Kinesiological Control of Teleoperated Robotic Manipulators

Christopher Bodden
University of
Wisconsin-Madison
1210 W. Dayton St.
Madison, WI 53706
cbodden@cs.wisc.edu

Danny Rakita
University of
Wisconsin-Madison
1210 W. Dayton St.
Madison, WI 53706
rakita@cs.wisc.edu

Alper Sarikaya
University of
Wisconsin-Madison
1210 W. Dayton St.
Madison, WI 53706
sarikaya@cs.wisc.edu

ABSTRACT

While robots have the potential for increasing dexterity for completing manufacturing tasks, the lack of naturalistic robot manipulation makes it difficult for non-experts to control the robot for a desired task. We explore the question of naturalistic control of a robot arm for tasks that have one-to-one mapping to natural human movement, and those that do not against typical joystick control. Through our exploration, we have developed a system that uses computer vision and a data glove to determine an individual's hand position and orientation in three-dimensional space. We map this position and orientation input to the robot's end effector. We show that using a combination of kinesiological control plus specialty functions can achieve similar performance and user perceptions to a joystick. Additionally, kinesiological control without direct mapping to the full range of the robot's actuated motion impairs performance for tasks that could benefit from it. Interestingly, task type had a strong effect on user perception of the control method. We note that further research in this area is needed to fully explore the potential of kinesiological control of co-working robots.

Author Keywords

Robot manipulation, naturalistic control, user study

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

Manipulation of external robot interfaces can be a challenging task, and moreso to enable novice users to control actuated motion with dexterity. The multitude of methods and techniques for manipulating many robot actuators to accomplish seemingly simple tasks generally require extensive training and practice. Many typical control methods for actuated robots require the operator to make a cognitive map from control space to the three-dimensional space in which the robot

Figure 1. The context of our model experiment. The Kinect is on the tripod with a clear view of the participant and his right arm, while a data glove captures hand orientation. The participant is motioning with his off-hand for the robot to open its gripper.

operates. In our work, we explore kinesological control of a robot arm for novice users, looking at precision tasks that have a one-to-one mapping with human motion and those that do not. We contrast this kinesological control with conventional joystick manipulation, which provides more direct input to the robot.

In the implementation of our work, we have developed a system that uses computer vision to track an individual's arm in three-dimensional space and map that input to the end effector of a Kinova Mico robot arm. Our kinesological implementation allows for real-time manipulation and control of the robot arm, and in conjunction with gyroscope readings from a smart glove worn by the individual, allows a user to move, rotate, and actuate fingers of the hand without direct manipulation of a joystick (see Figure 1 for sample setup). In our experimentation, we also allow users to use the Kinova-included joystick to accomplish similar tasks. Through our study, we show how tasks that do not map one-to-one with natural movement can have limitations that need non-kinesological (e.g. direct) control to overcome. However, we also show that depending on the task type, the control type had a strong effect on user perception.

BACKGROUND

Advances in the areas of computer vision and robot control have enabled us to rapidly prototype and use these techniques to allow for novice control of a robot arm. In particular, we utilized the Kinect for Windows SDK [6] to quickly capture an individual's arm with a Microsoft Kinect. By piping hand locations over the network to a machine running ROS (Robot Operating System) [7] interfaced to the Kinova robot arm, we are able to directly control the robot using kinesiological control.

Several prior studies have looked at how remote control of robots can assist in manufacturing and human-robot collaboration tasks. Our work context follows a long line of research in bilateral teleoperation (see Hokayem and Spong for a wide-spanning survey [3]), which concerns issues of stability and telepresence. Critically, the two-way feedback mechanisms between the human operator and the robotic analog needs to be such to minimize perceptible latency in the connection, and also provide enough feedback to judge and adapt input. Park *et al.* [8] represents some early work in teleoperation to help smooth error in input to the robot's output trajectory.

In more recent work, research has started to generalize insights from individual application of telepresence applications. In particular, Dragan *et al.* [2] explore teleoperation with customizable interfaces. Importantly, they identify that both the task context and assistive scaffolding (e.g. input goal estimation) are necessary to support teleoperation and manipulations of complex systems. Specific to the goals of our project, Gi-Hun *et al.*'s work on online retargeting for teleoperation [9] shows the utility of using the Kinect to collect natural movement of an operator and mapping input to the end-effector of a robot, while Labonte *et al.* [4] identify potential scaffolds to assist novice users using different viewpoints in telehomecare applications. While this work sets the context for our work, no work to date has looked at supporting and empirically evaluating different kinesthetic methods for novice control of an actuated robot.

In constructing our qualitative scales for post-hoc questionnaires, we used two seminal studies to report user preferences. Davis [1] presents a methodological approach to measuring participants' perceived usefulness, ease-of-use, and acceptance of information interfaces. Although we adapt this to robot-human interaction, this adaptation of this scale to other interfaces has some precedence—Lin *et al.* [5] uses such an adaptation to measure interaction and perception of experience on the Internet.

EXPERIMENTAL STUDY
Our study involved different control methods of a Kinova Mico arm, while looking at different types of tasks that either do or do not map easily to natural human movement. We use the Kinect to capture the position of the participant's right hand in three-dimensional space, and use a VML data glove to capture fine-grained hand orientation. The participant has the ability to use their off-hand to change the gripper state on the robot arm—a closed fist and an open palm close and open the gripper, respectively. Input is captured on one machine and passes along hand position, orientation, and gripper state via UDP packets to a receiving machine running the ROS application that commands the Mico robot arm to update its pose at 4Hz.

Our research question concerns the effect of kinesiological robot arm control on novice user task performance and perception for tasks that do or do not have kinesiological mappings to human motion. Based on our two tasks, we derived three input modalities, two of which are based on our kinesiological capture system. One modality captures the hand position and orientation, while the other augments this with direct control of non-natural robot actuation (e.g. rotating the robot wrist more than a full rotation). We call this second modality "kines+" in our work. The third input control is the Mico robot's included joystick. The joystick has several modes—the primary moves the end effector in three-dimensional space through a bidirectional pad and twists of the control knob. The other modes modify elbow orientation or wrist orientation and hand gripping.

Study Design
We designed a 3×2 mixed-methods design with the three input modalities: joystick, kinesiological control, and kinesiological augmented with direct input (kines+); and two task types: direct mapping to natural movement (movement), and no direct mapping to natural movement (large rotations). We implemented our study as a mixed-methods design to minimize learning effects of manipulating the robot. Control modality was between-participants and task type was within-participants. Each participant was randomly assigned a control modality and asked to complete two tasks (in counterbalanced order).

Hypotheses
H1: We hypothesize that kinesiological control of the robot arm for natural mappings of tasks will perform better than the two other modes of control, and likewise hypothesize that direct control of the robot with the joystick will help users perform better on tasks that do not have direct mappings. Furthermore, we hypothesize that the combined control method (kines+) will perform as well or better than kinesiological control for tasks with natural mappings, and as well or better than joystick control for tasks without natural mappings.

H2: We hypothesize that the same relationships as **H1** will hold for our participants' perceptions (ease-of-use, usefulness, and enjoyment) of the control method as well. We believe this because kinesiological control should feel more natural and easier to control for tasks with direct mappings, while the additional range of motion provided by the joystick should be perceived better on tasks with no direct mapping.

Participants & Procedure
We recruited participants ($n = 12$) from within a university setting between the ages of 19–40 ($\mu = 27.1, \sigma = 5.5$; 2 females, 10 males). Participants received a candy bar as compensation, and all participants completed the study within 10 minutes.

Participants were randomly assigned their input modality. Each participant was given an instruction sheet with how to manipulate the robot and given an unbounded amount of time

Ease of Use ($\alpha = 0.81$)
1) The control method made it easy to accomplish the task.
2) I felt confident controlling the robot.
3) I could accurately control the robot.
Usefulness ($\alpha = 0.74$)
1) Controlling the robot was easy to understand.
2) I would like to control a robot like this in the future.
3) I found the control method useful.
Enjoyment ($\alpha = 0.85$)
1) Controlling the robot was fun.
2) I felt satisfied while controlling the robot.
3) I felt happy while controlling the robot.

Table 1. Subjective questions asked after each trial for task type for each participant.
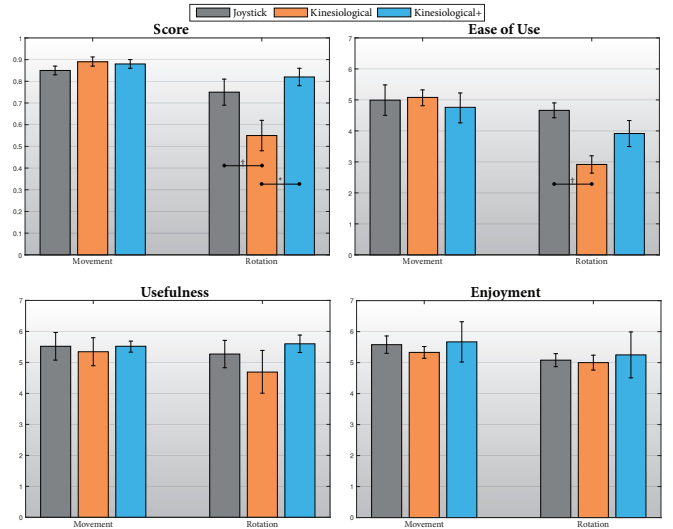

Figure 2. Results for objective (top-left) and subjective measures. Kinesiological control impairs user performance and perceived ease of use for the rotation (no 1-to-1 mapping) task. However, there is no difference between joystick and kines+ control. *Error bars represent standard error.* $* : p \leq 0.01, \dagger : p \leq 0.05$

to practice. Once confirmation was given to proceed, they were given task instructions. After confirming that no clarification questions were needed, a timer was started and stopped when the desired action was completed, with an upper-bound of five minutes. The one-to-one mapping task requested the participant to move a cup from one location on a table to another location (we call this the "movement" task), while the non one-to-one mapping required a 360° rotation of the cup in-place (requiring lifting of the cup; "rotation" task). Upon completion, the remaining task type was administered in the same fashion. After the completion of the two tasks, demographic and robot familiarity information was collected. Each participant completed each task for their randomly assigned input modality once.

Measures
To evaluate participants' performance, we measured one objective metric, *score*, by normalizing the time taken to complete each task by the time allotment of five minutes.

To measure participants' perception of different control types for each task type, we administered a questionnaire, inspired by scales proposed by Davis and Lin [1, 5], after each unique combinations of factors measuring participant perception of the manipulation method with the task type along dimensions of *usefulness*, *ease-of-use*, and *enjoyment*. Three questions per measure were asked along each of the subjective dimensions, shown in Table 1, using a seven-point rating scale from strongly disagree (1) to strongly agree (7). Cronbach's α was ≥ 0.7 for each dimension, confirming the reliability of each scale. Factor analysis was also performed. Three factors were above the Kaiser criterion, and within these factors the loadings for each question were grouped as described in the table.

Results
Participants data was analyzed for each measure using full-factorial analysis of variance (ANOVA). For each measure, control type was modeled as between-participants and task type was modeled as within-participants. Pairwise comparisons were made using Tukey HSD Post Hoc tests. Our analysis also includes equivalence analysis, where our threshold for equivalence is $p \geq 0.25$. Our hypotheses are concerning interaction effects between control type and task type; however, main effects from independent variables are also reported here. Results are shown in Figure 2.

Task performance
Participants scored ($R^2 = 0.79$) higher (took less time to complete the tasks) using *kines+* control ($M = 0.85, SD = 0.06$) than *joystick* control ($M = 0.80, SD = 0.10$). *Joystick* control likewise scored higher than *kinesiological* control ($M = 0.72, SD = 0.20$). Control type had a marginal main effect on score ($F(2, 9) = 3.94, p = 0.06$). Pairwise comparisons showed a significant difference between control types *kines+* and *kinesiological* ($p = 0.05$). Score was found to be equivalent for control types *kines+* and *joystick* ($p = 0.55$). Participants scored higher on the *movement* task ($M = 0.87, SD = 0.04$) than on the *rotation* task ($M = 0.71, SD = 0.15$). Task type was a significant main effect on score ($F(1, 9) = 28.6, p < 0.001$).

The interaction of control type and task type was also significant ($F(2, 9) = 7.62, p = 0.01$). Participants scored higher using *kines+* control ($M = 0.82, SD = 0.07$) than *kinesiological* control ($M = 0.55, SD = 0.13$) for the *rotation* task type. Likewise, participants scored higher using *joystick* control ($M = 0.75, SD = 0.12$) than *kinesiological* control for the *rotation* task type. Both of these interactions were significant effects on score (*joystick-kinesiological*: $p = 0.04$; *kines+-kinesiological*: $p = 0.003$). There were other significant interactions effects, but not relevant to our hypotheses.

User perception
Participants rated ease of use ($R^2 = 0.65$) for the *movement* task ($M = 4.94, SD = 0.78$) higher than the *rotation* task ($M = 3.83, SD = 0.95$). The main effect of task type was significant on ease of use ($F(1, 9) = 14.6, p = 0.004$). The

interaction of control type×task type marginally affected ease of use ($F(2,9) = 3.55, p = 0.07$). Specifically, the *kinesiological-joystick* pair for the *rotation* task was a significant effect on ease of use ($p = 0.04$). Participants rated ease of use higher for *joystick* control ($M = 4.67, SD = 0.47$) than *kinesiological* control ($M = 2.92, SD = 0.57$) for the *rotation* task type. The interaction of the *kines+* and *joystick* control type pair for both task types appears to come from the same population (*rotation*: $p = 0.72$; *movement*: $p = 1.00$). Perceived ease of use was not significantly affected by control type ($F(2,9) = 2.28, p = 0.16$).

Perceived usefulness ($R^2 = 0.84$) was not significantly affected by control type ($F(2,9) = 0.47, p = 0.64$), task type ($F(1,9) = 1.90, p = 0.20$), or the interaction of control type×task type ($F(2,9) = 1.16, p = 0.36$). However, equivalence testing between *kines+* and *joystick* control for both task types seem to come from the same population (*rotation*: $p = 0.99$; *movement*: $p = 1.00$).

Participants rated enjoyment ($R^2 = 0.89$) for the *movement* task ($M = 5.53, SD = 0.78$) higher than the *rotation* task ($M = 5.11, SD = 0.84$). The main effect of task type was significant on enjoyment ($F(1,9) = 6.08, p = 0.04$). Participant enjoyment was not significantly affected by control type ($F(2,9) = 0.12, p = 0.89$) or the interaction of control type and task type ($F(2,9) = 0.08, p = 0.92$). The interation of the *kines+* and *joystick* control pair for both task types appears to come from the same population (*rotation*: $p = 1.00$; *movement*: $p = 1.00$).

Discussion
Our results were able to provide some support for **H1**. Performance for kines+ is similar to kinesiological control for direct mapping tasks and similar to joystick control for tasks with no direct mapping. Joystick control outperforms kinesiological control for tasks with no direct mapping. However, contrary to **H1**, kinesiological control was not significantly better performing versus joystick control for our "movement" task.

Our results provide limited support for **H2** as perceptions of kines+ is similar to kinesiological control for direct mapping tasks and similar to joystick control for tasks with no direct mapping. However, the hypothesized perception difference between joystick and kinesiological was only apparent for ease of use in the no direct mapping task. We hypothesize several factors could contribute to the lack of significant results. First our sample size is small ($n = 12$). Second, we believe for many novice robot users, the novelty of controlling the robot is perceived well even when performance is impaired.

FUTURE WORK & CONCLUSION
This work explored the use of kinesiological control of robot arms as an alternative to traditional joystick and knob controls. We explored control types with respect to two task modalities. While we lacked stastical power to provide evidence for our entire hypotheses, we did show that kinesiological control performs as well as and is perceived similarly to traditional joystick control if the kinesiological control is combined with special abilities provided by the robot. We believe this finding is important to guide improved kinesiological control designs. Designers should consider additional abilities afforded by the robot when implementing retargetting and provide these abilities to the user.

In the future we would like to perform our study with more participants, as well as more trials for each task per participant. We believe this would increase the power of our findings and help to differentiate between control types. We would also like to explore more advanced retargetting, as our work presented here only accounted for the end-effector of the robot. More advanced retargetting could allow manipulation of the position and orientation of each robot link to match the user's demonstration. This improvement could potentially improve how natural kinesiological control feels to novice users.

REFERENCES
1. Davis, F. D. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q. 13*, 3 (1989), 319–340.

2. Dragan, A. D., Srinivasa, S. S., and Lee, K. C. Teleoperation with intelligent and customizable interfaces. *Journal of Human-Robot Interaction 2*, 2 (2013), 33–57.

3. Hokayem, P. F., and Spong, M. W. Bilateral teleoperation: An historical survey. *Automatica 42*, 12 (2006), 2035–2057.

4. Labonte, D., Boissy, P., and Michaud, F. Comparative analysis of 3-d robot teleoperation interfaces with novice users. *Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on 40*, 5 (2010), 1331–1342.

5. Lin, A., Gregor, S., and Ewing, M. Developing a scale to measure the enjoyment of web experiences. *Journal of Interactive Marketing 22*, 4 (2008), 40–57.

6. Microsoft Corporation. Kinect — Windows App Development. `https://dev.windows.com/en-us/kinect`. Accessed: 2015-12-14.

7. Open Source Robotics Foundation. ROS.org — Powering the World's Robots. `http://www.ros.org`. Accessed: 2015-12-14.

8. Park, J., Cortesao, R., and Khatib, O. Robust and adaptive teleoperation for compliant motion tasks. In *Proc. of the Int. Conf. on Advanced Robotics* (2003), 513–519.

9. Yang, G.-H., Won, J., and Ryu, S. Online retargeting for multi-lateral teleoperation. In *Ubiquitous Robots and Ambient Intelligence (URAI), 2013 10th International Conference on*, IEEE (2013), 238–240.