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The Robot Show Must Go On: Effective Responses to Robot Failures

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***Abstract*—This paper consists of a failure analysis of two robot performance productions. Both productions included three-week rehearsal periods, and culminated in live performances including both robots and humans. To develop these productions, a theater artist collaborated with a robotics lab to develop, (1) a narrative dance performed live on stage, and, (2) an improvisational performance in a public space. While the interdisciplinary team did not set out to explore robot failures, during the eighteen rehearsals and two live performances, failures played an ever-present role. This paper presents the technical and choreographic failures encountered, and details strategies for addressing, planning for, and rehearsing responses to robot failures on stage. In addition to scaffolding future robot theater performances, we discuss how these strategies apply to other customer- and audience-facing robots, including sponsor demos. The on-stage exploration of robot chairs and human performers also suggests that humans can conceptualize minimal robots as both characters and props, moving fluidly from one to the other. We hope these insights ensure that future audiences will *want* the robot shows to go on, as well as expand ideas about the types of robots that can be cast in future human-robot productions.**

***Index Terms*—Robotics, Human Robotics Interaction, Service Robots, Performance, Interdisciplinary Theater, Dance, Robots Failures.**

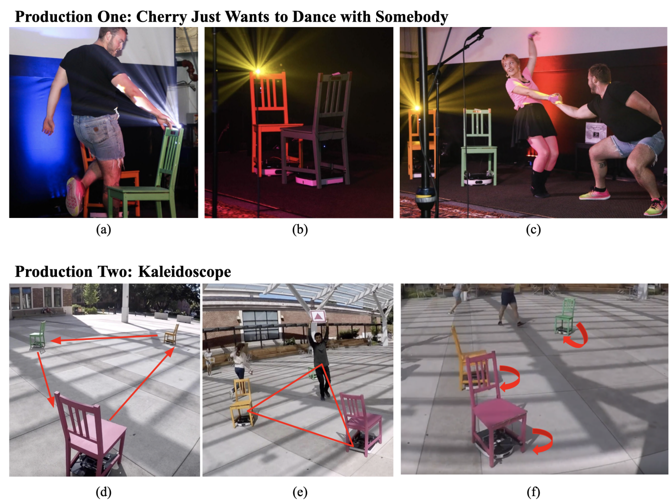

Fig. 1. The theatrical rehearsal process not only surfaces common robot failures, allowing for corrections, but also creates an opportunity to develop and practice effective backup plans. This paper considers failure during the development of two ChairBot-centric productions: (1) Cherry Just Wants to Dance with Somebody, a narrative dance performance, (top), and (2) Kaleidoscope, an improvisational geometry exploration in which bystanders could participate.

I. Introduction

"HAVE you tried turning it off and on again?" Anyone in the modern world trying to use technology knows it often fails. But when robots perform to live audiences in theaters, hitting restart is not an option. What are the types of failure in this context and what are some strategies or responses to it? In order to answer these questions, we studied the development and exhibition of two robot performances enlisting the help of a lead theater artist(second author) working with a team of engineering students. The group set creative objectives, developed technology design, and place the rehearsal schedule. Tracking of the performances showed that failures occurred on 17 of the 18 rehearsal days and during live performances, and yet, both productions were deemed a success. This paper offers a theater-inspired perspective to robot failure: try to avoid it, but also plan for it.

Our learning from performing robots in this context applies to many contexts other than theater. For example, sponsor demos can decide the future of a particular project's funding. Or, with interactive service robots, rapid impressions could influence whether a customer stays in a store. Such robots in these non-theater contexts would benefit from effective backup plans that allow them to continue function, even in the midst of failure. Additionally, refining to development process may help teams plan for future failures and practice effective solutions. Ultimately, the fluency of a robot performance impacts people's impression of both the robot and the team behind it.

Both productions (Fig. 1) included three week rehearsal periods, and culminated in a live performance including both robots and humans. This paper consists of a failure analysis of two robot performance productions. In particular, we share four effective strategies to address robot failures at different segments of the robot performance process:

1) **Showstoppers**: require rethinking a technical or choreographic strategy and require significant time investment. Examples include adding touch-sensing, rewriting a sequence of choreography in light of actual robot

capabilities, or adding that ability to trigger a sequence of choreography remotely.

2) **Stop, Fix, Try Again**: addresses minor issues revealed during rehearsal (or pre-performance), and can usually be addressed in less than 10 minutes. Examples include small fixes like robot timing, position, or recharging of battery.
3) **Co-Performer Accommodation**: leverages human flexibility to accommodate variance in a robot's performance and requires practice, but no technical implementation changes. This is the strategy to use if no previous plan has been built and for the cases of simple robot timing or spatial failure. It can be also used if human actors have practiced it during rehearsal.
4) **Human-Centric Replacement**: is a strategy used to handle catastrophic robot failures on stage, and needs to be pre-planned and practiced, e.g., having a backup remote control, a wheeled chair that a person could push around, and someone free on the team that is available and trained. The metaphor in human theater is having an "understudy".

Robotic chairs were selected as the robot performer platform precisely because of their limitations. The performances described in this paper build on our previous work developing minimal social robots [1]. We enlisted the help of a theatre artist (the second author) to explore the expressive limits of several of these ChairBots. Would the audience think of the chair as a character or an object? Thus, the artistic development also allowed us to explore the social fluidity of minimal social robots on stage.

The following sections first detail prior work (Section II), the robots and the productions (Section III). The results include a typology of common robot failures (Section IV), and the frequency and contexts of our team's failure response (Section V). We discuss the applicability of these results to a broad definition of entertainment robots (Section VI), concluding with lessons learned (Section VII).

II. Related Work

A. Past Work in Robot Theatre

Past work at the intersection of robots and performance includes work targeted at entertainment, and work using theatrical settings for robot research purposes [2], [3], [4], [5], [6], [7]. Artists such as Blanca Li, Louis-Philippe Demers, Wade Marynowsky, Oriza Hirata, and by dance troupes such as Philobolus and Cirque de Soleil have used robotic technology as characters in the performance, props supporting the narrative, and even explored making the stage itself a robot. The two performances developed for this paper take inspiration from these and many more previous works. Previous work has also taken inspiration from entertainment and acting to design more effective robot expressions [8], [9], [10]. We believe theatre is a rich source of both methods and ideas for exploring robot behavioral expressions [11]. Other researchers have also taken inspiration from acting techniques [12], [13] and the physical

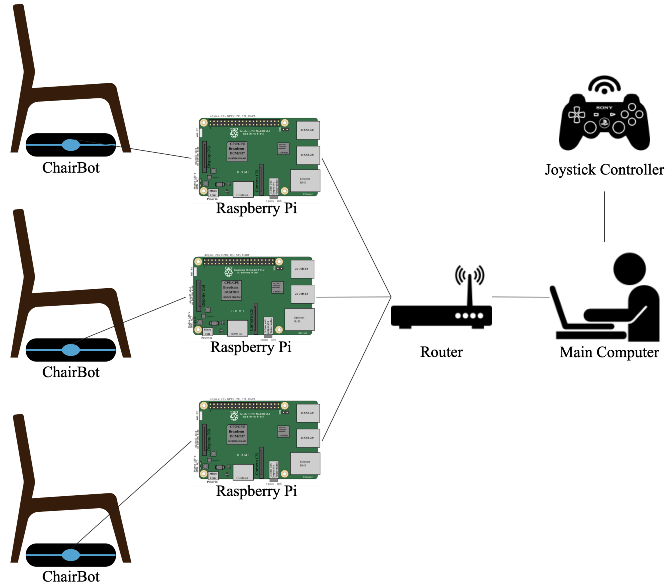

Fig. 2. Both productions made use of the ChairBot robots. The ChairBots are inexpensive robots composed of IKEA Chairs and Neato Botvacs with some connection hardware, that communicate with a central computer via Raspberry Pis, and can also control themselves locally.

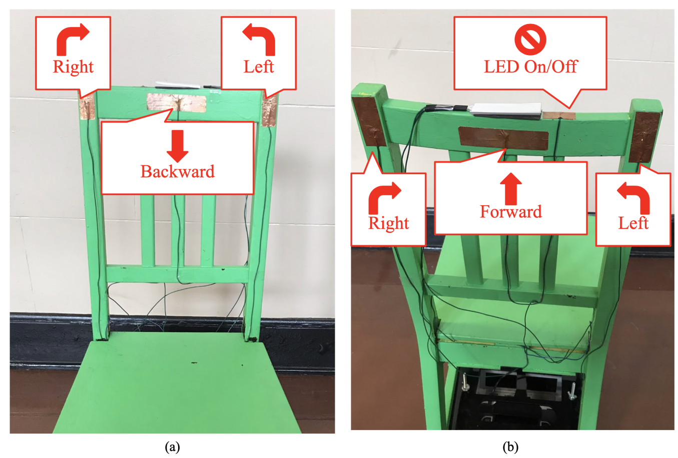

Fig. 3. Capacitive Touch Sensors on the ChairBots enable human co-performers to move the robots around on stage. When dancing, the human acts as the lead, and the robot as the follower.

theater [5], [14]. They also propose theater as a good testing space for robotics. Both [15] and [16] used live human-robot performances to familiarize audiences with robots, with the former suggesting that collaborating with audience members could aid in the robot design process. In this work, we use theatrical productions to better understand how to develop reliable robots that functions both on and off stage.

B. Past Work in Robot Failure

Historically, factory robot failure was often articulated as a concept inversely correlated to human safety [17]. Thus, much failure-detection work has been dedicated to safety systems

Fig. 4. Bump Sensor Closeup: three on/off buttons that were covered with a long horizontal panel during operation.

that can automatically stop robot motions [18], or vary actions based on likelihoods of failure [19]. Other work involves triangulating the origin of a failure [20]. The most recent work in defining paradigms of failure, however, takes a more complex social view, considering how to handle robot failures during human-robot collaboration: from a factory line [21] to a ballroom dance floor [22]. Continued work in human-robot interaction has considered how robot failures impact a live interaction [23], and how robot failure impacts human-robot trust and collaboration[24], [25]. This paper extends previous failure response efforts to the domain of robot failures on stage, explicitly taking inspiration from theatrical approaches to preparing for, rehearsing, and responding to robot failures on stage. Despite efforts to make robots reliable, surveys of previous work in human-robot interaction illustrate the universality of robot failures [26], thus we expect such results to be widely applicable.

III. Theater Program

This section describes the robots and each of the two productions, both of which also include human performers. The differences between the two productions is detailed in Fig. 6. Both productions involved the same performance-development team: a robotics professor, a robotics PhD student, an undergraduate researcher, and a local theater artist who was the creative lead for both projects.

A. The ChairBots

The ChairBot design, originally presented in [1], uses Stefan IKEA Chairs affixed to Neato-Botvac robotic vacuum cleaners. Using a dedicated wi-fi network, the robots can be controlled using pre-programmed motion sequences or teleoperated using a PlayStation's DualShock controller.

Touch Sensors: The ChairBots include capacitive touch sensors to capture physical touch, enabling a person to move the chairs forward, backward, right, and left. These sensors (presented in Fig. 3 and Fig. 1(a)) are improved during the rehearsal process for Production 1. The redesign included a LED light that indicates whether the touch-control mode was ON or OFF (as seen in Fig. 3).

Bump Sensors: As part of Production 2, the ChairBot design was also augmented to incorporate a bump sensor in the front face of its seat. This bump sensor was activated when a ChairBot drove into an obstacle, a person, or another ChairBot, allowing the chairs to navigate using something we affectionately labeled "Collision-Based Navigation," i.e., backing up and turning a new direction after a collision.

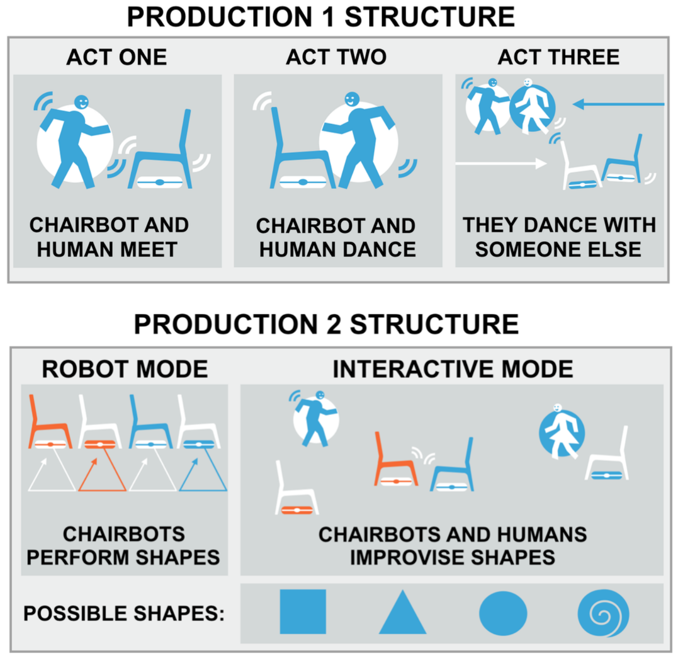

Fig. 5. Visual Summary of Two Performance Structures

	PRODUCTION 1	PRODUCTION 2
Title	Cherry Just Wants to Dance with Somebody	Kaleidoscope
Genre	Narrative Storytelling	Improvisational Dance
Setting	Indoor Stage	Outdoor Public Space
Performers	2 ChairBot 1 Technology Facilitators 1 Choreography Facilitators 2 Professional Dancers	4 ChairBot 1 Technology Facilitators 2 Choreography Facilitators Public Participants
Goal	• Use the ChairBots as Story Characters • Make the ChairBots Perform a Dance	• Introduce the ChairBots to Geometric Shapes • Make the ChairBots Improvise Shapes

Fig. 6. Production Summaries: Artistic Goals and Cast

B. Production 1: Cherry Just Wants To Dance With Somebody

"Cherry Just Wants to Dance with Somebody" was a narrative love story featuring dancing robot chairs. The scripted movements established character and relationship via non-verbal gestures. The specifics of the story structure are outlined in Fig 4. The final performance occurred in a traditional theater space in front of 70+ live audience members.

The simple story was inspired by the 1980s. (The following description is narrative, not technical): PHASE 1: Human walks in with a boombox and sets it on ChairBot1. The human begins to dance. ChairBot1 notices and begins to imitate human's dancing. PHASE 2: Human and ChairBot1 share an extended dance together in which the human uses touch sensors on ChairBot1 to make it move and spin. PHASE 3: Another human interrupts, enters and sits on ChairBot2, who therefore awakens. The two humans fall in love, while the chairs look on. The two chairs fall in love, dancing well

Production's 1 Performance	Production's 2 Performance
The unexpected carpeted stage → **Timing Failure**	ChairBots executed programming differently → **Timing**
The unexpected carpeted stage → **Spatial Relationships**	Missing parts for a ChairBot → **Hardware**
The wireless controller's batteries had depleted → **Hardware**	Bump-sensor design was not robust enough → **Hardware**
	A ChairBot did not have the last updated code → **Software**

Table I. PERFORMANCE DAY FAILURES

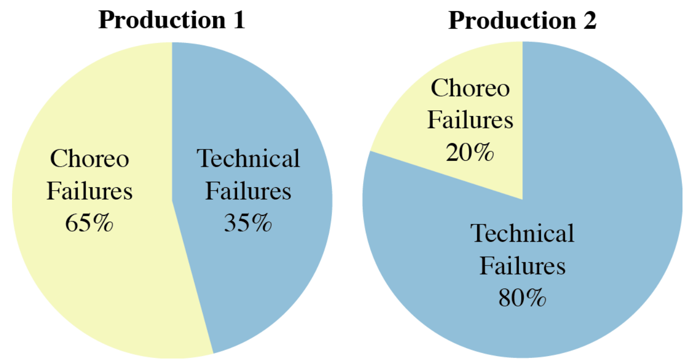

Fig. 7. Failures data rate in both Production 1 and 2 divided by technical (blue) and choreography (yellow)failures

after the humans leave. ChairBot1 and ChairBot2 have a final moment on stage, ending in a LED-lit kiss. *The end.*

C. Production 2: Kaleidoscope

"Kaleidoscope" was an improvisational dance inspired by four geometrical shapes (circle, square, triangle, and spiral). For this production, the objective was to explore angular and spherical shapes with the ChairBots, and to improvise physically between other robots or people in the environment.

Story structure specifics are outlined in Fig 5. The interactive mode(part two), accounted for the largest aspect of the piece. This section was dedicated to geometric improvisation achieved through a progression of randomized options. At the start of part two, each ChairBot was given either triangular or rectangular movement. As the ChairBots interacted by bumping into people or other ChairBots, their vocabulary of movement expanded to include spherical movements like circles and spirals.

Kaleidoscope's final performance occurred in a public setting where bystanders were encouraged to participate (See Fig 1). Similar to the Chairbots' programming, participating public were given "shape signs." The specific shape dictated the topography. If they bumped into another human with a "shape sign," the individuals were instructed to switch signs and their corresponding topography.

IV. DOCUMENTING & CLASSIFYING ROBOT FAILURES

This section presents the failures encountered and documented by team members during both the live performances and the rehearsals. Solutions used to resolve these failures were also documented, and will be explored in Section V. After each production, team members and collaborators were interviewed about obstacles faced, effective failure-response methods, and experiences working with the interdisciplinary team.

After the data collection, a grounded coding process was used to group failures into common types. We also present the numerical failures data between the two productions (Fig. 7), and over the rehearsal (Fig. 8) and performance days, pulling out several insights about the presence of failure in live robot productions.

A. Failure Typology

We classify generic robot failures that are not specific to robot theater into two overarching categories: (1) **choreographic** - involving the temporal and spatial movement goals for the robots, and (2) **technical** - involving the technology hardware, software, or connections. We briefly cover the categories within each of the above encountered failure types during the development of performances, also summarized in the following subsections.

Choreographic failures included timing, spatial relationships, and sequence failures:

- **Timing Failures** are instances where the synchronization within the production elements fails. For example in Production 1 rehearsal day 3, the ChairBot was slow compared to the human dancers, making it hard to synchronize movements of the humans and robots.
- **Spatial Relationships Failures** are instances where the proxemics relation between the production elements relative to each other fails. Such cases happened when two ChairBots collided during a duet or when there was not enough room for two couples (human duet and robot duet) to do all the scripted choreography.
- **Sequence Failures:** refer to the order of the dance steps the production elements have to do. The recorded failure data reveals that the story structure was simplified several times in Production 1, e.g., because the ChairBot was not able to complete a desired sequence in the interval originally planned for. Also in Production 2 rehearsals day two, the spirals movement was initially indiscernible from the circle movement.

Technical failures involved hardware, software, sensing, and communication:

- **Hardware Failure** refers to the malfunctions of physical devices or hardware. In Production 2, for example, the team planned on using four ChairBots, but closer to the performance, one chair lost a screw, and no spare parts were on hand to replace it.
- **Software Failure** refers to coding errors in which a desired objective was not achieved. Software Failure could be, in part, attributed to poor integration of the

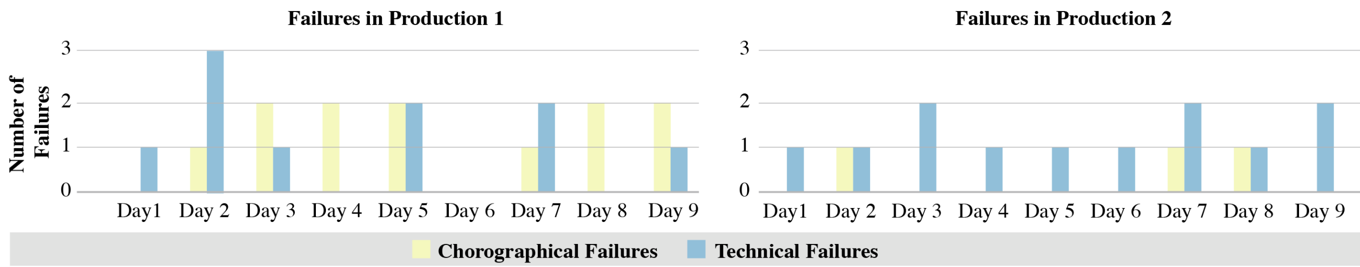

Fig. 8. REHEARSAL DAY FAILURES: Both Production 1 and 2 had nine rehearsal days over the three week period up leading up to their live performances. We present a summary of the technical (blue) and choreography (yellow) failures

robot hardware, or a misunderstanding or mistake in the code structure. To illustrate software failure, Team member 2 observed during a post-performance interview, "If the [hardware-]performed shapes are small, we can get away with small angular mistakes [in software coding structure], but when they're big, the angular mistakes become obvious."

- **Sensing Failure** refers to a malfunction of robot perception. For example, the a bump sensors might not detect moderate collisions, leading to erratic robot behavior. These types of failures also occurred at the beginning of Production 1, where the newly installed touch sensors only worked "once out of 10 tries," according to one team member interview.
- **Communication Failure** refers to losing a connection between any two elements of our ChairBot system (see links diagrammed in Fig. 2). For example the team encountered a failed Bluetooth connection between the central computer and the PS DualShock controller on Performance Day 1.

B. Failure Results

For the purposes of this paper, we focus the two overarching sub-types from the above typology: choreographic and technical failures (Fig. 7). Slightly more than half of the failures for Production 1 were choreographic, while 80% of the failures in Production 2 were technical. We explain the rate differences by the varying technical difficulty of each project: **choreographic failures only occur when the technology is working.**

A second insight is determined by analyzing Fig. 8, in which the robot failures are broken down by performance day. Production 1 was heavily choreographed, thus there were more opportunities to fail via deviation from a predetermined script, whereas improvisational performance, by definition invites deviation. That said, Production 2 included significant hardware or technical failures. Some of the bump sensors broke after repeated collisions, and one of the three ChairBots had an older version of the code, unbeknownst to the development team, that only manifested once the performance had begun. Our second insight from our failure data is based on this difference in Performance 1 and 2: **rehearsal is best used to optimize for the artistic goals of a particular choreographed performance**. Literature in theatrical journals

CLASS OF FAILURE / TIME OF FAILURE	CHOREOGRAPHY	TECHNOLOGY
REHEARSAL	(1) Showstoppers (2) Stop, Fix and Try Again	
PERFORMANCE	(3) Co-Performer Accommodation	(4) Human-Centric Replacement

Fig. 9. Responses used to resolve both technical and choreography failures during performance and rehearsal days for each production.

highlighted the significance of the physical rehearsal in reducing human error [27], so it is particularly interesting that we have replicated this result for robot performers.

We summarize the Performance Day Failures in Table I. During the on-stage performance of Production 1, the ChairBots encountered carpet for the first time, leading to choreographic failures of both timing and space. Moreover, one of the wireless remote controls lost connection a few minutes before the show. Underscoring the importance of this paper's topic, neither production went without day-of-performance failures. Thus, we end this section with our final insight: **the purpose of rehearsal is not to avoid failures, but rather to become prepared for them**.

V. FAILURE-RESPONSE STRATEGIES

While this paper does not consider mistakes people made on stage, we did extract four thematic failure responses from our experiences handling robot failures on stage. In participating in the performance development cycle, this insights operate as a kind of auto-ethnography, allowing us to become part of the theater development cycle, while the theater artists become part of the robot development team, each sharing insights with each other. Fig. 9 summarizes these failure response strategies and their common uses. The numerical frequency of these responses are presented in Fig. 10.

A. (1) Showstoppers

Showstopping failures involve rethinking an approach. For example, if robot performers are repeatedly failing during a given sequence, the entire system, may need to be improved. The team took such a system-level approach to addressing

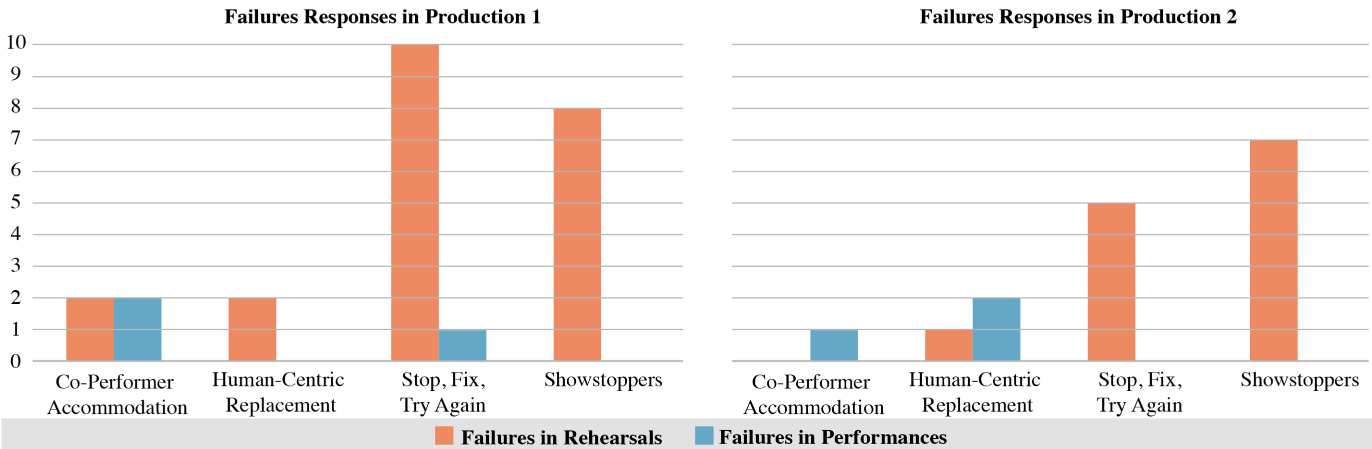

Fig. 10. The distribution of actions and hand placement the participants found suitable to arrange the chairs

failure during Production 1's re-creation of the ChairBot touch sensors, which included a human performer leading the robot chairs around the stage. Initially, in rehearsal, the placement of sensors resulted in unclear and conflicted movement, or in some cases, no movement at all. Thus, half of the first rehearsal was spent testing and improving the placement of these sensors as a system. By the next rehearsal day, the touch sensing was shielded, and significantly more reliable.

Showstoppers can also inspire improved choreography. For example, one ChairBot and human duet that had been intended to begin and end synchronously, could not be reliably performed. These technical limits required a new approach to performative timing, requiring human adaptation for successful performance:

> TEAM MEMBER: I remember the Friday, I was asking them, "Hey, can you dance for another 8 bars so that the chairs can finish our dance?"

Another failure that required a response came during part two of Production 2. This performance required the ChairBots to receive input from multiple sensors, without which, a ChairBot might improvise a circle and bump directly into a pillar. While receiving shape code, the ChairBot was originally unable to receive input from the bump sensors until the movement had been completed. This exemplified a software failure. Later versions of the code prioritized inputs and dependencies, so that robots were forced to stop a movement when the bump sensors were activated.

A final example occurred a few days before a live performance, the hardware that connects the Neato vacuum robot to the IKEA chair was unknowingly damaged, resulting in lost parts. An order was placed for the missing parts, however, not in time for the scheduled performance date.

> TEAM MEMBER: I don't want to gloss over this: one of our performers died.

Unfortunately, there was no quick or clear-cut failure response to this material shortcoming. The scheduled performance went live without the fourth ChairBot.

B. (2) Stop, Fix, and Try Again

Stop, Fix, Try Again involving uncovering and correcting a small technical or choreographic failure that can be simple remedied before trying again. Production 2 required ample time to *Stop, Fix, and Try Again* both when creating the geometric shapes and when implementing new technology. In fact, the entire first week was dedicated to programming and re-programming code that would result in four geometric shapes: squares, triangles, circles, and spirals. The coding process involved testing, evaluating, and recreating until a clear sphere or triangle manifested in the ChairBot's movement. This endeavor exemplified the use of *Stop, Fix, Try Again* when creating the ChairBot's motion and performance.

> TEAM MEMBER: Getting the shapes right, for them to be readable by the audience, was trial-and-error. We applied mathematics to calculate how large the circles should be, how many points of turning, but that math doesn't cleanly convert to Neato robot language. Days were spent creating and recreating shapes.

Let it also be said that the humans involved in both productions also required ample troubleshooting time to clarify both their movements together and with the robots. Instances of humans using *Stop, Fix, Try Again* have not been included in the data, however, it was frequently adapted into the resolution of robotic failures.

In one instance, this resulted in changing the technology from pre-programmed to tele-operated motion; in Production 1 there was a scripted sequence wherein one dancer suspended another in the air, with her back facing the chair, while a ChairBot wheeled underneath. Originally, this sequence was designed as a pre-programmed motion lasting around eight seconds. The difference between a well-timed lift and a ChairBot-human collision became delicate, garnering distrust between the lifted performer and the ChairBot.

The problem was "fixed" by switching the movement from pre-programmed to tele-operated, allowing the engineer to adjust both the speed and time in which the ChairBot wheeled underneath the suspended dancer. This resolved the dancer's distrust, improved overall safety, and allowed for more flexibility in timing. The *Stop, Six, and Ary Again* method was used at least five more times in Production 1 in situations where the ChairBots faltered in terms of performative objectives.

> TEAM MEMBER: We would segment the performance, so we could really rehearse each part in depth and then spend time bridging them together...we would just tackle it, run it, troubleshoot it, adjust it, fix it, run it again.

C. (3) Co-Performer Accommodation

Despite careful planning and dedicated rehearsing, performers must anticipate the unexpected during live performance. Mishaps could come in the form of dropped lines of dialogue or missed entrances. The responsibility to improvise solutions and communicate through the uncertainty is shared between the performer and co-performers.

During the rehearsal process for Production 1, Co-Performer Accommodation accounted for 28.6% of responses to choreography failures, such as timing or spatial positioning. This meant human dancers were adjusting their timing, positioning, or even the choreography sequence itself, to account for variability in the ChairBot's performance. For example, on the morning of the Performance Day for Production 1, we discovered the venue floor was carpeted, which decreased chair speed due to increased friction, and caused the chairs to drag. This obstacle affected both the quality and topography of robot movement. There was not sufficient time to reprogram the code, thus, it became the responsibility of the human performers to adjust spatially to where the chairs ended their motions, or, in another case, loop choreography they had already created to allow extra time for the robots to arrive in their desired position.

> TEAM MEMBER: We had to match the robot movements even when they didn't perform in regular counts.

D. (4) Human-Centric Replacement

This concept of replacement can be applied to human performers replacing or humans manipulating technology to replace robotic scene partners in times of failure. In a situation where robotic performers failed, responding by replacing this technology, either with a human or additional technology, accounted for 18.2% of solutions used while rehearsing Production One and 33.3% of solutions used while rehearsing Production Two. Technology was used to replace technology in both rehearsal processes with simple failures, such as battery depletion in controllers or ChairBots. A backup ChairBot or controller would replace the faulty technology.

> TEAM MEMBER: We always had a human resiliency plan because humans are much more adaptable than technology.

For example, there was an "understudy," or third ChairBot performer, prepared to roll-in and replace a faulty ChairBot in Production 1. If this third ChairBot also failed, a team member was prepared to execute all chair choreography by manipulating a chair on wheels. In Production 2, it also happened that one bump sensor was not operating correctly. Thus, a team member maintained close proximity to this ChairBot throughout the performance so as to replace the bump-sensor function and avoid a dangerous collision. By replacing failing technology with humans, the objective of improvisational geometric movement was able to be explored safely during this piece.

VI. Discussion

Robots frequently fail. While some robots can just fail and be fixed, many rising robot applications would suffer from highly visible robot failures. Increasing the robot reliability in social settings is important not only because people are highly reactive to robots, but also because many robot actions require continuation despite failures. When actors stumble during a live performance, they regain their balance, and this is the lesson theater can offer to general robotics application: both robots and their human operators should be ready to improvise.

In this paper, we provide a typology of robot failures and a number of failure responses, and offer the following insights live performances and demos:

- Improvisational training will be useful for both human and technological performers.
- Failures should be presumed to happen.
- Technical and human-centric backup plans should be in place.

If robots are expected to perform consistently, repeatedly, and gracefully in public-facing roles, time must be invested in rehearsing these roles and developing effective back-up plans. During the described research, rehearsal allowed the team to understand the ways in which robots can fail. These failures were then designed into pre-defined backup plans. While these strategies are rooted in theater methodology, they can be applied both on and off the stage. Collaborative robots, for example, by definition have a person around them that could potentially save the show. But more broadly, almost every robot has a human team behind it.

Our experiences also offer insights into interdisciplinary collaboration. To direct robots to perform, one must have a clear idea of what the robots are capable of. Similarly, to program robots to perform, one must have a clear idea of how to program or accomplish the desired robot expression and a working understanding of the story structure. The collaborative nature of these endeavors invited members to bring both their disciplinary expertise and fresh perspective into both the creative and technical aspects of the production.

VII. Conclusion

Live performance invites the unexpected.In having a theater artist visit our lab, we realized that practicing our mistakes also helped us practice our solutions. Inevitably, mistakes occur. Extracting data from the two productions, we include a typology of common robot failures covering both choreographic and technical failures. This typology aids the reader in understanding what can go wrong and which solutions are appropriate responses to these failures.

In particular, four primary methods have been offered to deal with robotic failures. **Showstoppers** are best addressed (and sought out) during the rehearsal process. **Stop, Fix, and and Try Again** is a rapid solution that should be sought out in rehearsal, but can also be used on-site during the final check before the show. **Co-Performer Accommodation** is most flexible if one is required to improvise around a live failure, particularly one that is unexpected.Finally, **Human-Centric Replacement** must be planned out before the performance, but enables a backup robot, remote control, or human-centric character to take the place of a faulty system.

The stakes of live performance are highly relevant to sponsor demos which can decide the future of a particular project's funding. They are also relevant to contexts where customers interact with robots. Rapid impressions during these live, interactive performances can determine whether a customer stays in a store. From the factory floor, to giving directions at a mall, such interactive robots will need to continue work, even when they're not totally working, and both human and technological backup plans are likely to keep them online.

Human-robot performance teams are much more reliable than robot starlettes operating alone. The combination of human and robot performers is also an opportunity to explore human-robot relationships and the role minimal robots can play in interaction. The robot's programmers can help the robots before a show, and the robot's co-performers and colleagues can help the robots if there are problems during the show. In our future work, we may invite you to take your seats, or we may just ask you to stand up and dance with them.

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