Adapting the Laban Effort System to Design Affect-Communicating Locomotion Path for a Flying Robot

by

Megha Sharma

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Thesis advisor

James E. Young and Rasit Eskicioglu

Author

Megha Sharma

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Abstract

People and animals use various kinds of motion in a multitude of ways to communicate their ideas and affective states, such as their moods or emotions. Further, people attribute affect and personalities to movements of even abstract entities based solely on the style of their motions, e.g., movement of a geometric shape (how it moves about) can be interpreted as being shy, aggressive, etc. In this thesis, we investigated how flying robots can leverage this locomotion-style communication channel for communicating their states to people.

One problem in leveraging this style of communication in robot design is that there are no guidelines, or tools that Human-Robot Interaction (HRI) designers can leverage to author affect communicating locomotion paths for flying robots. Therefore, we propose to adapt the Laban Effort System (LES), a standard method for interpreting human motion commonly used in the performing arts, to develop a set of guidelines that can be leveraged by HRI designers to author affective locomotion paths for flying robots. We further validate our proposed approach by conducting a small design workshop with a group of interaction designers, where they were asked to design robotic behaviors using our design method. We conclude this thesis with an original adaption of LES to the locomotion path of a flying robot, and a set of design guidelines that can be leveraged by interaction designers for building affective locomotion path for a flying robot.

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Publications

Some ideas and figures in this thesis have appeared previously in the following publications by the author:

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Megha Sharma, James E. Young, and Rasit Eskicioglu. Developing guidelines for in-the-field control of a team of robots. In adjunct *Proceedings of the 7th ACM/IEEE international conference on Human-Robot Interaction (HRI '12)*, ACM, New York, NY, USA, 233-234.

Chapter 1

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. For example, we can often tell if a person is angry or stressed simply by the way they are walking. Similarly, animals show others if they are calm or aggressive, happy or in pain, by how they move.

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., [9, 14]). Much of this relies on robots exhibiting human- or animal-like affect, a common and effective tool for communicating their state information in ways that are easy for people to understand [9, 19, 27]. For example, the Keepon robot [22] uses affective human-like body movements for communicating its internal states to people, or Kismet robot [4] uses its facial expressions for communicating information to people.

Previous work has shown that complex multi-degree-of-freedom gestures are not always necessary to communicate states. For example, an animated triangle moving erratically may be seen as being “angry” [14], or a disc robot can appear “afraid” or “happy” based only on how it moves [39]. This highlights that robots can use all of their motions and nuances, not only full-body human like gestures for broadcasting affect.

Thus, we point out that even robots without an anthropomorphic or zoomorphic design can leverage motion-based communication channels; for example, 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 exhibiting hesitating movements.

In this thesis, we specifically explored how a flying quadrotor robot, as shown in Figure 1.1, can modify its existing and necessary locomotion path – how it moves between locations – to communicate affect to people. The robot we use for our research is a Parrot AR.DRone. We selected this robot because it is fast, and has six-dimensional movement (position and tilt angles). All these properties of the quadrotor provided us the desired flexibility in exploring movement and communication possibilities.

Figure 1.1: Our robot: Parrot AR.DRone version 2.0

1.1 Research Questions

Our exploration into this locomotion-style of communication channel led to the following research questions that we explored through this thesis :

Q1. Do people readily perceive the locomotion path of a flying robot in affective terms? While a lot of past work explores how people perceive motions of robots that move close to the ground (for example, an iRobot Roomba, a disc-shaped vacuum cleaner robot [39]) or are fixed to a spot (for example, the iCat robot [31]). However, the question "How people perceive the locomotion path of a flying robot?" has not been investigated.

Q2. Which characteristics of the locomotion paths are perceived by people in terms of affect? If we learn from Q1 that people perceive quadrotor's locomotion paths in affective terms, the problem then becomes exploring how can we construct the motion paths that can communicate affect.

Q3. Which guidelines, frameworks, or tools can be developed to aid HRI designers in constructing movements for their robots to achieve their desired affective response? If Q1, and Q2 are true, then how can HRI designers leverage this to design their own affective robotic interfaces?

1.2 Our Methodology and Approach

Past work in the field of psychology, design, and robotics have explored how low-level parameters (such as, direction, curvature, speed, acceleration, position) of motion impact perceived affect (for a good review see [31]). However, little of this work explores how HRI designers can use these parameters in designing their robotic interfaces; for example, if they want to create high-level expressive motions for particular communication purposes, then how should they adjust various low-level parameters. Moreover, interaction designers or HRI practitioners are lacking guidelines or vocabulary on designing desired affective motions for robots.

In our research, we took an exploratory approach towards this design problem, and investigated what we can use as a design vocabulary to build locomotion paths for a quadrotor robot. We explored what people from theatre such as actors, and dancers are doing, what they use as a vocabulary to create affective content when they are acting or dancing. If we can understand how they design motions, then perhaps we can find a way to leverage their method and map it to design motions for a flying robot.

From our exploration involving meeting with artists around the University of Manitoba, we settled on using the Laban Effort System (LES), a framework for describing and discussing human motions. Thus, we proposed to use LES, a standard methodology from performing arts to help designing affective robotic motions for the quadrotor. LES describes motions with four parameters, *space, weight, flow* and *time*, where each parameter can be used to describe certain aspect of motion. However, one limitation of using LES is that HRI designers – without any training in LES – may not be familiar with how to use LES vocabulary, i.e., *space, weight, flow* and *time*, to achieve their desired robotic communication outcomes. Therefore, we also developed a set of guidelines that can help bridge this gap, and enable HRI designers to leverage the benefits of LES approach for content creation. To explore this, we attacked the following four problems:

1.2.1 Adapting The Laban Effort System

We investigated how to adapt all the parameters of LES to the qualities of our flying robot by re-defining them in terms of how these parameters will impact the locomotion movements of the robot (Chapter 3).

1.2.2 Flying-Robot Motion Test-Bed Implementation

To create robotic motions with our LES adaption, we built a content creation system. The overall process of creating content (locomotion paths) have two components: content authoring and robot output playback. For content authoring, our goal was to hire a Laban–trained artist to author a range of motions, and for playing back the robot's output, we needed software that converted recorded data into the quadrotor's movements. Thus, we created a motion-capturing studio system that enabled artists to directly demonstrate LES based robotic motions (Figure 1.2), and developed software for the robot to reproduce those motions (Chapter 4).

1.2.3 User Study: Investigating People's Perception of LES Based Robotic Motions

To investigate how people interpreted LES based locomotion paths of our quadrotor robot, we ran an exploratory user study. In our study, we were particularly interested in exploring whether people perceive the robot in anthropomorphic terms, or perceive it in affective terms, such as how happy or sad the robot may appear to be. We analyzed the study data and used the results to develop a preliminary set of guidelines for authoring affective locomotion paths for flying robots.

1.2.4 Evaluation

To evaluate our overall method of using LES to design affective locomotion paths for a flying robot, we conducted a small design workshop with a group of HRI designers. By bringing designers together in this workshop, we were able to investigate how non-artist experienced HRI designers interpreted and used our method to design affec-

Figure 1.2: A Laban-trained artist authoring quadrotor motions by demonstrating within a motion-capture tracked space.

tive locomotion paths for a flying robot. The observations from this workshop helped us determine how successful our approach is to fit into the designer's understanding of designing affective locomotion paths.

1.3 Research Contributions

Based on our overall process of adapting LES, building a flying robot motion test-bed, conducting user study and evaluation, we present:

- *An Adaption of the Laban Effort System*: We contribute to the core field of HRI by presenting a method to apply the Laban Effort System for designing locomotion paths of a flying robot.
- *A Comprehensive Set of Design Guidelines*: We present a concrete set of design guidelines to be leveraged by HRI designers for designing affective locomotion paths for flying robots.

The remaining of this thesis is organized as follows: in Chapter 2, we provide a literature review to describe the related work relevant to our exploration. Chapter 3 describes the theoretical background of LES and how we adapted LES to the locomotion paths of a flying robot. Chapter 4 details the flying robot motion test-bed implementation, followed by Chapter 5 which describes our exploratory study to investigate how people perceived LES based locomotion paths of the quadrotor. We present the evaluation of our method in Chapter 6 and conclude the thesis in Chapter 7.

Chapter 2

Related Work

Human-Robot Interaction (HRI) is defined as "a field of study that focuses on understanding, developing and evaluating robotic systems for people to use or work with [12]." Ongoing research in the field of HRI shows that people find themselves interacting with robots in many places and scenarios, for example, from vacuum cleaner robots in homes [35, 8], to dangerous bomb diffusing robots in the army [10], to companion robots in elderly homes and hospitals [30]. One important aspect of HRI related to our work is social HRI, which deals with how people perceive robots socially. Social HRI emphasizes on the social component of interaction, that is, social tendencies of people towards robots and how this can be leveraged, for example, by robots using human-like social communication, which is critical for understanding interaction between people and robots [38].

Researchers in the field of HRI are working on robots that use social communication, such as, full-body gestures, gaze, speech etc., to interact with people. For example, the Keepon robot [22] uses affective human-like body movements for communicating its internal states to people, or Kismet [4] uses its facial expressions for communicating information to people.

In general, when people socially interact with each other they use different kinds of communication channels, such as speech, written languages, or gestures, and rely heavily on them. One such mode of communication that people often use is motion. People use motions in wide variety of ways to communicate their ideas and affective states, which makes motion an integral element of social communication. For example, non–verbal postures like pointing and movements like walking fast, can effectively communicate a person's intent [21]. Even animals and abstract shapes use motions to communicate intent [14]. For example, Disney uses movement of its characters to convey their feelings [36].

In this chapter, we present prior work that highlights that robots can similarly use their motion as a communication channel and people are very good at understanding it. Further, we discuss what kind of methods have been used in HRI to build expressive robotic motions. We end this chapter by introducing the Laban Effort System (LES), and discussing the related work that has leveraged the benefits and insights of LES.

2.1 Robots and Affect

There has been extensive work in psychology and animation that shows that people attribute affect to motion, ranging from movement of abstract shapes such as triangles, circles [14], or widgets moving around on a screen to lights moving around a room [37], and attach personalities based on movement qualities [8, 11, 24, 26].

Similarly, robot-specific work has revealed that people attribute affect to robotic motions, for example, the Keepon robot uses rhythmic movements to elicit emotional responses from people [22]. In another project, a search and rescue robot uses its movement style to be less daunting to people during a rescue operation [6]. This shows that robots can use full-bodied gestures to communicate [16], or a disc-shaped vacuum robot [31, 39] or even a robot in abstract “stick” form [13] can communicate affect based on how it moves. Our work builds on these past efforts by extending and adding detailed motion vocabulary specifically to flying-robot locomotion paths for affective communication, and investigating how a flying quadrotor robot can modify its existing and necessary locomotion to communicate affect to people.

2.2 Low–Level Motion Parameters Impact on Perceived Affect

A key point of related work in the field of HRI 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 [11], speed and direction of a synthetic stimuli can be used to create an impression of it being alive [37], and acceleration can be used to predict perceived arousal and valence information [31]. These results are very important for understanding how people perceive a particular motion. However, the reverse direction – synthesizing complex affective motions from the base parameters is not well investigated. For example, if we want to create high-level expressive robotic motions for particular communication purposes, such as create a fatigued or tired motion, then how should low-level motion parameter be adjusted. It is hard to think about spline coefficients, or acceleration profiles and relate them to make a motion path. In our work, we contribute to this research by applying LES as one such mechanism for aiding the design of affective robotic motions, and investigating how these resulting motions are perceived by people in terms of affect.

2.3 Robotic Motion Creation Method – Programming by Demonstration

An alternative to using motion parameters 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 [15, 20]. A variant of this called style-by-demonstration emphasizes the expressive and affective qualities of the demonstration and learning [39]. While the strength of this approach is enabling trained artists to create affect communicating motions for robots, it may not help HRI practitioners or the interaction designers who are not artistically inclined, as they may not be aware of what to use as a design vocabulary to create behaviors. Further, we need ways to modify existing path data; for example, making the robot look more tired. Our adaption of LES provides such practitioners with a vocabulary that they can use to create their own behaviors without relying on trained artists.

2.4 The Laban Effort System

LES is only a small part of the larger Laban Motion Analysis (LMA)[1] approach, which has been widely used to observe and describe all forms of human bodily motions [7]. LMA has evolved into a comprehensive system that has been used to describe motions in dance, drama, nonverbal research, psychology, anthropology, ergonomics, physical therapy, and many other movement-related fields [1, 5].

In Human-Computer Interaction (HCI), LMA has been applied to design affective quality of motion in user interfaces for better user experience [26], mobile interfaces [7], and to the design of on screen animations [19]. While these projects have successfully applied LMA and its concepts for motion, interface or virtual characters body movements design, we are more interested in exploring LMA for designing locomotion path of a flying robot. In HRI, LMA has been used with humanoid robots to design emotional and expressive full-bodied gestures [23], used to design ways that robots can use their personal surrounding space [32], used as a framework to develop computer vision classifiers (to identify qualities of others' movements [33], and used to synthesize expressive limb and torso movements) [40]. While these projects successfully apply Laban's framework to robots, LMA has not been applied to flying robots, particularly for designing locomotion path of a flying robot.

In our work, we apply the *effort* aspect of LMA – the Laban Effort System (LES) to

[1]Please refer to Chapter 3 for detailed explanation on LMA.

the design of expressive robotic locomotion paths. We build our research on previously successful work on LMA and extend it to investigate how LES impacts the perceived affect of the resulting motion by: (i) adapting LES to flying robot's locomotion path, (ii) building a flying robot motion prototype to show LES based motions to people, and (iii) running an exploratory study to find out how people perceive them. Ultimately, through this process we hope to create a method that interaction designers will be able to leverage for building desired affect communicating robotic interfaces.

Chapter 3

Adapting The Laban Effort System to the Locomotion Path of a Flying Robot

The Laban Effort System (LES) is a part of Rudolf Laban's (1879–1958) much larger and complete framework known as Laban Motion Analysis (LMA) which is a method for observing, describing, visualizing and notating all forms of human motions [17]. Rudolf Laban was a notable European dance artist and theorist who laid out the foundation of LMA, one of the most widely used technique for human movement analysis. According to him, in dance, every human movement can be described through the following four parameters [40]:

- *Body*: Describes the physical characteristics of a person's body while moving. For example, when a person is dancing, body parameter deals with which parts of the body moves, where the movement initiates and where it ends, the sequence of movement between parts of the body, and so on.

- *Shape*: Describes the way a human body changes its shape during a movement. For example, in dance sequences, people can enclose their bodies in such a manner that they are able to project a wall-like or a ball-like shape.

- *Space*: Describes the connection between human motion and the environment. With respect to dance, space describes the area within which dancers are moving, and the directions and points they are using.

- *Effort*: Describes the general characteristics of how a movement is performed with respect to the inner intentions. For example, dancers can change the speed of their body movements to show different kinds of feelings they want to convey.

All these parameters together describe and constitute a language and a notation system for describing human movements. Various artists, such as dancers or actors, can choose their preferences for combining these parameters in their personal artistic way.

Over the years, researchers and his colleagues have considerably expanded the concepts that were initially developed by Laban. Many researchers have applied Laban's theory in various motion related fields, such as acting, dancing, drama, psychology, physical therapy, and to robots as well.

LMA's creative approach to describe human movements along with its interdependence on feeling and action made it an ideal choice for our investigation towards finding a method that can be applied to create flying robot's motions. After exploring how LMA's parameters describe movements, we found that for our work the *effort* parameter is the most relevant, 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. Therefore, we adapted the *effort* aspect (the Laban Effort System) of LMA to the design of robotic locomotion paths. 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. Moreover, our robot cannot change its shape, as it does not have body parts.

In this chapter, we describe LES and its parameters, along with our adaption of these parameters to re-define them in terms of the locomotion paths of the flying robot.

3.1 The Laban Effort System

LES is a standard methodology from the performing arts for describing expressive motion. People such as dancers or actors use LES as a vocabulary to describe and discuss motions. LES uses four parameters, *space, weight, time* and *flow* to describe motion within a space, where each parameter is on a continuum with two opposing extremes [25], as we outline below. All LES parameters can be combined for many variations in movement. Below we present general definitions of these parameters with their two opposite extremes in terms of describing human motions [25].

3.1.1 LES Parameter: Space

Space explains how a human body moves along its path in terms of whether it takes a direct or indirect route. People can choose the way they want to move while dancing or walking, for example, they can move in a straight path to reach where they want to go or meander along the path. These two different types of ways a movement is performed are two extremes of the space parameter. The official names of these extremes are: *indirect* – multi-focused approach to the environment, for example, while running down a crowded street, we follow a deviated path to reach our destination, and *direct* – undeviating approach to the environment, for example, while running in a race, we follow a given path and do not linger on our way.

3.1.2 LES Parameter: Weight

Weight describes the amount of force involved in a movement, or describes how much effort goes into an action. For example, how moving a heavy object has a distinct trajectory than moving a light object. According to Laban, the two extremes of weight comes from the observation that some people indulge in gravity and some resist it. The official names of these extremes are: *light* – movements that can easily overcome gravity, for example, movement of a feather, or a light jump, and *strong* – powerful or forceful movements, for example, slamming a tennis ball with racket, or pushing a heavy object.

3.1.3 LES Parameter: Time

Time describes the speed with which a movement is performed, or can be described as duration of a movement. According to Laban, speed of movements can range from being very fast to very slow, which are the two extremes of time parameter. The official names of these extremes are: *quick* – more hurried and urgent movements, for example, diving to catch a ball, and *sustained* – more lingering movements, for example, yawning.

3.1.4 LES Parameter: Flow

Flow describes the precision with which a movement is performed. Flow can be considered as to be free or bound. It is free when it is uncontrolled and continuous. On the other hand, flow is bound when the movement is controlled. The two extremes of flow are termed as: *bound* – more controlled movements, for example, painting a window and being careful not to get any paint on the glass, and *free* – less controlled movements, for examples, painting a wall and not caring about the brush strokes.

3.2 Adapting LES Parameters to the Locomotion Path of a Flying Robot

The above description of LES parameters gave us an of understanding of how all LES parameters describe various characteristics of human motion. However, in our research we wanted to explore how a flying quadrotor robot can modify its existing and necessary locomotion path – how it moves between locations – to communicate affect to people. Towards this purpose, we simplified the above definitions of LES parameters and re-defined them in terms of the flying qualities of the quadrotor robot. Below we present our adaption of the parameters and how these parameters impacted the locomotion path of our robot.

3.2.1 Space

Space defines the movement of the robot in the space, *indirect* – the robot meanders and wanders more while moving towards the next immediate goal; *direct* – the robot moves towards the next immediate goal with little deviation in path. With a robot, this can be accomplished by taking a multi-focused approach to the environment, or a single-focused approach to the environment.

3.2.2 Weight

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. With a robot, this can be accomplished by appearing heavy and using strong accelerations, or showing difficulty in turning and using weak accelerations.

3.2.3 Time

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 movements; *sustained* – robot moves towards the next immediate goal by making lingering movements. With a robot, this can be achieved by high speed, or low speed motions.

3.2.4 Flow

Flow defines the continuous and ongoing aspects of robotic motion, *bound* – robot hits exact way-points; *free* – robot does not hit exact way-points. With a robot, this can be accomplished by more pronounced starts and stops, or less pronounced starts and stops.

3.3 Summary

Overall in this chapter, we described the background of LES and described how we adapted LES to the locomotion paths of our robot. This adaption was necessary in terms of understanding how all LES parameters can be used to reflect movement capabilities of our robot. We hope, with our adaption of LES in terms of the locomotion path of a flying robot, we will be able to create a vocabulary that can be used for designing LES based robotic motions.

While our adaption helped in understanding how all LES parameters impacted the movements capabilities of the flying robot, however, the core focus of our research is to investigate how this adaption will be perceived by people. For this purpose, we created a flying robot motion test-bed to show these motions to people (Chapter 4), and commissioned a Laban-trained artist to author a full set of flying-robot motions using all combinations of LES parameters. Further, we tested these motions by conducting a user-study (Chapter 5). The results of this study reflected back to our core research question of finding how people perceived the locomotion path of the flying robot.

Chapter 4

Flying-Robot Motion Test-Bed

In the previous chapter, we described the background of The Laban Effort System (LES) and how we adapted LES to the locomotion paths of the quadrotor. This gave us an understanding of how all LES parameters impacted the movement capabilities of the flying robot. With this, we arrived at a method that can be used to create locomotion paths for our robot, however, a question that arises here is: if we want to go through the process of creating robotic motions with LES, then how can we do it? Towards this purpose, we aimed at creating a content creation system.

In our research, the overall process of creating content (locomotion paths) had two components: content authoring and robot output playback. For content authoring, a Laban–trained artist to author a range of motions, and for playing back robot's output, we needed software that reproduces robot's motions. We created a motion-capturing studio system that enabled artists to directly demonstrate LES based robotic motions, and developed software for the robot to reproduce those motions. In this chapter, we present implementation details of our content creation system.

4.1 Content Authoring

Our overall process of content authoring involved an artist in the design loop, where we hired a Laban–trained artist (Gem Newman) to demonstrate quadrotor motions to be learned simply by holding and puppeteering a light quadrotor prop (Figure 4.1). The artist performed a range of motions by holding a prop, and not directly acting himself. We believe involving a Laban–trained artist in our design and implementation loop was critical for our work, as artists can use and provide their own interpretation of LES parameters to design motions, which is difficult for a non–trained person to do so. Further, artists can author motions by performing them in-situ, rather than sketching on paper or in a computer tool. This enables a better perception, action and presentation of the paths, maximizing creativity, since the physical act of performing is an important part of the process [34].

Our artist authored a full set of flying robot motions, one for every combination of LES parameters (four parameters with two extremes each give sixteen combinations). A graphically rendered example of one of the actual recorded motion path is shown in figure 4.1 (rest of the motions are discussed in Chapter 5). The movement visualization[1] of the motions were generated using Direct3D by extracting position and orientation information from the motion tracking data for each captured point

[1] All the movement visualizations are graphically rendered by Dale Hildebrandt.

Figure 4.1: Graphically rendered example of one of the recorded robotic motion path demonstrated by the artist. Path is shown as a ribbon to highlight robot's tilt angle

in time. The position information was used to define the basic shape of the path: a series of line segments connecting each of the positions. In order to add width to the path, to give it a ribbon-like appearance, we used the orientation information to produce a vector directed outside of the tracked quadrotor. This vector is orthogonal to the direction of the current path segment, and the normal of the quadrotor's plane.

We used the Vicon motion-tracking system, as shown in Figure 4.2 to record all the motions demonstrated by the artist. Figure 4.2 shows our artist thinking of a motion path (white bubbles), demonstrating it with a quadrotor prop (yellow circle), along with motion being tracked by Vicon cameras (red circles).

Figure 4.2: A Laban-trained artist authoring quadrotor motions by demonstrating within a motion-capture tracked space. White bubbles show the motion path that the artist is thinking to demonstrate, yellow circle shows the quadrotor prop used by the artist, and red circles show the motion tracking Vicon camera

4.1.1 Motion Recording Setup and Object Preparation

We used six motion-tracking Vicon cameras (Figure 4.1 shows two of the six Vicon cameras in the space) mounted on tripods. During the demonstration of the motions, all the Vicon cameras were aligned in our lab space such that each camera sees as much of the total motion possible and that at least two cameras can see all the markers throughout the motion. We placed cameras by iteratively manually placing and aiming them, testing some motions, and checking the results to make sure we were able to capture enough space for all motions.

The cameras sense only within the infrared spectral range. Infrared Reflective markers (figure 4.3a) were placed on the quadrotor prop to be seen by the cameras, and the cameras recorded the motions by tracking the positions of the markers. The artist had to remove reflective items such as jewelery, etc. Note that, in general Vicon system requires at least three markers to identify motion of any object. For our recording, we placed eight markers on the quadrotor prop to increase the stability and capture the entire prop properly. All markers were attached to the marker in the middle of the prop, so that it can be identified as a total object (marker set) to be tracked by the cameras in a 3D view (Figure 4.3b). To obtain the Vicon coordinate system, first, we followed all the standard Vicon calibration process.

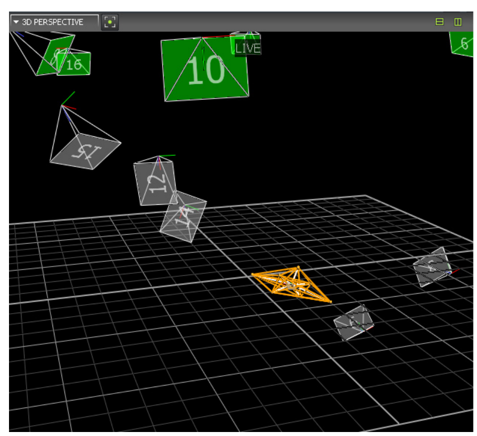
The Vicon cameras were connected to a central Vicon MX Giganet, which provided the power and data communication for these cameras. The Giganet also managed the flow of data to the host computer running the software we used to analyze the data.

4.1.2 Data Recording and Processing

We used a software package called Tracker, provided by Vicon, to record the motion by tracking the position of the quadrotor prop (object) held by the artist during each motion. Figure 4.4 shows a screenshot from tracker software during the real time recording, where camera positions are shown and tracked object is highlighted. Note that grayed cameras are an artefact of sharing a configuration with a different setup, and were disabled and not used for our recording. The Tracker consistently recorded the coordinate values of the prop when it was being moved by the artist to make all motions. We configured the cameras to track and save the prop locations at 100Hz to reflect the response time of our robot.

Tracker software did the initial position processing of the data and relayed this information to the DataStream SDK software package, provided by Vicon, running on another PC. We configured DataStream SDK software to obtain the relayed data from tracker in the form of a text file. The relayed data in the text file included position information such as, *Global Translation, Global Rotation Matrix,* and *Local Rotation Helical* etc., of our object in the Vicon coordinate system. For our research, we required *Global Translation: x, y, and z coordinates* and *Global Rotation Euler: z* information for further conversion into quadrotor control signals. Note that *Global Translation coordinates* gave the position of the AR-Drone Vicon space that was defined after the standard calibration process. The *Global Rotation Euler: z* was used to track the angular rotation around the perpendicular axis of the AR-Drone.

(a) IR-reflective markers attached to the quadrotor prop



(b) Vicon software Tracker's 3D perspective identifying the quadrotor prop as an object

Figure 4.3: Vicon motion tracking system setup

This information extracted from the Vicon motion tracking system was sufficient to track all the possible movements supported by AR-Drone.

4.2 Robot Output Playback

In the previous section we explained our content authoring system in which the path we want our robot to play was demonstrated by the author, and recorded by Vicon motion tracking based system. Now that we have a system in which the desired motions can be recorded, we needed our robot to reproduce those motions. Towards this purpose, we developed a custom software by using an open source Linux version of AR.Drone SDK 2.0, to convert the recorded data into a series of robotic movements. In this section, we describe the implementation of our robot output playback software.

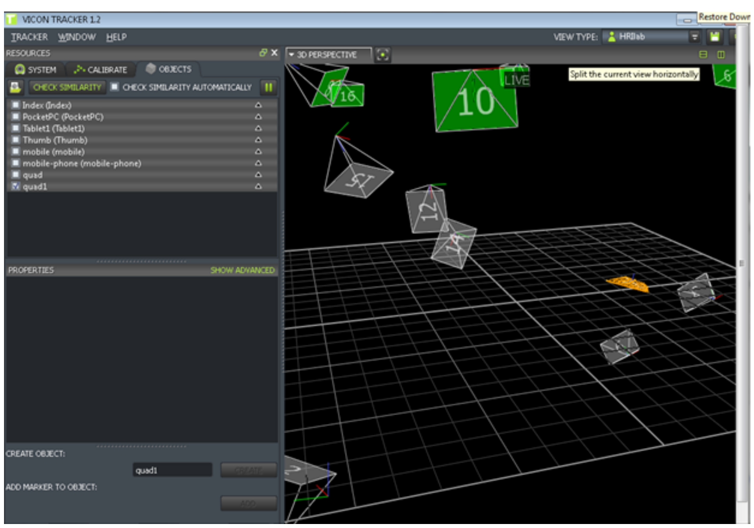


Figure 4.4: A screenshot from tracker software while a motion is being recorded in real time

4.2.1 Control Signals of AR-Drone

For the motion playback, the motion information captured by our content authoring system had to be processed and mapped into control signals understandable by the AR-Drone. The challenge was to design the motion mapping system to convert the motion information captured in the Vicon frames into the corresponding control signals for AR-Drone.

As per the documentation provided by the makers of AR-Drone quadrotor robot we found that, AR-Drone can move front–back, left–right, up–down, and can rotate on its axis. These motions are controlled by the following four components in a frame of the control signal sent to AR-Drone: the *pitch* component controls the front–back speed of the drone. If the *pitch* is zero, there would be no front–back motion. An increase in the negative value of pitch leads to faster front–back motion of AR-Drone. Similarly, the *roll* and *gaz* components of the control signal controls the left–right and up–down motions respectively. The important point to note here is that AR-Drone cannot tilt left–right and forward–backward without any motion in the direction of the tilt due to which AR-Drone cannot take 6 DOF (degree-of-freedom) commands. The last component of the control signal is *yaw*, which controls the angular rotation around the vertical axis of the quadrotor. The gain values to be passed for these four components of the control signal has to be between -1 and 1.

4.2.2 Initial Data Collection for the Playback Software

After motions were recorded by our content authoring system, the movement information of the AR-Drone was captured based on the change in the position information between the Vicon frames, configured to record data at 100 frames per second. The absolute coordinate values (*Global Translation*) in the space captured in the Vicon frames were used to calculate the linear displacement in each dimension (Δx, Δy and Δz) on each time step. The angular displacement (Δyaw) around the vertical axis of the AR-Drone was calculated from the difference in the yaw values (*Global Rotation EulerZ*) in the consecutive Vicon frames. Before calculating the deltas between the consecutive Vicon frames captured with the frame rate of 100 Hz, the frames were first filtered down to 50 Hz to remove noise and to better reflect the response time of the robot.

4.2.3 Mapping Process

The mapping process involved the mapping of the delta values calculated from the Vicon data to the corresponding values of the control signals of AR-Drone. The values calculated for the linear displacement Δx, Δy and Δz were to be mapped to the values of *pitch*, *roll* and *gaz* respectively, all between quadrotor's -1 to +1 range, based on the magnitude of the displacement. For example, when the x, y, and z axis of the world space aligned with x, y, and z axis of the defined Vicon space, the higher positive value of Δx was a faster forward motion of quadrotor and hence, a higher corresponding positive value of the *pitch* component of the control signal was required to replicate the motion. One important point to note here is that, during the motion path, usually the facing direction of the robot changed on rotation around the axis perpendicular to it. Based on the new facing direction, the alignment of the x, y, and z axis of the world space of the robot changed. However, the data generated by Vicon system for the motion tracking of AR-Drone was still based on the defined Vicon space, thus, did not represent the actual motion the robot in the world space. For example, when quadrotor rotated +90 degree from x axis of Vicon space, the facing direction of the quadrotor changed to y axis. In this situation, when the quadrotor moved in forward direction, it was tracked as sideways by Vicon motion tracking system and recorded as a Δy value instead of Δx value.

Hence, we had to do a basis change operation, using a transformation equation, after every rotation motion to transform the data captured by the Vicon tracking system to the x, y, and z axis of the robot's world space. The magnitude and direction of rotation was tracked from the deltas of the yaw values (*Global Rotation EulerZ*) between the Vicon frames.

The values of robot's control signals lie in the range from -1 to 1, whereas Vicon tracker software was calibrated to record the displacement in millimeters. To solve this problem, we recorded the acceleration of quadrotor for different values of each component separately. For example, we recorded the acceleration values produced for the forward motion of AR-Drone by varying the values of *pitch* component in an interval of 0.1, 0.2 and so on ranging from 0 to 1. These readings were stored in a table. The same steps were followed for the rest of the components (*roll, yaw* and *gaz*) and recorded readings for each component of the control signal were stored in a table. This table was used as a reference table to decide the corresponding values of the components of control signals for the delta values calculated from Vicon frames. For example, if the robot was supposed to be moving forward at 500mm/s, then we calculated an appropriate *pitch* value in the range of -1 and 1 by referencing the stored table, to reproduce the motion.

We noticed that, our robot drifted during sharp turns and stopping due to inertia, for example, for stopping the movement was set to 0 (which means no additional movement) but it did not stop due to inertia. To solve this problem, we compensated inertia by monitoring and amplifying deceleration (sometimes to move in the opposite direction), thus making the robot to stop on rapid deceleration. Overall, our control system did not have any real-time feedback, that is, the robot made all motions based on the control signals sent to it.

4.3 Limitations in the Implementation

Our implementation had limitations which need to be improved to help obtain stronger results in future. 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, which was important for flow-bound movements. Further, robots often cannot move as expected on various surfaces; our robot was a flying machine with some constraints due to inertia, such as not stopping due to inertia even when the movement was set to 0 (which means no additional movement). Although we compensated inertia by monitoring and amplifying deceleration (sometimes to move in the opposite direction), the robot was not able to replicate some of the recorded motions.

4.4 What is next?

In this chapter we discussed how we developed our flying robot motion test-bed that enabled recording and playback of robotic locomotion paths. However, a remaining question of our research is to investigate how will people perceive locomotion paths of our robot? Therefore, towards this purpose, we ran an exploratory user study in which we created a set of quadrotor motions and showed these motions to people to rate them. People were asked to rate the robotic motions in terms of affect, and we used emotion assessment tools to assess participant's interpretation of robots affective states. We present details of our exploratory study and its results in the next chapter.

Chapter 5

Investigating People Perception of LES Based Robotic-Motions

In previous chapters, we mapped various parameters of the Laban Effort System (LES) to the locomotion path of our quadrotor robot and built a flying robot motion test-bed for creating robotic motions. However, an important research focus of this thesis is to investigate how people perceive locomotion path of a flying robot, and we are particularly interested in affect, such as how happy or sad the robot may appear to be, or do people perceive the robot in anthropomorphic terms? Towards this purpose, we ran an exploratory user–study. In this chapter, we describe: our user–study design, study procedure and methodology, and its results. Further, we conclude this chapter with a set of design guidelines for creating robotic locomotion paths using the Laban Effort System.

5.1 User–Study Design

The primary purpose of our user–study 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. Therefore, we developed locomotion paths for our robot to test, and adopted a standard model of affect from the field of psychology, known as Russell's circumplex model of affect, to measure participant's interpretations of these motions in terms of affect. For receiving responses from participants, we used a self–reporting technique, wherein participants were asked to rate their interpretations of the affective states on a standard psychological instrument, called Self-assessment Manikin (SAM). Ultimately, from the results of the user study and analysis, we addressed our research questions (described in chapter 1) by learning how people perceived locomotion paths of a flying robot.

5.1.1 Developing Quadrotor Motions

Our Laban–trained artist, Gem Newman (introduced in chapter 4), authored a full set of flying robotic motions by using our content creation system, 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 figures 5.1, and 5.2 – only eight are shown as the *time*: sustained/quick were just fast and slow versions of the same motion. The images are split across two sets, the first set contains images with *space* as *direct* and the other contains *space* as *indirect*. Note that LES parameters mentioned below every image were discussed in chapter 4: 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.

5.1.2 Research Instruments

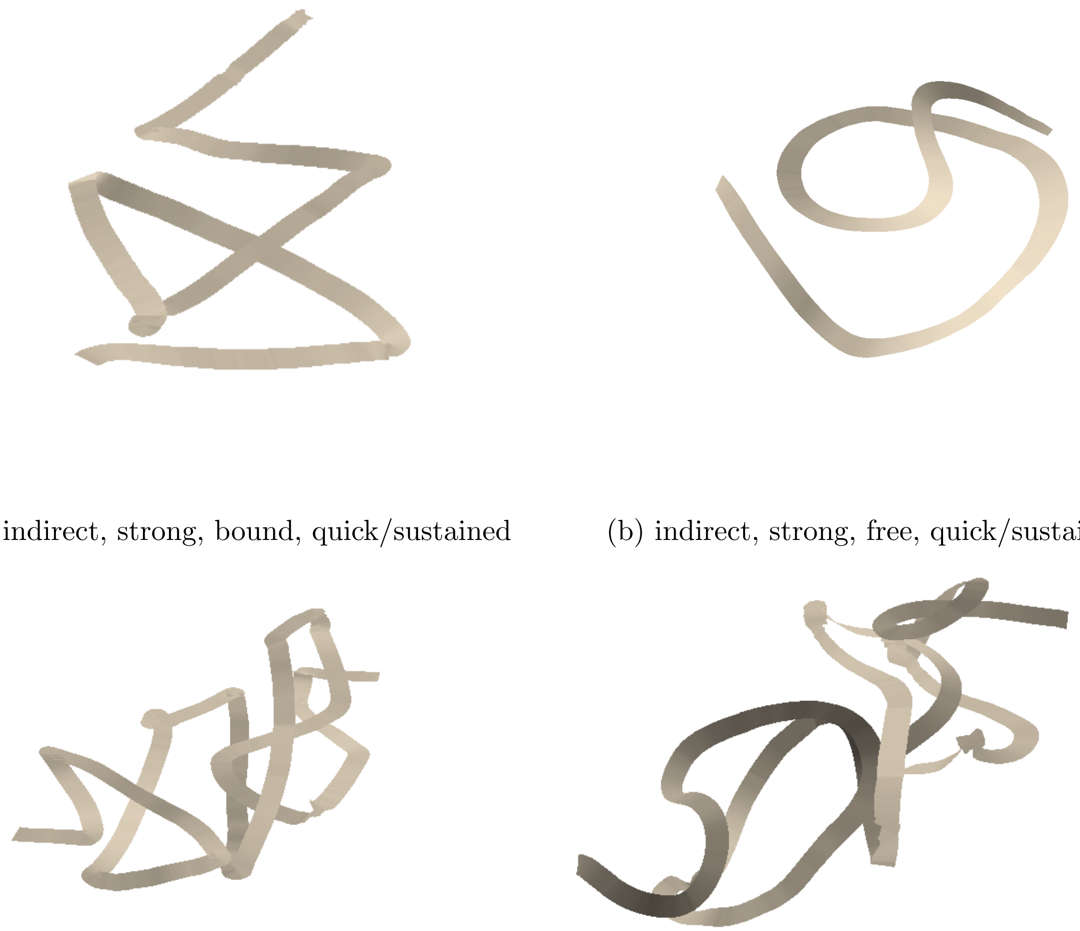
In order to measure how people perceived our set of motions, we adapted a standard model of affect from the field of psychology, known as the Russell's circumplex model of affect [29]. This model is widely used to describe and explain affective states or emotions on two dimensions: *valence (pleasure)* and *arousal* [29]. 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.

The above model gave us a standard model to represent people's interpretation of the motions, however, since the model itself does not serve as an assessment measurement tool, we needed a standard tool that participants can use to rate their perception of the robot's affective state. Thus, we administered a standard psychological instrument for rating affective states on the valence and arousal dimensions, the Self-Assessment Manikin (SAM) [18].

(a) direct, light, bound, quick/sustained (b) direct, light, free, quick/sustained

(c) direct, strong, bound, quick/sustained (d) direct, strong, free, quick/sust

Figure 5.1: Graphical renderings of artist-developed flying robotic motions with *direct* – *space*, where caption below each figure denotes the Laban Effort System parameter configurations. Path is shown as a ribbon to highlight robot tilt angle



(a) indirect, strong, bound, quick/sustained

(b) indirect, strong, free, quick/sustained

(c) indirect, light, bound, quick/sustained

(d) indirect, light, free, quick/sustained

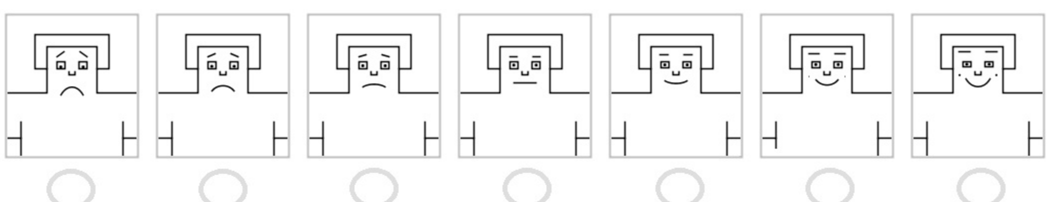
Figure 5.2: Graphical renderings of artist-developed flying robotic motions with *indirect – space*, where caption below each figure denotes the Laban Effort System parameter configurations. Path is shown as a ribbon to highlight robot tilt angle

SAM uses a range of language-independent cartoon-like figures, where the valence images range from a sad frowning figure to a widely smiling figure (Figure 5.3), and the arousal images range from a relaxed, sleepy figure to an excited, wide-eyed figure

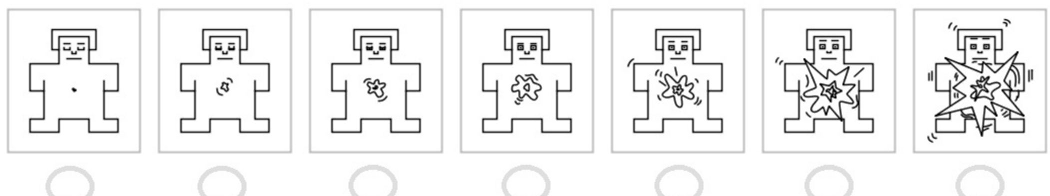
(figure 5.4) [18]. SAM is easy to understand, fast to administer, and requires no understanding of the underlying psychological model. We note that SAM is a well used and validated model, and can be used both for rating one's own affective state as well as for measuring perceptions of others' affect [28, 31]. In our study, we used seven point versions of the SAM scale (5, 7, and 9 versions are avaialbe) [18].

5.2 Study Procedure and Methodology

We recruited 18 participants from our university population (11 male and 7 female, 19-31 years of age), who were reimbursed $15 for their approximately one hour participation. Each participant completed an informed consent form, pre-test demographics questionnaire, observed and rated all 16 locomotion paths with the SAM's



(a) valence scale ranging from a sad frowning figure to a widely smiling figure



(b) arousal scale ranging from a relaxed sleepy figure, to an excited, wide-eyed figure

Figure 5.3: Seven–point version of Self-assessment Manikin (SAM) scale [18]

valence and arousal dimensions, and completed a semi-structured post-study interview. Participants were asked to rate motions based on "how they think the robot is feeling while making the motions, not their own feelings?". In addition to SAM, participants were asked to write down keywords that they feel to describe the robotic motions.

The layout out of the study environment is shown in Figure 5.4, where participants were seated at a desk positioned to easily view all the motions playbacked by the robot. Each motion lasted for approximately 30 seconds, and the order of presentation was counter balanced across all participants by a balanced Latin square design [3] for the 16 motions.

Figure 5.4: A participant watches a quadrotor moving around with an expressive locomotion path designed using the Laban Effort System

5.3 Data Analysis and Results

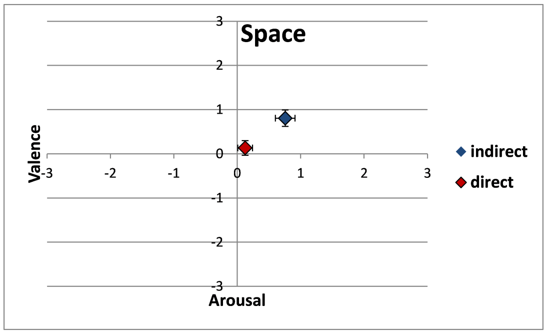
We performed quantitative analysis on the valence and arousal data measured with SAM to investigate differences in how each Laban Effort System parameter impacted perceived affect. Further, we performed qualitative analysis of participants' written descriptions of each motion, as well as their general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

5.3.1 Quantitative Results

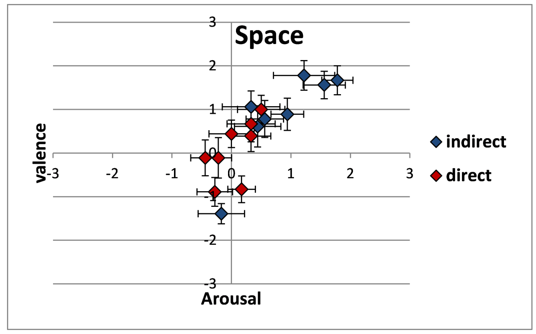
We conducted two four-way within-subjects repeated-measures ANOVAs (valence and arousal as dependent variables) on the 16 motions with the four Laban Effort System parameters (space, weight, flow and time, two levels each) as the independent variables. There was a main effect of *space* on valence $F_{1,17}$=14.19, p=.002, η^2=.45 and arousal $F_{1,17}$=10.5, p=.005, η^2=.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 5.5).

There was a main effect of *time* on valence $F_{1,17}$=9.65, p=.006, η^2=.36 and arousal $F_{1,17}$=20.09, p=.000, η^2=.54, where *quick* (M=4.83) 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 5.6).

There was a trend effect of *weight* on valence $F_{1,17}$=3.54, p=.077, η^2=.17 and a main effect on arousal $F_{1,17}$=5.40, p=.033, η^2=.24 where *strong* (M=4.60) was perceived as having higher valence than *light* (M=4.27), and also as higher arousal

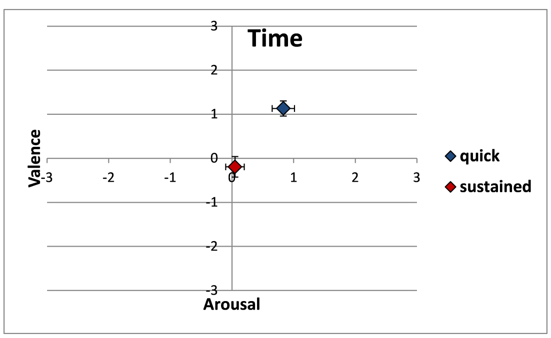


(a) space: grand means of all 16 motions across all participants

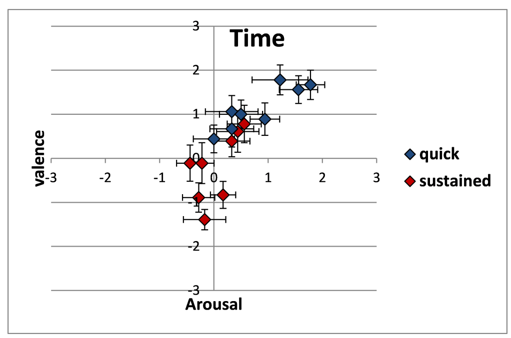


(b) space: plot of each of the 16 motions, split by the parameter indirect and direct

Figure 5.5: space: valence $p<.05$, $F_{1,17}=14.19$ and arousal $p<.05$, $F_{1,17}=10.5$, with error bars indicating 95% confidence interval



(a) time: grand means of all 16 motions across all participants

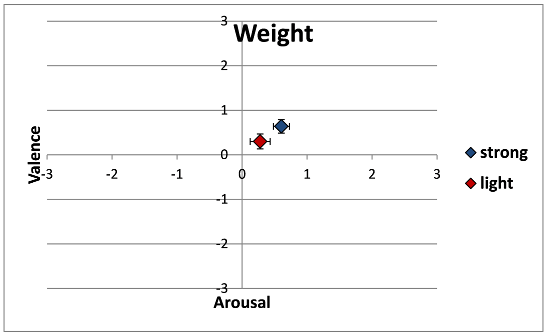


(b) time: plot of each of the 16 motions, split by the parameter quick and sustained

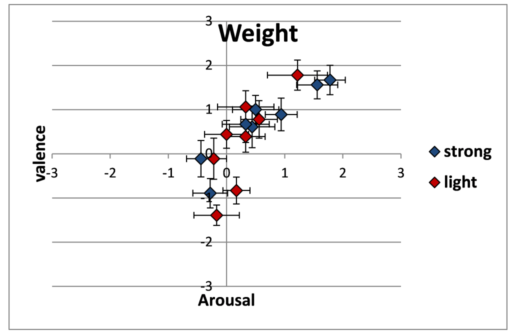
Figure 5.6: time: valence $p<.05$, $F_{1,17}=9.65$ and arousal $p<.05$, $F_{1,17}=20.09$, with error bars indicating 95% confidence intervals

(M=4.63) than *light* (M=4.29) (Figure 5.7).

No main effect of *flow* on valence was found $F_{1,17}=.03$. A main effect was found of *flow* on arousal $F_{1,17}=7.28$, $p=.015$, $\eta^2=.30$, where *free* (M=4.465) was perceived having higher valence than *bound* (M=4.417), and free (M=4.681) was also perceived

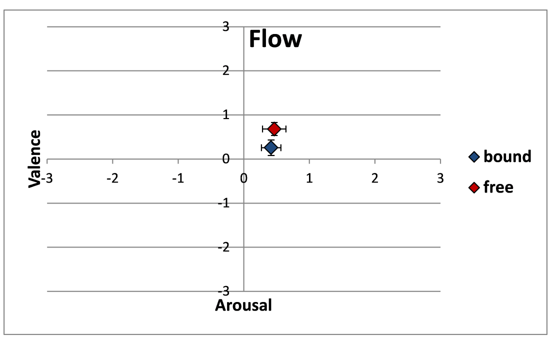


(a) weight: grand means of all 16 motions across all participants

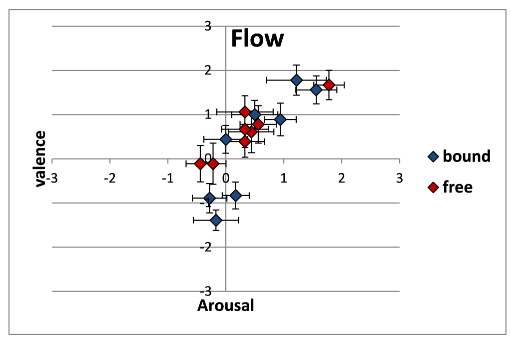


(b) weight: plot of each of the 16 motions, split by the parameter strong and light

Figure 5.7: weight: valence $p<.05$, $F_{1,17}=3.54$ and arousal $p<.05$, $F_{1,17}=5.40$, with error bars indicating 95% confidence intervals



(a) flow: grand means of all 16 motions across all participants



(b) flow: plot of each of the 16 motions, split by the parameter bound and free

Figure 5.8: flow: valence p=ns, $F_{1,17}=.03$ and arousal $p<.05$, $F_{1,17}=7.28$, with error bars indicating 95% confidence intervals

as having higher arousal than *bound* (M=4.257) (Figure 5.8). Overall, no interaction effects were found (all $p>.05$).

5.3.2 Qualitative Analysis

We analyzed participants' description of various motions, and their general thoughts reported in the post-study semi-structured interviews using qualitative analysis techniques [2]. To identify themes related to participants' interpretation of motions we: a) created an affinity diagram (Figure 5.9) to aid in open coding of participant's responses, and b) performed axial coding to find similar themes from the data. In the affinity diagram, for each LES parameter we first split 16 motions into two groups based on that parameter's two elements, and compared how motions were discussed between those groups, for example, for space we compared between indirect and direct, and so on. Further during axial coding, similar responses from the participants' were gradually clustered to identify major emergent themes. In this section, we describe the themes that emerged after the analysis.

People interpreted our set of robotic motions in terms of affect. Their interpretation of motions in affective terms was dependent on the parameters that constituted the motion, moreover, there was consistency across participants' ratings. For example, we found that:

- For time's *quick* versus *sustained* elements, most participants used words like "excited," "high energy," "happy with energy" or "enthusiastic" for *quick*, and *sustained* was more often described as "less excited," "little bit excited," or "not happy."
- For space elements, a majority of participants made comments such as "searching for something" or "following something" for *indirect*, but only a few used

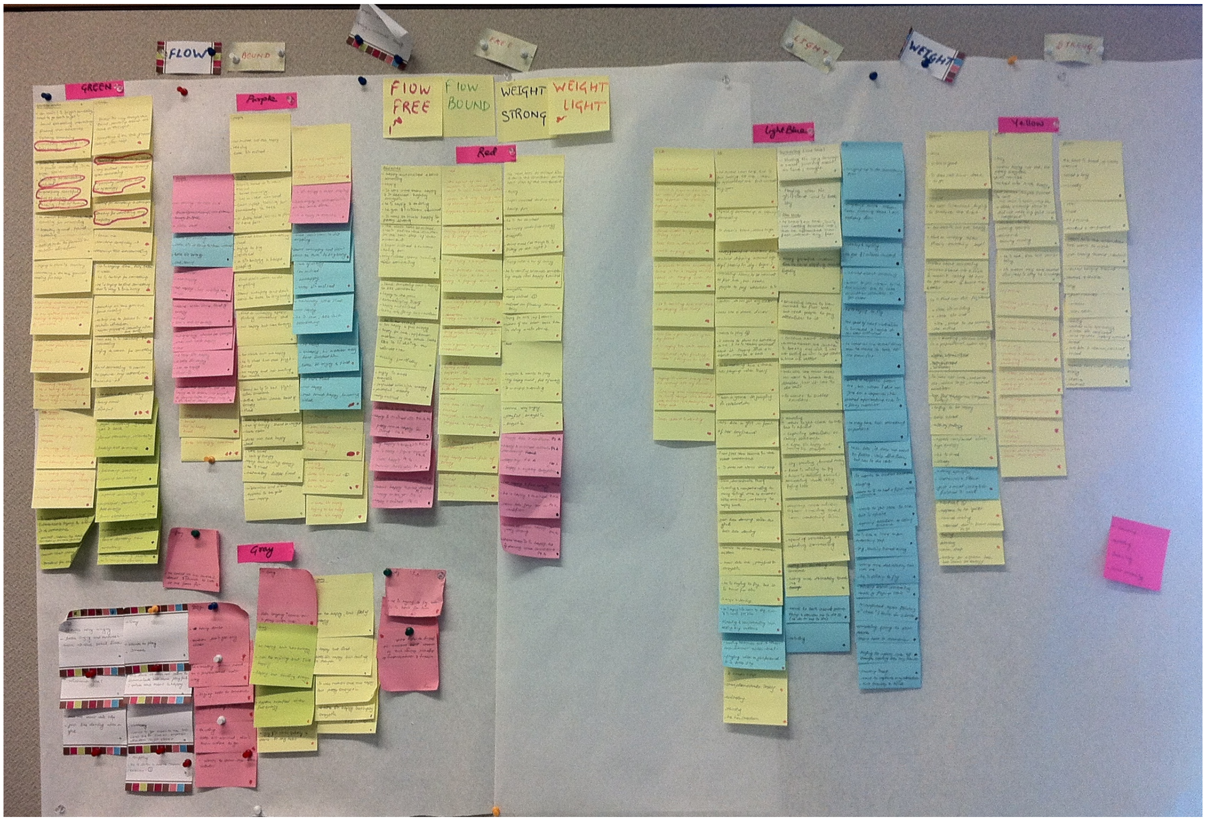


Figure 5.9: A picture of the affinity diagram that was created to aid in open coding of participant's responses

these words for *direct*. Further, many participants said the robot looks "happy and excited" with space being *indirect*, but this was not mentioned for *direct*.

- A large majority of participants used words like "wants to play" or "playful" and "flaunting itself" or "demonstrating itself" when flow was *free*, but few used such words for *bound* flow. Further, many participants used words like "robot is bored", "tired", and "unhappy" when flow was *bound*.

- 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 as "calm" or "[sic] thinking something." Further, sometimes *light* motions were described by participants' as "robot is doubtful," and "wondering."

Based on participants' responses to the keyword questionnaire, we found that they formed intricate stories based on the motion path of the robot. For example, one participant mentioned "when the robot is moving in a certain direction, it feels like he wants to point at something in this direction (p7)," "spinning or moving in a circle feels like he wants to capture my attention (p4)," or "going backward means it is afraid of something or someone (p11)." At least half of the participants related to the robot moving in a circular path as "trying to grab attention." We informally found that participant's building meaning into motions appeared to be related to the robot's facing direction, that is, people seemed to see more meaning in the motion when the robot was making motions while facing the person.

All participants were found to attribute internal intentions to the robot based on how it moved, claiming such things as the robot "is searching for or thinking of something (p2)," "is trying to capture my attention (p7)," "wants to play with me (p4)," "coming towards me, makes me feel that it is happy to see me (p8)," and so forth. Furthermore, they described the robot as having feelings, emotions, and character; e.g., it "looked like a child skipping around lightly (p13)." This was also found in the interviews, where many participants referred to the robot as being lifelike, describing it as a "bird (p11)," "bee (p2)," "puppy (p9)," "excited kid (p15)," and even a "shy boy (p10)."

From the responses of the semi–structured interviews, we observed that 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."

5.3.3 Discussion

Our results indicated that people understood the idea of flying robot communicating by expressive motion paths, used affect and intentionality to describe the robot and its motions, perceived the robot as life-like, and rated motions fairly consistently. We found statistically-significant differences on valence and arousal data across different LES parameters. Thus our results support our proposed method of adapting LES and modifying a flying robot's locomotion path to express affect, affirming our leading research question that people do perceive robotic motions in terms of affect.

Our statistical results shows that participants' interpretations of robotic motions as affect was consistently dependent on the parameters. Moreover, we found that valence and arousal seemed to be linked to LES parameters, for example, as seen in table 5.1, *quick–time* was perceived as having higher valence and arousal as compared to *sustained–time*, which was perceived as having lower valence and arousal. We did not find a way to increase one without the other, for example, increase in *valence* without an increase in *arousal*, except only with *flow* parameter. This addresses our second research question, that "which characteristics of the locomotion paths are perceived by people in terms of affect?" (discussed in chapter 1) by showing which LES parameters were perceived by people in terms of affect, that can be further used to construct the motion paths to communicate affect.

Although participants used a range of keywords to describe their impressions, there were strong similarities for particular motion parameters between participants highlighting that there was consistency across participants' rating. These results can be used to inspire design guidelines or vocabulary that interaction designers can use for building affective locomotion paths for their robots, such as, a designer can choose from LES parameters or combination of parameters depending upon what they want the robot to communicate. For example, they can increase or decrease the speed of robot motion to make the robot show urgency of some task.

Overall, our results show that people were able to understand affective robotic states of the flying robot: our particular motions were successful in communicating a consistent perception of affect to people (we had primarily statistically significant results), and we found a great deal about how particular Laban Effort System parameters and elements impact perceived affect. Thus we believe that our approach of

LES parameter	People's interpretations in terms of valence and arousal
quick–time (high speed)	more valence and arousal than *sustained–time* (low speed)
indirect–space (more area covered)	more valence and arousal than *direct–space* (less area being covered)
strong–weight (powerful motions)	more valence and arousal than *light–weight* (soft-motions)
free–flow (curvier motions)	more arousal than *bound–flow* (motions with sharp turns)

Table 5.1: A brief summary of the statistical results thats shows a comparison of the extremes of all four LES parameters based on participants' ratings

using LES for creating expressive robotic locomotion was successful, and interaction designers can choose from a range of these parameters to design interfaces to communicate their desired information. Based on our results, we developed a preliminary set of design guidelines presented in the next section. Our set of design guidelines addresses our third research question by providing method can be used as a practical tool by the HRI designers for designing robotic motions for desired affective response.

5.4 Preliminary Design Guidelines

Our results supported our proposed method and showed some interesting results that interaction designers can use LES for designing affect–communicating locomotion paths for flying robots. However, HRI designers – without any training in LES – may not be familiar with how to map LES vocabulary, i.e., *space, weight, etc.* to their desired resulting robotic communication. Therefore, we formed the following preliminary set of guidelines based on the results we obtained from our user–study, so that HRI designers can leverage our proposed method for communicating affective robotic states via locomotion paths.

To Increase Valence or Arousal:

- use more meandering movements,
- perform the motion with more speed,
- use more powerful motions.

To Decrease Valence or Arousal:

- use less meandering movements (with little deviation in path),
- perform the motion with less speed,

- use less powerful motions.

To Increase Valence:

- use curvier motion paths.

To Decrease Valence:

- use motions paths where the robot follows the way-points (motions with sharp turns).

If an HRI designer wants their robot to communicate affective states, in addition to any existing techniques they may apply (e.g., gestures, or sounds), our design guidelines can be used to accentuate or modify the communication by altering the robots 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.

Further, based on the analysis of participants' description of written answers and suggestions given by them, we outline some points which may be used in addition to the above guidelines, as a part of design vocabulary by the interaction designers. Note that these points are not results but are some directions for creating robotic motions, inspired from our qualitative study results. These set of points list down the motions in a descriptive manner, and give an idea of the kind of robotic states that these motions can be used to communicate:

- *upward elevated motions* – increase in the level of energy,
- *circular motions* – searching or exploring an area, or trying to grab attention,

- *backwards motions* – robot is scared,
- *curvier motions* – robot is in a playful mood, or wants to play,
- *up and down motions* – robot is playing,
- *direct robot towards people* – robot is happy to see them,
- *direct robot in a particular direction* – robot is pointing at something.

With the results of our user study, we have formed and presented preliminary set of our design guidelines. However, these were just initial results and we were not sure how interaction designers can practically use these guidelines to create robotic motions that communicate desired affective states. To investigate this, we conducted a small design workshop where interaction designers used our design guidelines to create robotic states of a flying robot working in different scenarios (described in the next chapter). Results from this workshop validated our proposed approach of adapting and simplifying LES to a framework that designers can use for building affective locomotion paths for their robots.

Chapter 6

Evaluation

In the previous chapters, we described how we applied the Laban Effort System (LES) to the locomotion paths of a flying robot, conducted a user–study and found that people perceive these motions in terms of affect. With this, we presented our preliminary set of guidelines that designers can leverage to build their desired affect communicating robotic interfaces. However, one important point of exploration of our thesis is to validate our method of using LES to design affective locomotion paths for a flying robot. Towards this purpose, we conducted a small design workshop where interaction designers used our design guidelines to create robotic states of a flying robot working in different scenarios. Note that they were asked to design the states and were not programming the real robot. For example, if a companion robot wants to show its happiness on seeing its owner then designers used our design guidelines to design the locomotion path for the robot. This workshop helped us in exploring how interaction designers practically use our LES adaption to design affective locomotion paths of a flying robot, and helped us in finding where our method was less or more useful.

6.1 Workshop Setup and Procedure

The purpose of bringing designers together in our design workshop was to investigate how non-artist experienced HRI designers interpreted and used our method to design affective locomotion paths for a flying robot. Further, through this workshop we wanted to explore whether our method was easy to understand, easy to use or need any further improvements. The observations from this workshop helped us in determining how successful our approach is to fit into designer's understanding of designing affective locomotion paths and verifying that our guidelines can be actually used for designing affective robotic states.

We recruited five students from the Human Computer Interaction (HCI) lab at the University of Manitoba for participating in an hour-long workshop (Figure 6.1). The workshop started with briefly explaining participants the purpose of the workshop and their involvement in it. In the beginning, participants were shown a brief tutorial explaining the simplified version of our design guidelines, including a video showing some examples of the quadrotor making LES based motions.

Next, we handed sheets to participants containing descriptions of flying robots working in two scenarios, along with some states (such as, robot is assigned a task to thoroughly search the area) that the robot can communicate in each scenario. The two scenarios given to them were: 1) robots in urban search and rescue operations (robot assigned task of searching the area and report back to the human controller),

2) robots used as companions (owner of the robot enters the robot's space and the robot reacts to it). Each participant was given a choice of designing robotic states for any one of the given two scenarios or creating their own scenario.

Participants were asked to pick the sheet related to the scenario of their choice, and we had some extra sheets in case they wanted to create their own scenarios. They were asked to list down states which according to them, the robot can communicate in that scenario, and asked them to attempt to design detailed robotic behavior for all the listed states by using our design guidelines. After all the participants completed creating behaviors, they were asked to fill a post-study questionnaire that included questions related to their overall experience in designing the states using our design guidelines, such as describing the strengths and weaknesses of our design guidelines, and suggesting some ideas for improvements.

6.2 Analysis and Results

All the participants opted to design robotic behaviors for the given scenarios instead of designing behaviors for the choice of their own scenario. Three out of five participants did one scenario each, and two participants did both the scenarios.

Overall, our design guidelines were very well received by all the participants. We received positive comments about the simplicity, and ease of use of the guidelines for creating robotic states for the given scenarios. Participants commented about a number of positive and negative aspects of our guidelines, and they provided some suggestions to improve the design guidelines.

Figure 6.1: Participants engaged in the workshop

Participants described our guidelines as "helpful," "very useful" for designing behaviors that a flying robot can exhibit in the given scenarios. They found guidelines to be "broad," "flexible," and "diverse" to describe states of flying robots in other different scenarios as well. One participant (p1) even described guidelines as a "master list of the robot's language," and another participant (p2) said that it was a "good template for the interaction designers." Our design guidelines described robotic motions in terms of affect based on the perception of people (investigated in chapter 5), thus, p3 wrote that "the motions will be easily recognized by people when watching robot making those motions."

When asked about the limitations of our design guidelines, a participant raised concern about not having more range of options to cover a wider range of design possibilities. For example, "use acceleration and deceleration instead of only using high or low speed to show some complex motions (p2)." Also, one participant (p4) pointed out that "some complex emotions such as anger, and love were difficult to design by using only your design guidelines."

In addition, there were some improvements suggested by the participants such as, "incorporate other communication techniques such as sounds, and pictures in addition to the motions (p3)." We believe that by incorporating other channels of communication along with our method, robots will be able to communicate affect more effectively. For example, in a search and rescue operation if along with flying at high–speed, a robot can make some sound, perhaps it will enable people to understand the behavior more easily and quickly. Another point of improvement suggested by a participant (p5) was to "extend the guidelines to describe more complex motions." One possible way to incorporate this suggestion is by including more descriptive keywords to describe some robotic behaviors, which may give more choices and flexibility to the designers for designing certain behaviors. For example, use of keywords such as jittery, erratic etc., can ease communication of certain robotic intent, such as, perhaps jittery motion can be used to show that the robot is reluctant to hover over some area.

Overall, results indicated that people were comfortable with our method of presentation in the form of design guidelines to create robotic states, and most of them were easily able to use our design guidelines. We learnt about how interaction designers used our design guidelines to create robotic states of a flying robot working in different scenarios and found that our method of adapting LES for designing affect communicating locomotion paths can be used to communicate affective robotic states.

The observations from this workshop helped us in solidifying our design guidelines (described in Chapter 7), by highlighting the strong points and providing us with some insights into how can we improve our guidelines to expand it into a more comprehensive tool. We hope that our set of guidelines will enable interaction designers leverage the benefits of LES to create desired affective locomotion paths for their robots.

Chapter 7

Conclusion

In this thesis, we investigated how a flying quadrotor robot can use its locomotion path to communicate affective states to people. We conclude our thesis by discussing several areas for future research and development in this direction and present our research contributions.

7.1 Limitations and Future Work

The work presented in our thesis is a first step towards exploring locomotion style of communication and using the Laban Effort System (LES) to create affective locomotion paths for flying robots. This work raises many new questions to be addressed, as briefly discussed below:

There are several areas for future research and development in this direction, and our implementation had limitations which need to be improved to help obtain stronger outcome. 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, which was important for flow-bound movements. Further, robots often cannot move as expected on various surfaces; our robot was a flying machine with some constraints due to inertia, such as not stopping even when the movement was set to 0 (which means no additional movement). Although we compensated inertia by monitoring and amplifying deceleration (sometimes by moving in the opposite direction), the robot was not able to replicate some of the recorded motions. In the future, perhaps we can build a better control system, so that the robot will have fewer problems in reproducing the motions.

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 and down to say "yes," tilting side-to-side to say "no," or finer-detailed motions with more texture, as specific motions may already have some meaning to people. Further, participants' suggestions for additional robotic motions (e.g., circling is searching) may be interesting to investigate in future studies.

During analysis of our study data, we found that participants used a range of keywords to describe their impressions. There were strong similarities for particular motion parameters between participants; for example, *space's* indirect motions were often labeled as "the robot is searching for something." For future work, we could perhaps investigate if such similarity holds across different motion sets created with the same LES parameters and use the resulting participant-generated keywords as a way to strengthen the mapping between the LES and the design intentions such that designers could use the keywords to better understand LES parameters.

During our design workshop, people pointed out that some complex emotions such as anger, and love were difficult to design by using only our design guidelines. In the future, we would like to investigate how we can extend our design guidelines to incorporate more complex robotic emotions, and how these kinds of guidelines relate to states that designers want their robots to communicate.

Our current work places people outside of interaction zone where they simply just observe the robot moving from afar. In real interactions, the robot is typically in people space and interacting with them. In the future, we would like to explore proxemics, where people will be placed within the robot's space. This will enable us to consider the full dynamics of such interaction and how this impacts perceived affect.

Our research presented the first step of adapting LES to the locomotion path of a flying robot and our study and results reflected only one set of authored motions and study results. We hope that this thesis will help inform and inspire similar work in the area, such that in the future we can continue to improve our methods, mappings, and guidelines for designing expressive flying robot locomotion paths for communicating affect.

7.2 Research Contributions

In this thesis we, explored how flying robots can use their locomotion paths to communicate affective information, presented an adaptation of LES which re–defined LES parameters in terms of the locomotion paths of the flying robot. Next, we commissioned a Laban-trained artist to author a full set of flying-robot motions using all combinations of LES parameters and developed a flying robot motion test-bed to show these motions to people. Next, we conducted a formal quantitative and qualitative study that showed people consistently rated LES based locomotion paths of our robot as affect, developed a set of design guidelines from these results, and conducted an interaction-designer workshop that showed how interaction designers use our LES as a vocabulary via our design guidelines and highlighted the strong points and area of improvements.

Our results indicate that people understood the idea of a flying robot communicating its states by its locomotion path, perceived the robot in anthropomorphic terms, and used affect and intentionality to describe robotic motions. This shows that our approach of using LES for creating expressive robotic motions was successful and affirmed our leading research questions described in Chapter 1. Based on our results, we contributed to the core field of HRI by presenting:

- *An Adaption of the Laban Effort System*: We presented a method to apply the Laban Effort System for designing locomotion paths of a flying robot.
- *A Comprehensive Set of Design Guidelines*: We presented a concrete set of design guidelines (Chapter 5, Section 5.4) to be leveraged by HRI designers for

designing affective locomotion paths for flying robots.

As a direct result of our research, we conclude this thesis by giving an example of how designers can leverage our proposed guidelines to design their own affective robotic interfaces. If designers want their robot to communicate affective states in addition to any existing techniques they may apply (e.g., gestures, sounds), 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 a slower speed to increase the sense of sadness or fatigue. Further, when designing states for a search and rescue robot working in the field, a designer can use decelerated movements to show that the robot's battery is about to die, or can use circling motions to show that the robot has found something around an area.

Ultimately, our method and resulting set of design guidelines will be an important contribution to the field of HRI, such that even without the availability of a Laban-trained artist, designers who are not artistically inclined will be able to use our method as a vocabulary for the creation of their desired robotic behaviors.

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