# An Initial Discussion of Timing Considerations Raised During Development of a Magician-Robot Interaction


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## ABSTRACT

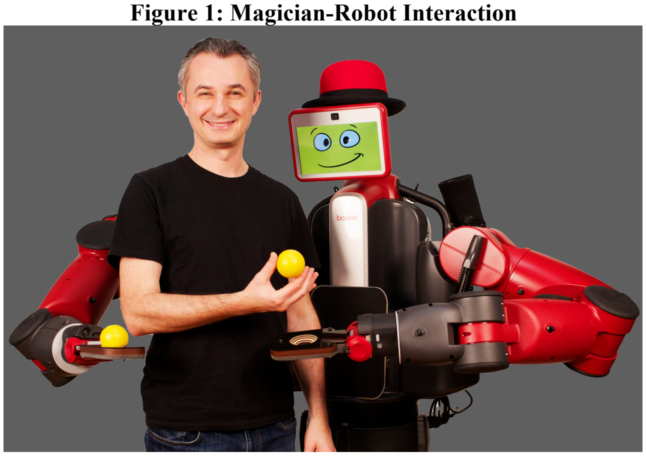
In this work-in-progress paper, we present our development of a magician-robot interaction for a theatrical stage performance and discuss our encounters with timing and chronology concerns at a variety of scales. We describe a system for choreographing robot movement, our design observations for cueing between robot and human, and timing considerations specific to artistic and logistic concerns for a production of this type.


## 1. INTRODUCTION

Robots are finding their way on stage with human performers with increasing regularity and in a variety of formats. [1][2][3][4] Since May 2013, we have been developing a platform to support a six-minute stage performance involving a robot and magician (see Figure 1). The act consists of patter between the robot and magician, direct object manipulation and handoffs, and magic effects that are accomplished with the help of the robot. We are using a heavily modified Baxter Research Robot from Rethink Robotics and have developed a suite of original composition and control software on top of the ROS platform[5], using OpenFrameworks[6] to create user-friendly tools. The act is scheduled to first appear at a large, highly visible event in March 2014.

We first describe our system by discussing our approach and workflow towards generating robot choreography and briefly enumerating some of the update loops involved. Then, we further present some ideas behind our HRI design framework for magician-robot collaboration cueing. Next, we examine timing as it pertains specifically to a live performance from both an artistic and production perspective. Finally, we propose a set of topics we intend to further investigate as we develop this work.

**Figure 1: Magician-Robot Interaction**



## 2. MAGICIAN-ROBOT SYSTEM

During a performance, the magician and the robot will be positioned very closely on stage. The magician talks about and communicates with the robot, which uses animated facial expressions, pre-recorded voices, and choreographed gestures to interact with the magician. Additionally the human and robot manipulate objects (ex. hat and ball) to perform magic effects; this includes passing the ball from human to robot and vice versa in a number of entertaining maneuvers.

## 2.1 CHOREOGRAPHY

We represent our robot movements as a series of poses analogous to key frames in animation and created tools to help compose these frames into coherent sequences. This is a well-explored methodology for robot choreography [7][8]. For timing, we suggest durations for the robot to achieve a given pose and also a "wait" value for a robot to hold the pose. As the system executes a pose sequence, it will begin at the first key frame pose, attempt to complete the movement, and then continue to the next pose on the list; the two time values are additive. For example a pose that has a move time of 3.0 seconds and a wait time of 1.5 seconds will consume 4.5 seconds of choreography before the system executes the next pose in the sequence.

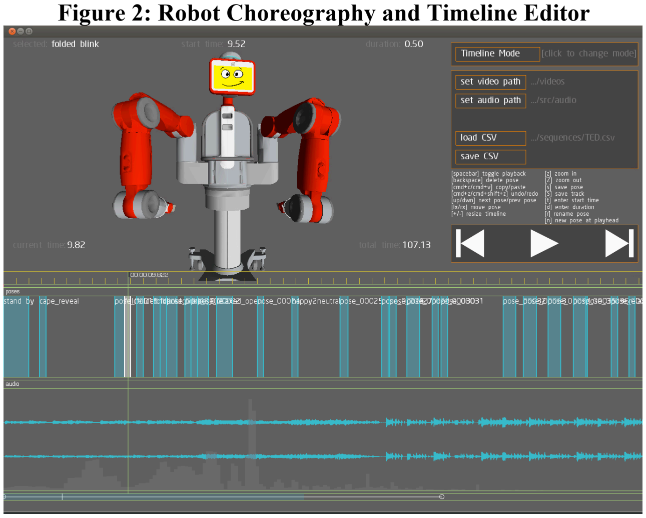
We are also experimenting with various acceleration curves through each individual pose execution and also a global description of acceleration through an entire pose sequence [9][10]. The nature of these accelerations might provide expressive nuance to movement and we hope to study parametric descriptions of this design space to suggest a choreographic vocabulary for pose sequence movement.

A higher level of organization to arrange pose sequences in a sequence or "playlist" describes the overall performance. This is a useful compositional tool as both narrative flow and pacing beats can be visualized and ordered; furthermore, pose sequences can be authored and refined in isolation and then used and reused in context of other pose sequences.

We discovered that an efficient workflow is for the artist to create choreographies in phases. First the magician creates a rough set of pose sequences "on-line," using the compliant manipulation and posing built into the robot by physically moving the robot into a key frame pose. We built an interface that uses the physical buttons on the robot to allow for fine adjustment of joints; the artist can move the robot into a generally correct pose and then hone in on a position. Using either a remote control to trigger or pressing a physical button on Baxter executes a "save pose" command. Thus, poses are generated and recorded in sequence.

To facilitate the further development of these choreographies, we have developed a robust tool that can visualize the choreography using a timeline editing tool and a 3D model of the robot that plays back the pose sequences in real-time (see figure 2). Video and audio playback are placed within the sequences on the timeline, as well. Using a play head metaphor, we can interpolate positions between key frame poses to start playback at any time in the choreography. Furthermore, this tool is also used for performance playback and can directly command the robot. During playback, the magician or robot choreographer can interrupt the robot movement, make in-line adjustments to the robot's pose, and continue the performance; visual feedback on the workstation is large and readable from a distance. This has been a crucial methodology for an efficient act development as it enables many rapid iterations of the choreography. We also decided to use a human readable file format to represent these pose sequences and play lists as sometimes it's easier for the a solo operator to simply modify a column in a spreadsheet to adjust timing of a particular pose.

**Figure 2: Robot Choreography and Timeline Editor**




An important timing concern occurs due to the nature of robot motion algorithms and the potential for "impossible" choreographies. We discovered that small adjustments to joint positions might represent a significant computational strain or even an unsolvable motion path when taken as one movement in a general choreography. Furthermore, when we attempted to create pose sequences that exceeded the capabilities of the robot to physically move to a position (ex. The movement created a self-collision, the motor speed was insufficient, etc), the robot could not complete the pose. Our system gracefully handles these failures by simply prioritizing the overall pose sequence and interpolating through the key frames when the robot cannot keep up. Interestingly, this conceptually maps to the Laban Movement Analysis Flow effort (I.e. How rigidly a movement adheres to points in space)[11].

## 2.2 Multiple Update Loops

In order to maintain a cohesive and stable performance system, we discovered the necessity to reconcile multiple update loops operating at varied frequencies, fusing into a single timeline.

Some of these loops require PID or other continuous feedback and adjustment whereas others are fairly autonomous and do not require much oversight; we are investigating how to prioritize timeline monitoring of certain movements and events based on their impact on overall latency compared to what an audience ultimately experiences.

**Table 1: Multiple Update Loops**

| |
|---|
| 1. A ROS-based canonical timeline against which we can attempt to measure refresh rates. |
| 2. Our own heartbeat update loop corresponding to play head. |
| 3. Video frames per second. |
| 4. Video streaming playback rate. |
| 5. Audio soundtracks (sound effects and multiple continuous tracks (ex. Voice over and music). |
| 6. Impulse events occurring at specific frames but with no measured duration (ex. "Fire projectile at frame 3921"). |
| 7. Continuous events and actions that occupy duration of time and have stop and start time requirements (ex. Robot movement). |

# 3. HRI TIMING

## 3.1 Collaboration

As part of this performance, the robot and human must collaboratively maintain consistent and compatible pace and synchronicity with each other. During this act, the magician and robot will interact in close physical proximity and must arrive at their respective poses in proper time. For instance, they might pass objects to each other as part of a magic routine, relying on perfect timing and execution from both the magician and robot so as not to spoil the effect. If there is even a small mismatch between the robot and human timing (ex. Either actor arrives at a pose slightly ahead of the other), the believability of the performance is greatly reduced.

The robot, under most circumstances, should perform its choreography at a predictable pace; it might need to keep in time with music and animate its face to match sound effects, for example. The human performer, however, will be influenced by the context (ex. he might be nervous) and might perform his choreography at an unpredictable pace. Therefore, the system must readily adapt to these pacing fluctuations.

## 3.2 Cueing

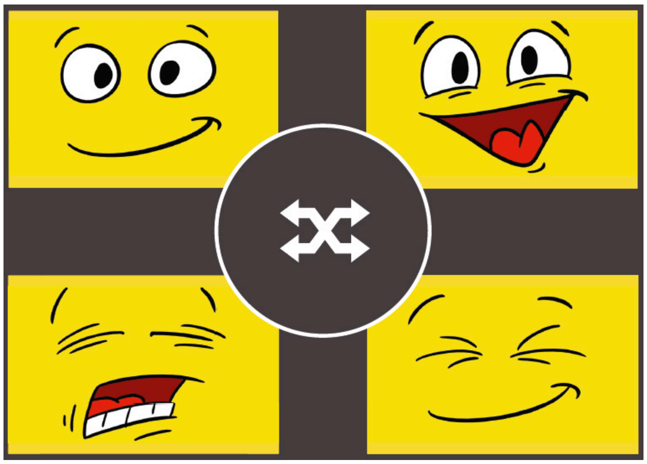
In practice, this means performance cues are necessary during the routine to direct either the robot or the human on how and when to proceed to the next movement. However, to maintain believability, these cues should not be readily obvious to the audience (although we make opportunistic exceptions to this rule as we discuss further below). We roughly categorize cues as anticipatory or procedural.

## 3.3 Anticipatory Cues

Anticipation and projection of actions are important in successful HRI [12]–[15]. Anticipatory cues are explicit or accidental hints to the human about where the system is, currently, in a given pose sequence or playlist. They usually occur prior to an event to prepare the performer. For example, the robot might utter a sound effect right before it executes a new pose; more subtle sounds, like the growling noises motors make when they are about to move, can be exploited by the magician as he is in close proximity to the robot and the audience will not perceive these noises. Another imperceptible cue might be related to kinesthetic feedback; as the magician touches the robot's arm, the robot could execute a small movement that could only be felt as a slight pressure to signal an impending gesture.

Indeed, the robot might project its upcoming moves using typical HRI heuristics. For example, it could use its eye gaze animation to "look at" where it is about to move its end effector. The human can observe these and other face animations as cues to understand what the robot is about to do next (see figure 3). Slight predicate movements, like a pulling-back of an arm before thrusting forward, might help the magician understand how the robot choreography is timed. We also designed a vocabulary of blinks in the face animation so the magician can read and anticipate the robot's next moves.

**Figure 3: Facial Expressions Used as Anticipatory Cues**



## 3.4 Procedural Cues

Procedural cues are moments or rhythms explicitly designed into the choreography of the performance that act as guideposts along the timeline. Triggered by the system or the magician, they are useful for maintaining an appropriate level of narrative pacing and can provide a timing buffer for the performer to rest or modulate the pace of the performance to match audience reaction. In our act, about 5-6 pause cues are built into the routine; during these moments, the choreography halts until the magician triggers a continuation using a hidden switch.

These procedural cues are strategically placed in moments of performance transition where an audience might be laughing or reacting to a magic effect, for example; the magician can choose how long to extend the applause break. The timing of these breaks are useful as the robot might need to buffer a new pose sequence, and a spectator who is clapping might not notice an otherwise static robot. The audio track runs on its own update loop, so it can also help bridge the gap during these pauses.

Of course the musical score is a designed collection of procedural cues that drives the rhythm behind the performance and contains movement and inflection points to delineate sections of choreography. In one moment of the performance, for example, the music turns ominous as the robot begins to squeeze the magician between its arms. This explicit signal both prepares the magician for this movement and also projects a transition to the audience members.

Regardless of whether the cues are anticipatory or procedural, the magician must rehearse extensively using the robot to become an expert in the robot's cueing and to understand how his own cue timing will impact the flow of the performance.

# 4. ARTISTIC TIMING

Of course, timing is an important concept for performing arts, and magic is no exception. A magician's job is to influence an audience's focus, crafting stories as an actor on stage; his use of pacing can help an audience follow a narrative. Timing performances with robots can help with comedic beats, anticipation, and suspense. We believe a performance's pace reads differently on stage than on a sharable video; dramatic pauses in a theater might feel like awkward, empty space in a recording. When choreographing a live robot act that is also destined to become a viral video, pacing for both scenarios must be carefully balanced. In this way, timing is an aesthetic device requiring careful artistry.

Magic, in particular, uses timing as a mechanical tool to accomplish particular effects. For example, a magician might need to secretly "load" props in preparation for moves that come later in the act. This order and pacing is necessary to playfully deceive an audience. Our robot helps the magician with this timing of misdirection by animating at precise moments when the magician wants the audience's attention to not fall on his own hands.

Despite our best efforts to maintain perfect timing during a magician-robot performance, we will likely always have difficulty achieving perfect synchronicity and a completely accurate timeline execution. However, we can use these faults opportunistically and even exploit them proactively to enhance the performance and believability of the robot character. For example, the robot could delay its responses to the magician's actions to introduce "thinking" or "processing" time or we could intentionally introduce mismatched timing to modulate the expectations the audience might have about the robot. We have even discussed introducing some slight randomness in the timing of the robot choreography so that the magician would need to remain more engaged with the robot, perhaps creating more vibrant performances.

# 5. LOGISTICS TIMING

Finally, it is important to consider timing on a project scale for productions of this level of complexity and professionalism with a firm performance deadline. Novel robotic performances usually require the development of custom software and hardware; innovating and troubleshooting technology is an unavoidable and resource intensive element to these projects.

In parallel to this, the content of the act must be developed with high production value. Videos, voiceovers, animation, GUI elements, narrative scripts, and magic elements are a sampling of additional critical components to this development. Finally, we must also consider the logistics of preparing all of the props, computer infrastructure, and even robot shipping containers in time for the premier performance.

All of these components must come together despite the differing and unpredictable paces necessary to fully and robustly cross-develop each individual piece. We have discovered this is a very difficult task particularly when the technology is in flux. For example, not completely understanding the capabilities of a new robot makes it almost impossible to choreograph a reasonable and believable series of movements immediately. Initially, we spent quite a bit of effort simply trying to make the 3rd-party robot move fast and fluidly, experimenting with multiple control modes (ex. trajectory, velocity, or position).

Content production often had to halt until we fully vetted particular elements of technology, as vital story points rely on the robot moving appropriately. The reality of intermingling a research context and professional production schedule meant that team members who have graduate student responsibilities and are used to the pace of university lifestyle often could not provide predictable hours to support the urgency needed by the rest of the team.

As we consider the pacing of such a production schedule, we suggest maintaining a list of features onto which the team liberally defers time-consuming ideas until after the initial production. Our project included the development of APIs and other messaging protocols that meant components could be developed in isolation and replaced, piecemeal; this was helpful as a remedy for collaboration with team members who may have external constraints. Furthermore, identifying the critical path to project completion means being ready to bring on external support to solve show-stopping problems that are not necessarily interesting from the research perspective.

In a performance environment, such as a theater, timing issues related to unpredictable computer network latency and message overhead becomes a serious concern. It is inadvisable to attempt to use wireless networking because of bandwidth limitations, for instance.

There is usually a very limited time available backstage load-in and pre-show setup at a performance venue. A system involving robotic technology should include a variety of tools for non-technical users, related to robot setup and safety. For example, quick tools to arm and disarm the robot, a sequence of diagnostic test poses, and animation and audio playback compositions for sound and video checks will prove to be useful aides.

## 6. FUTURE WORK

Areas of exploration in choreographic timing of human-robot performances include more dynamic or complex playlist structures (ex. Branching story lines) that take advantage of narrative pacing theory and computationally generation of dramatic timing. We also look forward to exploring parametric global adjustment of pose sequences based on narrative arcs and expressive descriptions that abstract away from specific robotic poses (ex. "The energy level should build throughout the performance"). We believe that we can create affective animations or movement "flavors" (ex. Bored, nervous, intimidated) that carry their own impact on timing and pacing, and, in turn, could be triggered by inexpensive sensor data from the human performer; if the magician is moving rapidly towards the robot or speaking at fast pace, for example, the robot might cue more agitated behaviors. We could explore using anticipation techniques so that the robot can dynamically react to the magician's actions. Finally, formalizing a syntactical format for human-robot choreography might prove to be useful when sharing and publishing robot pose sequences to communities of performers in the same way musicians share scores.

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