# INTERACT: Applying Theory and Methods from the Visual and Performing Arts to Robots

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## ABSTRACT
This paper considers the impact of visual art and performance on robotics and human-computer interaction and outlines a research project that combines puppetry and live performance with robotics. Kinesics—communication through movement—is the foundation of many theatre and performance traditions including puppetry and dance. However, the aesthetics of these traditions vary across cultures and carry different associative and interpretive meanings. Puppetry offers a useful frame for understanding the relationship between abstract and imitative gestures and behavior, and instantiates the complex interaction between a human operator and an artificial actor or agent. We can apply insights from puppetry to develop culturally-aware robots. Here we describe the development of a robotic marionette theatre wherein robotic controllers assume the role of human puppeteers. The system has been built, tested, and demonstrated in public settings. We then describe INTERACT, a proposed research project that stages the robotic marionettes in a live performance. The interdisciplinary project brings humanities research to bear on scientific and technological inquiry, and culminates in the development a live performance which functions as an empirical measure of our research findings.



## Categories and Subject Descriptors
D.3.3 [**Human Robot Interaction**]:

## General Terms
Human Factors.

## Keywords
Culture-Aware Robots, Aesthetics, Puppetry, Robotic Puppets, Visual Art.

## 1. INTRODUCTION

"Art lies halfway between scientific knowledge and mythical or magical thought."

-Claude Lévi-Strauss [1]

Anthropologist Claude Lévi-Strauss suggests that culture is a system with underlying structures that are common to all societies regardless of their differences. However, we know from the visual and performing arts that there are aspects of culture that do not translate readily across all cultures, everywhere. For example, while it may be true that people generally think of the world in binary terms such as "up and down" or "life and death," it is also true that these beliefs are reflected differently in the aesthetics of the visual and performing arts across cultures. Performance traditions such as dance and puppetry are rooted in *kinesics*—the generation and interpretation of non-verbal behavior expressed as movement of the body. These art forms make use of unique choreography and control techniques that reflect underlying cultural and belief systems that do not always translate easily across cultures.

Puppetry is among the most ancient and widespread of cultural performance traditions.

Whether rooted in ritual or entertainment, puppetry makes manifest the enduring appeal of bringing inanimate objects to life and creating objects that act in our stead [2]. While there are certain features that are common to all forms of puppetry (for example the distinction between the object and the performer, where motor and vocal sources of power are not attributes of the performing object but outside of it [3]), the aesthetics of puppetry and the range of design and control techniques are as numerous and varied as the cultures and traditions from which they emerge.

Puppets have proved useful to the design of robots because they are agents of expression and they model complex mechanical systems [4][5][6]. The ontological link between puppetry, automata, androids, and robots is well documented [7] [8] [9]. Puppets are rooted in cultural expression and designed to operate in interactive, communicative and physics-based scenarios. Therefore, puppets are ideally suited to help conceptualize and develop approaches for modeling behavior and human-robot interaction. Because puppets are non-living entities that serve as proxies for humans, the art form may offer clues about how culture-related information can or should influence design and control aesthetics for robots. Our goal is to apply insights from puppetry to the development of culture-aware robots that communicate through kinesics and non-verbal, expressive behaviors.

While engineering and computer science are platforms for understanding the geometry and physics of motion, the visual and performing arts are platforms for understanding how expressive movement conveys meaning and information. The relationship between automated movement and artistic expression has been the subject of traditional puppetry as well as robotic and kinetic art for centuries. Efforts to combine puppetry and automation date back to antiquity, but the idea gained traction and relevance in the modern period with the development of android technologies. German philosopher Heinrich von Kleist formulates the problem of automating graceful motion in his 1810 essay "Über das Marionettentheater." Kleist articulates the challenges posed by the mechanical design of puppets and highlights role of the human operator in generating expressive movement: "The puppeteer knows he cannot control each limb separately, and thereby imitate in perfect detail the natural movements of human bodies. Rather, the manipulator learns to yield himself to the specific weight, the pendular motion and momentum of that thing suspended from strings. That's where the puppet's soul is found, in its merely physical center of gravity, which is the line of its spirit" [10]. In many respects this problem has relevance for contemporary engineers and artists working with behavior-based robots and cybernetic art: how to automate motion that is expressive and graceful. If a puppet's graceful movement arises from the interaction between the puppeteer and the object, then puppetry is not only a method for imitating recognizable human behavior but also constitutes a type of human-machine interaction wherein the human operator learns to adapt to the technical constraints of the system. This is the subject of our research.

INTERACT is a proposed three-year project led by the Robot Culture and Aesthetics (ROCA) research group at the University of Copenhagen to unite cultural and aesthetic theory with practice-based insights that investigate the intersection of culture, artistic production, and engineering research. While the project is still in development, we are able to formulate a research agenda based on our prior work with robotic marionettes described below. INTERACT uses puppetry to investigate the role of aesthetics in human-robot interaction by combing traditional and experimental puppetry with automated robotic controllers and a custom-built software platform. The project will culminate in a live performance which functions as a control experiment wherein we can evaluate audience engagement and interaction with automated marionettes and the software system. In this experiment, puppetry becomes a model for investigating two topics: the puppeteer/puppet relationship as a model for human-robot interaction, and the puppet/spectator relationship as an example of modelling and understanding kinesics.

INTERACT builds on our prior research wherein we designed and constructed a platform for automating robotic marionettes [11]. Having achieved proof of concept, we aim to further this research by testing the hardware and software outside of the lab and in a public performance setting. We also consider how puppetry and robotics have been combined in other types of performances, such as the live musical theatre productions of *How to Train Your Dragon* and *King Kong* [12]. One significant goal of this research is to understand how artists and designers use puppetry to create interactive and engaging characters that have appeal across cultures.

## 2. PUPPETS AND ROBOTS

Puppetry provides an established framework for creating graceful and compelling choreography that accounts for the physics of motion while taking into consideration the technical constraints of the mechanical system. Similar to robots, puppets are mechanical figures that communicate through movement. Puppets rely principally on motion to create characters that are recognizable to the spectator and convey a certain artistic truth. Unlike animated characters that appear in computer-generated environments, puppets are mechanical devices that are subject to laws of physics and constrained by their design. The puppet's power of expression is therefore not determined by how well it precisely imitates human behavior, but rather by its ability to abstract human motions and behaviors and offer an artistic projection these motions given these constraints [13]. Understanding how puppeteers negotiate mechanical constraints to generate artistic choreography that is expressive and communicative is potentially useful for designing program robots to communicate through movement.

Over centuries, puppeteers have developed ways to generate expressive and fluid motions within the mechanical constraints imposed by puppets and the exigencies of live performance. From the perspective of movement and control, puppets are interesting because they partly resist a puppeteer's attempts to direct them: puppeteers are forced to reach a compromise with the physical dynamics of the puppet to generate motions and create believable or expressive characters.

Engineers have long been interested in emulating the aesthetics and control techniques of puppets to create automated systems that operate independently. From the pneumatic and hydro-powered automata of Heron of Alexandria (first century BCE) and Al-Jazari (ninth century) to the clockwork mechanisms of Vaucanson and Pierre and Henri-Louis Jaquet-Droz (eighteenth century), efforts to develop automated figures demonstrate the strong linkage between entertainment and scientific inquiry [14]. In Japan, the eighteenth century *karakuri ningyo* puppets were automata designed to perform in theatre and religious festivals. *Karakuri* dolls are influenced by the aesthetics and control techniques of human-operated puppetry, and have in turn inspired the design of sociable robots at the Fukuda Laboratory at Nagoya University in Japan [15]. This is just one example of the mutual influence of culture and engineering practice.

The approach to modeling expressive behavior in robotic art has typically involved what performance theorist Chris Salter calls "a continual comingling between the *mimetic* and the *machinic*," where mimetic refers to the imitation of human behavior in appearance and machinic is defined as electromechanical behavior that is animate but not anthropomorphic [16]. Attempts to automate robot motions have often sought to imitate human gestures and motions such as walking or waving by mapping them directly onto humanoid or other anthropomorphic robots. Because of the constraints imposed by the mechanical design and kinematic approach to motion, the resulting movements can appear rigid or mechanical. If the focus is only on the precise imitation of gestures, then the task of automating graceful motion remains elusive. Rather than focus solely on imitation, we can learn from puppetry how to create expressive agents by modeling the relationship between puppeteer and puppet. Puppetry then becomes a platform for studying human-robot interaction.

## 3. ROBOTIC MARIONETTES

While puppets have proved fertile terrain for understanding and evaluating expressive movement, they have rarely been used as a model for human-robot interaction. Rather, attempts to merge puppetry with robotics have typically focused on automation of puppet movement, which can often result in the same rigid or mechanical-looking movement that hinders robotic motion. Our project is unique because we automate traditional string marionettes that are highly dynamic and do not allow for direct-control techniques found in other forms of puppetry, such as glove puppets or rod puppets.

In marionette puppetry, the puppeteer is distanced from the act of animation and must therefore rely on a different set of approaches for generating choreography. Our work is focused first on modeling the interaction between the puppeteer and the puppet. We then consider the abstracted movement as it is understood or interpreted by an audience or spectator. While imitation and mimesis are our starting points, we arrive at the expressive behavior by reproducing the physical relationship between puppeteer and puppet rather than automating the puppet motion directly.

Marionettes are an ideal platform for exploring human motion because they have significantly more degrees of freedom than many humanoid robots and generate recognizable and entertaining human characters. Marionettes rely on recognizable human movement as the primary means of communication. Because marionettes are actuated by strings, the mechanical description of the puppets creates either a multi-scale or degenerate system which makes simulation of the constrained dynamics challenging. Moreover, our marionettes have 40-50 degrees of freedom with closed kinematic chains. Unlike the puppeteer who can rely on heuristics and improvisation, we must account for issues of abstraction and control before they arise. To do this we generate motion primitives from observed human motions, and then combine them in such a way that preserves the stability of the system. This approach results in an optimal control timing problem which is discussed in detail in [17].

We designed an automated marionette platform that uses custom software and hardware platform to generate choreographic sequences and phrases for humanoid marionettes based on human-inspired choreography [Figure 1]. The result was an approach to automated motion that was both imitative of human gestures and behavior and abstracted because of the physical constraints of the marionettes.

(a) (b)

Figure 1. The robotic marionette system in (a) is actuated by small, wheeled robots that run on the underside of a tarp. The goal is to use motion captured from the dancers in (b) as reference data for the marionettes. Software must transform the the dancers' motion into dynamically admissible motion for the marionettes.

The system is comprised of two parts: a custom software program called *trep* that generates puppet choreography based on human motion capture data and a corresponding hardware platform for generating automated performances. The hardware platform consists of small, wheeled robots that run on the underside of a tarp. Working together, three robotic controllers work to manipulate the six strings of a single marionette using a winch system. One advantage of this system is that the robotic controllers are not fixed, and the puppets are able to traverse the stage and utilize the entire stage, similar to traditionally puppetry. Secondly, puppet strings are passive and there are no electrics or motors located on the puppet body, making the puppets lightweight and safe for audiences to interact with.

The second feature of the robotic marionette platform is the *trep* software program used to abstract human choreography and generate feasible trajectories for the automated puppets. Using a Microsoft Kinect® to track and record a motion sequence generated by a human (Figure 2), the program executes the necessary computations to generate a "play" that enable the three controllers to reproduce a similar motion on the puppet.

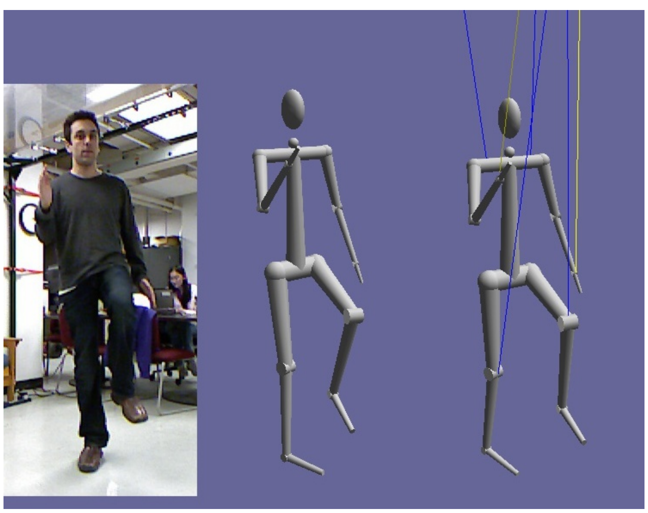

Figure 2. These three images show a single frame from the motion-capture optimization. The left-most picture shows an RGB image recorded by a Microsoft Kinect®. The center figure is the motion capture data found from the Kinect's depth map. The right-most figure is the optimized trajectory.

Once the choreography is captured the inputs are used to program the robotic controllers to effect the desired movement on the marionettes (Figure 3). Because the software accounts for the mechanical design of the puppet (which is made of wood, string and clay), the resulting motions are necessarily abstracted and make use of the natural swing dynamics of the marionette. This prevents the motions from appearing too mechanical or rigid.

Now that we have demonstrated proof of concept, our next task is to introduce the software and hardware platforms into a performance setting. We have already experimented with demonstrating the software for the general public at the Museum of Science and Industry in Chicago. The next phase of our project will take this research further as we begin to work with dancers and puppeteers to design plays and choreography for live performance.

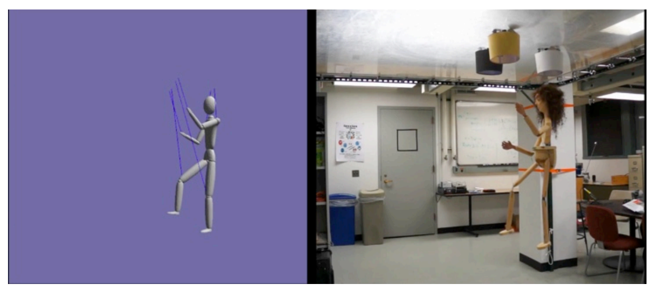

Figure 3. The robotic marionette system is actuated by small, wheeled robots that run on the underside of a tarp. Software transforms motion captured from human dancers into dynamically admissible motions for string marionettes, allowing one to combine these motions together using choreography.

## 4. INTERACT

INTERACT is a research project by the Robot Culture and Aesthetics (ROCA) research group at the University of Copenhagen. We are currently designing the experiment, due to commence in fall 2014. The project is comprised of five research topics positioned at the intersection of visual and performing arts and robotics: creative dramaturgy, measurement, motion, vision and sound. Through the development of a series of short robot performances and installations, we will explore issues related to the design aesthetics of robots and use puppetry as a model for human-machine interaction. The live public performance allows us to take our research outside of the lab and evaluate the performative and communicative outcomes of our research in a public setting.

A unique feature of the automated marionette platform is how the software and computer simulation allow users to experiment with tele-operating the marionette system directly and intuitively. Using the real-time tracking data obtained through the Kinect®, users are able to interact with the system in real-time and observe the effects of their movements on the simulated marionette (Figure 4). The Kinect® has been used to design animations in 2D and virtual environments; our system demonstrates a further advantage because the software has the proven ability to animate motion for inanimate objects in the physical world. The INTERACT project will use this platform to develop a public performance demonstrating and evaluating the aesthetic potential of these tools.

### 4.1 Designing Graceful Automated Motion

Communication through movement is an essential feature of human-robot interaction. The custom software program allows users to interact in real time with the software component of our system and evaluate what types and range of motions are feasible for the marionettes. The simulation essentially puts the user in the role of the puppeteer designing and choreographing movements and plays. The visual representation afforded by the simulation indicates how stable or graceful the motions on appear on the puppet. We have observed that some users are able to generate complex sequences of movement, and we have also observed that users quickly learn from the simulation to best direct the robotic controllers to keep motion smooth and graceful.

For the INTERACT project, we will record the movement sequences generated by expert puppeteers and dancers to arrive at a set of fluid and graceful motions for the marionettes. These motions will then be recorded and enacted by the marionettes, allowing us to measure the effect of the choreography through audience evaluation and feedback.

### 4.2 User-Interface

Section 4.1 outlines how we use the software to design graceful motions for the marionettes. This approach centers on the imitative and mimetic properties of the puppets, and on the perception and interpretation of movement by the spectators. In this section, we focus our attention on the interaction between the human users and the interface for the automated marionette platform. (Figure 4). We have previously demonstrated the user-interface to the general public at museums and academic conferences. A key feature of the interface is that it teaches users about the physical constraints of the mechanical system. The interface allows users to control the movement of the simulated robotic actuators directly and thereby learn the dynamics of the marionette system (including its fragility) in an intuitive way. Even in the absence of haptic feedback, the visual observation of the simulated marionette and actuators indicates the system dynamics and users report “feeling” or “sensing” the pull of the marionette in an embodied way. We aim to record and evaluate these actions more thoroughly in a performance setting with audience members, experimenting with automated marionette choreography as well as tele-operated marionettes.

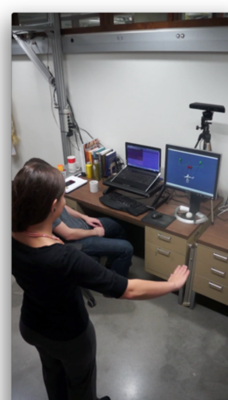

Figure 4. The user-interface allows users to intuitively operate the robotic marionette platform while learning the constraints of the mechanical system.

### 4.3 Creative Dramaturgy

Dramaturgy is the theory and practice of dramatic composition. Puppet dramaturgy has evolved differently than other forms of theatre, and allows for more abstract and open-ended forms of storytelling. Because puppetry is rooted in movement, kinesics are privileged over spoken text. In many puppetry traditions it is not uncommon to have a separate puppeteer responsible only for the voice of the puppet (as in Japanese *Bunraku* where the speaker is seated onstage in full view of the audience, physically separated from the puppet). In some puppet traditions, there is no spoken text at all.

In the 1920s and 1930s Futurist and Bauhaus artists used theatre and live performance to explore new modes of perception and investigate new technologies made available by the Machine Age. These experiments were characterized by abstraction, stylization, and a focus on geometrical and mathematical precision that demonstrate an interest in understanding the mechanics of physical expression. Lacking the technological tools to realize their artistic visions, these artists used puppetry to develop autonomous performing objects. Their goal to was to create deliberately nonrepresentational, expressive art objects that created the illusion of moving and operating in the world autonomously. Their vision of an autonomous theatre was left unrealized although there are published playscripts. Fortunato Depero's *Colori* and *Minismagia* are two texts that we intend to perform using our automated marionette platform.

## 5. CONCLUSION

"The yearning of an audience to be deceived, its illogical willingness not only to enter a space of spatial transformation but to accept all kinds of obvious and not so obvious tricks, devices, and suggestions, seems to argue for a deep felt human need, a desire to glimpse the unknown, the irrational…The experience of watching theatre constantly offers us some tantalizing limitation and possibility. While Kleist offers us the sublime object in theory, performance actively exposes it onstage. It makes its attempt to realize the sublime—momentarily, fragmentarily sometimes unsuccessfully but always hopefully—through the embodied live experience of the performer, object, and audience." Trimingham, M. [18].

Puppetry and theatre are established conceptual frameworks where the willing suspension of disbelief enables us to grant temporary life to fictive characters. This imaginative leap is not unlike the human tendency to anthropomorphize or attribute mental states to robots. Seen this way, theatre is an ideal venue for staging tele-operated or automated robots because a stage production is a narrowly defined domain in which automated figures can excel. In a scripted production, the dialogue, technical cues, and choreography of the other actors are predetermined and guided by a human agent (the stage manager), who oversees the event from offstage. This approach makes it relatively straightforward task to insert tele-operated robots into a live performance alongside human or other robotic actors [19]. However, we hope to move beyond simply inserting robots into a performance and rather combine robots and puppets to discover new modes of storytelling, new models for expressive behavior, and new methods for exploring human-robot interaction.

In our work with robotic marionettes, we have an example of a system that can both simulate and control complex mechanical systems. The marionettes play a vital role in driving the system development: the aesthetics and control techniques of traditional puppetry guided the development of the hardware and software. Because we are interested in modeling the relationship between the human puppeteer and the puppet, we were able to design a system that does not merely imitate human gestures by mapping them on to inanimate objects, but rather a system where the principles of abstraction are accounted for the in design of automated motion. The benefits of this system are that users can interact with the system intuitively, quickly learning the mechanical constraints of the overall system and developing expressive choreography accordingly. As Kleist suggested for human puppeteers, our system allows for the designers of robotic-controlled motion to “enter the gravity of the marionette.” We suspect this may lead to more nuanced and expressive choreography.

The INTERACT project applies our prior experiments to a larger performance project for the general public. In the live performance we merge puppetry and robotics to investigate the role of aesthetics in robotics and human-robot interaction, thereby bringing humanities research to bear on scientific and technological inquiry. Through audience feedback, we can evaluate the user response to the system and spectator responses concerning the expressive and communicative properties of the puppets. Drawing on humanities, engineering, and computer science, this art-based research platform is uniquely positioned to investigate how culture-related information can or should influence design and control aesthetics for robots. We can apply insights from our experiments to the development of culture-aware robots that communicate through kinesics and non-verbal, expressive behaviors.

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