OUTPUT: Translating Robot and Human Movers Across Platforms in a Sequentially Improvised Performance

Catie Cuan[1], Ellen Pearlman[2] , and Andy McWilliams[3]

Abstract. "OUTPUT", a performance piece between a fifteen foot tall ABB IRB 6700 robotic arm named, "Wen", and a human performer was created over the course of a 16-week "Mechanical and Movement" residency at ThoughtWorks Arts in New York City, in conjunction with the Pratt Institute's Consortium for Research and Robotics (CRR). The performance's purpose was to create relationships between vestiges of real (human) and technologically captured bodies. This piece also initiated the development of two new software tools, CONCAT and MOSAIC. This paper explores tensions between the impact of a live human or a live robot and their representation by reprocessing through machines - cameras, animations, sensors, and screens.

1 ARTISTIC MOTIVATION & CONTEXT

Contemporary popular media often reinforces fearful notions of the future between humans and robots: a dystopian, hierarchical landscape where menacing robot overlords rid humans of agency, subjugating them into mere perfunctory slaves. Humans appear physically and mentally inadequate while robots are dominant and inviolable. These sentiments may be especially threatening for individuals who do not have personal, real-life experiences with robots.

However, different non-fiction views contrast this robot apocalypse. A 2018 study by researchers from Uppsala University and the London School of Economics demonstrated that the introduction of industrial robots (like the Wen) increased wages for employees, as well as the number of highly skilled jobs across 14 industries in 17 countries, from 1993 to 2007 [1]. A 2018 survey article in Science Robotics listed power sources for long-lasting mobile robots and functional artificial intelligence as unresolved and critical challenges [2]. Many of today's robots, from the iRobot Roomba to Google's Alpha Go, are single purpose robots requiring a human collaborator in order to function meaningfully in the real world.

Narrative discourse and live performance are methods to not only initialize, but also reshape individual's impressions concerning their relationship to robots. For example, how might

a nine-foot Wen arm be recast when modified into an animation or film presented alongside a dancing human performer? Cuan personally experienced this reshaping while experimenting with the robot. After an initial work session with the Wen, Cuan recognized two opposing identities embedded within the robot. In the first, the Wen was a physically large, power-devouring, and forceful robot, capable of stretching steel and slicing at high speeds. In the second, the Wen had a limited motion range, was confined to an indoor track, and relied on activation through laborious, error-ridden programming. The physical identities were contradictory, with the latter directly contrary to the idea of a dominant, fear-inducing robot.

Figure 1. Cuan in performance with the CONCAT software.

Figure 2. Cuan holds a web camera and wireless mouse to create an improvised grid of captured videos with MOSAIC.

---

[1] Dept. of Mechanical Engineering, Stanford University, 94305, USA. Email: `ccuan@stanford.edu`.

[2] Parsons/New School University, New York, 10011, USA, RISEBA University, Riga, Latvia Email: `pearlme@newschool.edu`

[3] ThoughtWorks Arts, New York, 10011, USA. Email: `andy@thoughtworks.io`

Figure 3. Cuan in performance with projected video of the Wen robot in the background.

In addition, this ABB model is primarily utilized in manufacturing and research contexts; one could imagine stark lighting, repetitive motion, and industrial scenery at those junctures. Yet when Cuan first experienced the robot, her immediate reaction was to find it beautiful, cloistered like a secret on the third floor of a Brooklyn warehouse, lit warmly by the enormous windows blanketing one wall. The robot's painted monochromatic grey limbs punctuated by colored wiring and raised text inspired her to consider the robot's aesthetic qualities equally to its functional ones.

Cuan observed the distinctive movement qualities of the Wen, recognizing the smooth continuity and fixed speed of each joint in relationship to the other. The cylindrical nature of the robot removed many of the planar attributes typical to a human body (ex. Front corresponding to the face and eyes) and thereby provided a new palate of choreographic potential. She elected to create choreography for the robot that would emphasize these distinctive qualities and choreography for herself that would initially support and then oppose them.

A central artistic motivation emerged to reframe the Wen robot as an attractive source and performer of dance, rather than an intimidating, industrial machine. In doing so, OUTPUT formulated and highlighted the tension between the functional and aesthetic qualities of humans and machines, as well as their respective expectations and representations when live versus recorded. The representations of both the human performer and the robot were reprocessed through digitized methods: cameras, animations, software, sensors, and screens. Sensors, video, and joint angles perform a similar function of parsing a complex entity into discrete re-represented elements. OUTPUT showed these elements together on stage in a narrative manner – beginning from and returning to the whole form of the human and robot with the representations in between - to accentuate the complexity and limitations of each.

ThoughtWorks, a global software consultancy, incubates contemporary art and technology works through its ThoughtWorks Arts program [3]. OUTPUT was created during Catie Cuan's 2018 artistic residency at ThoughtWorks, in conjunction with ThoughtWorks developers Andy Allen, Andy McWilliams, and Felix Changoo, filmmaker Kevin Barry, and CRR staff Mark Parsons, Gina Nikbin, Nour Sabs, and Cole

Belmont. OUTPUT premiered September 14th, 2018 at Triskelion Arts' Collaborations in Dance Festival in Brooklyn.

2 BACKGROUND

The history of science fiction paints robots as terrifying and enchanting, from Mary Shelly's *Frankenstein* to the first appearance of the word "robot", in Karel Capek's "Rossum's Universal Robots" [4]. Later stories in other mediums have echoed these sentiments, from "The Terminator" to "Black Mirror". This historical context backgrounds the work of roboticists and artists alike.

Roboticists and performing artists have collaborated on performance and interface projects for many years in order to explore human and robot interaction. Robotic technologies were presented in the context of theater towards the development of sociable robots [5]. A narrative performance explored relationships between humans and caregiving robots [6]. Prior work described developments about nonverbal interaction between humans and robots during theatrical practice [7]. A performance was created featuring a cast of humanoid robots [8]. Dancers generated expressive movement for robots in [9].

Dancers' movement expertise was utilized to create a model for non-anthropomorphic robots' socialization and interaction [10]. An improvised performance between a dancer and two industrial robot arms explored questions of space and movement in dance and architecture and improvised control methods for robots [11]. Creative approaches for generating robot motion developed in entertainment robot contexts was described in [12]. Robot motions were generated from a model employing ballet warm up exercises and demonstrated in performance [13].

Choreographers have utilized motion-capture technology to generate animation, videos, and new movement for live performance in collaboration with programmers and digital artists [14] [15] [16]. Animation has been used within live performance including dance and theater [17]. The body of a machine in performance illuminates distinctive questions from that of a human body, as explored in [18].

For dancers, sensory information like the feeling of the stage floor and the visual effect of lighting are integral to expression and self-protection. Similarly, robots are equipped with sensors to safely and expressively actuate through their environment. Brooks [19] stated the need for robotic motion to be based on sensor motor coupling in conjunction with joint position sense and hand-eye coordination. Goldberg [20] wrote extensively on the relationship of distance and knowledge in relation to robots and their operators. This has led to a perceived tension between the sensory motor input information of a robot in relation to the desired simulation of that movement.

3 PERFORMANCE DESCRIPTION

OUTPUT is a multi-part project composed of choreography, software, short films, an improvisational structure, and a methodology for choreographing robots. These elements have been presented individually in installation formats and were composed into a live performance also referred to as OUTPUT and described below.

OUTPUT created sensor-based motion capture, animated and cinematic relationships between the vestiges of real (human) and captured (technological) bodies in real and time-delayed

sequencing using the CONCAT and MOSAIC software. It achieved this by employing a narrative arc that started with a single female dancer engaged in a solo, after which the dancer journeyed through the representations of her and her movement as translated onto the robot. Choreography specifically created for the robot was demonstrated via video, while the dancer attempted to move similarly in an improvised segment. The arc closed with the same single dancer and original solo movement material, now performed with the video of the Wen projected in the background. The dancer performed the solo facing the projected Wen video rather than the audience, to reveal the Wen as both partner and inspiration for the performance process throughout (Figure 3).

The first representation after the opening solo was a projected animation of the dancer's live skeleton gathered through the Kinect infra-red depth sensor. Partway through this segment, a second animation, of the Wen robot, appeared next to the human skeleton on one projected screen. The software CONCAT created the combination of this live Kinect skeleton with the rendered robot. All three elements on stage: the live dancer, her Kinect skeleton, and the animation of the Wen, were moving in the same sequence. A second software, MOSAIC (Figure 2), facilitated a layering of these three elements into video grids with a live web camera on a second projected screen.

The set elements were two screens with projectors on stage in addition to a wireless keyboard, web cam, two laptops, and a Kinect v2. The MOSAIC and CONCAT software tools were projected onto these different screens at the back of the stage. MOSAIC functioned by Cuan selecting various keys on the wireless keyboard to record short videos and layer them together into expanding and contracting grids of videos. Cuan improvised with the MOSAIC software during the OUTPUT performance to craft new projected grids throughout the show.

Cuan served as both a performer and choreographer with these two different software tools, effectively bringing the audience into the process of composition and performance. The improvisational elements of the performance, governed by specific physical and technological parameters, led to a feeling of being "inside the machine". This also demonstrated the human agency behind seemingly autonomous processes.

4 SOFTWARE IMPLEMENTATION

OUTPUT was aided by the development of two new software tools, CONCAT and MOSAIC.

The artistic motivation necessitated different representations of the Wen through software. The creation of CONCAT allowed Cuan to generate choreographic material for herself, utilizing the moving Wen as inspiration, outside of the CRR space. The fact that Wen could not be transported from CRR due to its sheer bulk and size also supplemented the desire for CONCAT [21]. Thus Cuan as the dancer was able to practice and respond to the Wen movements from any physical location outside of the CRR lab. The limbs of the human (highlighted in red), and the Wen robot's movements (animated in white), were both framed against a black background (Figure 5). CONCAT ran live time using a Kinect and laptop computer during the final performance (Figure 1).

The CONCAT code combined two input sources into a single visualization: one input represented a dancer's real-time movements, and the other represented the movement of the Wen

robotic arm.

For the representation of the Wen, first Cuan choreographed a movement sequence for the robot by mapping the robot's joints onto her own body. For example, during one work session, she elected that joint one – the uppermost joint of the robot referred to as the head – would map to her head, and that joint seven – the lowermost joint – would be her right ankle. She internalized the capabilities of each joint – from simple hinge motion to full rotation – while choreographing from this basis. A second strategy Cuan employed was to formulate moving notion for the robot, for example, "recoiling in shame after extending too far" and visualized ways to achieve this with the robot's motion.

These motion sequences could then be programmed onto the robot in two ways: 1 - by drawing a line with a mouse inside the Rhino 3D desktop modeling software that the robot's head (uppermost joint) would follow or 2 – by programming each joint individually to move sequentially or simultaneously using the ABB native software and a joystick with two degrees of freedom. In the first case with Rhino, the precise joint angles of the remaining joints (not the head) are determined by the software to minimize the space traveled by each joint in order to reach the desired head position. Therefore, the joint angles could not be known until the movement sequence runs. In the second case with the ABB native software, the sequence was tested at several intervals before running from beginning to end, to ensure none of the programmed joint angles violate the robot's joint limitations. Both programming processes were incorporated to choreograph the robot.
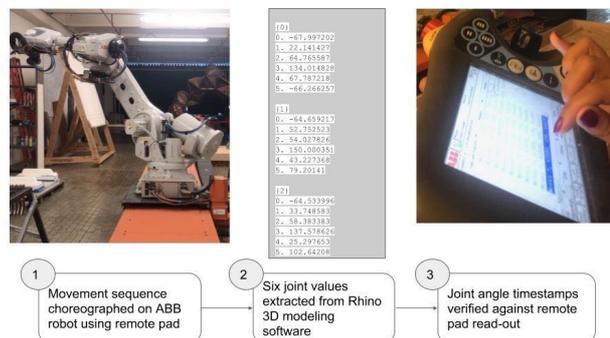

Figure 4. The phases of the translation process: from the original Wen movement (1) into a series of joint angles (2) matched to timings on a remote pad (3).
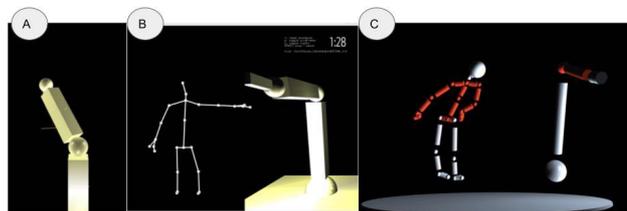

Figure 5. The changing visual representation of the original Wen robot (A), then with the added Kinect skeleton in two dimensions (B), and the final appearance of the three dimensional skeleton and Wen (red highlight) (C).

The Wen robot then executed the sequence and its joint angles were captured on video and on the tablet with corresponding timestamps. The recording of the Wen joint angles were mapped to a rendering of a 3D representation of the robot movements on a screen (Figure 4). The dancer's body was simultaneously monitored using a Microsoft Kinect v2 infra-red depth camera. The motion data from the Kinect was exported from Microsoft Visual Studio with a plugin that broadcast the motion data to a C++ OpenFrameworks program. The final sideby-side representation of the Wen joint angles and the dancer's body was also written in the OpenFrameworks toolkit.

The OUTPUT performance included an improvised platform in the form of the second specialized software MOSAIC, created by creative coder Jason Levine [22]. MOSAIC used a web cam to make small, short videos, and displayed them in a grid using various key commands. It layered looped videos of human movements from multiple sources and angles onto a live time projected screen. These software displays were shown alongside the video of the moving robot and the live dancer as part of the performance (Figure 2).

5 CONCLUSION

The performance piece OUTPUT created a unique relationship between traces of a real human and a captured technological body by using a nine-foot tall ABB IRB 6700 robotic arm named, "Wen". It explored the space and inherent tensions of a simultaneously live and remote representation between these entities in order to reshape people's perceptions of a looming, dystopic future with robots. The artistic motivation and the Wen's non-portability necessitated the development of two new software tools, CONCAT and MOSAIC. These tools led to a sentiment of ubiquitous computing and live-time development during the performance, parsing complex sections into discrete re-represented elements. OUTPUT demonstrated that artistic, analogue, and digitized methods of human agency were behind seemingly autonomous processes. This contributed to the perception of a more symbiotic relation between humans and robots.

REFERENCES

[1] G. Graetz and G. Michaels. Robots at Work. In: *The Review of Economics and Statistics*. A. Khwaja (Ed.). MIT Press (2018).
[2] G. Yang, J. Bellingham, P. Dupont, P. Fischer, J. Floridi, et. al. The grand challenges of Science Robotics. In: *Science Robotics*. (2018).
[3] ThoughtWorks Arts Residency. https://thoughtworksarts.io/
[4] J. Cohen. *Human Robots in Myth and Science*. AS Barnes (1967).
[5] C. Breazeal, A. Brooks, J. Gray, et. al. Interactive Robot Theater. In: *Procs. 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems* (IROS), (2003).
[6] E. Jochum, E. Vlachos, A. Christoffersen, et.al. Using Theater to Study Interaction with Care Robots. In: *International Journal of Social Robotics*, Springer Netherlands (2016).
[7] H. Knight. Eight Lessons about Non-verbal Interactions through Robot Theater. In: *Procs. International Conference on Social Robotics* (ICSR), (2011).
[8] C. Lin, C. Tseng, W. Teng, et.al. The realization of robot theatre: Humanoid robots and theatrical performance. In: *Procs. International Conference on Advanced Robotics* (2008).
[9] A. Nakazawa, S. Nakaoka, K. Ikeuchi, et.al. Imitating human dance motions through motion structure analysis. In: *Procs. International Conference on Intelligent Robots and Systems* (IROS) (2002).
[10] P. Gemeinboeck and R. Saunders. Towards socializing non-anthropomorphic robots by harnessing dancers' kinaesthetic awareness. *Cultural Robotics*. (2015).
[11] C. Varna. Improvisational Choreography as a design language for Spatial Interaction. PhD Thesis at Fascinate Conference. (2013).
[12] E. Jochum, P. Millar, and D. Nunez. Sequence and chance: Design and control methods for entertainment robots. *Robotics and Autonomous Systems*. K. Berns, R. Dillmann, M. Gini, R. Grupen, J. Ota (Eds.). Elsevier (2017).
[13] A. LaViers, L. Teague, and M. Egerstedt. Style-based robotic motion in contemporary dance performance. *Controls and Art*. Springer (2014).
[14] A. Dils. The Ghost in the Machine. In: *PAJ: A Journal of Performance and Art*. (2002).
[15] J. Abouaf. "Biped": a dance with virtual and company dancers. In *IEEE MultiMedia*. (1999).
[16] K. De Spain. Digital Dance: The Computer Artistry of Paul Kaiser. In: *Dance Research Journal*. (2000).
[17] B. Hosea. Substitutive bodies and constructed actors: a practice-based investigation of animation as performance. PhD Thesis, University of the Arts, London. (2012).
[18] L. Demers. The Multiple Bodies of a Machine Performer. In: *Robots and Art*. D. Herath, C. Kroos, Stelarc (Eds.). Springer (2016).
[19] R. Brooks. Elephants Don't Play Chess. In: *Robotics and Autonomous Systems*. K. Berns, M. Gini, J. Ota (Eds.). Elsevier (1990).
[20] K. Goldberg. Telerobotics and Telepistemology in the Age of the Internet. MIT Press (2001).
[21] A. McWilliams, A. Allen, F. Changoo, and C. Cuan. CONCAT software. https://github.com/thoughtworksarts/concat/ (2018).
[22] J. Levine, A. McWilliams, and C. Cuan. MOSAIC software. https://github.com/jasonlevine/video-mosaic-tool (2018).