Communicating Affect via Flight Path

Exploring Use of the Laban Effort System for Designing Affective Locomotion Paths

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***Abstract*—People and animals use various kinds of motion in a multitude of ways to communicate their ideas and affective state, such as their moods or emotions. Further, people attribute affect and personalities to movements of even non-life like entities based solely on the style of their motions, e.g., the locomotion style of a geometric shape (*how* it moves about) can be interpreted as being shy, aggressive, etc. We investigate how robots can leverage this locomotion-style communication channel for communication with people. Specifically, our work deals with designing stylistic flying-robot locomotion paths for communicating affective state.**

To author and unpack the parameters of affect-oriented flying-robot locomotion styles we employ the Laban Effort System, a standard method for interpreting human motion commonly used in the performing arts. This paper describes our adaption of the Laban Effort System to author motions for flying robots, and the results of a formal experiment that investigated how various Laban Effort System parameters influence people's perception of the resulting robotic motions. We summarize with a set of guidelines for aiding designers in using the Laban Effort System to author flying robot motions to elicit desired affective responses.

***Index Terms*- social human-robot interaction, human-robot interaction, affective computing, laban effort system, motion parameters**

I. Introduction

The use of motion in its many forms is an integral element of social communication for many species; people use a plethora of gestures and complex body language for everyday interaction, and animals, for example, show others if they are calm or aggressive, happy or in pain, by how they move. As such, researchers in the field of Human-Robot Interaction (HRI) have been working on robots that can similarly use their body motions and gestures for communicating their states, and other relevant information, to people (e.g., [4, 7]). Much of this relies on robots exhibiting human- or animal-like affect, a common and effective tool for communicating robotic state information in ways that are easy for people to understand [7, 15, 23].

Previous work has shown that complex multi-degree-of-freedom gestures are not always necessary, for example, an animated triangle moving erratically may be seen as being "angry" [10], or a disc robot can appear "afraid" or "happy" based only on how it moves [30]. This highlights that robots can use all of their motions and nuances – not only full-body human-like gestures – for broadcasting affect.

Thus even robots without an anthropomorphic or zoomorphic design can leverage motion-based communication channels: any robot can show urgency by exaggerating movement speed, show fatigue by moving slowly or exhibiting a sense of difficulty moving, or show uncertainty by hesitating. In this paper we specifically explore how a flying quadrotor robot can modify its existing and necessary locomotion path – how it moves between locations – to communicate affect to people. We use a flying robot for its flexibility in exploring movement and communication possibilities: it is fast, and has six-dimensional movement (position and tilt angles).

Figure 1: Experiment space: a participant watches a quadrotor moving around with an expressive locomotion path designed using the Laban Effort System

Although a plethora of work in psychology, design, and robotics has explored how low-level parameters of motion impact perceived affect (for a good review see [25]), little of this work explores how an interaction designer can use such basic parameters to create high-level expressive motions for particular communication purposes. Unfortunately, it is not trivial to synthesize complex motions for particular affective responses from knowledge of low-level parameters such as robot position, direction, curvature, speed, acceleration, etc. Rather, we propose the use of the Laban Effort System, a standard methodology from the performing arts for describing expressive motion, as a means of providing practical motion parameters which are more closely linked to the kinds of affect designers will want to create.

A key tenet of the Laban Effort System is the use of expression-oriented keywords to describe motion, and the reliance on a trained artist to provide their own interpretation of these keywords to design a motion; the inclusion of the artist in the design loop is critical as it acknowledges the fundamental artistic element of affective communication. What makes our approach different from programming by demonstration – where a qualified artist can simply create desired motions – is that the Laban Effort System provides a vocabulary and framework which HRI designers and artists can both use to communicate and collaboratively author affective robotic locomotion styles.

One current limitation of our proposed approach is that uninitiated HRI designers may not be familiar with how the Laban Effort System vocabulary (e.g., bound, free, strong, weak) may map to resulting robotic communication. This paper provides an initial data point to help bridge this understanding: we commissioned a Laban-trained artist to author a full set of flying-robot motions using all combinations of the Laban Effort System parameters, and conducted a study to evaluate how these impacted perceived affect.

The contributions of this paper are a) the adaption of the Laban Effort System to the design of flying quadrotor locomotion paths, and b) results from a study which provides an initial data-point for mapping the use of Laban Effort System parameters to perceived affect. This research provides a new method and toolkit which HRI designers can use to aid in the authoring of affective flying-robot motions, or the use of locomotion to communicate affect for any robot.

II. Related Work

There has been extensive work that shows that people attribute affect to motion, ranging from abstract shapes such as virtual triangles, circles, or widgets moving around on a screen to lights moving around a room, and attach personalities based on movement qualities [1, 2, 5, 6, 8, 19, 21, 29]. Robot-specific work has found similar relationships, for example, robots can effectively use human-like gestures to communicate [12], and even a disc-shaped vacuum robot [25, 30], or abstract "stick" robot [9] can communicate affect based on how it moves. Our work builds on these past efforts by extending specifically to flying-robot locomotion paths for affective communication.

A key point of related work has been to unpack the complexities of motion into fundamental parameters (e.g., velocity, acceleration, curvature), and to explore how each parameter impacts perceived affect. For example, spline-coefficient combinations or changes in direction and velocity are useful in classifying motion in terms of liveliness [8], people interpret complex motions and synthetic stimuli in animate or inanimate terms based on changes in speed and direction [29], and acceleration can be used to predict perceived arousal and valence information [25]. These results are very important for understanding how people may perceive a particular motion. However, the reverse direction – synthesizing complex affective motions from the base parameters, for example, to create a *fatigued* motion – is not well investigated. In our work we contribute to this research by adapting the Laban Effort System as one such mechanism for aiding the design of affective HRI motion styles, and, for studying how parameters of the Laban Effort System themselves impact perceived affect.

An alternative to using motion parameters and frameworks for creating affective robotic motion is programming by demonstration, where a designer could simply demonstrate what they want the robot to do rather than to work with a set of parameters [11, 16]. A variant of this called *style-by-demonstration* emphasizes the expressive and affective qualities of the demonstration and learning [30]. While the strength of this approach is that it enables trained artists to create quality behaviors, this may not be of help to HRI practitioners who are not artistically inclined. Our adaption of the Laban Effort System provides such practitioners with a framework they can use to create their own behaviors or to communicate effectively with artists.

The Laban Effort System is only a small part of the larger Laban Motion Analysis approach, which has been widely used to observe and describe all forms of human bodily motions [5]. In human-computer interaction, Laban's framework has been applied to user interface design [21], mobile interfaces [5], and to the design of on screen animations [11]. In HRI, it has been used with humanoid robots to design emotional and expressive gestures [18], to create a 3D animation system to define natural synthetic gestures [4], to design ways that robots can use their personal surrounding space [17], used as a framework to develop computer vision classifiers (to identify qualities of others' movements) [27], and used to synthesize expressive limb and torso movements [31]. While these papers successfully apply Laban's framework to HRI, Laban Motion Analysis has not been studied for designing robot locomotion paths. We apply the most relevant portion Laban Motion Analysis (the Laban Effort System) to the design of expressive robotic locomotion paths, and investigate how the parameters of this method impact the perceived affect of the resulting motion, to develop initial guidelines for use.

III. Adapting the Laban Effort System

Laban's complete framework, Laban Motion Analysis, is a method for observing, describing, visualizing and notating human motions [13]. Laban's theory is based on four movement parameters: *body*, the physical characteristics of a body while moving, *shape*, the way a body changes shape during movement, *space*, the connection between motion and the environment, and *effort*, the general characteristics of how a movement is performed with respect to the inner intentions. In our work, we adapt the *effort* aspect (the Laban Effort System) to the design of robotic locomotion paths, as it specifies how movement should be conducted to convey a particular *intent*; this intent is precisely the kind of communication we target in our work. The body, shape and space aspects are less immediately relevant as they focus on the robot's physical characteristics and interactions with the environment and not on the movement path itself.

The Laban Effort System uses four parameters to describe motion within a space, where each parameter has two opposing extremes [20]. Below we present our adaption of the four parameters in relation to describing flying-robot locomotion paths:

Space (indirect-direct): defines the movement of the robot in the space, *indirect* – the robot meanders and wanders more while moving towards the next immediate goal (takes a multi-focused approach to the environment);

direct – the robot moves towards the next immediate goal with little deviation in path (takes a single-focused approach to the environment).

Weight: defines how the robot uses the impact of its body weight during a motion, *strong* – robot moves towards the next immediate goal with power or force; *light* – robot moves towards the next goal more effortlessly, being less influenced by gravity.

Time: defines the speed-related aspects of a robotic motion, *quick* – robot moves towards the next immediate goal by making hurried and urgent movements that are less time consuming (high speed movements); *sustained* – robot moves towards the next immediate goal by making lingering (low speed) movements.

Flow: defines the continuous and ongoing aspects of robotic motion, *bound* – robot moves through the movements more carefully to execute the succession of the motion precisely (more controlled movements); *free* – robot moves through movements without caring about the precision (uncontrolled movements).

While the above descriptions explain how the Laban Effort System parameters will impact the locomotion movements of a flying robot, we require a mechanism for evaluating how these parameters will impact the perceived affect of the resulting robotic motion. Below we describe how we adapt Russell's circumplex model of affect [24] for this purpose.

A. The Circumplex Model of Affect

Russell's circumplex model of affect is a standard and widely-used psychological model which can describe and measure affective states or emotions on two dimensions: valence (pleasure), and arousal [24]. Valence indicates how pleasant an emotion is (from very negative to very positive), and arousal indicates the intensity and energy (from very low to very high arousal). For example, anger is an unpleasant emotion with high intensity, and calm is a pleasant emotion with low intensity.

For our study, we adopt this model to map the affect perceived from robotic motions on two of the dimensions: valence and arousal.

IV. Flying-Robot Motion Prototype

For our prototype we required a means for artists to author behaviors, and a means to re-play them. For authoring, the artist demonstrated quadrotor motions to be learned simply by holding and puppeteering a light prop in the shape and size of our quadrotor (Figure 2). We believe it is crucial to enable an artist to author motions by performing them in-situ, rather than sketching on paper or in a computer tool, as it enables a better perception, action and presentation of the paths, maximizing creativity – the physical act of performing is an important part of the process [28]. We used a Vicon motion-tracking studio to record the motions at 100hz, where IR-reflective markers were attached to the quadrotor prop (Figure 2).

For playback, we developed software for motion playback without using the motion-tracking equipment. The recorded

Figure 2: A Laban-trained artist authoring quadrotor motions by demonstrating within a motion-capture tracked space.

data was converted into a series of relative movements (turn left, pitch forward, etc.), filtered from 100hz to 50hz for noise removal and to better reflect the response time of the robot. We further compensated for inertia by amplifying deceleration (sometimes to move in the opposite direction). Our robot was a Parrot AR.Drone quadrotor 1; for programming we used the freely available AR.Drone SDK 2.0.

V. Experiment

The primary purpose of our experiment was to serve as a proof of concept, both to test the efficacy of using the Laban Effort System to author expressive robot locomotion paths, and to test if people understand the idea of flying robots using this to communicate affect. We conclude this experiment with a set of guidelines for creating robotic locomotion paths using the Laban Effort System.

A. Tasks and Research Instruments

We recruited a Laban-trained artist to author a full set of flying robotic motions, one for every combination of Laban parameters: 4 parameters with 2 extremes each give 16 combinations. Graphical renderings of the actual recorded data are given in Figure 3 – only eight are shown as the Time: sustained/quick were just fast and slow versions of the same motion. Note that indirect motions were single focused while direct were multi-focused, strong motions were more forceful than light motions, free motions were curvier than bound motions, and quick motions were faster than sustained.

Participants observed each of the 16 motions, one at a time, and then rated their perception. We did not inform the participants which part of the robot was "forward," although it was possible to guess from its decorations. Our robot was asymmetric in shape, and all our motions started with the robot moving forward. To assess participant interpretation of the robot's affective state, we use a standard psychological instrument for rating affective states on the valence and arousal dimensions, the "Self-assessment Manikin" (SAM) [14]. We note that SAM can be used both for rating one's own affective state as well as for measuring perceptions of others' affect [22]. SAM uses a range of language-independent cartoon-like figures, where the valence images range from a widely smiling to a sad frowning figure, and the arousal images range from an excited, wide-eyed figure to a relaxed, sleepy figure. SAM is easy to understand, fast to administer, and requires no understanding of the underlying psychological model. We use seven point versions of the SAM scale. Participants were asked to rate motions on the basis of their impressions, on "how you think the robot is feeling while making the motions, not your own feelings."

Each motion lasted for approximately 30 seconds, and order of presentation was counter balanced across all participants by a balanced Latin square design for the 16 motions [3]. In addition to answering SAM, participants were asked to write down keywords to describe the robotic motion.

Post-test, we conducted a semi-structured interview to investigate overall impressions of our approach and method.

B. Procedure and Methodology

We recruited 18 participants from our university population (11 male / 7 female, 19-31 years), who were reimbursed $15 for their approximately 1 hour participation. Each participant completed an informed consent form, pre-test demographics questionnaire, observed and rated all 16 locomotion paths with the per-test SAM and keyword questionnaire, and participated in a semi-structured interview before completing the experiment. The experiment was approved by our university ethics review board.

VI. Results

We performed quantitative analysis on the valence and arousal data measured with SAM to investigate differences in how each Laban Effort System parameter impacted perceived affect. Further, we briefly analyzed participants' written descriptions of each motion, as well as their general thoughts reported in the post-study semi-structured interview.

A. Quantitative Results

We conducted two four-way within-subjects repeated-measures ANOVAs (valence and arousal as dependent variables) on the 16 motions with the four Laban Effort System parameters (space, weight, flow and time, two levels each) as the independent variables. There was a main effect of space on valence $F_{1,17}$=14.19, p=.002, η^2=0.45 and arousal $F_{1,17}$=10.5, p=.005, η^2=0.38, where indirect (M=4.76) was perceived as having higher valence than direct (M=4.12), and indirect (M=4.80) was also perceived as having higher arousal than direct (M=4.13) (Figure 4a).

There was a trend effect of weight on valence $F_{1,17}$=3.54, p=.077, η^2=0.17 and a main effect on arousal $F_{1,17}$=5.40, p=.033, η^2=0.24 where strong (M=4.60) was perceived as having higher valence than light (M=4.27), and also as higher arousal (M=4.63) than light (M=4.29) (Figure 4b).

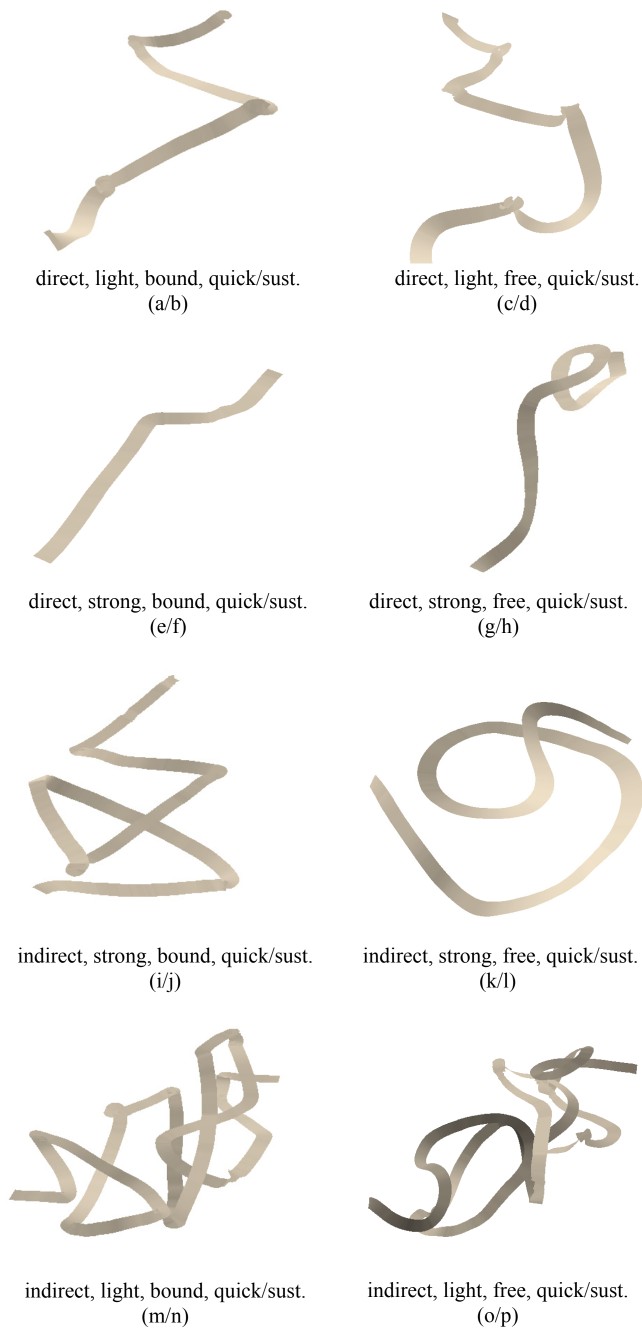
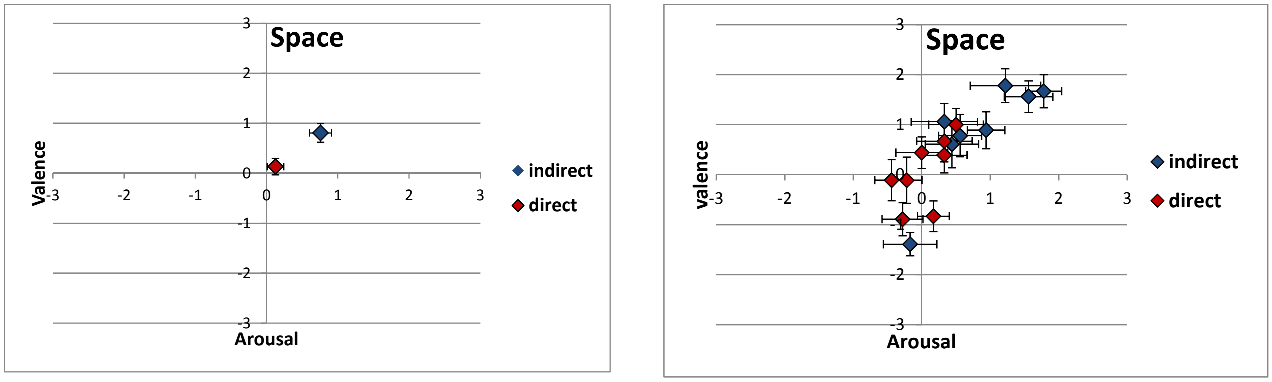
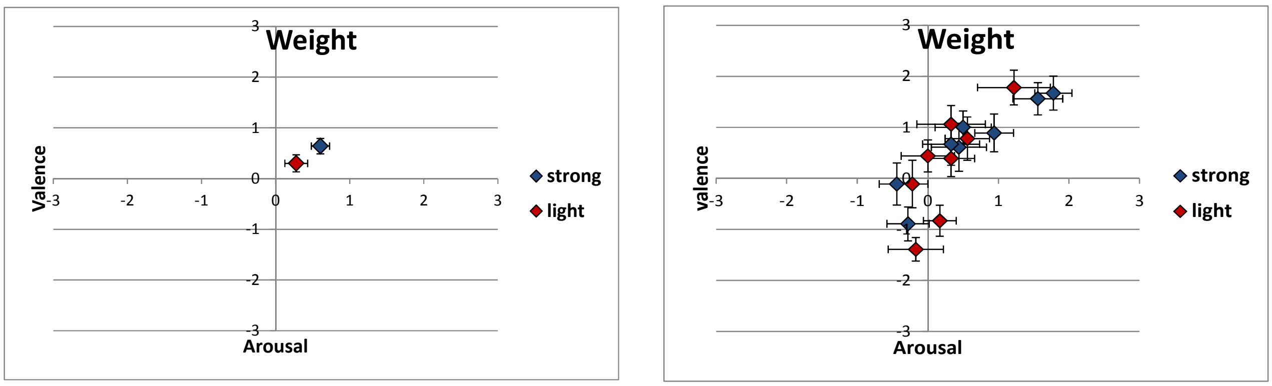


Figure 3: Graphical renderings of the sixteen artist-developed flying robotic motions, where caption below each figure denotes the Laban Effort System parameter configurations. Path is shown as a ribbon to highlight robot tilt angles

There was a main effect of time on valence $F_{1,17}$=9.65, p=.006, η^2=0.36 and arousal $F_{1,17}$=20.09, p=.000, η^2=0.54, where quick (M=4.83) $F_{1,17}$=9.65 was perceived as having higher valence than sustained (M=4.04), and also as having higher arousal (M=5.13) than sustained (M=3.81) (Figure 4d).

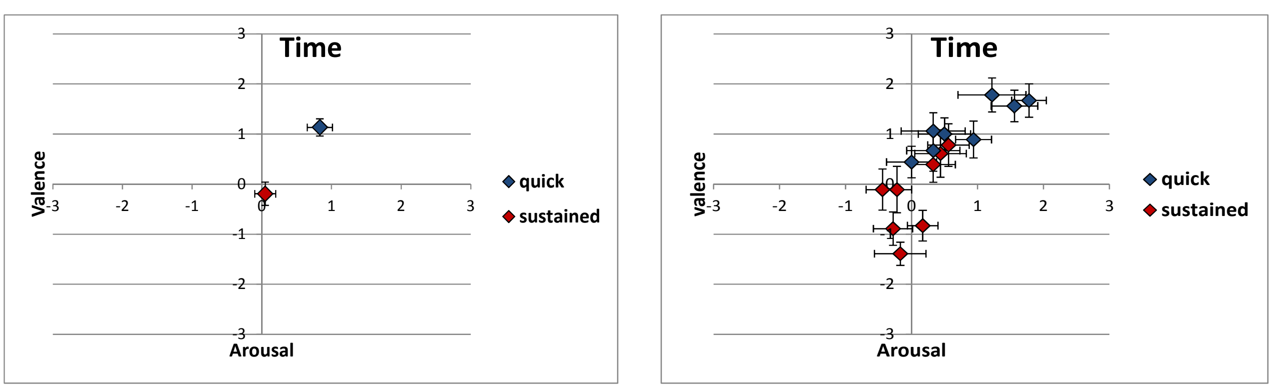


(a) Space: valence $p < 0.05$, arousal $p < 0.05$



(b) Weight: valence $p < 0.1$, arousal $p < 0.05$

(c) Flow: valence $p > 0.1$, arousal $p < 0.05$



(d) Time: valence $p < 0.05$, arousal $p < 0.05$

Figure 4: Left graphs show plots of means, on right is plot of all motions, split by parameter element. Error bars indicates standard errors

TABLE 1. Significance (p) values and F ratios for the effects of space, weight, time and flow on valence and arousal

	Valence		Arousal	
	$F_{1,17}$	p	$F_{1,17}$	p
Space	14.196	0.002	10.5	0.005
Weight	3.546	0.077	5.404	0.033
Flow	0.039	0.846	7.287	0.015
Time	9.651	0.006	20.098	0.000

No main effect of flow on valence was found $F_{1,17}$=0.03. A main effect was found of flow on arousal $F_{1,17}$=7.28, p=.015, η^2=0.30, where free (M=4.465) was perceived having higher valence than bound (M=4.417), and free (M=4.681) was also perceived as having higher arousal than bound (M=4.257) (Figure 4c). TABLE 1 shows the results of ANOVAs.

No interaction effects were found (all p>.05).

B. Analysis of Written Answers and Interviews

Here we present our analysis of how participants described the various motions, investigated based on the Laban Effort System parameters, and of their overall impressions as reported in the post-study interviews.

For each Laban parameter we split the 16 motions into two groups based on that variable, and compared how motions were discussed between those groups, for example, for space we compared between indirect and direct, and so on.

For space's indirect versus direct elements, a majority of participants made comments such as "searching for something" or "following something" for indirect, but only a few used these words for direct. Further, about half of the participants said the robot looks a "little bit happy" with indirect space, but this was not mentioned for direct.

For weight's strong element, about half of the participants used words like "just normal" or "nothing specific," but for the light element it was much more often described such as "calm" or "[sic] thinking something."

When looking at time, most participants used words like "excited," "high energy," "happy with energy" or "enthusiastic" for the quick style, but sustained was more often described as "less excited," "little bit excited," or "not happy."

A large majority of participants used words like "wants to play" or "playful" when flow was free, but none said the same for bound flow. Apart from this, no other similar responses were observed across flow parameter.

A majority of participants found the overall idea of communicating using a robot's locomotion path to be easy to understand. We also received many suggestions for applications, for example: "motions should be used as communication means when robots are trying to alert us from some danger," or "should be used for passing urgent information," or "can be used while interacting with children, they would love it."

In people's descriptions in the per-motion questionnaire, they described the robot as having feelings, emotions, and character, e.g., it "looked like a child skipping around lightly." This was also found in the interviews, where many participants referred to the robot as being lifelike, describing it as a "bird," "bee," "puppy," "excited kid," and even a "shy boy."

Further, all participants were found to attribute internal intentions to the robot based on how it moved, claiming such things as the robot "is searching or thinking for something," "is trying to capture my attention," "wants to play with me," is "coming towards me, makes me feel that it is happy to see me," and so forth. Several participants wrote that this attribution of intention was related to the robot's facing direction, that is, people seemed to see more intentionality when the robot was making motions while facing the person.

One additional interesting result from both the written responses and interviews was that participants presented suggestions for how motions could be used, for example, that perhaps "elevated motions shows increase in energy," "moving in particular direction shows it is pointing at something," or "moving backwards means it is scared of something or someone." At least half of the participants related to the robot moving in a circular path as "trying to grab attention".

VII. Discussion

Participants were all comfortable with the idea of robots communicating by expressive motion paths, used affect and intentionality to describe the robot and its motions, and rated motions fairly consistently across participants. Our results show that all findings were statistically significant except for flow's effect on valence. Thus our results support our core method of modifying a flying robot's locomotion path to express affect.

Although participants used a range of keywords to describe their impressions, there were strong similarities for particular motion parameters between participants. For future work we could perhaps investigate if such similarity holds across different motion sets created with the same Laban parameters, and use the resulting participant-generated keywords as a way to strengthen the mapping between the Laban Effort System and design intentions; designers could use the keywords to better understand Laban parameters. For example, since the *space: indirect* motions were often labeled as searching for something, a similar result may hold for other motions created with the same parameter.

Participants' suggestions for additional robotic motions (e.g., circling is searching) may be interesting to investigate in future studies, both in relation to and separate from the Laban Effort System.

Our overall experience with applying the Laban Effort System to flying robot locomotion design was positive: our particular motions were successful in communicating a consistent perception of affect to people (we had primarily statistically significant results), and we learned a great deal about how particular Laban Effort System parameters and elements impact perceived affect. Thus we believe that our approach of using the Laban Effort System for creating expressive robotic locomotion was successful, and with our design guidelines presented in the next section, that we have presented how the Laban method can be a practical tool for designing robotic motions for desired affective response.

VIII. Preliminary Design Guidelines

We present preliminary design guidelines for authoring affective locomotion paths for flying robots, based on the results from our Laban Effort System application and study. Although we had statistically significant results on all four parameters (space, weight, flow, time), we focus here on the space and time parameters: the effect sizes for the weight and flow parameters were small and observed results were quite varied, making it difficult to make strong recommendations on them at this time. We further note that, on these variables, valence and arousal were related, where one increases or decreases with the other.

To Increase Valence or Arousal: use space more indirectly, or perform the motion more quickly.

To Decrease Valence or Arousal: use space more directly, or perform the motion in a more sustained fashion.

If an HRI designer wants their robot to communicate affective states, in addition to any existing techniques they may apply (e.g., gestures, sounds, etc.), our design guidelines can be used to accentuate or modify the communication by altering the robot's locomotion path. For example, when designing affective states for a flying companion robot, a designer can use more meandering movements to emphasize a happy or excited state, or can use less speed to increase the sense of sadness or fatigue. A designer can choose to use either the space or time elements based on the physical configuration of the environment, i.e., whether physical space or time is more limited or available, whether there is room for accelerated or decelerated movements, etc.

IX. Limitations and Future Work

There are several areas for future research and development in this direction, and we intend to continue to develop our set of guidelines into a more comprehensive tool to be leveraged by HRI practitioners for designing affective locomotion paths. In addition to continuing our exploration of simple motion characteristics, we will expand our approach to include new directions such as considering specific motion "gestures" as proposed by participants, for example, "butterfly" movements, nodding up or down to say "yes," or tilting side-to-side to say "no." We will also explore proxemics: our current work places the participant outside of interaction where they simply just observe the robot moving from afar. In real interactions, the robot will be in the person's space and interacting with them; future work should consider the full dynamics of such interaction and how this impacts perceived affect.

Finally, our implementation had limitations which need to be improved to help gain stronger results for future work. Much of this was related to our open-loop control, for example, without real-time feedback the quadrotor implementation had difficulty with the hard stops and sharp turns characteristic of bound movements, and participants noted that they wanted to see finer-detailed motions with more "texture."

X. Conclusion

In this paper we explored how flying robots can use their locomotion paths to communicate affective information, and presented an adaptation of the Laban Effort System as a means to aid interaction designers in authoring such expressive robotic motions. We conducted a study to investigate how different Laban Effort System parameters impact perceived affect, and concluded with preliminary guidelines for designing expressive robotic locomotion paths. Finally, we detailed our test-bed for authoring and replaying robotic locomotion paths

Our work only presents the first step of adapting the Laban Effort System, and our study and results reflect only one set of authored motions and study results. We hope that this paper will help inform and inspire similar work in the area, such that we can continue to improve our methods, mappings, and guidelines for designing expressive flying robot locomotion paths for communicating affect.

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