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FORCE-TORQUE CONTROL OF INDUSTRIAL ROBOTS FOR INDUSTRIAL APPLICATIONS

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Summary: *The paper deals with the force-torque control for industrial robots for various types of applications such as grinding, drilling, automatic assembly or other applications where contact forces and respective moments need to be controlled in real-time. The experimental set-up is based mainly on a KUKA robot (KR3 or KR15/2) and a FTC sensor (by SCHUNK). Main practical results are concerned with automatic grinding of specific parts provided by industrial partners. Another prospective area covered in this paper is also the interaction between the robot and an operator known as Human Robot Interaction or Cooperation drawing on the FTC paradigm. This cooperation can be used in any technological processes where semi-automatic assembly could prove benefits.*

1. Introduction

Industrial robots have become standard equipment for flexible manufacturing systems. It is mainly due to the flexibility and universality of a 6 DOF industrial robot that are integrated into manufacturing systems fulfilling various tasks and based on statistics of the International Federation of Robotics (www.ifr.org), the number of robots used in practice is still rising. However, industrial robot programming is still an annoying task and expert knowledge is expected in most cases. It is the main reason that the robots are used in fixed installations performing periodic and repeatable tasks (without changes) and programmed either online or offline by an expert. Another limitation is concerned with a very rare interaction with the worker; the worker and the robot are usually separated through mechanical fences or other safety systems. Finally, such robot utilization concept is considered to be profitable rather only with medium to large lot sizes.

Nevertheless, new demands on robot programming and applicability are emerging nowadays. At first, there is a need to automate applications that are nonstandard for robots. Such applications require the robot end-effector (tool) to be in direct contact with the environment. It means that the contact forces an moments need to be controlled to ensure a proper task performance and right results. This field belongs to the finishing operations (Bogue, 2009; Pires et al., 2002) such as grinding, polishing, deburring etc. Despite many research projects and results were presented and published, it has not reached a proper industrial usage so far.

The second demand is concerned with a new robot programming technique that is based on human robot interaction and cooperation. This technique along with a new generation of in-

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dustrial robots (Bischoff, 2009) allows the robot to be flexibly relocated within the shop floor, the tasks can be frequently and easily changed and robots can be instructed online: by demonstration (Pires et al., 2009) of a non-expert or supported by off-line techniques using CAD objects data. There is also a frequent robot interaction with the worker (even the force interaction) and concerning the safety issue, the robot workspace is fully shared with the worker. Finally, such concept is expected to be sustainable and profitable even for small lot sizes; typical for SMEs. A typical example of this next generation robot is the KUKA Light-Weight Arm (Figure 1).

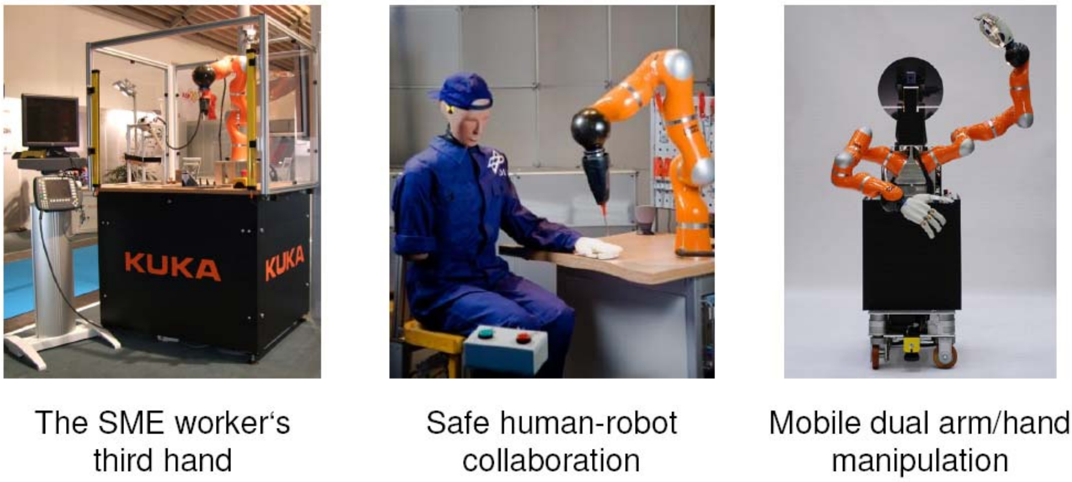


Figure 1 Ongoing R&D projects with the KUKA Light-Weight Arm (Bischoff, 2009)

To implement a robotic cell concerned with finishing operations or human robot interaction, there is required a proper force-torque feedback based on a force-torque sensor (Perry, 2002). Various control architectures can be applied. Theoretically, the best way would be a force controller based on the complete model of the robot. Concerning this type of controller, there is a problem that the outputs from such controller are motor torque (force) what is difficult to implement on the actual range of industrial robots since they have had more or less a closed architecture rarely allowing the direct control of the motor torque. However, in this work we applied a cascade force controller (Figure 2) regardless of the fact that it does not take into account the whole model of the robot. Depending on the "closed architecture" of standard robot controllers (e.g. KUKA KR C2/C3), the cascade force controller allows rather only the tool position to be controlled.

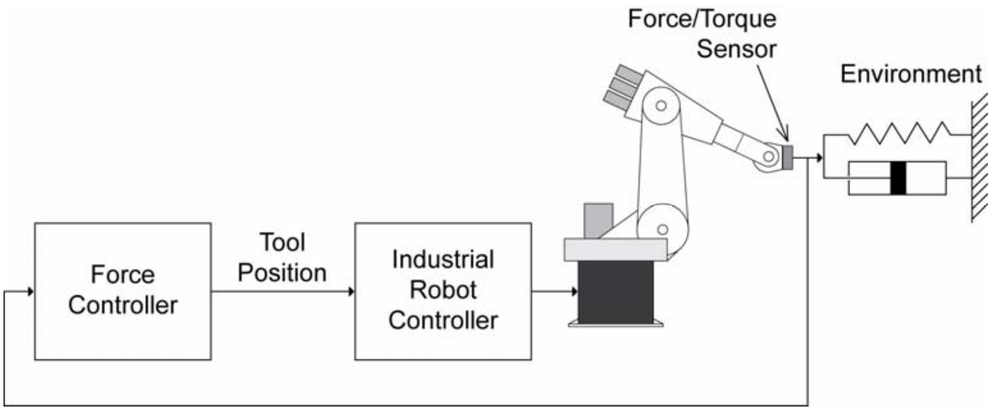


Figure 2 Cascade force controller conception for industrial robot

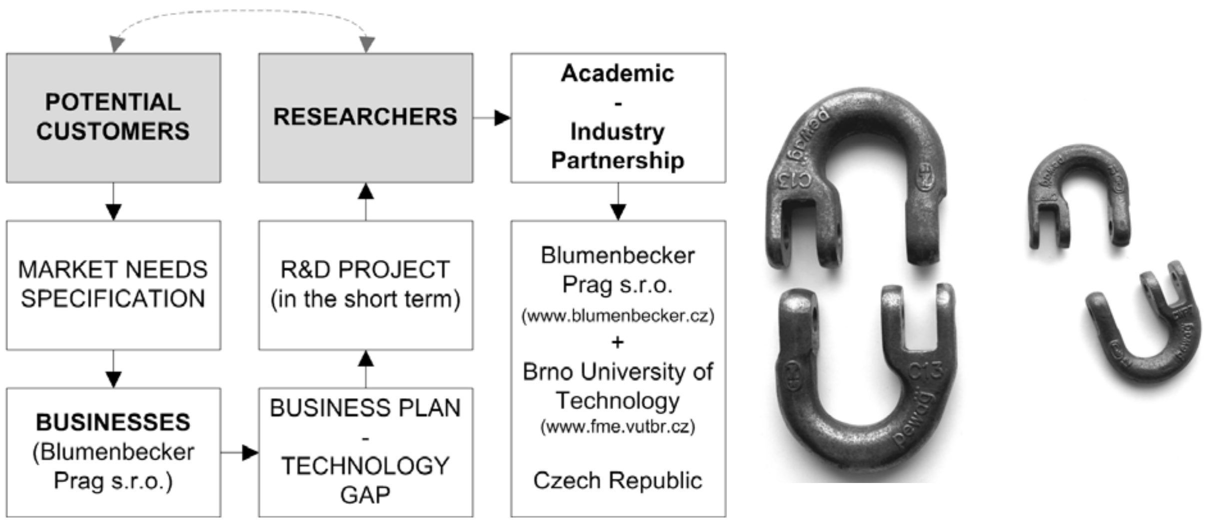
2. Technology transfer in practice

Despite many models for technology transfer in practice have been described in the literature, few successful R&D projects fulfilled the industrial (customer) requirements concerned mainly with advanced robotic applications such as force-torque robot control, bin-picking based on 3D vision, continuous image analysis of various surfaces in high speed etc.

In general, one extreme approach starts from a researcher doing basic research that might lead to a successful industrial application in the near future. Another approach concerns with specific market needs and a search for a researcher able to cope with the problem. Many models also claim that a successful technology transfer in practice needs to be based on close collaboration between researchers and practitioners.

A model example is covered for example in (Gorschek et al., 2006) where a seven-step technology transfer model based on close cooperation and collaboration between university researchers and practitioners is applied. The model is concerned mainly with identifying industry needs, formulating a research agenda, formulating a solution and comprehensive validation based on small lab experiments, pilot projects leading to release the full solution step by step.

In our case, the following model (Figure 3a) based on some ideas from the previous example for technology transfer has been applied within the R&D project concerned with the force-torque robot control for various industrial applications and based on the academic–industry partnership. The key topic in this project is robotic grinding of specific objects supplied by potential customers (e.g. Figure 3b) – grinding of functional surfaces or grinding of casting extensions. Another topic is the human robot interaction/cooperation that can be applied on the robot programming-by-demonstration concept or the robot is a coworker for a human worker.



a) b)

Figure 3 Technology transfer model used in this work (a); objects for robotic grinding (b)

This technology transfer based on academic – industry collaboration was also partly supported by the ESF project: Knowledge and Skills in Mechatronics - Innovations Transfer to Practice (CZ.1.07/2.3.00/09.0162).

3. Motion control architectures with force feedback

There are two main approaches for a robot force controller. At first, force controller without the whole robot model employing dynamics robot properties can be applied. This conception is represented by the cascade force controller (Figure 4). A strong point in this case is concerned with a flexible implementation though it is limited rather only for non-complex object shapes and robot trajectories (Bigras et al., 2007).

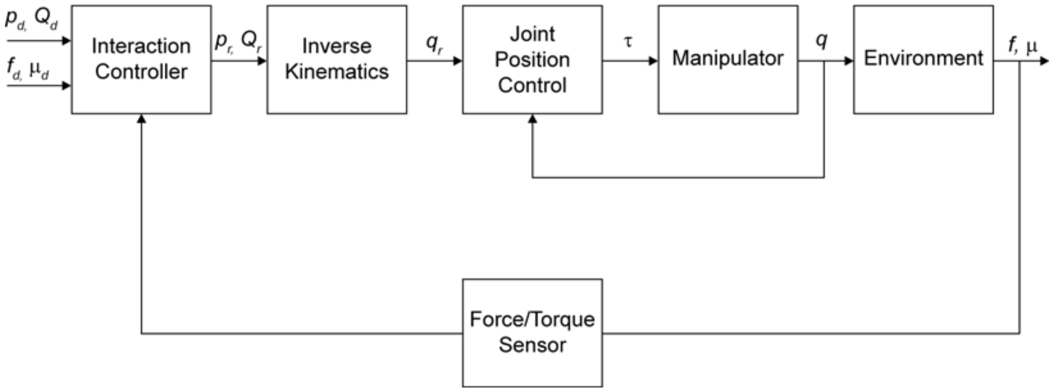


Figure 4 Cascade force controller architecture for industrial robot

The desired trajectory is represented by a desired position $\boldsymbol{p}_d$, orientation $\boldsymbol{Q}_d$ and force-torque constraints: force $\boldsymbol{f}_d$ and moment $\boldsymbol{\mu}_d$. The output of the Interaction Controller is the reference trajectory (position $\boldsymbol{p}_r$ and orientation $\boldsymbol{Q}_r$) in Cartesian space that takes into account real data from the force-torque sensor. Further, there is Inverse Kinematics module that calculates a motion trajectory in Joint space (orientation $\boldsymbol{q}_r$). The output from inner Joint Position Control loop is joint torques ($\boldsymbol{\tau}$). On the end-effector there are measured real forces and moments ($\boldsymbol{f}$, $\boldsymbol{\mu}$). Such control architecture is also used in this work.

For better stability of the closed loop and for more complex object shapes and trajectories there is possible to use a task space motion controller (Blomdell et al., 2005) where a planned trajectory is accessible to be corrected by the user; both at Cartesian level and Joint level (Figure 5). Unfortunately, it is rarely possible since the majority of current industrial robots are concerned with closed control architectures.

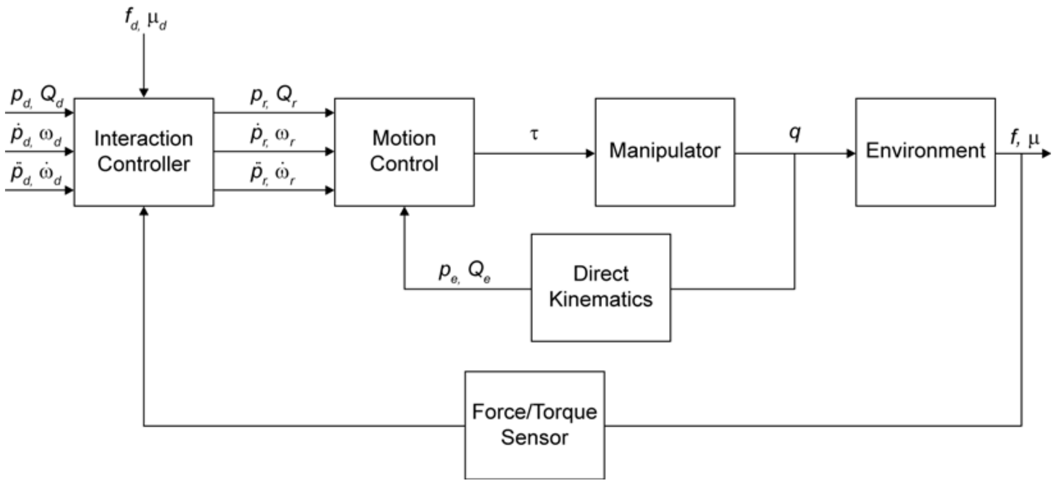


Figure 5 Task space motion controller for industrial robot

Both control architectures, as described above, have its respective advantages and drawbacks. Detailed theoretical comparison of the control approaches are presented in Caccavale et al., 2005.

4. Force-Torque robot control: pilot results

In this chapter we present pilot results regarding the force-torque robot control. Initially, the testing workplace (Figure 6) was established. It is concerned mainly with the KUKA KR 3 industrial 6 DOF robot, force-torque sensor SCHUNK FTC 050-80-V, linear gripper (SCHUNK PGN 100-1) and other modules for control (Beckhoff Embedded-PC CX), communication (DeviceNet or RS-232) and safety.

Figure 6 Experimental set-up of FTC robot control for “programming-by-demonstration”

The following figure (Figure 7) represents the force controller step response while maintaining a desired contact force (5 N) along with an object surface in one direction.

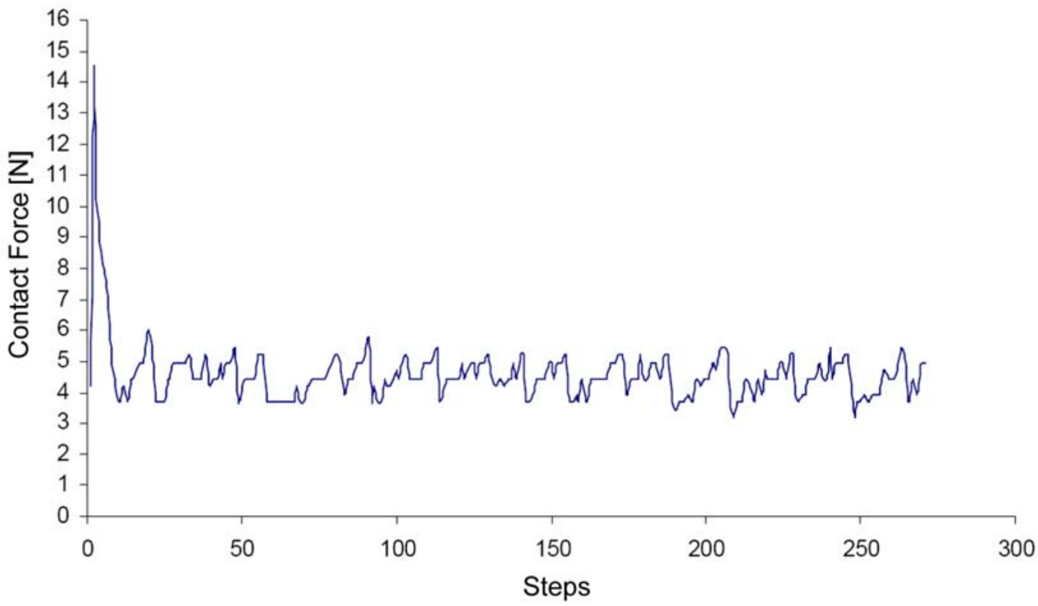


Figure 7 Force controller step response; desired contact force 5 N

Relative motion instructions were used for trajectory generation of the robot and the RS-232 communication protocol was used for data acquisition. For further development we rely on an advanced conception for trajectory generation as well as a faster data acquisition via DeviceNet field-bus for a better performance.

5. Conclusion

This R&D project has been focused on the industrial robot force-control applicable in various applications. Pilot results were presented using the cascade control architecture where a desired contact force with object surfaces can be controlled allowing the robot to follow object profiles (for grinding applications) or for the programming-by-demonstration concept.

Acknowledgement

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References

Bigras, P., Lambert, M., Perron, C. (2007) New formulation for an industrial robot force controller: Real-time implementation on a KUKA robot, in: *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics (SMC 2007)*, Montreal, QC, Canada, pp. 2794-2799.

Bischoff, R. (2009) From research to products: The development of the KUKA Light-Weight Robot, in: *Proceedings of the 40th International Symposium on Robotics (ISR 2009)*, Barcelona, Spain.

Blomdell, A. et al. (2005) Extending an Industrial Robot Controller: Implementation and Applications of a Fast Open Sensor Interface, IEEE Robotics & Automation Magazine, Vol. 12, No. 3, pp. 85-94.

Bogue, R. (2009) Finishing robots: a review of technologies and applications. *Industrial Robot*, Vol. 36, No. 1, pp. 6-12.

Caccavale, F., Natale, C., Siciliano, B., Villani, L. (2005) Integration for the next generation: embedding force control into industrial robots. *IEEE Robotics & Automation Magazine*, Vol. 12, No. 3, pp. 53-64.

Gorschek, T., Garre, P., Larsson, S., Wohlin, C. (2006) A Model for Technology Transfer in Practice, IEEE Software, Vol. 23, No. 6, pp. 88-95.

Perry, D. (2002) Optimize your robot's performance by selecting the right force/torque sensor system. *Industrial Robot*, Vol. 29, No. 5, pp. 395-398.

Pires, J.N., Ramming, J., Rauch, S., Araujo, R. (2002) Force/torque sensing applied to industrial robotic deburring. *Sensor Review*, Vol. 22, No. 3, pp. 232-241.

Pires, J.N., Veiga, G., Araujo, R. (2009) Programming-by-demonstration in the coworker scenario for SMEs. Industrial Robot, Vol. 36, No. 1, pp. 73-83.