Robust peg-in-hole manipulation motivated by a human tele-operating strategy

L.-P. Ellekilde*, B. Nemec†, D. Liljekrans*, T.R. Savarimuthu*, D. Kraft*,
F. Abu-Dakka†, A. Ude†, N. Krüger*
∗ The Maersk Mc-Kinney Moller Institute, University of Southern Denmark, Denmark
{lpe, danni, trs, kraft, norbert}@mmmi.sdu.dk.
† Jozef Stefan Institute, Department of Automatics, Biocybernetics, and Robotics, Slovenia
{bojan.nemec, fares.abu-dakka, ales.ude}@ijs.si

EXTENDED ABSTRACT

We present an algorithm to perform a peg-in-hole operation which is motivated by the human performance of peg-in-hole actions in a tele-operating setting. The algorithm was tested on a platform consisting of a robot arm (equipped with a dexterous gripper) of only limited precision in terms of internal parameters and robot-sensor calibration (see Fig. 1). The proposed algorithm should be able to deal with pose estimation uncertainties and also – because of dexterity – with peg slipping in the gripper during the manipulation process. In the following, we briefly describe the results of our analysis of execution of peg-in-hole operations by humans in a tele-operating system and then the robot strategy deducted from that.

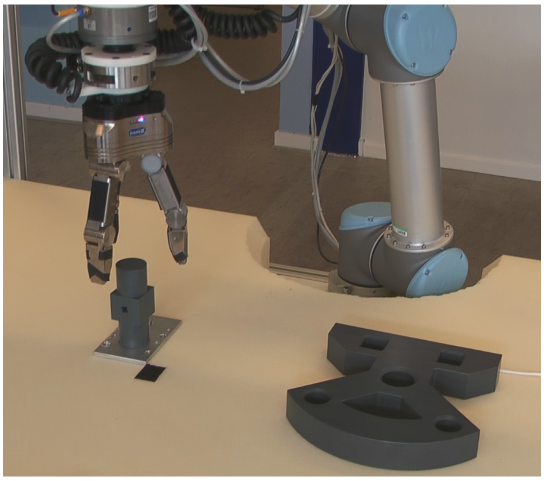


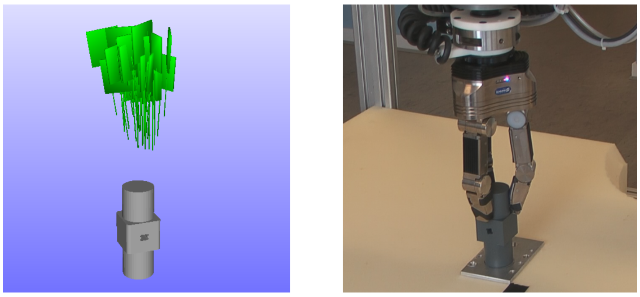
Fig. 1. Setup comprised of a Universal Robots UR-5 and a Schunk SDH-2.

We investigated executions of peg-in-hole actions using a tele-operating system, where the human operator controlled the robot hand by moving its own hand. To measure human hand motion, we mounted magnetic sensors on the human hand. The difference between the peg and hole diameter was very small, which resulted in a tight fit. We made three important findings (for more details see [1]):

H1 **Grasping:** When standing upright as in Fig. 1, the peg was in general grasped with a three finger power grip as indicated in Fig. 2. This grasp enabled optimal force control. However, this optimal grasp is not possible when the peg lies on the baseplate. In this case, the human operator grasped the pin side-wise in such a way that enabled a peg-to-hole relation in the insertion phase with sufficient space for manipulation.

H2 **Approach:** In the approach phase, the angle-distance relation changes systematically so that the relative orientation of the peg with respect to the hole at the moment of touch of the peg and the baseplate is approx. 20 degrees.

H3 **Insertion:** The insertion phase is indicated by force-torque event that arises due to the collision of the peg with the baseplate (see above). A final adjustment of the orientation relative to the hole is necessary to make the peg insertion possible.



(a) Stick representation of various power grasps, which can be applied for grasping the peg.

(b) Grasp executed for grasping the peg.

Fig. 2. Left: Stick representation of possible grasps for the peg. Right: The executed grasp.

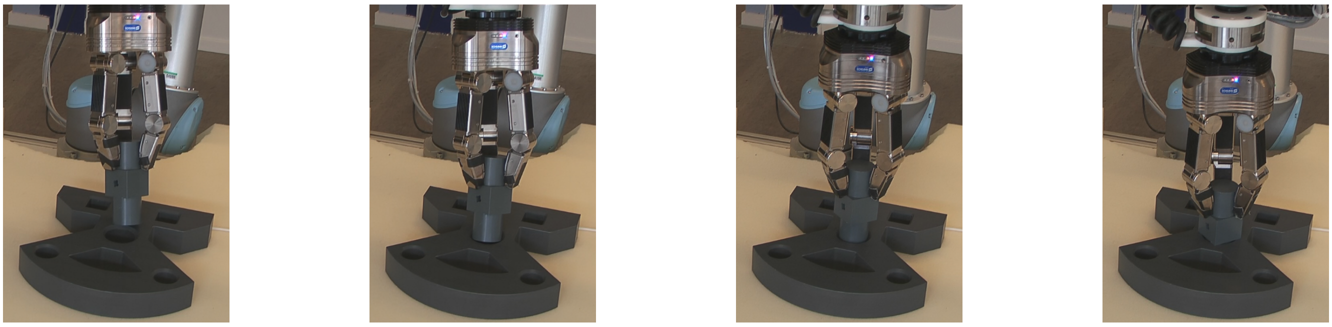
Informed by these insights about the human-guided peg-in-hole performance, we implemented the following strategy on the platform shown in figure 1:

R1 **Grasping:** We assumed the peg to be standing and used the same power grip as done by humans as described in H1 (see figure 2b).

R2 **Approach:** The trajectory from the grasp to the inser-

---

*This work has been supported by the EU project IntellAct (FP7-ICT-269959).



(a) Initial touching between peg and base plate.
(b) Searching for the hole.
(c) Inserting peg using force feedback.
(d) Peg fully inserted into hole.

Fig. 3. The 4 steps in the peg-in-hole procedure.

tion position is executed using a dynamic movement primitive (DMP) [2], following a similar pattern as found under H2.

R3 **Insertion:** A simple reproduction of trajectories obtained by tele-operating the robot during the peg insertion phase is not appropriate because of the position tolerances and grasp uncertainties. In order to overcome this problem, we combined position and force-torque control. Due to higher pose uncertainties than in the tele-operating scenario, we first had to account for a situation in which the peg does not enter the hole after the approach phase (Fig. 3a). We therefore implemented an initial search phase based on random exploration where force and position feedback is used to detect the hole (Figure 3b). During the peg insertion, only the positional part of the trajectory is controlled by a previously learned DMP, whereas force-torque feedback control is used to guide the orientation. Nevertheless, high forces might arise due to the uncertainties. In this case, we have to 1) stop the PiH trajectory execution, 2) apply appropriate corrective strategy to resolve high contact forces (Fig. 3c) and 3) continue with the peg insertion until the peg reaches the bottom of the hole (Fig. 3d). To halt the PiH trajectory, we used DMP phase stopping procedure [2], which was triggered at excessive force-torques deviations. During the DMP stopping, impedance control itself minimizes the force deviations [3], [4]. If the pin remains stuck, we apply an appropriate corrective strategy, which we derived from observing human behavior in such situations. After the peg starts moving again, the DMP is automatically restarted and executed until the peg reaches the bottom of the hole.

The approach works in general well, but the lack of visual guidance in the searching for hole phase occasionally results in failures searching the hole. Movies of the human operations used for learning as well as the robot execution has been made available on the web[1]. To conclude, we have shown that an analysis of human peg in hole operations performed in a tele-operating set-up could guide the implementation of an efficient robot strategy.

ACKNOWLEDGMENT

This work has been supported by the EU project IntellAct (FP7-ICT-269959).

REFERENCES

[1] D. Liljekrans, "Investigating peg-in-hole strategies through teleoperation," *Master thesis at the University of Southern Denmark, http://covil.sdu.dk/publications/ThesisDanniL.pdf*, 2012.

[2] S. Schaal, J. Peters, J. Nakanishi, and A. Ijspeert, "Learning movement primitives," in *Robotics Research: The Eleventh International Symposium*, P. Dario and R. Chatila, Eds. Berlin, Heidelberg: Springer, 2005, pp. 561–572.

[3] I.-W. Kim, D.-J. Lim, and K.-I. Kim, "Active peg-in-hole of chamferless parts using force/moment sensor," in *IEEE/RSJ International Conference on Intelligent Robots and Systems*, Kyongju, Korea, 1999, pp. 948–953.

[4] S.-K. Yun, "Complaint manipulation for peg-in-hole: Is passive compliance a key to the contact motion?" in *IEEE Int. Conf. on Robotics and Automation*, Pasadena, CA, 2008, pp. 1647–1652.

---

[1] See videos http://covil.sdu.dk/videos/ThesisVideo.mov and http://covil.sdu.dk/videos/PegInHoleIntellAct.avi