convey emotions in artistic expositions.

REFERENCES

[1] F. Levillain, D. St-Onge, E. Zibetti, and G. Beltrame, "More than the sum of its parts: Assessing the coherence and expressivity of a robotic swarm," in *2018 IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, Aug 2018, pp. 583–588.

[2] G. Dietz, J. L. E, P. Washington, L. H. Kim, and S. Follmer, "Human perception of swarm robot motion," in *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, Denver, Colorado, 2017, pp. 2520–2527.

[3] P. Ekman, "Facial expression and emotion," *American Psychologist*, vol. 48, no. 4, pp. 384–392, 1993.

[4] M. Santos and M. Egerstedt, "From motions to emotions: Can the fundamental emotions be expressed in a robot swarm?" submitted, arXiv version available at https://arxiv.org/abs/1903.12118.

[5] G. L. Collier, "Affective synesthesia: Extracting emotion space from simple perceptual stimuli," *Motivation and Emotion*, vol. 20, no. 1, pp. 1–32, 1996.

[6] J.-H. Lee, J.-Y. Park, and T.-J. Nam, *Emotional Interaction Through Physical Movement*. Springer Berlin Heidelberg, 2007, pp. 401–410.

[7] A. de Rooij, J. Broekens, and M. H. Lamers, "Abstract expressions of affect," *International Journal of Synthetic Emotions*, vol. 4, no. 1, pp. 1–31, 2013.

[8] F. E. Pollick, H. M. Paterson, A. Bruderlin, and A. J. Sanford, "Perceiving affect from arm movement," *Cognition*, vol. 82, no. 2, pp. B51 – B61, 2001.

[9] J. Aronoff, "How we recognize angry and happy emotion in people, places, and things," *Cross-Cultural Research*, vol. 40, no. 1, pp. 83–105, 2006.

[10] J. A. Russell, "A circumplex model of affect," *Journal of Personality and Social Psychology*, vol. 39, no. 6, pp. 1161–1178, 1980.

TABLE II

CONFUSION MATRIX OF THE SURVEY RESPONSES

		Proposed Emotion					
		Happiness ▶	Surprise ▶	Anger ▶	Fear ▶	Disgust ▶	Sadness ▶
Response (%)	Happiness	**64.44**	17.78	8.89	4.44	4.44	13.33
	Surprise	11.11	**57.78**	8.89	2.22	0.00	0.00
	Anger	8.89	0.00	**55.56**	13.33	15.56	4.44
	Fear	6.67	13.33	20.00	**40.00**	35.56	15.56
	Disgust	6.67	4.44	4.44	26.67	**40.00**	2.22
	Sadness	2.22	6.67	2.22	13.33	4.44	**64.44**