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FACULTY OF COMPUTER SCIENCE AND AUTOMATION

COMPUTER SCIENCE MEETS AUTOMATION

VOLUME II

Session 6 - Environmental Systems: Management and Optimisation
Session 7 - New Methods and Technologies for Medicine and Biology
Session 8 - Embedded System Design and Application
Session 9 - Image Processing, Image Analysis and Computer Vision
Session 10 - Mobile Communications
Session 11 - Education in Computer Science and Automation

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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

Table of Contents

C O N T E N T S

10 Mobile Communications

11 Education in Computer Science and Automation

52nd Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
10 – 13 September 2007

S. Lambeck

Use of Rapid-Control-Prototyping Methods for the control of a nonlinear MIMO-System

Abstract

In the last few years different Rapid-Control-Prototyping (RCP) Methods, like "Hardware in the Loop (HiL)", "Software in the Loop" (SiL) and automatic code generation, became an important part of the control design and implementation for industrial applications. Our aim is to familiarize the students with the knowledge in this special field of control testing and realization. Therefore different experimental set-up´s associated to the juniorprofessorship of automation technology at the technical university of Ilmenau are built up. In this paper one the set up associated to a 3D-model of a helicopter will be described by its equations of motion and the different ways of control design will be shortly summarized. The use of the RCP-Methods related to the specifics of a control education course will be also presented in this paper.

Introduction

The system treated in this paper is illustrated in Fig.1 and represents a classical example of a Multi-Input Multi-Output (MIMO) System.

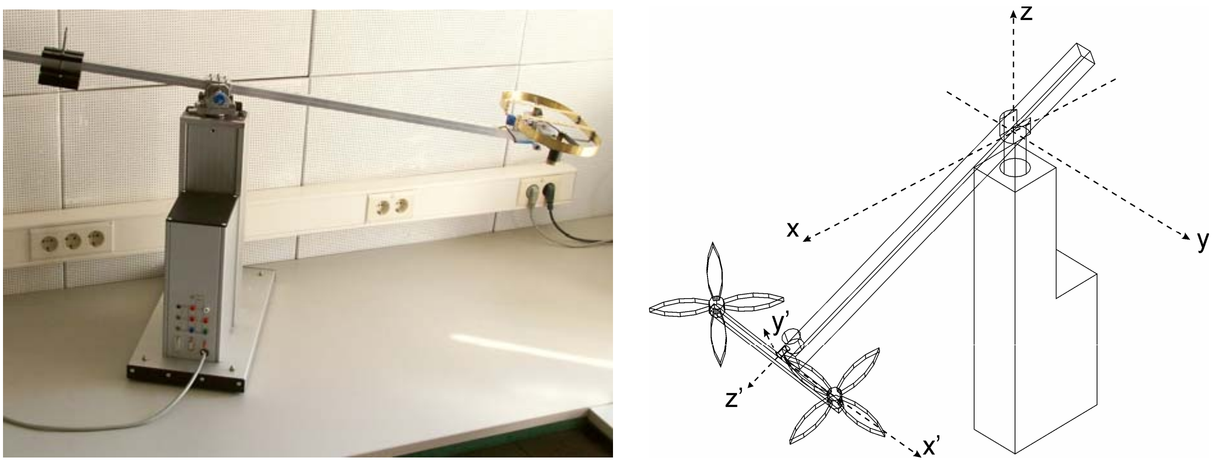

Fig. 1: Experimental set-up

The two inputs of the system are the lift forces engendered by the two rotors, which are related to the control voltage of the driving motors in an approximately linear manner. As outputs of the system the 2 angles φ_1 and φ_2 illustrated in Fig.2 can be chosen.

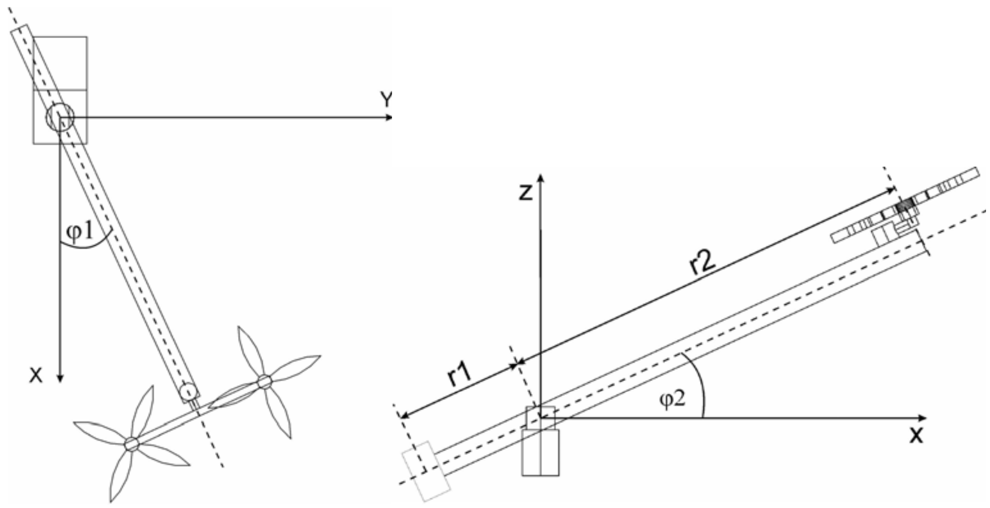

Fig. 2: Output-Angles of the system

The equations of motion will be derived in the next section using the Lagrange formalism. We receive a representation in state space form with two coupled subsystems (turning and raising of the helicopter), which complicates the control design. In a first step, the design of simple decentralized controllers for each separate axis can be done using well-known techniques in the frequency domain (e.g. root locus) which are applicable by undergraduates at the beginning of a control theory course. The performance is only satisfactorily in the near of a predefined operating point. Advanced control design techniques (shortly summarized in Sectiion 3) like state space controllers based on a linearized model or Input-Output Linearization can be applied in a second step with the result of a better control performance in the case of simultaneous movements of the different axes.

In our set-up´s MATLAB / SIMULINK was chosen as a standard tool for simulation and control design. For the realization of the different RCP-Methods described in Section 4, Hardware and Software components developed and distributed by the dSPACE GmbH[1] were used. So a fast and efficiency control design with online testing of the developed algorithms became possible and in connection with a comfortable GUI, where the different control- and manipulated variables are visualized, the whole set-up represents a challenging possibility for the students to consolidate the knowledge from the control theory courses.

Model Derivation

The equations of motion for the three axes can be derived using the Lagrange formalism

[1] www.dspace.com

based on the kinetic and the potential energy of the system which results in the following relations for φ_1 and φ_2 [1]

$$\ddot{\varphi}_2 = \frac{M}{J_2} + \frac{g}{J_2}\cos(\varphi_2 + \varphi_0)[m_1 r_1 - m_s s - m_2 r_2] - \frac{1}{2}\frac{J_2 - J_{Stab}}{J_2}\sin(2[\varphi_2 + \varphi_0])\dot{\varphi}_1^{\,2}$$
$$\ddot{\varphi}_1 = \dot{\varphi}_1\dot{\varphi}_2\frac{J_2 - J_{Stab}}{J_1}\sin(2[\varphi_2 + \varphi_0]) - \frac{r_2}{J_1}\cos(\varphi_2 + \varphi_0)\sin(\varphi_3)(F_1 + F_2) \tag{1}$$

J_i represents the moment of intertia in the different movement directions. The corresponding equation for φ_3 contains the driving forces from the rotors as inputs of the system.

$$\ddot{\varphi}_3 = \frac{r_3(F_{AR} - F_{AL}) - 2\cdot m_{Motor}\cdot g\cdot r_{s3}\cdot\cos(\varphi_2)\cdot\sin(\varphi_3)}{2J_3} \tag{2}$$

The nonlinear system can be noted in state-space representation after a linearization near the operating point (0,0,0), which implies different approximations for the trigonometric expressions in (1) and (2).

$$\begin{pmatrix}\dot{\varphi}_1\\ \ddot{\varphi}_1\\ \dot{\varphi}_2\\ \ddot{\varphi}_2\\ \dot{\varphi}_3\\ \ddot{\varphi}_3\end{pmatrix} = \begin{bmatrix}0&1&0&0&0&0\\0&0&0&0&0&0\\0&0&0&1&0&0\\0&0&0&0&0&0\\0&0&0&0&0&1\\0&0&0&0&\frac{-m_{Motor}\cdot g\cdot r_{s3}}{J_3}&0\end{bmatrix}\begin{pmatrix}\varphi_1\\ \dot{\varphi}_1\\ \varphi_2\\ \dot{\varphi}_2\\ \varphi_3\\ \dot{\varphi}_3\end{pmatrix} + \begin{pmatrix}0&0\\ -\frac{r_2}{J_1}\varphi_3 & -\frac{r_2}{J_1}\varphi_3\\ 0&0\\ \frac{r_2}{J_2}&\frac{r_2}{J_2}\\ 0&0\\ \frac{r_3}{2J_3}&-\frac{r_3}{2J_3}\end{pmatrix}\begin{pmatrix}F_{A1}\\ F_{A2}\end{pmatrix}$$

$$\underline{y} = \begin{pmatrix}1&0&0&0&0&0\\0&0&1&0&0&0\end{pmatrix}\begin{pmatrix}\varphi_1\\ \dot{\varphi}_1\\ \varphi_2\\ \dot{\varphi}_2\\ \varphi_3\\ \dot{\varphi}_3\end{pmatrix} \tag{3}$$

Control Design

Following the design proposed in [2] a simple control strategy which is based on a linear state-space controller can be chosen. Due to the coupled two axes respectively the coupling of the two manipulated signals with the movement of the two axes, the design of a decoupling controller in connection with a stationary filter seems to be suitable in a first step. The filter can be calculated using (3)

$$\underline{S} = \begin{pmatrix} \underline{c}_1 \underline{A}^{\delta_1 - 1} \underline{B} \\ \dots \\ \underline{c}_p \underline{A}^{\delta_p - 1} \underline{B} \end{pmatrix}^{-1} \begin{pmatrix} \mu_1 & & \underline{0} \\ & \dots & \\ \underline{0} & & \mu_p \end{pmatrix} \qquad (4)$$

The corresponding controller results following [2] in

$$\underline{K} = \begin{pmatrix} \underline{c}_1 \underline{A}^{\delta_1 - 1} \underline{B} \\ \dots \\ \underline{c}_p \underline{A}^{\delta_p - 1} \underline{B} \end{pmatrix}^{-1} \begin{pmatrix} \underline{c}_1 \underline{A}^{\delta_1} + \sum_0^{\delta_1 - 1} a_{1n}{}^* \underline{c}_1 \underline{A}^n \\ \dots \\ \underline{c}_p \underline{A}^{\delta_p} + \sum_0^{\delta_p - 1} a_{pn}{}^* \underline{c}_p \underline{A}^n \end{pmatrix} \qquad (5)$$

δ represents the difference order of the system and a* are real parameters which can be calculated based on a simple pole placement. Fig. 3 illustrates the control of the two axes from a predefined starting point into the operating point (0,0,0) on the left side and the control behaviour after a sequence of setpoint changes on the right side.

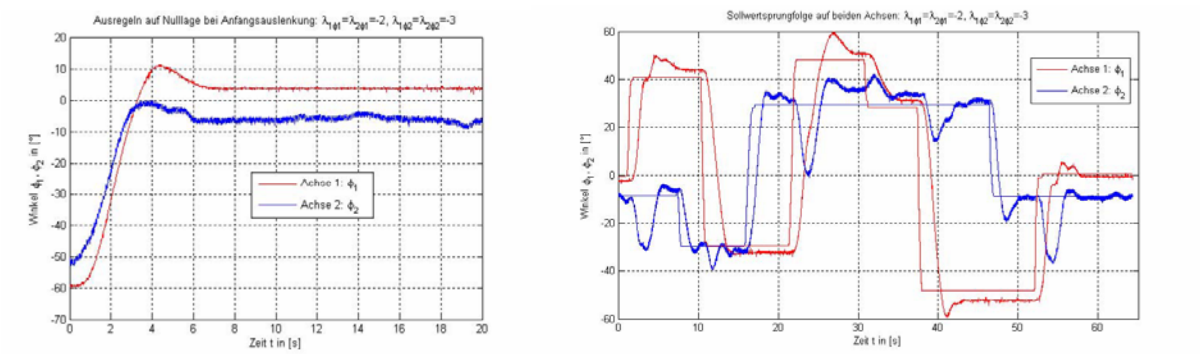

Fig. 3: Control performance

The movement of φ_1 has a significant influence of φ_2 as can be seen on the right side of Fig.3. This effect is caused by the limitations of the design based on a linearized model. We can improve the performance by an alternative control design, e.g. exact input-output linearization [3]. The application of this method for the considered system is described in detail in [1]. The idea is to calculate a linear controller in connection with a matrix, which eliminates the nonlinear coupling between the inputs and the outputs. With the input-output linearization a significant better performance can be reached. The inter-influence of the different movement directions is minor compared to Fig. 3.

Rapid Control Prototyping

In [4] a systematic procedure for the control design and implementation was presented, which is related to the known V-Model from software engineering. The procedure is illustrated in Fig. 4. Beginning on the upper left side of the V, the complete system analysis, modeling, simulation and control design takes place on the left side. After coding and implementing the algorithm on the specific target, the tests of the different components up to the test of the overall system takes place on the right side of the V.

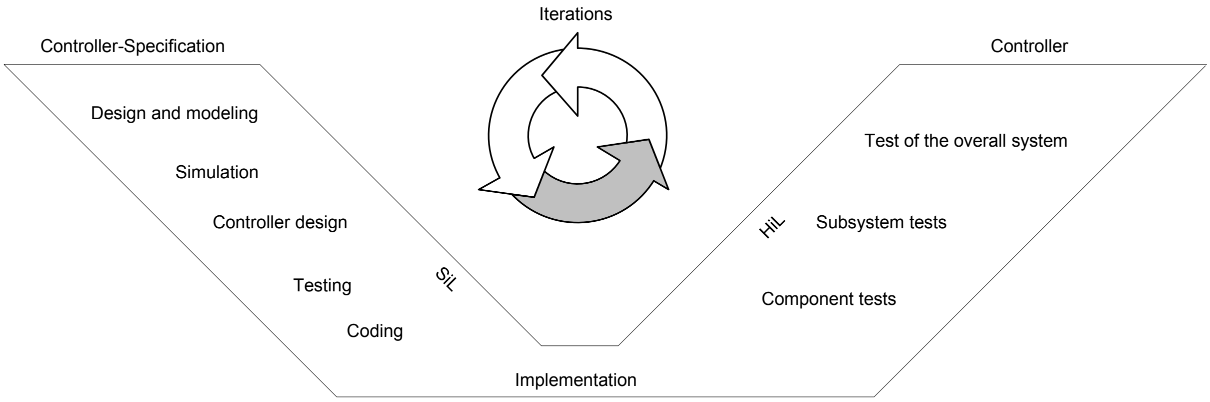

Fig. 4: V-Model

The classical V-Model contains the iterations at first only in vertical direction, which implies different drawbacks [4]. The idea of RCP was the introduction of horizontal iterations, whereby e.g. the applicability of the developed control algorithm on the specific system can be tested direct after the design. The most known terms in this field are “Software in the Loop” (SiL – the control algorithm will be executed on a high-performance Hardware, which is connected with parts of the real process) and “Hardware in the Loop” (HiL – the control algorithm will be implemented on the target, which is connected with a simulation model of the real process). So, the focus using SiL is the investigation of the suitability of the algorithm and the focus using HiL is the investigation of the implemented algorithm on the target considering the different restrictions concerning the computational power and the environmental conditions.

For an effective use of the mentioned RCP-Methods a continuous tool-chain is a necessary supposition. We use MATLAB/SIMULINK in connection with different tools distributed by the dSPACE GmbH. The two different configurations are illustrated in Fig. 5. For the SiL-tests the configuration on the right-side of the Figure is used. The different control strategies are developed using MATLAB/SIMULINK. After this, real-time code is generated from the block diagrams (using the so-called “Real-time Interface” RTI) and automatically downloaded on a high-performance Power-PC. Using AD- and DA-Channels the process values are visualized on a host PC and the performance of the control algorithm can be online evaluated. As a specific target for the control algorithm the 32bit Controller TC1775 (Infineon) is used in the set-up. So, for the HiL-tests (left side of Fig. 5) the developed algorithm has to be transferred on this target.

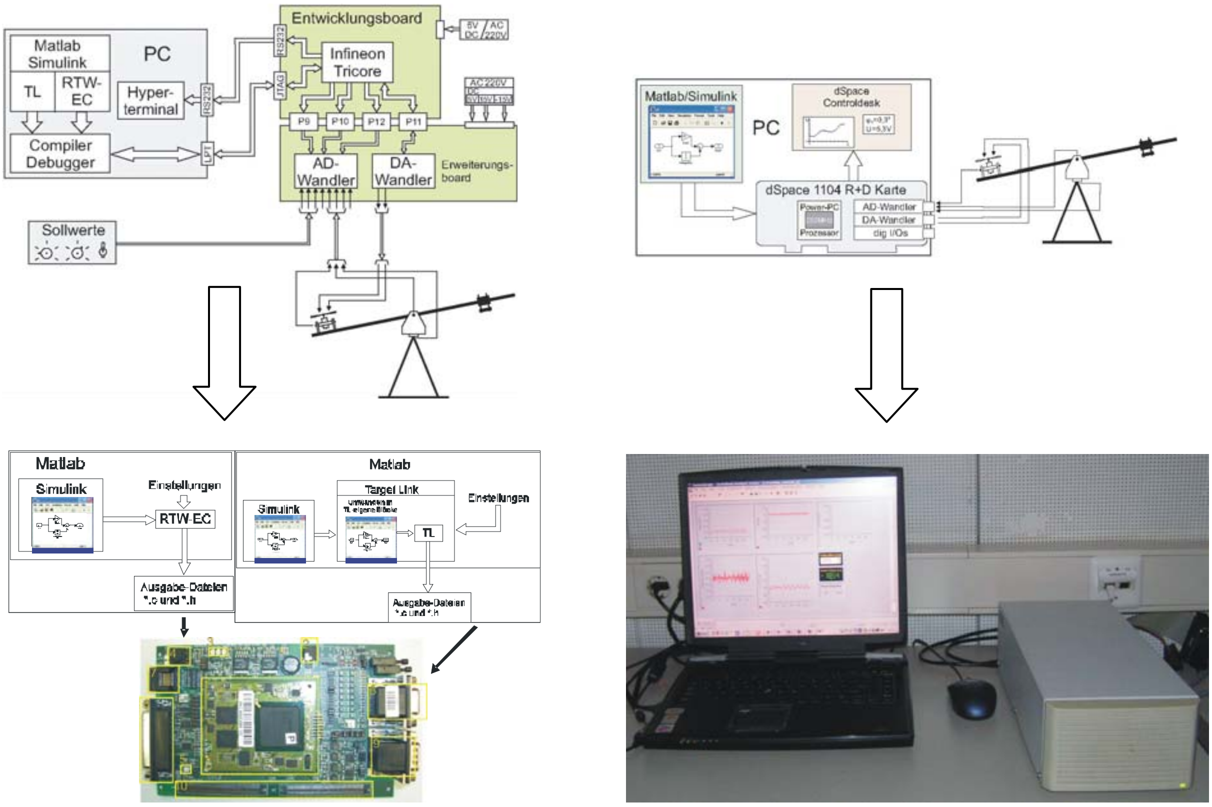

Fig. 5: Different RCP-Configurations for the helicopter set-up

We choose two different Code generators with the capability to generate optimized real-time code for specific targets. The first one is “TargetLink” distributed by the dSPACE GmbH and the second one “RTW-Embedded Coder” developed by “The Mathworks”. A comparison between these two tools was done in a diploma thesis [5].

References:

[1] Busch, Christian:” Entwurf eines linearisierenden Entkopplungsreglers für ein nichtlineares MIMO-System”, Studienarbeit am Institut AS, Juniorprofessur Automatisierungstechnik

[2] Föllinger, Otto: “Regelungstechnik”, 8. Auflage, 1994, Hüthig Verlag Heidelberg

[3] Wey, Torsten: „Nichtlineare Regelungssysteme – ein differentialalgebraischer Ansatz“, 2002, Teubner Verlag

[4] Abel, Dirk; Bollig, Alexander: „Rapid Control Prototyping – Methoden und Anwendungen“, 2006, Springer Verlag Berlin

[5] Tischer, Felix: “Vergleichende Untersuchungen zur Effizienz automatischer Codegeneratoren und deren Anwendung auf regelungstechnische Problemstellungen“, Diplomarbeit am Institut AS, Juniorprofessur Automatisierungstechnik, Februar 2006

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