This is a popular science summary of the Master's thesis *Accurate Simulation of a Collaborative Robot Arm with Cartesian Impedance Control* [1].

Accurate Simulation of a Collaborative Robot Arm with Cartesian Impedance Control

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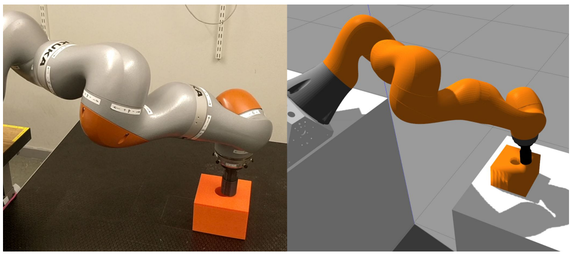

For several decades robots have been used for different physical repetitive tasks and for tasks that have well-defined solutions. However, humans have for a long time been superior in learning and solving certain tasks where, for example, eye–hand coordination and fine motor skills are useful. Tasks that humans will solve effortlessly, such as opening a water bottle or inserting a key and unlocking a door, requires high sensitivity and often even an intuition of friction, which is a complex phenomenon to model and for a robot to handle. However, robots are today used for similar complex contact-rich tasks, often in an industrial setting where, for example, insertion and screwing are common parts in an assembly line.

This has brought increased attention in the robotics community to topics such as force sensing and machine learning to make robots learn and solve a range of tasks in a more generalized way. Together with force-sensing requirements, the accuracy of a simulated model is considered one important challenge for learning contact-rich tasks in robotics. Simulation is a useful tool in robotics in general, both to facilitate faster testing and setup, as well as to achieve safe operation. Robotic instruments are expensive and therefore availability is often restricted to a few units. Therefore, it is crucial to make sure that the robot is acting as predicted to avoid damage on equipment or damage to person. As an additional benefit, simulation may also increase "availability" by enabling testing by multiple and remote users. For those reasons, it is of great interest to increase knowledge about simulating robot manipulators, as well as tools for getting increased accuracy in simulation.

In this thesis, the goal was to find a controller solution to control the position and acting forces of the tool of the robot arm (also called the end-effector). The controller is also expected to work for a simulated model, with the goal to get as similar behaviour as possible using the same controller. The robot used is a KUKA LBR iiwa lightweight robot arm that has 7 degrees of freedom, which corresponds to the seven joints and result in similar dexterity as for a human arm. It is a robot commonly used for assembly tasks and tasks that involve human interaction (collaborative tasks). For such tasks, the robot is expected to mainly interact with the end-effector, where a tool (e.g., a gripper) often is mounted to help solving the particular task. Since the controller is expected to control the position and orientation of the end-effector rather than the position of the individual joints, it makes operation and solutions more intuitive for tasks where interaction is expected to happen at the end-effector.

Impedance control is often the suggested control strategy for contact-rich tasks, since this type of controller relates kinematics with dynamics to ensure appropriate interaction forces by making the robot behave like a mass-spring-damper system. It is also often implemented for collaborative robots and has in particular shown to improve the learning process for reinforcement learning. The controller used for this thesis is called *Forward Dynamics Compliance Control* (FDCC) [2] and is using impedance control together with a virtual model of the robot. This strategy enables a great freedom in shaping the dynamic behaviour of the robot, as well as an easy implementation on a wide range of different robot manipulators. However, it has only been documented to be used for robots with lower than 7 degrees of freedom, and the controller documentation states that it is expected to be used for robots with a dedicated force sensor mounted on the end-effector. Both of these characteristics do not apply on the KUKA robot used in this thesis, and the implementation was not therefore expected to be as swiftly done as for other robots.

To implement this controller for the real and the simulated robot, extensive tuning of the controller was required to get desired behaviour. Regarding the force sensor, the joint sensor signals acquired from the iiwa software needed to be transformed to correspond to the output of a wrist-mounted force sensor signal. A filter was also used on force-sensor signals, to remove noise and to achieve reasonable interaction. For experiments of both commanding derived positions and commanding derived forces, it showed promising results with stable and similar behaviour for both the real and the simulated robot. As a final experiment and an example of application, the robot was tested to solve a peg insertion task. By commanding a search motion when the end-effector was close to the hole, the task was solved both in simulation and for the real robot. This task included commanded motion while in contact with the surface, and it was noticed to be more difficult for the simulated model to predict accurately. It is presumed to be because of the fact that the friction model used in simulation was not an accurate representation of the setup for the real robot.

With the results of this thesis, it can be concluded that the FDCC controller can be used for an even wider range of robot manipulators than previously documented. It is also shown to be a good choice for getting a close match of a real and a simulated robot model. With further improvements on simulation model and sensor filtering, it is deemed possible to increase responsiveness and further narrow the simulation-to-reality gap.

References

[1] Holmesson, J. (2021) *Accurate Simulation of a Collaborative Robot Arm with Cartesian Impedance Control*, MSc Thesis TFRT-6142, Department of Automatic Control, Faculty of Engineering, Lund University.

[2] Scherzinger, S., A. Roennau, and R. Dillmann (2017). *Forward Dynamics Compliance Control (FDCC): A new approach to Cartesian compliance for robotic manipulators*. In: *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (24-28 Sept - Vancouver, BC, Canada)*, pp. 4568–4575. DOI:10.1109/IROS.2017.8206325