An easy and cheap way to increase the accuracy of robots

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This is a popular scientific summary of my master's thesis, [16], with the title *Prediction of position errors for an industrial robot, using a model of the robot with parameters acquired from the clamping procedure*. The master's thesis was done at *the Department of Automatic Control*, *LTH*, *Lund University*, and at *Cognibotics*.

1 Preamble

There are unmodeled effects in robots that make them less accurate. These effects include strains in the robot's gearboxes due to the load that the robot experiences. The strains make the robot's position deviate from the desired position, even though the load that the robot is going to experience in many cases is known in advance. If the load information should be known, but not used, it is a waste of information which could have improved the accuracy. For more information about the general problem, the methods used, and the used tools see [16], [20], [15], [13], [1], [3], [2], [6], [7], [4], [5], [11], [12], [19], [9], [8], [18], [17], [10] and [14].

2 How to increase the accuracy

First the information of how the gears behaved was to be derived from the robot. This was done by locking the robot to a stiff point in its workspace (also referred to as clamping), and then carefully try to run the motors, and record the small corresponding displacements in the gearboxes. The robot used for experiments in the thesis work is seen in Figure 1. Since the robot was stuck, there was very little motion, and the main part of the displacements was due to strains in the gears. The recorded displacements in the gears and data from the motors (how much force that had been used), then contained information about the robot's gearboxes.

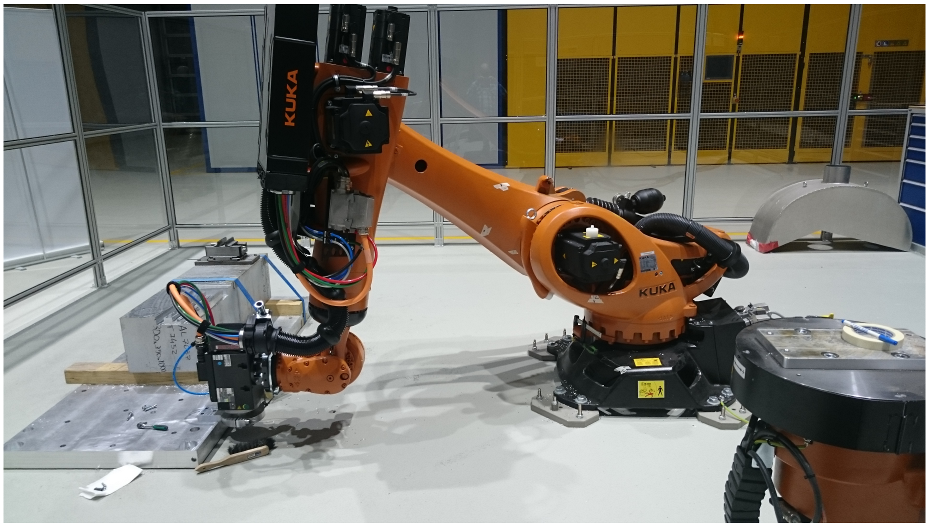

Figure 1: The experimental setup for the clamping experiment. The robot is going to be fixed in the metal block seen in the picture.

The next step was to use the recorded information to derive parameters that described the gearboxes, and that later could be used in a model of the robot. The parameters that described a gearbox was a spring constant (how much strain will a given force result in), a backlash, and friction. A program was written that took the recorded information from the robot, and calculated these parameters. The recorded information from one joint is seen in Figure 2.

A model of the gear was used, were the parameters had come from the experiment of trying to move the robot, during clamping. The model was able to recreate the recorded data for some of the gearboxes. This proved that the model well captured the behavior of the gearboxes, and that the calculated parameters were enough to describe the behavior. A simulation is shown in Figure 3, where the simulated data is plotted on the experimental data.

Because the models of the gearboxes, with the right parameters, were able to recreate the recorded data (see Figure 3), the position accuracy could be improved. This was to be done by running a simulation before the actual run of the real robot, and use the result of the simulation to compensate for deflections and thereby increase the position accuracy for the real robot. This kind of evaluation will be subject to future studies.

The idea to let the robot lock itself to a stiff point in space, and record the strains that is caused by its own motors, is called the clamping procedure. The clamping procedure is an easy and inexpensive way to derive the properties of the robot, since no external measurement devices are needed. It can be performed on individual robots to increase the accuracy. The advantage by letting the robots be tested and controlled individually, is that even robots of the same type differ in their properties. The properties also change with time as wear take place. By using the described methods the accuracy can be increased, and maintained over time, at a very low cost.

In this thesis parameters that describe the gearboxes of a robot have been derived from clamping experiments. Software was developed that was used to identify the parameters from the data that was logged during clamping experiments. Logged data from a clamping experiment for joint 1 is seen in Figure 2. A model of the gearbox was implemented where the identified parameters were used. The model was then able to recreate the logged data with great accuracy. The result for joint 1 is seen in Figure 3. The effects in Figure 2 make the robot deviate from the desired path, but since they can be recreated, see Figure 3, if the process forces are known, the accuracy can be increased when these effects are accounted for.

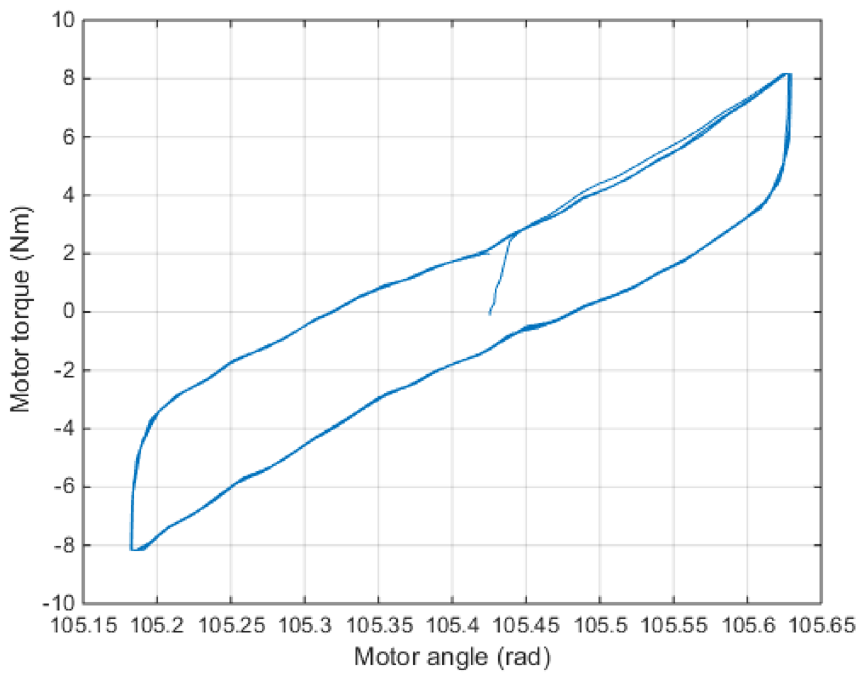

Figure 2: The experimental data from a clamping experiment for joint one, i.e., the base joint of the robot in Figure 1.

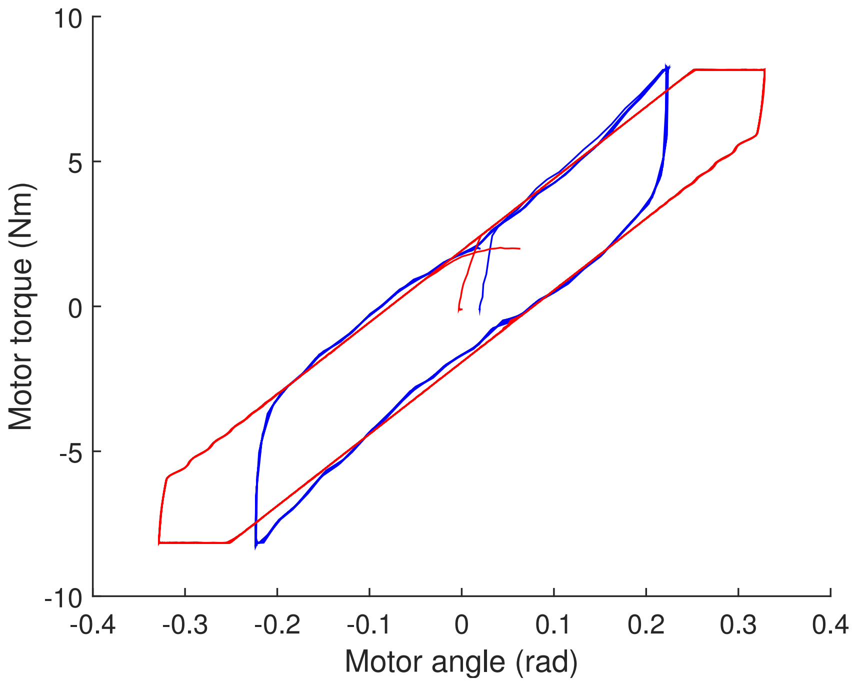

Figure 3: The simulated clamping curve is plotted on the experimental data for joint 1. The red curve is from the simulation and the blue curve is the experimental data.

References

[1] E. Abele, M. Weigold, and S. Rothenbücher. "Modeling and Identification of an Industrial Robot for Machining Applications". In: *CIRP Annals* 56.1 (2007), 387—390.

[2] Abele, E. and Bauer, J. and Hemker, T. and Laurischkat, R. and Meier, H. and Reese, S. and von Stryk, O. "Comparison and validation of implementations of a flexible joint multibody dynamics system model for an industrial robot". In: *CIRP Journal of Manufacturing Science and Technology* 4.1 (2011), pp. 38–43.

[3] Abele, Eberhard and Rothenbücher, Stefan and Weigold, Matthias. "Cartesian compliance model for industrial robots using virtual joints". In: *Production Engineering* 2.3 (2008), pp. 339–343.

[4] Bennett, David J. and Hollerbach, John M. and Henri, Paul D. "Kinematic calibration by direct estimation of the Jacobian matrix". In: *Robotics and Automation, 1992. Proceedings., 1992 IEEE International Conference on.* IEEE. Nice, France, 12-14 May 1992, pp. 351–357.

[5] Bittencourt, André Carvalho and Wernholt, Erik and Sander-Tavallaey, Shiva and Brogårdh, Torgny. “An extended friction model to capture load and temperature effects in robot joints”. In: *Intelligent Robots and Systems (IROS), 2010 IEEE/RSJ International Conference on.* IEEE. Taipei, Taiwan, 18-22 October 2010, pp. 6161–6167.

[6] Dumas, Claire and Caro, Stéphane and Garnier, Sébastien and Furet, Benoît. “Joint stiffness identification of six-revolute industrial serial robots”. In: *Robotics and Computer-Integrated Manufacturing* 27.4 (2011), pp. 881–888.

[7] Hovland, Geir and Hanssen, S. and Gallestey, E. and Moberg, S. and Brogårdh, T. and Gunnarsson, S. and Isaksson, M. “Nonlinear identification of backlash in robot transmissions”. In: *Proceedings of the 33rd ISR (International Symposium on Robotics).* Stockholm, Sweden, 7-11 October 2002, pp. 1–6.

[8] Lehmann, Christian and Olofsson, Björn and Nilsson, Klas and Halbauer, Marcel and Haage, Mathias and Robertsson, Anders and Sörnmo, Olof and Berger, Ulrich. “Robot Joint Modeling and Parameter Identification Using the Clamping Method”. In: *IFAC Conference on Manufacturing Modelling, Management and Control (MIM2013).* Saint Petersburg, Russia, June 19-21 June 2013, pp. 813–818.

[9] Klas Nilsson. *Method and system for determination of at least one property of a joint.* WO Patent App. PCT/SE2013/051,224. 2014. URL: `http://www.google.com/patents/WO2014065744A4?cl=en`.

[10] Martin Otter, H. Elmqvist, and S. E. Mattsson. “The New Modelica Multibody Library”. In: *Proceedings of the 3rd International Modelica Conference (P. Fritzson, ed.), (Linköping), The Modelica Association and Linköping University.* Linköping, Sweden, 3-4 November 2003, pp. 311–330.

[11] Pan, Zengxi and Zhang, Hui. “Improving robotic machining accuracy by real-time compensation”. In: *ICCAS-SICE, 2009.* IEEE. Fukuoka, Japan, 18-21 August 2009, pp. 4289–4294.

[12] Reinl, C. and Friedmann, M. and Bauer, J. and Pischan, M. and Abele, E. and von Stryk, O. “Model-based off-line compensation of path deviation for industrial robots in milling applications. IEEE”. In: *ASME International Conference on Advanced Intelligent Mechatronics (AIM).* Budapest, Hungary, 3-7 July 2011, pp. 367–372.

[13] Michael Ruderman, Frank Hoffmann, and Torsten Bertram. “Modeling and Identification of Elastic Robot Joints With Hysteresis and Backlash”. In: *IEEE Transactions on Industrial Electronics* 56.10 (2009), pp. 3840–3847.

[14] Christian Schweiger and Martin Otter. “Modeling 3D Mechanical Effects of 1D Powertrains”. In: *Proceedings of the 3rd International Modelica Conference (P. Fritzson, ed.), (Linköping), The Modelica Association and Linköping University*. Linköping, Sweden, 3-4 November 2003, pp. 149–158.

[15] Sörnmo, Olof and Olofsson, Björn and Schneider, Ulrich and Robertsson, Anders and Johansson, Rolf. “Increasing the Milling Accuracy for Industrial Robots Using a Piezo-Actuated High-Dynamic Micro Manipulator”. In: *The 2012 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*. Kaohsiung, Taiwan, 11-14 July 2012, pp. 104–110.

[16] Anders Söder-Hoorn. *”Prediction of position errors for an industrial robot, using a model of the robot with parameters acquired from the clamping procedure”*. October 2015. Lund University. The thesis is available for download at http://www.control.lth.se/Publications.html.

[17] The Modelica Association. *Modelica documentation*. URL: `http://modelica.github.io/Modelica/` (visited on 05/31/2015).

[18] The Modelica Association. *The Modelica Association*. URL: `https://www.modelica.org` (visited on 08/19/2015).

[19] Tyapin, Ilya and Hovland, Geir and Brogårdh, Torgny. “Method for estimating combined controller, joint and link stiffnesses of an industrial robot”. In: *Robotic and Sensors Environments (ROSE), 2014 IEEE International Symposium on*. IEEE. Timisoara, Romania, 16-18 October 2014, pp. 1–6.

[20] Jianjun Wang, Hui Zhang, and Thomas Fuhlbrigge. “Improving Machining Accuracy with Robot Deformation Compansation”. In: *The 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems*. St. Louis, USA, 10-15 October 2009, pp. 3826 –3831.