Tonight We Improvise!

Real-Time Tracking for Human-Robot Improvisational Dance

Elizabeth Jochum[†]
Department of Communication and Psychology
Aalborg University
Aalborg, Denmark
jochum@hum.aau.dk

Jeroen Derks
Independent Scholar
Copenhagen, Denmark
jeroenderks88@gmail.com

ABSTRACT

We present an exploratory study based on dance improvisation to explore embodied interaction between human dancers and a mobile robot. Following extensive iterations with expert dancers, we developed a sequence of basic motion algorithms based on improvisation exercises to generate three unique, original performances between a robot and human performers trained in various dance styles. We developed a novel method for tracking the dancers in real time using inputs to generate choreography for the non-anthropomorphic robot. Although the motion algorithms were identical, the individual dancers generated vastly different performances and elicited unexpected motions and choreographies. We summarize our study and identify some challenges of devising performances between robots and humans, and outline future work to experiment with more advanced algorithms.

CCS CONCEPTS

• **Human centered computing → Human computer interaction**; *Interaction Design*; **Computer systems organization →** *Robotics*

KEYWORDS

Human-robot interaction, dance, embodiment, improvisation

ACM Reference Format:

Elizabeth Jochum and Jeroen Derks. 2019. Tonight We Improvise! Real-time tracking for human-robot improvisational dance. In *6th International Conference on Movement and Computing (MOCO '19). October 10-12, 2019, Tempe, AZ, USA*. ACM, New York, NY, USA. 11 pages. https://doi.org/10.1145/3347122.3347129

1 Introduction

One challenge in robotics is to develop motion planning tools that enable robots to move safely and predictably in public spaces with people. Navigating public spaces requires significant information about context and environment, which can be partly identified by understanding how people move. Designing robots to move reliably and safely in human environments is difficult in part because public spaces are dynamic and people move in unpredictable ways. Dance forms have recognizable styles and specific interaction patterns (turn-taking, tempo changes, etc.) that reveal important information about behavior and context, which might be helpful when designing motion planning algorithms. Projects such as [1] and [2] utilize computer vision and machine learning to identify human movements and infer social context that adjust the robot's behavior and motion trajectories to suit the environment. Another approach is to use dance motions to identify and replicate expressive human movement. J. Bailliuel and K. Özciminder [3] use salsa dance to develop motion primitives to investigate the link between expressive motion and communication. Laviers and Egerstedt [4] developed a framework using Laban dance notation to classify human motion and abstract movements for robots to better mimic human movement styles. Artists approach the problem of developing motion trajectories for mobile robots from more performance-oriented perspectives. Gemeinboeck and Saunders leverage knowledge from expert dancers and choreographers to develop non-humanoid robots using a technique called Performative Body Mapping [5]. Louis-Philippe Demers investigates the link between embodiment and AI and movement across a wide range of robot morphologies. Demers' dance performance *The Tiller Girls* features thirty-two autonomous robots that perform synchronized walking gaits for low-degree of freedom robots [6]. Inspired by these and other artistic approaches to motion planning, we developed an exploratory study for improvisational movement for a mobile robot and human dancer. The goal was not to teach robots how to dance nor was it necessarily to replicate specific dance styles. Rather, we use improvisation as a bottom-up approach for thinking about embodied interaction, specifically what it means for robots and people to move spontaneously together. Because we are both artists, we preferred to work in the context of live performance. We are also keen to work with expert movers who have trained in improvisational techniques and for whom performance involves conscious mental processes such as prediction and motion planning [7]. We first describe the motivation to ground the exploratory study in dance improvisation. We then describe the research design, including a description of our method for tracking dancers using inputs to generate robot choreography, and the iterative development of motion algorithms, first in the studio and later in live performance.

MOCO'19, October 10-12, 2019, Tempe, AZ, USA

ACM ISBN 978-1-4503-7654-9/19/10...$15.00
https://doi.org/10.1145/3347122.3347129

Following the video data and first-person accounts of the dancers' experiences, we summarize the initial results and outline future work.

Figure 1: *The Dynamic Still* is an improvised dance performance between a mobile robot and a human dancer. Pictured: Sandro Masai (SM).

2 EMBODIMENT AND IMPROVISATION

Our central aim was to explore aspects of human-robot interaction (HRI) through the study of embodied interaction and dance improvisation. Embodiment is a philosophical concept central to phenomenology [8] and has emerged as an important concept in human computer interaction (HCI) [9] and HRI [10-12]. Embodied interaction is an approach to the design and analysis of interaction centered on physical and cognitive engagement with the world. The concept of embodiment is not limited to the physical manifestation of people and objects, but also extends to social relationships and participation between people and things. Following Dourish, we understand embodied interaction as the creation and sharing of meaning through engaged and sustained interaction with systems and artefacts. Related to embodiment is the concept of intersubjectivity: the interchange of thoughts and feelings between subjects as motivated by empathy and understanding. Meaningful interaction between subjects arises in part because of the natural attitude that people adopt towards persons or things based on their understanding and experience of their own and others' actions in the world [13] [14]. This pragmatic view of intersubjectivity between people and things is relevant for HRI, and movement can be a powerful means for promoting intersubjectivity between people and robots. Engineers and designers can leverage this understanding when designing physical systems, especially systems based on communication through movement.

Our approach follows previous work by creative technologists working at the intersection of cognition and perception within artistic contexts, and draws on techniques from improvisation in the performing arts. Several studies have used improvisation as the basis for inquiry between human and technological interfaces, and especially robot performance [15-18]. In our study, the object is a mobile robot that performs spontaneous and unpredictable movements in response to a human dancer's movements. Improvisation can be defined as spontaneous, unplanned creativity, but it can also denote an outcome or product that results from improvisational activity [19]. While improvisation is a feature of many human activities, improvisation in the arts is not an *ad hoc* activity but requires high levels of skill, training, planning and forethought [20]. Performers draw on this training during performance or when creating original art works [21].

Dance scholar Barbara Haselbach [22] defines dance improvisation as the playful, experimental, transient, spontaneous handling of previously experienced and collected movement material that acquires its instantaneous form through the theme or motivation, the individual’s potentialities and the conditions arriving from the momentary situation.

Traditionally, dance improvisation has been used as a tool for composition (choreographic sourcing) rather than a technique for performance. However, dance scholars have repeatedly advocated for the relevance of improvisation beyond training and for its use in live performance [23-24] and for cultivating a dancer’s internal and external awareness. Schwartz defines this awareness as embodiment: when the image, feeling or quality being evoked is clearly revealed through the dancer [23]. While dance improvisations may become compositions, improvisation primarily functions as a testing ground for compositions, allowing performers to experiment without preconceived ideas of movement or narrative content. This seemed a good place to start for generating an improvised performance with robots.

Following an interdisciplinary workshop on dance improvisation, we were inspired to explore how dance improvisation could be used for studying robot motion. Our research was motivated by two related questions: 1) What does it mean for a robot performer to improvise? and 2) What minimum level of information is needed, from a sensing and computational perspective, to generate an original and significant exchange with a human performer? Improvisation provides a “bottom-up” approach to constructing performance sketches; at the most basic level it models a process of imparting (sending) and understanding (receiving) communicative content. We were also inspired by a dance technique known as “contact improvisation” - a system where two or more dancers improvise together while maintaining physical contact. In contact improvisation, dancers remain alert and responsive to the influences on their own bodies exerted by physical dynamics such as momentum, gravity, balance, stillness and tension [24]. We were keen to explore aspects of t improvisation for embodied interaction between expert movers and robots, and observing interactions between the high levels of skill, training, planning and forethought of human dancers alongside the relatively basic movements of the robot.

Improvised robot performances are still rare (*The Tiller Girls* is a notable exception). Most robot performances are pre-scripted and robots perform pre-determined choreography, either through recorded sequences of motion or a puppeteering method know as Wizard of Oz (WOZ) ([25] provides a useful taxonomy of robot performance). There are several reasons for this, namely safety and reliability. When robots do perform autonomously, they rarely appear in close proximity to live performers, as the risks to the human performer are too great. We titled our exploratory study *The Dynamic Still*. The title was inspired by Mary Bryden's essay [26] which considers the relationships between motion, stillness and character in Beckett's plays. In Beckett's writing, Bryden observes

> movement patterns are often jerky, irresolute, subject to delays and dilemmas. In the later work, no Beckett character is exempted from a difficult relationship with his or her body in space. If able to move, the Beckettian character paces restlessly in predetermined patterns. If mobility does not come easily, s/he is condemned to ceaseless aspiration towards stasis or towards alternative movement configurations.

Bryden's descriptions are delightfully evocative and invite ready parallels with robotic motion and robot performers. While motion planning algorithms might appear smooth in simulation, these same algorithms can result in jerky, irresolute and unpredictable motions when enacted through robot bodies. Such unpredictability is related to a robot's material embodiment, and part of their idiosyncratic charm as performers. Material embodiment is also fundamental to establishing intersubjectivity and the perception of robots as expressive, desiring subjects. While we were keen to develop a project linking robots and motion planning with Beckettian narrative, we opted first to generate short improvisational sketches free of narrative content. Using dance improvisation as a frame, we were curious how dancers with different backgrounds and training would approach improvising with a robot. Through open-ended rehearsals in the studio, we hoped to discern what types of motion algorithms would produce novel interactions that were not rote or predictable, but would stimulate the human dancers and provoke alternative movement configurations and interactions. Rather than precisely choreographing human-robot duets, we opted to explore the aesthetic possibilities for human-robot improvisation.

It is important to make clear that the improvisation is a result of the embodied experience of the human performer and should not be attributed to any intentionality or movement expertise of the robot (it has neither). While our eventual goal is to design robots that can generate original improvisations, this preliminary study is focused on the embodied experience of improvisation. We are specifically interested in the intersubjectivity experienced by the dancers and the variety and originality of the compositions. It is also worth mentioning that expressive human movement and expressive robot movement are categorically different. Maxine Sheets Johnstone uses the terms *action* and *movement* to distinguish between the two [27]. She notes how the qualitative dynamics inherent to animate forms of life (kinetic movement) are distinct from motoric action executed by inanimate forms (motoric action). A robot or artificial system might convincingly emulate meaningful action, but this is not the same as the system acting meaningfully. A robot might look "scared" and retreat when yelled at, but this is only a sophisticated illusion [28]. Similarly, while our robot's movements are unpredictable and to some extent spontaneous, the robot cannot be said to experience its own movement in the way a thinking, feeling subject might. The robot does not improvise, but emulates improvisation.

Figure 2: The robot platform is a repurposed, out-of-use robot wheelchair base. Pictured: Hartvig Hansen (HH).

3 RESEARCH DESIGN

3.1 Overview

The Dynamic Still is the title of a live performance project aimed at developing improvisational movement sketches for real-time interactions between a human dancer and a robot. The robot platform (which we named "Dyna") is a re-purposed wheelchair base operated by a 24VDC motor that moves in response to input from a tracking device placed on the human performer. None of the choreography is pre-programmed: the only time the operator intervenes in the sketch is to manually stop the program for safety reasons or to restart the program when it crashes. We experimented in an open studio setting, first by tele-operating the robot using handheld controllers and later by programing different robot motions based on real-time movement data from the performer. We composed a scene with three sketches where dancers from three distinct performance traditions (breakdancing, physical theatre and modern dance) generated a 7-10 minutes long improvisation. There is no set time signature, therefore each improvisation evolves according to the individual dancer's pace.

3.2 Hardware

The hardware setup involves the use of recycled, repurposed robot combined with off-the-shelf parts.

3.2.1 Robot platform

The robot platform is a repurposed, out-of-use wheelchair base with a 24VDC motor controlled by an Arduino and Raspberry Pi microcontroller [Figure 2]. The base is battery operated and equipped with four wheels and an onboard microcontroller that controls the acceleration, deceleration, and braking. Documentation for wheelchair control modules is generally difficult to find, we therefore explored publicly-available hacking solutions (available on Github) for strategies to control similar robots using Raspberry Pi and Arduino controllers.

3.2.2 Tracking

We experimented with several different tools for capturing the performer's movement data, including handheld controllers for the HTC Vive, the Microsoft Kinect, and inertial measurement units (IMUs), which are small electronic devices that measure and report a body's specific force, angular rate and orientation using accelerometers and gyroscopes. Each of these interfaces had disadvantages, mainly that they could only track the position of the dancer in x, y coordinates, or horizontal movement. As many dance styles rely on movement in the vertical plane (which can be a distinguishing feature of specific dance styles), it was necessary to find a tracking system that could track motion in 3D space, even if the robot can only move in the horizontal plane.

We selected the HTC Vive Bluetooth handheld controllers and beacon with infrared sensors [Figure 3] with one handheld controller mounted to the robot and the other mounted either on the body or head of the performer [Figure 4]. HTC Vive is a virtual reality headset developed by HTC and Valve corporation that uses tracking technology to allow people to move in 3D space while using motion-tracked handheld controllers to interact with virtual objects in virtual environments. The ability to work with off-the-shelf, affordable hardware was a consideration for this project.

HTC Vive controllers have multiple input methods, but as we planned to use them primarily for tracking, we did not utilize these inputs.

Twenty-four infrared sensors are configured around the ring of the controller that detect the base stations to determine the location of the controller in space. Update ratings range from 250Hz to 1kHz. [source: https://www.vive.com]. Typically, the handheld controllers are used only to interact with virtual objects. The sensors on the controllers are tracked by the base stations [Figure 5]. We did not have need for the VR headset other than to configure the space at the beginning of each rehearsal/performance session. However, in order to operate the controllers and beacons, it is required that the headset be operational at all times. One advantage of using handheld controllers is that they can be mounted anywhere on the dancer's body (although the awkward shape made this somewhat difficult to find a stable mounting position). Different mounting positions were required for the performers based on the dance style: the modern dance and physical theatre performers each chose to mount the controller on their heads using an elastic and Velcro strap, and the break-dancer chose a chest-mount so his head would be unencumbered during the performance (e.g. for head-spinning).

The HTC Vive base stations, also known as a Lighthouse tracking system, track sensors from the headset and controllers. The placement of the base stations (which were designed for home use, not theatrical applications) created a three-dimensional play space wherein we could track simultaneously the movement of the dancer and the robot. The base stations were mounted diagonally at a height of approximately 2.5 meters using tripods. The product guidelines specify the maximum distance between the two base stations as 5 square meters. Each base station has a 120-degree field of view. The base stations were angled downward, at

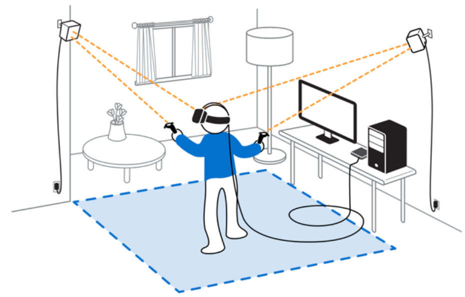

Figure 3: HTC Vive is a virtual reality headset technology. Handheld controllers track the movement of the robot and human dancers using Bluetooth beacons and infrared sensors.

Figure 4: HTC Vive handheld controllers track the movement of the robot and human dancers: one controller was mounted on the robot, the other was mounted on the head or body of the human dancer. Pictured: Hartvig Hansen (HH).

Figure 5: HTC Vive base station beacons were mounted onto tripods, creating a play space of approximately 5 squared meters.

approximately 40 degrees. The base stations emit timed infrared pulses at 60 pulses per second that are picked up by the controllers.

Because they are designed for use in virtual reality, the controllers allow for tracking motion in three-dimensional space, (x, y, and z coordinates). They also have a significantly large range, allowing for a seven-square meter stage. This gave us a plenty of room and data to work with: we could measure changes in the dancer's vertical height and map this to specific behaviors. For example, the performer could control the speed of the robot's approach simply by moving the controller up or down in the vertical plane.

3.3 Software

3.3.1 Program

The robot was equipped with a Raspberry Pi and an Arduino. The Raspberry Pi ran two pieces of software: a Redis (https://redis.io/) database system, and a custom script tracking the position and orientation of the controllers. Redis works as a data channel that allows devices to publish data to it, while other devices subscribe to published data. Our script tracked the position and heading of the robot and the performer's controllers, and published this data to the Redis channel. The computer ran a Processing sketch that took the data from the Redis channel as input for the robot's movements. Processing is a programming sketchbook and language that allowed us to visualize the robot and the performer's positions and compute the behavior and movements. Movement commands were sent onto a second Redis channel to which the robot's onboard Arduino subscribed. Finally, the Arduino transferred these directions to the robot's onboard control system. Figure 6 illustrates the configuration of the hardware and software systems. All data was connected over a local wireless network.

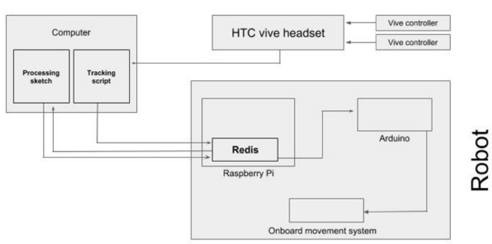

Figure 6: Diagram of hardware and software configurations. The robot was equipped with an onboard Raspberry Pi and Arduino to drive the robot remotely.

3.3.2 Sketches

We began by composing short sketches based on simple improvisation exercises such as *Mirroring* and *Leading and Following*, where the robot would simultaneously mirror the performer's path trajectory, or follow the performer by recording and tracing the dancer's path along the floor with following a small delay. These are standard exercises taught in improvisational dance technique for pairs and groups [22]. In our project, the human dancer initiates a movement (generating input) which produces a specific (although not fixed) behavior (output). These basic sketches emulate improvisation and warm-up strategies used in dance and theatre training. The goal of these exercises is tune one's awareness to the other performer(s) and to sharpen one's observational focus. When performed optimally, during the mirror exercise it can sometimes be difficult to decipher which partner is leading and which is following. For the robot and human pairs, the process was reciprocal only insofar as the performer generates new movement sequences based on the robot's behavior, which varied according to the changes we made to the program.

Initially the parameters for robot motion were programmed *ad hoc*, to discover which behaviors and interactions the dancers found compelling. The robot did not have the ability to generate any behavior without some input (either from the dancer, the programmer, or the environment). This self-imposed constraint grounded the exploratory study during the open studios. We made frequent changes to the code during rehearsals, and never informed the performers about the specific mapping, but instead let each dancer discover the robot's behaviors through embodied exploration. Because we constantly varied the mapping between input and output, each improvisation was a new experience for the performer as they could not easily predict what the robot might do. For example, when a dancer crouches low the ground, sometimes the robot would approach slowly, and other times it would move in the opposite direction quickly. The deliberate re-mapping of the relationships between input and output was devised to maintain an atmosphere of spontaneity and discovery in the rehearsal studio and to avoid building too much predictability into the system.

The open studio explorations were geared towards 1) understanding the robot's movement affordances and limitations, 2) identifying how each expert mover interacted with the robot according to their specific idiom, and 3) generating choreographic sketches with the goal of developing an open choreographic structure for performance. We experimented with both major and minor adjustments to the code: introducing variables, tweaking parameters, and developing short sketches. For the "memory" sketch, the robot would track a given motion until the performer stopped moving and then reproduce the dancer's path, orientation and speed. We observed how even basic motion algorithms elicited much experimentation from the dancers and established intersubjectivity. Frequently, the dancers would infer intentionality from the robot's behavior and respond in their own specific idiom. For example, during a *follow* sketch, if there was no delay and the robot's speed matched the performer's speed, the interaction created a comedic, almost slapstick effect as the human performer struggled to "break free" from being trapped. A performer once attempted to confuse the robot by altering his movement patterns to "escape" and reverse the chase by sneaking up behind the robot. However, if during a *follow* sketch there was a slight delay and the robot's speed was slower than the human's, this created the impression that the robot was a slow or reluctant partner. Expert movers, and especially those with basic acting training, responded intuitively to the robot's actions and discovered and developed small narrative or purposeful moments by invoking theatrical imagination. Again, it should be stressed that the emergent narratives have little to do with the robot's intentionality (it has none), but like in puppetry and object theatre, hinges on the human performer's ingenuity and the audience's predisposition to reading performative acts on stage as intentional (e.g. "filling in the blanks") [29-30].

The open studio sessions were essential for the dancers to develop an embodied understanding of the robot's physical affordances and limitations while generating a choreographic structure that would shape the live performance. That the robot's actions were based on the dancer's movement might invite speculation that the performances were pre-scripted or predictable. However, as the three unique and varied performances clearly demonstrate, the performances were highly improvisational and unpredictable. Video recordings and post-performance interviews evidence that the human performers were engaged in embodied improvisation and spontaneous, creative activity during the entirety of their performances.

Figure 7: Three expert dancers (physical theatre, modern dance, and breakdancing) were invited to interact with the robot in open studio. These interactions were video recorded and informed the basis of the performance sketches. Performer Miguel Castro (MC).

Following several initial sessions with the physical theater performer, we realized the benefit of working with expert movers and developing a generalizable, adaptable improvisation sketch that could be used for a variety of dance styles. We recruited two more expert dancers (modern dance and breakdancing) to participate in open studio sessions, and video recorded all of the interactions [Figure 7]. Based on these explorations, we settled on an improvisation structure based on a series of three sketches, each with two states, and clear transitional cues that shift procedurally from one sketch to the next. The sketches are sequential: the performance can only progress through the sketches in order. There is no repetition, unless the program is restarted. None of the performers were informed of the sketches (content, duration, rules) ahead of time. Without informing the dancers, we used descriptive language to describe the different behaviors. For example, in the description below "eye contact" refers to when the robot's controller and the performers' controller are in the same horizontal plane (e.g. "eye-to-eye").

Sketch 1 – "Unlocking" or "Getting to Know You"

State 1: When performer is within 60 centimeters of the robot, the robot finds a random position every Frame. (This triggers the sound of the relays and a detectable "micro-movement"
State 2: When the distance between the two performers is more than 70 centimeters, the robot idles until it makes "eye contact" with the performer (nothing happens between 60-70 cm). When they make eye contact, the robot rotates on the spot, and 'looks away' in avoidance. In order for the robot to react again, the performer must move to a new position to enter the viewfield again. The robot is 'shy' and continues to avoid eye contact, and so on until…
Transition: Once the robot has rotated 180 degrees from the relative starting position, Sketch 2 begins.

Sketch 2 – "Cat and Mouse"

State 1 – When the distance between the performers is more than 2 meters, the robot "wiggles" from side to side in anticipation in a single location while facing the performer, "taunting" the performer to come closer.
State 2 – When the distance between the performers is less than 2 meters, the robot mirrors the performer's location. The mirroring is active on both the x and y axis.
—When the robot has wiggled for a specified amount of time [2500 frames / 45 - 50 seconds] Sketch 3 automatically begins.

Sketch 3 – "Follow"

State 1 – the robot rotates in a single location, "following" the performer by facing them, without driving but still maintaining "eye-contact"
State 2— the robot traces the floor path of the performer has just walked, matching the performer's speed between the start and end positions. New start/end positions path points are set when the performer has moved a specified distance [30 cm and changed heading / orientation for more than 20 degrees].
Transition: The switch between states depends on the performer standing still, which indicates turn-taking. When the path is completed, the robot switches back to State 1.

To prevent the dancers from predicting the robot's behavior, we continued to alter the code and sketches up until the performance, making small adjustments based on thresholds that would elicit the most reliable but still varied responses from the performers. The aesthetic vocabularies of modern dance and breakdancing are vastly different, as are the implicit rules for communication and interaction. For example, modern dance frequently involves physical contact and sequences where dancers move together, whereas breakdancing is competitive and involves frequent turn-taking, escalation of physical prowess and increasing levels of difficulty and complexity. Physical theatre is less codified and more dependent on the movement vocabulary and idiosyncrasy of the individual performer. During the open studios we noted the performer's frequent use of clowning and physical miming. This made it difficult to make any reliable predications about how he would interact with the robot during performance. Because we sought a structure that would be amenable to all three performance styles, we sought sketches that were flexible enough to facilitate interaction without favoring one specific style.

5 Performance

The performances took place at an international improvisational festival and consisted of three unique improvised performances between three dancers and an autonomous mobile robot in identical conditions. We instructed the performers to aim for a performance lasting approximately seven minutes. Because there was no set time signature, each improvisation evolved according to the individual dancer's pace. The modern dance lasted seven minutes, the breakdancing lasted nine minutes, and the physical theatre performance lasted nearly twelve minutes. The live event was essential for harnessing the sense of "unfolding-while-happening" immediacy that improvisation provides. This immediacy draws the audience into the performance and makes them complicit in the improvisation while ensuring the authenticity of the experience. The motion algorithms were identical for all three performances, and the robot and human dancers performed together with live musicians without prior rehearsal. The musicians were unknown to the research team, but in the spirit of improvisation the musicians graciously offered to perform with our dancers. Three video cameras recorded the performances. Although the program was designed to operate without intervention, unforeseen mechanical failures required the programmer to intervene several times during the breakdancing performance. Because of safety concerns, interaction was limited to dancers involved with the project. We experimented with amplifying the diegetic sounds of the robot, filtering them through a program that augmented the clicking of the relays, the motor and wheel sounds in contact with the floor. In the end, we chose only to amplify the sound using contact microphone attached to the robots. The amplified sound allowed the audience to hear the efforts of the robot and indicated liveliness when the robot was not moving. Analysis of the video data, together with video cue recall (which allows for reconstruction of events from the teleoperator's or dancer's viewpoint), documented the moments where the individual performances follow and deviate from the sketches described above. Below we briefly summarize the performances and discuss some initial conclusions.

5.1 Case #1: Breakdancing

The breakdancing performance was the most problematic from a technical perspective and generated authentic moments of dramatic tension between the performers. Breakdancing is rooted in competitive sport and typically a dance "battle" is a staged competition between two crews. The robot proved to be a stubborn performer and this tension generated an uncharacteristic battle onstage: the engaged performer versus the misbehaving machine. The performance lasted nine minutes and required the operator (seated on stage to the left of the performer in partial view of the audience) to intervene several times through manual overrides and physically repositioning the robot onstage. The first override happened between Sketch 1 and 2: although the program appeared to be running, the robot was not responsive. After the manual switch, the robot spun in place for 45 seconds, which was not a programmed behavior. At this point, the operator interrupted the spinning by manually switching from Sketch 2 to Sketch 3. Immediately following, the robot unexpectedly veered at high speed towards the edge of the stage, threatening to crash into the audience. The operator quickly responded by stopping the program, narrowly preventing a crash. Immediately following the robot then charged at accelerating speed towards to the onstage musicians. The operator stopped the program roughly halfway through the performance (timecode 4:45) and manually repositioned the robot onstage to the center to restart the program in Sketch 2.

Although the performance failed from a technical perspective, seen another way, the performance was an authentic instance of embodied improvisation. The live performance context, which includes the presence of live audience with improvising musicians, required the performer to remain deeply engaged in the interaction and committed to the performance, even when the robot was failing. This effort is evocative of what Dourish terms "absorbed coping" in embodied interaction. The audience observed and even participated in the performer's frustration as he worked to coax the robot into a breakdancing battle. The robot's physical resistance, although not intentional, became a mark of an authentic improvisational performance. Ultimately, the battle might not have been as satisfying as a virtuosic performance, but the performance succeeds as an improvisation. The human dancer responds and adapts to the unpredictable movements of the robot. Like Beckett's characters, the robot's movement patterns are jerky, irresolute and subject to unpredictable delays and dilemmas.

An annotated video of the break dance improvisation is available at: https://vimeo.com/352457058

4.2 Case #2: Physical Theatre

The physical theatre improvisation was performed without musical accompaniment, per the performer's request. As a result, the augmented sounds from the relays projected through the theatre's sound system took on greater significance. The relay clicking sounds functioned as a kind of "voice" for the robot, and several times the performer uses this to comedic effect. The overall performance is redolent of a clown sketch or physical comedy. Narrative threads emerged during the performance, as the dancer feigned training an unruly or shy robot creature, who then became overeager and attempted to run the human performer offstage. This narrative interpretation is directly linked to how the performer related physically to the robot – not always as an equal, and frequently in the manner in which a person might relate to a pet or small child. At one point, the performer physically gripped the robot and allowed it to drag him across the length of the stage, demonstrating a reversal of the established performance conventions: the robot now controlled the human's motions. At another point, the handheld controller attached to the robot switched off unexpectedly and had to be restarted manually by the performer. The maneuver was done without interrupting the performance and was not noticeable to the audience. A full video of the physical theatre improvisation is available at: https://vimeo.com/212971242

4.3 Case #3: Modern dance

The final performance lasted six and half minutes and was, from a technical standpoint, the most successful as it required no outside intervention. The program ran through all three sketches without interruption or error. From an artistic standpoint, it also created and sustained the illusion that the human dancer and robot were moving together. The robot began moving almost from the beginning of the sketch: the duration of Sketch 1 ("Unlocking" or "Getting to know you") which seemed to last much longer in the previous two performances, lasts only a short time. This made the robot appear more responsive to the modern dancer. Other than the absence of mechanical failure, there are several reasons why this might be true. We speculate that the dancer, who is a choreographer and dance instructor trained in a variety of dance traditions including contact improvisation, was simply more attuned to the robot because of his expert training. It may also be that despite our efforts to optimize the algorithm for all three performances, we as designers subconsciously wrote a script that favored this dance genre over the others. Although the performance sketches and transitions functioned seamlessly, there was one moment of unexpected behavior from the robot. When the performer decided to end the scene, he exits the performance space upstage and outside the range of the base stations and infrared sensors. Normally, this action would trigger the robot to stop, as there is no longer any detectable input from the performer to drive the robot's behavior. However, in this case, the performer exits at timecode 5:47. The robot performs Sketch 3 ("Memory"), and remains on stage for a full 40 seconds, before exiting the stage at timecode 6:27. It is the first and only instance of the robot onstage, moving without a human partner. After completing the path, the robot exits outside of the range of the beacons, and completes a turn to face the audience. Technically, the robot should have stopped moving all together once out of the beacon range. This unpredictable motion created a heightened atmosphere, evoking feelings of loneliness or loss as the robot was left to navigate the stage and perform alone. The improvisation created the illusion the robot made a deliberate choice to end the scene and seek the human dancer offstage. A full video of the modern dance improvisation is available at: https://www.vimeo.com/211666686

Figure 8: Still image of live, improvised performance between modern dancer and robot. Performer Sandro Masai.

5 DISCUSSION

Our study was centered on exploring how a robot might emulate aspects of human improvisation in dance. We were also keen to use dance as a platform for investigating embodied interaction. With little knowledge of the robot's programming, we hoped that we could create a situation where dancers would respond to the robot as they might a human counterpart and develop improvisational choreographies without preconceived images or ideas of what the composition might look like. Based on video data from three public performances, our initial findings suggest that dynamic and unique improvisations between mobile robots and humans can emerge with relatively simple choreographic tools. Also, the robot need not have the shape of a human dancer to be conceived as a capable partner with the capacity for expressive movement. This can partly be attributed to the context of improvisation, and the sense of what Alperson calls the "anticipatory phase" of live performance that is loaded with expectancy for what will come next, and the attending sense of surprise, experiment and discovery [19]. Although the performers had previously worked in the open studio and knew the robot's behaviors were based on their input, they still found the robot responsive and experienced a sense of surprise and discovery, which became a catalyst for further improvisation:

> In the theatre, the robot was super responsive and more active. It made me move more spontaneously. I was more reactive than active, therefore also more improvised than I expected. (Sandro Masai, Modern dance)

We also see possibility for how a robot dance partner might be used as a tool for generating movement material through improvisation (choreographic sourcing). Additionally, the dancers found the improvisation with the robot inspiring and imagined using it as a training partner to overcome shyness:

> Even though I had participated in many staged choreographed shows and some dance battles, I always feel uncomfortable dancing in from of crowds. The pressure to avoid making mistakes increases with the number of eyes that are watching. I feel comfortable improvising in front of a friend, but never felt that way in a real event against an unknown dancer. Dancing robots may be good companions for shy performers or shy people, or even to help people overcome this type of phobia. (Miguel Castro, breakdancing)

The video data of the live performances reveal how basic motion algorithms can illicit creative and unexpected choreographies. Even when the robot was "misbehaving" and not functioning as intended, there was still evidence of embodied interaction and intersubjectivity that produced engaging and authentic performances. We might say that a robot performance succeeds even when it is failing. At times, the technical failures posed safety concerns for the operator, the audience, and the onstage musicians, underscoring the unreliability of machines and highlighting the necessity of safety precautions and human oversight. Despite their given reputation as precision performers, mobile robots are unreliable and subject to delays, breakdowns and unpredictable (and sometimes inexplicable) behavior. Safety is tantamount, and so is the need for "kill switches" that allow the operator to override the program and stop the robot to prevent harm or injury.

Working with expert movers who were unfamiliar with robots was a strength. One dancer was curious about the details of the robot's programming, while the others preferred not to know how the movements were mapped. The dancers had varying levels of programming knowledge, so for one a single glance at the computer screen while we adjusted the code would reveal much, while for the others it was less obvious. Interestingly, the dancer with the most technical knowledge and engineering background had the most difficulty with the robot during performance. We can only speculate as to why that might be, but it is fair to say that increased knowledge of the technical aspects of the system did not ensure a more successful performance or interaction.

When asked about their experience in the open studio and the live performance, the dancers revealed that they mostly conceived of studio explorations as opportunities to generate movement material for performance:

> I remember I was in the studio twice, before the show in the theatre. In order to stay honest to the experiment, I avoided knowing many details about the robot and its behavior. I also remember I realized quite fast that the robot would not respond to my movements one-to-one, there was a random element to it, which is good for dance improvisation. Though, in the last rehearsal in the studio the robot didn't respond to my dance for 7 or 8 minutes. From a performer's perspective that was not all bad, as my dance became a desperate search for interaction. It's a good show in itself: expectation vs. frustration. (SM)

> In the early stages, I tried to take part of the conversations about the robot's programming, but quickly pulled away because I felt that if I knew too much about how it was going to respond to my movements, it would cease to be an improvisational experience, and I was afraid to start repeating effective choreography. A risky decision, but I felt that there was more potential, both for me as a performer, constantly discovering new and unexpected things about the interactions with and the language of Dyna, but also for the research team. There were also frustrating moments when I didn't understand how to get Dyna to begin to do something. I felt that the beginning part of the tests became some sort of a code that I had to figure out and sometimes it was taking too long, if it would have been a live performance. (Hartvig Hansen, physical theater)

The dancers were inclined to interpret the robot's movements as rational and consistent with goals, causes and motivations, evidencing intersubjectivity. While the robot's movements cannot be described as intentional, the dancers experienced the robot as an autonomous, intentional agent. The dancers were engaged in what Dourish calls "absorbed coping": they were deeply engaged in the interaction and the performance context compelled them to remain committed to the performance even when it was clear the robot was failing. This was especially apparent during the breakdancing improv, when the program inexplicably crashed several times and the dancer was responsible for maintaining the illusion and continuing the performance. Although the performances used the same structure, each resulted in an authentic, original interaction that demonstrated the power of embodied interaction and intersubjectivity. Independently of the robot's functioning, the interaction between the two subjects onstage involved creative exchange that triggered narrative threads and thematic concepts. The performers were alert to this narrative potential.

> There were a lot of fun and interesting moments happening during the tests. Many interesting stories started to manifest between Dyna and me. (HH)

In the context of improvisation, the robot's non-responsiveness or unexpected motion became a source of movement material and inspired choreography. This is especially noticeable in the dancers' physically responses, for example during the breakdancing improvisation when the robot was trapped in a loop spinning circles in place for more than forty seconds (timecode 3:10). This unexpected behavior, although entirely unplanned, emulated the "back spin" choreography in traditional breakdancing. When it was clear the program was stuck in a loop, the programmer intervened. Before that, the dancer responded to the back spin as he might in a real dance battle, first reverse circling around the robot with increasing speed, and then executing a running leap and tumble dive over the spinning robot (timecode 3:40).

> Even though some parts of my dance tend to be cyclic/circular, the robot remained unresponsive until it also started spinning. Knowing that the robot is deterministic/programmed "still" and that it was not programmed to spin, it may be important to understand how the code generated that rotating response. It is important to evaluate whether the code got trapped into an infinite loop sequence of 'rotate right' for each new trap sequence, or whether the code was 'flexible' enough to accommodate random responses that somehow ended as a rotation. I doubt the latter, but in case one can be sure it was not behavior caused by a bug, I would certainly associate that to the circular nature of my motions. (MC)

We were struck by the impulse of the dancers to connect physically with the robot in motion, as they might with a human dance partner. There were instances of direct physical contact in all three of the performances. Generating movement through points of contact between bodies through touch are central aspects of contact improvisation [24]. Perhaps surprisingly given the shape and material, the robot's morphology did not hinder physical contact but instead provided opportunities for dancers to explore new ways of relating to it within the context of their specific dance idioms. The break dancer initiated a fist bump, the physical theatre actor allowed himself to be dragged across the stage, and the modern dancer interrupted and inhibited the robot's movement trajectory by impeding the robot's trajectory. Many of these actions were unplanned:

> I didn't expect I would have a physical contact with the robot on the stage. This physical interaction didn't happen during the rehearsals in the studio and I didn't expect it would happen in the theatre, but at a certain point I spontaneously stopped the robot from moving toward me with my foot. Maybe I expected the robot to respect my position in the space and move around me, never crossing my standing position in the space. Though, that 'disrespectful' behavior is more interesting for the interaction. (SM)

The transition from studio to public performance posed technical challenges that illustrate why there are so few autonomous robot performances. The level of unpredictability and unreliability make it difficult to anticipate a robot's spontaneous movement trajectories, which makes them exciting to work with as improvisational partners. In performance, the role of the musical score and the live improvisation of the musicians should not be underestimated. While we were focused principally on movement, the musical score was essential for establishing mood and supporting the dramaturgy of the individual performances.

Working with a non-anthropomorphic, wheeled robot poses certain advantages and limitations. The form eschewed the design trap of imitating human movements and prompted the dancers to interact according to spatial awareness and orientation rather than representational gestures. However, the robot's range of movement is extremely limited. Despite these limitations, a wide range of interesting spatial arrangements and coordinated action emerged. Stillness because an important action; alternating moments of stillness created poetic moments where even the performer experienced momentary uncertainty about who was following and leading. Our iterative approach to coding was akin to creative writing or devising; observing the effects of certain mappings and relationships, and making decisions based on our observations of the performers, their frustration, and the effects that small changes in the code had on the interactions. Building on this exploratory study, we aim to implement some the motion detection and classification algorithms, such as those in [3] and [4], in combination with machine learning, so the robot might use the dancer's movements to identify the specific dance idiom and respond with specific movements related this style. The eventual goal is to develop algorithms that render the robot a more capable dance partner, and ultimately a more competent mover in dynamic, public spaces.

6 Conclusion

We chose the context of dance improvisation as a platform to explore how expert movers intuitively respond to mobile robots in dynamic, shared spaces. Dance improvisation provided the basic building blocks of the performance sketches, and we observed how embodied interaction and intersubjectivity between people and robots could be established through simple motion algorithms. The need for a real-time, responsive system informed the development of a novel, simple tracking method for generating real-time, autonomous interactions between a robot and a human dancer. The tracking system uses off the shelf components and relatively simple control algorithms, which could benefit artists interested in exploring new tools for improvisation or choreographic sourcing. This system offers a novel, responsive system that, while still largely deterministic, offers more room for creative exploration than pre-programmed performances.

The decision to work in a live performance context illustrates the challenges and benefits of working with robots on stage. Improvising with a robot dancer partner was frustrating at times, but also led to creative explorations of movement material and devising narrative content, which could eventually be used to devise human-robot performances. The dancers' efforts to respond to the robot as they would a human partner illustrate the social and participative aspects of embodied interaction. Failure and breakdowns became a hallmark of the robot's authenticity as a performer, and revealed the technical difficulties that remain for staging autonomous robots. Robots are not yet ready for prime time, but through this exploratory study we present concrete approaches and suggestions for their potential as autonomous performers.

ACKNOWLEDGMENTS

This work was conducted within the RELATE Research Laboratory for Art and Technology. The performances of the Dynamic Still took place at International Improfestival held at Aalborg Theater on 9 March 2018. The performers were Sandro Masai, Hartvig Hansen and Miguel Castro. The authors wish to thank Maros Bomba, Barnabas Varszegi, and Alberte Husted Larsen, and especially Thomas Kristensen who contributed to the live performance.

REFERENCES

[1] Omar A. Islas Ramírez, Harmish Khambhaita, Raja Chatla, Mohamed Chetouani, Rachid Alami. 2016. Robots learning how and where to approach people. *IEEE International Symposium on Robot and Human Interactive Communication* (RO-MAN), 347-353 DOI: 10/1109/ROMAN.2016.7745154

[2] Angelique Taylor and Laurel D. Riek. 2016. Robot perception of human groups in the real world: state of the art. *Proceedings of the AAAI Fall Symposium on Artificial Intelligence in Human-Robot Interaction* (AI-HRI), 86-93.

[3] John Bailliuel and Kayhan Özciminder. 2014. Dancing Robots: The control theory of communication through movement. *Controls and Art*. Springer, 51-72.

[4] Amy Laviers and Magnus Egerstedt. 2014. Style-based abstractions for human motion classification. *ACM/IEEE 5th International Conference on CyberPhysical Systems*, 84-91. DOI: 10.1109/ICCPS.2014.6843713

[5] Petra Gemeinboeck and Rob Saunders. 2016. Towards socializing non-anthropomorphic robots by harnessing dancers' kinesthetic awareness. *Cultural Robotics*, 85-97. DOI: https://dx.doi.org/10.1007/978-3-319-42945-8_8

[6] Louis-Philippe Demers. 2016. The multiple bodies of a machine performer. In *Robots and Art.* Springer, 273-306 DOI: https://doi.org/10..1007/978-981-10-0321-9_14

[7] Barbara Montero. 2018. *Thought in action: expertise and the conscious mind*. Oxford University Press, Oxford, UK.

[8] Maurice Merleau-Ponty. 1962. *The Phenomenology of Perception*. Routledge, London, UK.

[9] Paul Dourish. 2001. *Where the Action Is*. MIT Press, Cambridge, MA.

[10] Joshua Wainer, David Feil-Seifer, Dylan A. Shell, Maja Matarić. 2006. The role of physical embodiment in human-robot interaction. *IEEE Conference on Robot and human interactive communication*, 117-122.

[11] Simon Penny. 2018. *Making Sense: cognition, computing, art and embodiment*. MIT Press, Cambridge, MA.

[12] Damith Herath, Elizabeth Jochum, and Evgenios Vlachos. 2018. An Experimental Study of Embodied Interaction and Human Perception of Social Cures for Interactive Robots in Public Settings. *IEEE Transactions on Cognitive and Developmental Systems* 10 (4), 1096-1105. DOI: https://doi.org/10.1109/TCDS.2017.2787196.

[13] Alfred Schutz. 1932. *The Phenomenology of the Social World*. Northwestern University Press, Evanston, Illinois.

[14] Daniel C. Dennett. 1987. *The Intentional Stance*. MIT Press, Cambridge, Massachusetts.

[15] Gil Weinberg and Scott Driscoll. 2007. The Interactive Robotic Percussionist: New Developments in Form, Mechanics, Perception and Interaction Design. *Proceedings of ACM SIGCHI/SIGART Conference on Human-Robot Interaction* (HRI 2007), 97-104.

[16] Greg Corness and Thecla Schiphorst. 2013. Performing with a System's Intention: Embodied Cues in Performer-System Interaction. *Proceedings of the 9th ACM Conference on Creativity & Cognition*, 156-164.

[17] Guy Hoffman and Gil Weinberg. 2012. Embodied Cognition for Autonomous Interactive Robots. *Topics in Cognitive Science* 4(4), 759-772.

[18] Heather Knight. 2011. Eight lessons learned about non-verbal interactions through robot theater. In *Social Robotics*. Springer, 42-51.

[19] Philip Alperson. 1998. Improvisation: An Overview. *Oxford Encyclopedia of* Aesthetics. Oxford University Press, Oxford, UK.

[20] Alili W. Bresnahan. 2015. Improvisation in the Arts. Philosophy Faculty Publications 7. University of Dayton, eCommons. https://ecommons.udayton/phl_fac_pub/7.

[21] Garry L. Hagberg. 2000. Forward: Improvisation in the Arts. *The Journal of Aesthetics and Art Criticism* 58 (2), 96-97.

[22] Barbara Haselbach. 1981. *Improvisation, Dance, Movement*. Magnamusic Baton, St. Louis, Missouri.

[23] Peggy Schwartz. 2000. Action Research: Dance improvisation as dance technique. *Journal of Physical Education, Recreation & Dance* 71(5), 42-46. DOI: 10.1080/07303084.2000.10605145.

[24] Cynthia Novack. 1990. *Sharing the dance: contact improvisation and American culture*. University of Wisconsin Press, Madison, Wisconsin.

[25] David Lu. 2012. Ontology of Robot Theatre. *Proceedings of the workshop on Robotics and Performing Arts: Reciprocal Influences* (ICRA),

[26] Mary Bryden. 2004. Beckett and the dynamic still. In *Samuel Beckett Today* 14, 179-192.

[27] Maxine Sheets-Johnstone. 1998. *Primacy of Movement*. John Benjamins Publishing, Amsterdam, The Netherlands.

[28] Ezequiel Di Paolo. 2005. Autopoiesis, adaptivity, teleology, agency. *Phenomenology and the Cognitive Sciences* 4, 429-452. DOI: https://10.1007/s11097-005-9002-y

[29] Elizabeth Jochum, Philip Millar and David Nuñez. 2017. Sequence and chance: design and control methods for entertainment robots. *Robotics and Autonomous Systems,* 87, 372-380.

[30] Fiametta Ghedini and Massimo Bergamasco. 2010. Robotic Creatures: Anthropomorphism and interaction in contemporary art. *IEEE Symposium on Robot and Human Interactive Communication* (RO-MAN), 731-736. DOI: 10.1109/ROMAN.2010.5598720