Generating Human-Like Motion on Robots Through Teleoperation in Functional Tasks

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Abstract-Creating efficient and natural-looking movement in remotely-operated robots may be beneficial in dynamic environments requiring human interaction. This paper examines two methods of pose control for a Rethink Robotics Baxter robot via an Xbox One controller and presents an outline of future work. The first method is a joint-by-joint (JBJ) method that specifies the movement of each joint in a sequential fashion. The second method, named Robot Choreography Center (RCC), utilizes abstractions created by movement experts to simultaneously move multiple joints of the robot in a predictable manner. Thirty-eight users were asked to perform four tasks with each of the methods of control. Performance and perception data were used to analyze the strengths and weaknesses of each method. Analysis indicated that while both methods performed well in static tasks, the RCC method was more successful for dynamic tasks. Additionally, the joint-byjoint (JBJ) method was considered more precise, easier to use, safer, and more articulate, while the choreography-inspired (RCC) method of control was perceived as faster, more fluid, and more expressive. Proposed work leverages the findings in this study to further evaluate the terms used to describe each method of control to better understand what defines human-like motion and explore it in the context of teleoperation.

I. INTRODUCTION

Moving through dynamic environments requires the use of complex movement designs. In teleoperation, these movements must be communicated by a human to a robot in a quick and efficient fashion. Additionally, the expression of the robot and the perceptions of any humans in the vicinity of the platform are also valuable aspects in teleoperation. To this end, we suggest that rapid pose-control for robots may offer increased flexibility and more success in dynamic environments, as well as generate more fluid and human-like motion.

Teleoperation presents various challenges for human operators, including remote perception and manipulation [1]. Determining the best way to transfer user input to robotic output given a particular set of constraints is something that demands a great amount of attention and researchers are investigating several methods of controlling a robot, including traditional joystick, body part tracking [2], and whole-body teleoperation [3].

The movement of articulated robots may be prescribed in a multitude of ways, two of which are end effector position and pose specification. Prior work has explored using 3D vision to perceive the motion of a human "teacher" and then estimate the body posture of a humanoid robot using inverse kinematics [4]. Several numerical solvers exists for inverse kinematics [5], [6], [7]; however, if used by itself, IK may present singularities in which a specific end effector position may be reached with a variety of joint angles. Furthermore, the greater the number of degrees of freedom of the robot, the more computationally expensive IK becomes [8].

Meanwhile, teleoperated robots with pose specification, such as the PackBot, are usually commanded in a jointangle-by-joint-angle fashion. However, this method is often labor intensive and results in low command frequency [9]. Pose specification may also be used to produce engaging, variable motion. This consideration has been discussed in telepresence as well, where the way the artificial body looks and moves affects the perception of the remote human [10].

This work focuses on pose control for articulated robots with the goal of having human-like motion that improves performance on dynamic tasks. Performance metrics for four tasks and perception ratings provide relevant results comparing joint-by-joint (JBJ) and choreography-inspired (RCC) methods of control.

The rest of the paper is structured as follows: Section II reviews the high-level, embodied ideas about motion that inspire this work, Section III reviews the procedure for the user studies, Section IV presents the performance and preference data comparing the methods of control, and Section V explicates how the findings of this study are being used to further examine the perceptions of observers viewing the movements generated by both methods. Finally, Section VI concludes the presentation of work.

II. DEVELOPMENT OF HUMAN-LIKE MOVEMENT TELEOPERATION SCHEME

Prior work has developed a motion specification scheme that showed promise for creating human-like motion across multiple platforms [11]. That method was then extended into a teleoperation scheme and tested against a benchmark method on a single user across four tasks in [12]. This paper extends the analysis of the two teleoperation methods in [12] to a pool of in-lab participants.

This section will introduce concepts from the Laban/Bartenieff Movement System (LBMS) that inspired this line of work and were used to train participants. Leveraging highlevel movement commands using the choreography-inspired method may be thought of as trying to synchronize an internal model of motion with the movement of the device being operated.

The Space component of LBMS describes the spatial orientation of a motion. The creator, Rudolph Laban, de-

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veloped *movement scales* to create a larger understanding of balance in motion [13]. Similar to musical scales played by musicians, these movement scales involve a series of complex, but related movements between spatial pulls, which are akin to notes in music. These scales are used to "install" new platforms into the RCC system [11] and index pose commands in [12].

Four distinct categories of kinesphere sizes were introduced to the participants of this study: near-reach, middlereach, far-reach, and further-reach. The near-reach kinesphere size is defined for movements that are close to or touching the body. Middle-reach spans the region between near-reach and the arm being fully extended. Far-reach is the kinesphere size that correlates to the arm being fully extended, while further-reach requires whole-body translation in order to occupy the desired space.

In addition to the concept of kinespheres, this work also utilizes spatial pulls, which are comprised of both plane and direction. Within each kinesphere, three longitudinal planes exist: the high plane, the middle plane, and the low plane. Within a single plane, eight spatial directions can be specified: forward, backward, right, left, and the diagonal directions in between.

The mappings between motion concepts and buttons on the Xbox One controller for each method and full descriptions of each method and how they were implemented may be found in [12] and [14].

III. EXPERIMENTAL DESIGN

To evaluate the performance advantages and understand the preferences of users for each of the methods of controlling the robot, a user study was conducted.

A. Movement Training

Participants began the study with a short embodied training so that they could understand how the concepts for each method related to their own bodies. Participants were then shown how the method was mapped onto the gamepad using visual guides for each method. After the movement training, participants had to pass a verbal test to prove that they understood the concepts related to the method in order to move on to controlling the robot.

B. Teleoperation Tasks

The study utilized four tasks that were designed in [12] and were described and implemented in [14]. Task 1 required the right arm of the robot be placed through closest hula hoop while Task 2 required both arms to be placed through both hula hoops. Task 3 involved using one arm to strike a balloon into a whiteboard in front of the robot and Task 4 added an obstacle in front of the robot such that it had to be removed prior to being able to strike the balloon into the whiteboard. The laboratory set up for each task is shown in Fig. 1 and a discussion of successful methods of approach for each task is provided in [12].

These tasks were used in order to compare the joint-byjoint (JBJ) and choreography-inspired (RCC) methods. Each task was categorized as either a one-arm or two-arm task, as well as a static or dynamic task. These tasks provided a range of activity with which the performances could be evaluated to compare the types of tasks in which each method would excel.

C. Questionnaire Design

After each task, the participant was asked to fill out a survey containing a NASA TLX questionnaire, which rates six different categories – mental demand, physical demand, pace, success, amount of effort, and insecurity or discouragement – on a scale from 0 to 20.

Once all tasks for both methods were completed, the participant answered an exit survey asking for demographic information, as well as information about the perception of the participant using the following eight questions:

- 1) Which method was faster?
- 2) Which method was more **precise**?
- 3) Which method produced more **fluid** movements?
- 4) Which method was **easier** to use?
- 5) Which method felt safer?
- 6) Which method felt more expressive?
- 7) Which method felt more **articulate**?
- 8) Which method did you feel a more **embodied** connection to the robot?

IV. USER STUDY RESULTS

Thirty-eight participants (9 females and 29 males) from the University of Illinois were recruited by advertising through fliers. The ages of the participants ranged from 19 to 34 with an average of 22.9 and a standard deviation of 3.7 years. None of the participants were familiar with the Laban/Bartenieff Movement System or other high-level movement command structures. A full description of the results of the user study are presented in [14].

A. Performance Measures

Performance metrics indicated that Task 1 and Task 2 were completed by over 80% of participants for both methods while Task 3 and Task 4 were more difficult and those who were able to successfully complete the dynamic tasks were more likely to do so with the choreographyinspired (RCC) method. Additionally, the average duration of successful tasks demonstrated that the joint-by-joint (JBJ) method was mildly more effective with static tasks, while the choreography-inspired (RCC) method was more useful for dynamic tasks in which the movement of several joints must happen quickly. Although RCC is shown to be slightly less effective at static tasks, Task 1 performances indicate that it is still a viable method of control for tasks requiring a particular end-position configuration.

B. Perception Measures

In addition to quantitative performance metrics, the average NASA TLX scores provided by the participants demonstrated that there was no statistically significant difference between the average scores for the two methods, except in the level of success and perceived amount of effort required for Task 2. The answers to the questions listed in Section III-C indicated that users found the joint-by-joint (JBJ) method to be more precise, easier to use, safer, and more articulate while the choreography-inspired (RCC) method was found to be faster, more fluid, and more expressive.

C. Qualitative Comments

Additional comments comparing the two methods of control and providing additional feedback further proved the strengths and weaknesses of each method of control. Users wrote that using the joint-by-joint method made it "difficult to achieve complex tasks". Meanwhile, the choreographyinspired method was viewed as "harder to learn", but "[that it] could be more powerful in the long run". Additionally, users wrote that the RCC method "is more natural and comparable to the way humans move".

V. EXAMINING HUMAN-LIKENESS OF RESULTANT MOTION

The research described in this paper was a stepping stone in acquiring more information about human perception of teleoperated robots. Useful data concerning user performance, perception, and preference were collected; however, future work will seek to verify the perceptions of the users with the perceptions of observers who are viewing the movement of the robot rather than controlling it.

This will be done by presenting future users with videos of in-lab participants controlling the Baxter robot to successfully perform the four tasks previously described. Observers will then be able to select words from a word bank to describe the motion of the robot. The words provided in the word bank will be taken from either the questionnaire provided in this work or from the qualitative comments provided by participants who completed the in-lab user study. Additional words may be inserted based on research into synonyms and antonyms for natural or human-like movement. Moreover, observers will be asked to assess whether the motion seen was generated by a human or an algorithm.

Based on the experience of the research team in conducting in-lab user studies, the initial hypothesis predicts that the movements produced by the choreography-inspired (RCC) method of control are more likely to be assigned descriptive words synonymous with human-like and natural.

Figure 1 outlines a user study that will be performed using the data collected from users in this study and displayed to human workers on Amazon Mechanical Turk. The results of this study will help us understand if this hypothesis could be correct.

VI. CONCLUSION

We have reviewed an evaluation of a novel choreographyinspired teleoperation scheme (RCC), comparing it to a more traditional approach (JBJ). The RCC method utilizes movement commands relating choreographic abstractions from the LBMS. This system is rooted in the ability of humans to express high-level movement commands with one another



Fig. 1: Design of in progress user studies. These online subjects will be shown videos of the robot motion produced by in-lab subjects and then select which descriptors they feel apply. We hypothesize that movement produced from our novel method will be seen as more human-like.

such that a group of unique platforms might perform the same movement [11]. Thus, these concepts hold promise for helping to generate human-like artificial motion.

The two methods were compared by attempting to complete the same four tasks. The results of this comparison demonstrated that the joint-by-joint (JBJ) method was more reliable and quicker for static tasks, while the choreographyinspired (RCC) method was more suited for dynamic tasks. Additionally, perception data affirms that the JBJ method is more precise, easier to use, safer, and more articulate while the RCC method is faster, more fluid, and more expressive.

Future work will examine the connection between the RCC method and qualitative descriptions of movement that participants used when describing the method. A better understanding of the properties necessary in deeming a motion as "natural" will help inspire the development of more expressive robots. The proposed extensions presented here may provide quantitative models of what humans perceive as fluid, human-like, and even graceful, motion.

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