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COMPUTER SCIENCE MEETS AUTOMATION

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Session 1 - Systems Engineering and Intelligent Systems

Session 2 - Advances in Control Theory and Control Engineering

Session 3 - Optimisation and Management of Complex Systems and Networked Systems

Session 4 - Intelligent Vehicles and Mobile Systems

Session 5 - Robotics and Motion Systems

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Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system’s performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in “classical” technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title “Computer Science meets Automation”, borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where “Computer Science meets Automation” are addressed by this colloquium at the Technische Universität Ilmenau.

All the University’s Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

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A. Winkler / J. Suchý

Position Based Force Control of an Industrial Manipulator

INTRODUCTION

Force control of articulated robots is a research field quite often investigated during the last thirty years, [1, 2, 3, 4]. However, industrial applications of force controlled robots are very rare. Reasons for this may be the cost of a six component force/torque wrist sensor (F/T sensor) which is necessary in robot force control or the inadequate integration between the F/T sensor and the robot controller.

This paper shows that it is possible to implement high efficient force control algorithms into a commercial robot controller. For this purpose a very sensitive task has been chosen. Robot task is to draw a figure on a blackboard using a piece of chalk. However, the exact position of the blackboard and its inclination with respect to the ground are unknown. The improved force controllers developed for this compliant motion task are explained in this paper. The results, especially the drawing time and the drawing velocity, are compared with results attained by standard force control algorithms available using the commercial technology packet.

SYSTEM DESCRIPTION AND EXPERIMENTAL SETUP

The development of the improved approach to force control of an industrial manipulator was performed using the robot Kuka KR6/2. It is a six axes articulated robot with payload of 6 kg. The robot is controlled by the Kuka Robot Controller KRC2. A six component F/T sensor is mounted in the robot wrist. Because the force/torque measurement is based on PSD diodes the F/T sensor includes an appreciable compliance. The F/T sensor is connected with the robot controller via DeviceNet.

Using the robot in industrial standard applications like handling, the programming is performed with the Kuka Robot Language (KRL). However, using KRL real time robot control is not realizable. Therefore an additional module called Robot Sensor Interface (RSI) is necessary. With this module it is possible to generate and link RSI objects using special KRL expressions. These objects provide sensor values, perform signal processing, and influence robots motion. A complex controller structure consisting of RSI objects can be built and used for sensor guided robot motion. It is executed in real time with the interpolation cycle of 12 ms. Robot motion can be influenced by RSI on the level of the position control loops. The functional scheme of RSI is shown in Fig. 1.

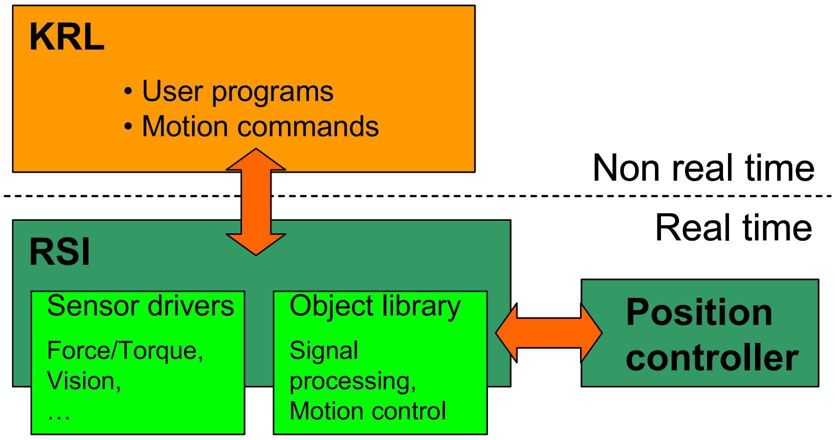

Fig. 1: Functional scheme of RSI.

To perform the drawing example task the robot is equipped with a two finger parallel gripper to hold a piece of chalk. The blackboard on which the figure has to be drawn is inclined with respect to the ground. Its exact position and the angles of inclination are unknown to the robot. Fig. 2 shows the experimental setup for the compliant motion task.

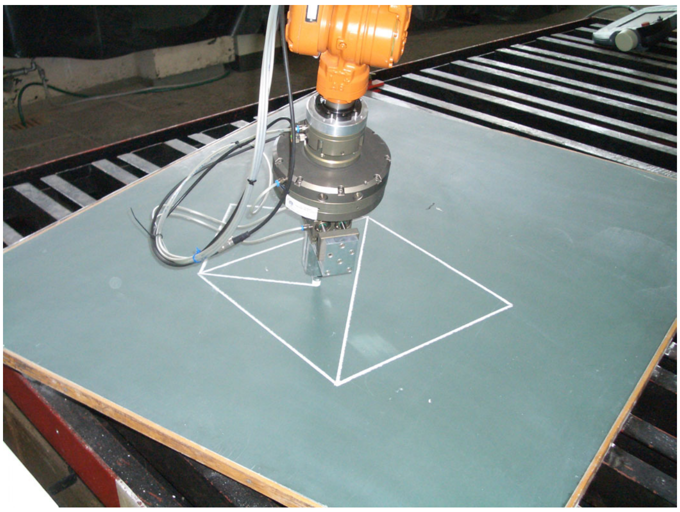

Fig. 2: Experimental setup.

The stiffness of the whole environment including the compliances of robot load limiter and F/T sensor is approximately 100 N/mm. To perform the drawing task two different force controllers have been designed. The first controller is used to bring the tool (piece of chalk) in contact with the environment (blackboard). The second controller has to keep the stable and safe contact while drawing.

DESIGN OF IMPACT CONTROLLER

First, the end-effector has to get into contact with the environment. The exact position of the environment is unknown. An overshoot of the contact force should be avoided to beware of the damage of the tool (chalk). The controller is a variable structure controller based on a proportional plus integral controller. Its signal flow diagram is shown in Fig. 3.

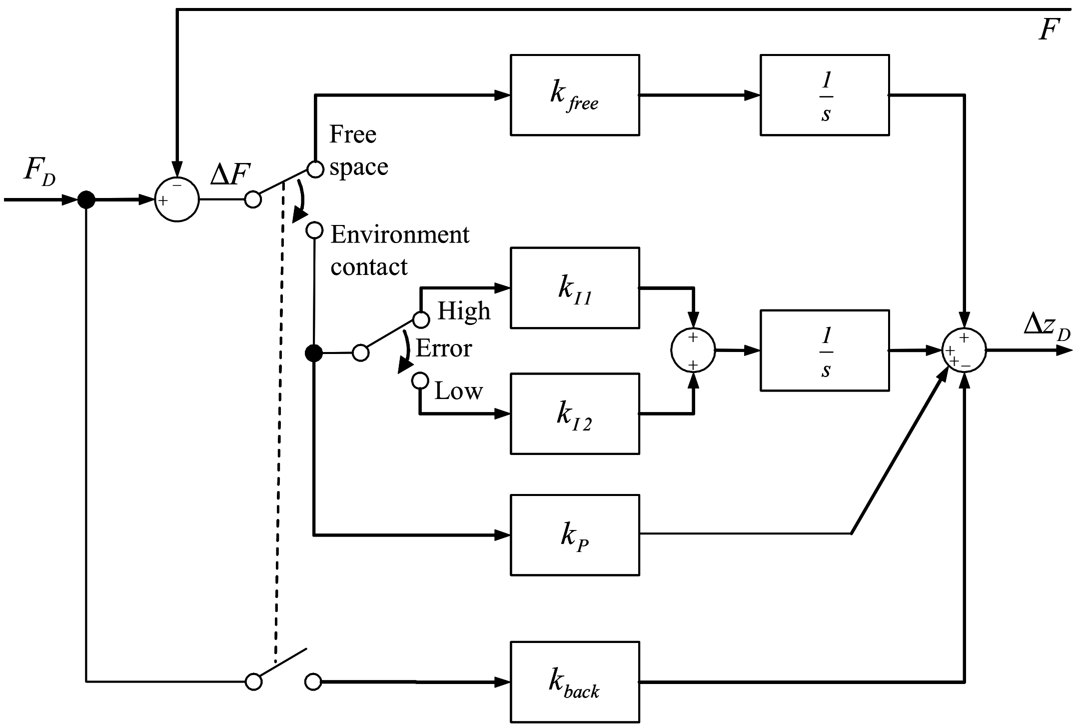

Fig. 3: Controller structure for impact control.

Controller inputs are the desired and the current contact force. The output signal is the desired end-effector position which is provided to the position control loops. If the contact force is zero, that means the end-effector is located in free space, only one integral branch is activated. Its controller gain is represented by factor k_{free}. During the environment contact the proportional part k_p starts functioning. The integral branch is switched between controller gains k_{I1} and k_{I2} for high and low force control error, respectively. This feature is necessary to obtain a fast and stable control behavior. To accelerate the contact detection process the factor k_{free} may be increased. To prevent contact force overshoots the additional branch presented by controller gain k_{back} has to be integrated into the controller structure.

CONTROLLER DESIGN FOR CONTOUR FOLLOWING

After the impact process is finished the controller structure has to been changed to perform the contour following task (drawing). The signal flow diagram of the controller used for the drawing task is shown in Fig. 4.

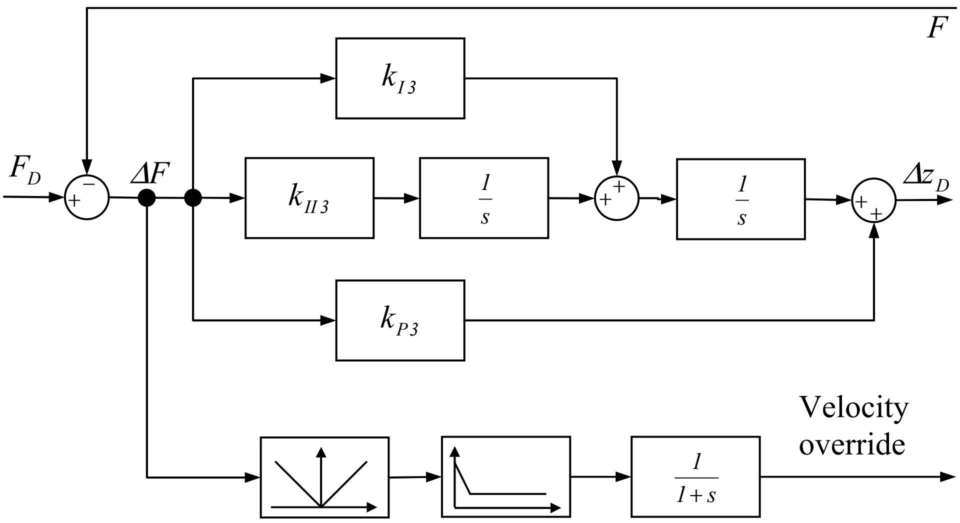

Fig. 4: Controller structure for the contour following task.

It consists of a proportional plus integral controller with controller gains k_{P3} and k_{I3}, Additional integral part is inserted in the control loop represented by factor k_{II3}, which results in the I^2-behavior. With this functionality it is possible to adjust the controller to the particular environment. This adaptation may be seen as the estimation of the environment orientation.

To draw the figure on the blackboard the robot is commanded to move its end-effector in parallel to ground (x-y-plane). The contact force is controlled in z-direction by the controller shown in Fig. 4. The velocity of the motion command is controlled by the so called override. To accelerate the drawing process and to guaranty the safe and stable contact between blackboard and chalk an additional feature is integrated in the controller. It is the modulation of the velocity override in dependency on the force control error. In the case of a high control error the override has been reduced. After the inclination of the particular drawing direction is adapted by the I^2-funtionality and the control error is decreased the velocity override can be increased.

RESULTS AND CONCLUSION

The two force controller structures described in the previous sections were implemented in the robot controller. Some supporting positions which represent the example figure to be drawn (see also Fig. 2) were taught in parallel to the ground without environment contact.

After starting the whole drawing program the robot moves its end-effector to supporting position No. 1. The controller structure for impact control is activated and the desired contact force F_d is set to the value of 10N. After the end-effector is in contact with the environment F_d is reduced to the value of 5N and the controller structure is change to contour following controller. Then the robot is commanded to move its end-effector to supporting position No. 2 using the path located in parallel to the ground. Because of the blackboard inclination, the end-effector coordinate in z-direction has to be adjusted to avoid the loss of contact or the damage of the chalk.

Reaching taught supporting location while drawing, the orientation of the end-effector has to be changed for the symmetrical wear of the chalk. The orientation change is performed in free space. It is followed by new contact detection.

The same compliant motion task was programmed using Kuka's Force Torque Control Technology Package (FTCtrl). It is also based on RSI programming. However, RSI is hidden in a comfortable Windows dialog and its functionality is restricted. The controller and its parameters were chosen to guarantee the stability during contact detection and contour following.

Fig. 5 shows the contact forces while drawing using the improved force controller presented in this paper and the standard force controller using FTCtrl. It can be seen that the whole drawing task was finished after 115s by the improved RSI force controller. Using FTCtrl the process took approximately 50% more time. It is finished after 175s. Because the orientation change and contact detection takes the same time in both controllers the time advantage while contour following (drawing) is approximately 100%. It is possible to calculate the average drawing velocity of 6 cm/s using the improved RSI force controller. For FTCtrl the average drawing velocity of 3cm/s can be determined.

With the approach to an improved force controller which has been presented here it was able to shown that it is possible to realize such demanding tasks based on force controlled commercial robot. The sensitive drawing task was chosen as an example because it has some relations to some industrial manufacturing tasks like polishing, grinding, or deburring.

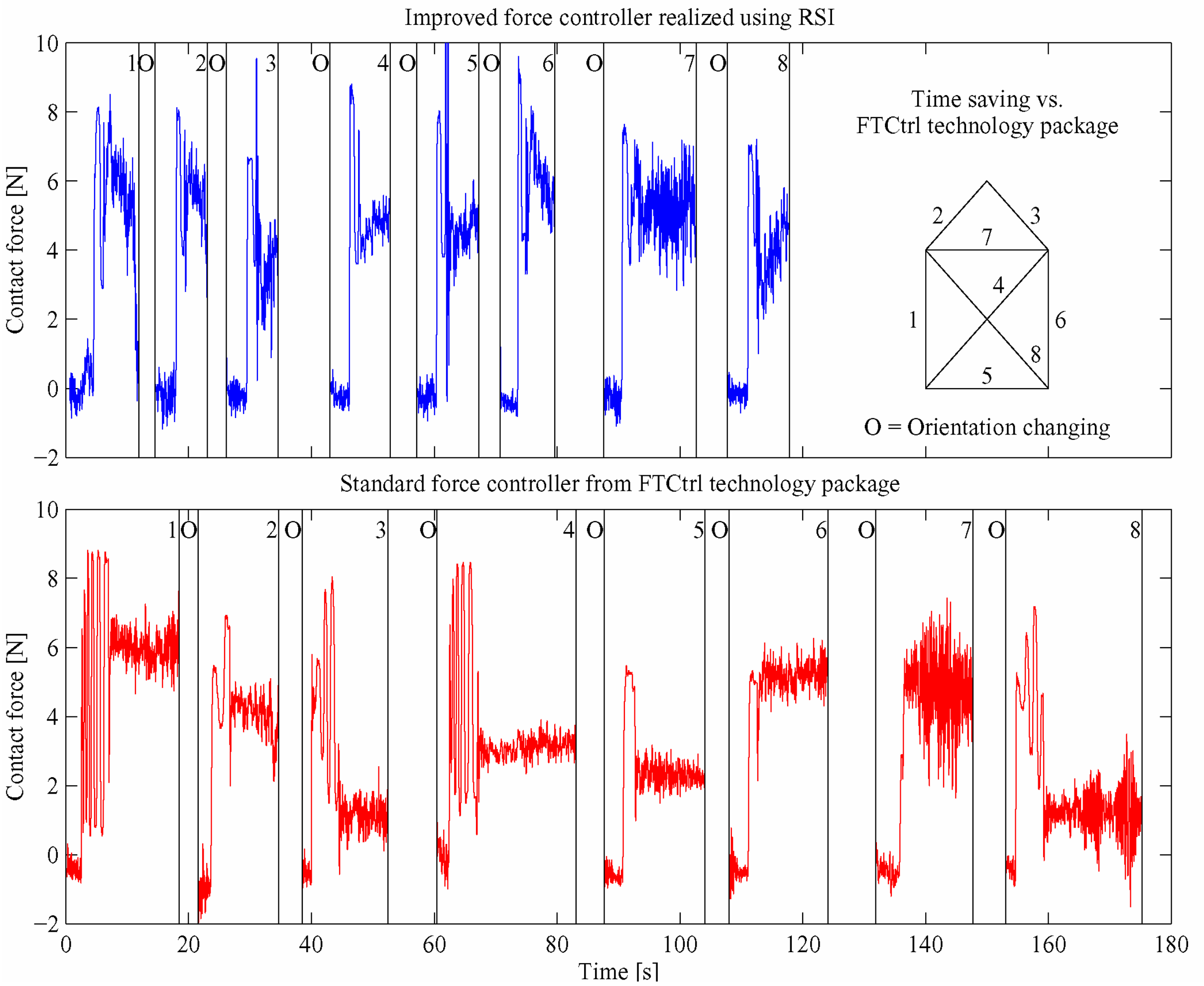

Fig. 5: Contact forces while drawing.

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