Progression of Human Hand Trajectory Variabilities during a Pick-and-Place Task

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Abstract: This paper investigates the progression of human hand trajectory variabilities during a pick-and-place task. A user study is conducted and human hand positions are tracked optically. Standard deviations of human hand positions over all trajectories within a trial are computed point-wise orthogonally to the direct path between start and goal positions. Statistical tests reveal a decrease of standard deviations from hand start to goal positions. Moreover, stronger variations of standard deviations are noted in during the center part of the trajectories. Contrary to expectations, a longitudinal study design does not reveal learning effects in terms of reduction of trajectory variabilities. The results suggest, that uncertainties of human hand positions increase with the distance to a goal location and could constitute a larger risk for collisions within a cooperative human-robot pick-and-place scenario, e.g. assembly.

1 INTRODUCTION

Human-robot interaction in terms of action coordination and physical interaction has been an intense research field since more than three decades. Especially in emerging fields as future production systems, requirements for ergonomic work systems are considered important aspects and the human operator is predicted to still be involved for a long time in the assembly process of many products, e.g. for performing certain assembly tasks (Faber et al., 2015), with synergies of human cognitive and sensorimotor skills and robotic power and endurance (Shen and Reinhart, 2013). Moreover, a trend to small batch sizes may render investments in complete automation uneconomical (Bley et al., 2004).

Especially, integrating human heuristics may help to improve cooperation as well as align operator's conformity with expectations (Mayer and Schlick, 2012). Contact and proximity sensing, e.g. (Lee, 2009; Lee and Song, 2014) may help to reduce collision risks, however, especially in highly dynamic interaction tasks, such approaches might be too slow and adaptive, respectively, collaborative online planning of robot action, e.g. (Kirsch et al., 2010), might be more effective.

In previous works, we pointed out the influence of different robot configurations on human hand trajectories as well as work load (Kühnlenz and Kühnlenz, 2019).

In the context of investigating robotic influences on human hand movements and optimizing robot action towards reduction of collision probabilities during cooperative tasks, we were in a next step interested in the uninfluenced progression of human hand trajectories and their variabilities in order to obtain a baseline. So, in this paper, we present results from a study on human hand trajectories during a pick-and-place task evaluating average variabilities in terms of standard deviations along the trajectories.

The remainder of the paper is organized as follows: Section 2 presents the hypotheses and study design; Results are presented in Section 3 and discussed in Section 4; conclusions are given in Section 5.

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2 HYPOTHESES AND STUDY DESIGN

In this section the working hypotheses, study design and experimental setting are presented.

2.1 Hypotheses

In the context of our investigations, pick-and-place tasks are considered as basic building blocks, e.g. for cooperative industrial assembly scenarios.

A fundamental assumption to be investigated here is, that the variability of human hand trajectories gradually approaches a minimum, when moving towards a specified goal location, e.g. for picking up or placing objects. This assumption seems likely as the goal location is precisely defined and goal oriented behaviour of the human is required in order to accomplish the task.

So, the first hypothesis to be tested in this paper is

H1: Human hand trajectory variabilities monotonically decrease, when moving from start to goal location.

Additionally, we hypothesize, that if repeating a pick-and-place task, trajectory variabilities would decrease due to learning effects leading to the second hypothesis to be tested:

H2: Repeated conduction of pick-and-place tasks reduces human hand trajectory variabilities.

2.2 Study Design and Measures

A within-subjects (repeated measures) design is chosen for the experimental study. The defined task to be accomplished for the investigations is to move a LEGO® block from one pre-defined location to another in order for the block to be picked up by a conventional industrial robot, which places it again at the start location. The task is composed of the following parts, which are repeated for 1min:

- Move to pick-up-location
- Pick up block
- Move to goal location
- Place block at goal location

(repeat for 1min)

As a measure for trajectory variability we chose to evaluate the progression of the standard deviations orthogonally to the direct path (from start to goal location in x-direction) computed point-wise along the hand path. So, for each repeated pick-and-place trajectory, we extracted the hand position at position x_i measured by an optical tracking system and computed the standard deviations of the point cloud over all trajectories at this point.

The repeated measures design for studying potential learning effects consists in two trials with a short break in between, where the participants are required to fill in a questionnaire on work-load, the results of which being part of another paper.

In order to obtain hand trajectories of approximately equal duration, a synchronous robot arm motion is designed in such a way that the participants are given 5s to pick and place the object until the robot picks it up from the goal location. The total duration of each trial of the pick-and-place is set to 1min.

The complete schedule of the experiment is shown in the following table.

Table 1: Schedule of the experiment.

Item	Content	Purpose	Duration
briefing	introduction into purpose of experiment; explanation of questionnaires, etc.		~5min
PRE-questionnaire	demographical data, dispositional parameters, etc.		~1min
participant placement	sensor placement; preparation of data recording		~5min
adaptation	no instruction	acclimatization, familiarization	~1min
Trial 1	Conduct pick-and-place task	Evaluation of trajectory variabilities	~1min
POST-questionnaire 1	work-load items		~1min
Trial 2	Conduct pick-and-place task	Evaluation of trajectory variabilities	~1min
POST-questionnaire 2	work-load items		~1min
de-briefing			

2.3 Experimental Setting

The experimental setting is composed of LEGO® plates for start and goal locations, a LEGO® block to be moved, a UR3 (Universal Robots) robot arm, a Trio optical tracking system (Optitrack) and three markers (start, goal and hand positions) as shown in the following figures. Marker positions are tracked with 120Hz.

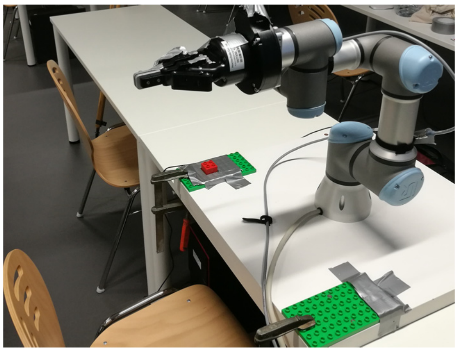

Figure 1: Complete setting.

Figure 2: Goal (left) and start (right) locations on LEGO® plates with optical markers.

Figure 3: Optical marker mounted at participant's thumb.

3 RESULTS

Experimental results were deduced from 20 participants (age between 21 and 30 years, 6 female and 14 male) with 40 interactions (two consecutive trials of each person). One data set had to be dropped due to corrupt sensor data.

3.1 Trajectory Variability between Start and Goal Locations

A typical progression of the participants' hand trajectories is shown in Figure 4 including an uncertainty tube quantifying the progression of standard deviations in terms of ellipses with main axes being orthogonal to the direct path between start and goal position.

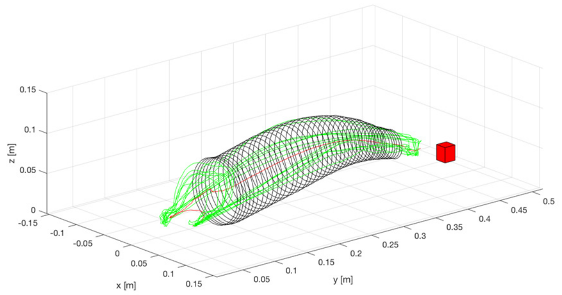

Figure 4: Example trajectories (green) of participant 6 with object (red) to be picked up and uncertainty ellipses.

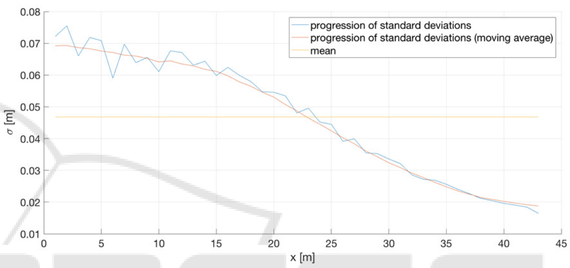

Figure 5: Example progressions of trajectory standard deviations (blue) of participant 10 and moving average filtered line (red).

Figure 5 exemplarily shows the progression of the standard deviations in y-direction orthogonal to direct path as well as the moving average (10 points) filtered progression.

A decrease of the standard deviations can be noted as the participants' hands move from start to goal location as expected.

In order to quantify this decrease, a paired samples t-test is conducted revealing significant results with a strong effect as shown in Table 2. Applying a Shapiro-Wilk test, assumption of normality is shown to be met (W = 0.989, p = 0.969).

Table 2: T-test results.

	t	df	p	Cohen's d
$\sigma_{start} - \sigma_{goal}$	7.570	37	<0.001	1.228

These results clearly show, that a significant decrease of the standard deviation along human hand trajectories from M = 0.046m (SD = 0.13m) to M = 0.028m (SD = 0.015m) is present.

3.2 Variability along the Trajectory

Looking at the measurement data of all participants, it is surprising, that even though a significant decrease of standard deviations is noted for all participants, the forms of the progression of standard deviations seem quite different.

So, in order to quantify this phenomenon, a repeated measures ANOVA is conducted including another measurement item of the standard deviation right in the middle (between start and goal) of the trajectory in addition to the standard deviations at start and goal locations. As Mauchly's test is significant ($W = 0.752$, $p = 0.006$) a Greenhouse-Geisser correction is conducted. Again, the ANOVA results show, that a significant difference between the standard deviations at the different locations with a strong effect can be noted, see Table 3. Post hoc results with Bonferroni correction (Table 4) show, that significant differences exist between all measurement points (start, middle, goal) supporting the assumption of a continuous decrease of standard deviations along the trajectories.

The descriptive statistics, however, also show, that the largest variability of standard deviations of human hand trajectories exists in the middle of the trajectories, see Table 5.

Table 3: ANOVA results.

	F	df	p	η_p^2
σ	45.492	1.602	<0.001	0.551

Table 4: Post hoc results.

		Mean Diff. [m]	SE	t	p
σ_{start}	σ_{middle}	0.005	0.002	3.106	0.011
	σ_{goal}	0.018	0.002	7.570	<0.001
σ_{middle}	σ_{goal}	0.013	0.002	7.536	<0.001

Table 5: Descriptive statistics.

	M [m]	SD [m]
σ_{start}	0.046	0.013
σ_{middle}	0.041	0.017
σ_{goal}	0.028	0.015

3.3 Longitudinal Effects

In order to investigate potential learning effects and resulting improvements of hand positioning in terms reduced standard deviations, t-tests on the differences between standard deviations at the start location for two consecutive trials, respectively, at middle and at goal locations, are conducted.

The t-test results for each of the measurement points turn out not to be significant, so significant differences between the two trials are not observed.

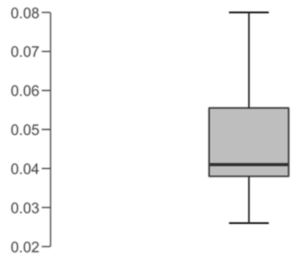

Figure 6: Boxplot of standard deviation measurements at start location of trajectories.

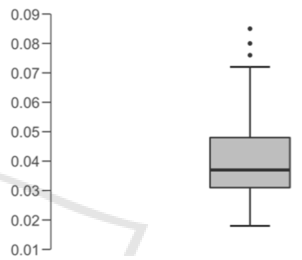

Figure 7: Boxplot of standard deviation measurements at center location of trajectories.

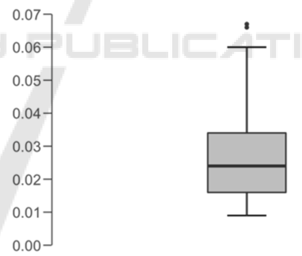

Figure 8: Boxplot of standard deviation measurements at goal location of trajectories.

4 DISCUSSION

The results presented support hypothesis H1 in terms of variabilities of human hand trajectories decreasing from a start to a goal location during a pick-and-place task. However, it is also found, that along the trajectories at some distance to start and goal locations, there is a decrease on average, but a larger uncertainty of the decrease between trajectories, meaning that the form of the trajectories strongly varies between pick-and-place runs. Both aspects suggest, that it might be opportune to include these uncertainty variations along the trajectories in a planning framework with respect to reduction of collision probabilities between human and robot arms.

With respect to hypothesis H2, no significant results are obtained, meaning, that learning effects cannot be confirmed and there is no longitudinal variation of trajectories between pick-and-place trials found. In consequence, a potential action planning framework for cooperative robots would not have to account for such learning effects over time, which simplifies the architecture.

This paper does not claim, that the study is representative in terms of broad variations of demographic, dispositional and situational parameters, but it is nevertheless remarkable, that statistically significant results are obtained with a rather small sample size, which provides at least some potential for generalization.

5 CONCLUSIONS

This paper presents first results on progressions of uncertainties along human hand trajectories during pick-and-place tasks, revealing that there is a significant decrease of uncertainties as the human hand approaches the goal location. However, between start and goal locations, a larger variation of these uncertainties is found due to the variation of trajectory forms.

The results suggest, that collision probability increases with distance to the goal location due to increasing uncertainties and that such spatial progressions of uncertainties should be integrated in robot action planning frameworks for cooperative interaction scenarios, e.g. in industrial assembly or assistive robotics.

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REFERENCES

Bley, H., Reinhart, G., Seliger, G., Bernardi, M., and Korne, T., 2004. Appropriate Human Involvement in Assembly and Disassembly, In: *CIRP Annals - Manufacturing Technology*, vol. 53, pp. 487-509.

Faber, M., Bützler, J., and Schlick, C. M., 2015. Human-robot Cooperation in Future Production Systems: Analysis of Requirements for Designing an Ergonomic Work System. In *Procedia Manufacturing*, vol. 3, Elsevier, pp. 510-517.

Kirsch, A., Kruse, T., Sisbot, E. A., Alami, R., Lawitzky, M., Brscic, D., Hirche, S., Basili, P., and Glasauer, S., 2010. Plan-based Control of Joint Human-Robot Activities. In: *Künstliche Intelligenz*, vol. 24, no. 3, pp. 223-231.

Kühnlenz, K. and Kühnlenz, B., 2019. Insights from a Study on Motor Interference and Task Load in Close HRI, *Advanced Robotics*, Taylor and Francis, *under review*.

Lee, H.-K., Chang, S., and Yoon, E., 2009. Dual-Mode Capacitive Proximity Sensor for Robot Application: Implementation of Tactile and Proximity Sensing Capability on a Single Polymer Platform Using Shared Electrodes. In *IEEE Sensors Journal*, vol. 9, no. 12, pp. 1748-1755.

Lee, S.-D. and Song, J.-B., 2014. Collision Detection for Safe Human-Robot Cooperation of a Redundant Manipulator. In: *Proc. of the 14th International Conference on Control, Automation and Systems (ICCAS 2014)*.

Mayer, M., Schlick, C. M., 2012. Improving operator's conformity with expectations in a cognitively automated assembly cell using human heuristics. In: S. Trzcielinski; W. Karwowski (Eds.) *Advances in Ergonomics in Manufacturing*, CRC Press, Boca Raton, FL, USA, 2012.

Shen, Y. and Reinhart, G., 2013. Safe Assembly Motion - A Novel Approach for Applying Human-Robot Co-operation in Hybrid Assembly Systems, In: *2013 IEEE International Conference on Mechatronics and Automation (ICMA)*.