Application in the context of “Innovatives Studium 2016”

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Embedded Control Project

where Cyber Physical Systems meet Model Based Development

The aim of the Embedded Control Project (ECP) is to let (international) master students experience the full cycle of control system design for cyber physical systems in a modern model based setting, in order to acquire crucial skills and insights with high industrial relevance. The main teaching idea is to let the students design and build a small and simple cyber physical system (CPS) of their own choice, i.e. a small hardware setup equipped with sensors and actuators and microcontrollers, to connect this setup to a modern rapid control prototyping environment, and to design the control system in a close interplay between computer simulations and physical experiments.

The Embedded Control Project fits the requirements of the “Innovationsfond” as well as the “Investitionsfond”.

BACKGROUND AND MOTIVATION

The so called “model based development” cycle that the students will experience in the ECP is becoming a modern industrial standard in most companies dealing with control of cyber physical systems (CPS). The main idea of model based development is to make extensive use of computer simulation models in order to perform model identification, model-in-the-loop, and hardware-in-the-loop tests before the control software is actually deployed on the cyber physical system hardware itself. In the ECP, the initial controller deployment itself shall be facilitated by a rapid control prototyping system, the use of which is becoming industrial standard in recent years.

To motivate the benefits of model based development and the choice of tasks to be performed in the ECP, let us regard the challenges which need to be addressed when a control system is designed in practice. The most important of these challenges are:

a) choosing the sensor- and actuation components and setting up their embedded system communication interfaces,
b) mathematical modelling of the system and choice of control methodology, and
c) choosing the real-time hardware for computations and communications, setting it up and implementing the controllers on this hardware.

While steps a) and c) are necessary and unavoidable tasks for any control system design, Step b) is only needed for model based control system design and necessitates knowledge in systems and control theory. It consists of a mix of physical modelling on paper and computer simulations in an environment such as MATLAB/Simulink. The advantage of model based development compared to just building and then tuning the embedded control system by Steps a) and c) alone is that many important design aspects such as control methodology, sampling time, sensor and actuator accuracies etc. can be simulated and optimized with help of powerful computing tools before actual deployment on the real control hardware. Thus, Step b) is the crucial and new step that the Embedded Control Project participants shall be trained in.

While Step a) is becoming faster and faster thanks to the existence of standardized communication interfaces, Step c) is often a very time consuming procedure in practice due to difficulties in matching the computational resources, implemented real-time control algorithms, and sampling times. In addition, data logging and visualization would be desirable during testing but need additional interfaces and computations that would not be necessary on the final product. Fortunately, when the aim is to only build and test a prototype of the control system, which is usually the first step in the development phase, Step c) can be accelerated significantly by use of a rapid control prototyping system such as the systems provided by the companies dSPACE or National Instruments. Here, the computational hardware and control software platform are integrated and known to work well with each other, and the computational resources are usually more powerful than necessary allowing them to offer extra functionalities such as data logging and visualization. Most important, in a rapid control prototyping system, Step b) and Step c) are highly integrated, which allows one to test a control methodology first in simulations and only a few minutes later on the real hardware, rapidly switching between the two steps in order to refine the model and control methodology.

WHAT IS NEW ABOUT THE EMBEDDED CONTROL PROJECT (ECP)?

Many large technical universities offer conventional control projects with prepared test setups such as an inverted pendulum, where only Step b) is performed by the students while Steps a) and c) are not done by the students but by experienced engineers in advance. The only task is then to go through Step b) and investigate different control methodologies on the real setup with help of the predefined interfaces, and on a predefined setup such as the inverted pendulum setup.

In the new Embedded Control Project at the University of Freiburg we want to go a different route: we want to allow groups of two up to four students to bring or invent their own physical system and then supervise them in the model based control system design using a rapid prototyping environment. This combination of Steps a) and b) is expected to lead to a more realistic training that includes setting up and controlling a new system, and resembles the situation in an industrial environment more closely than the conventional control project. Most important, it builds on the existing strength of Embedded Systems Engineering students, who are expected to be able to perform Step a) with relative ease, and is expected to increase motivation in working on the project significantly. An important ingredient to make this possible is to have an initial collection of sensor and actuator components with interfaces compatible with the rapid control prototyping system.

IMPLEMENTATION AND TIMELINE

The setup of the ECP and running it in the first year necessitates investments into hardware as well as working time. The aim is to create a project that can be done by about 15 students simultaneously, and to start the project in the winter semester 2016/17. Preparation of the hardware and software shall be performed during the summer semester of 2016, and the first group of students shall be supervised intensively by experienced PhD or master students. We can build on existing expertise and hardware in the groups of the Professors Leo Reindl and Moritz Diehl, in particular on the “Messtechnikpraktium” room that is equipped with PCs and real-time data acquisition systems. The software of Step b) should be MATLAB/Simulink based because it is the de-facto industrial standard and because all students have already a campus license for this software and it is used in the systems and control theory courses. The hardware platform for rapid control prototyping that appears to fit both MATLAB/Simulink and the needs of the ECP best is a ClassRoom MEDKit from the company dSPACE. Because we want to work in groups of three people in average, the additional hardware for 15 students comprises 5 of the dSPACE MEDKits. This hardware offers interfaces such as USB, CAN, and JTAG as well as analog inputs and outputs. In addition, we have to provide some building blocks for the sensors and actuators and hardware such as Inertial Measurement Units (IMU), small scale electrical drives, propellers, joints, power electronics, temperature, distance, and pressure sensors, electrical heaters, small scale pumps, as well as to provide already two control setups such as a Furuta pendulum or a levitating magnetic ball. The aim is not to constrain students to use these setups or components, but to offer them to those students that are in need of ideas and inspiration.

On the personnel side, we expect to need, for the duration of one year, the following people:

- one experienced control engineer (PhD student or postdoc, 25% of full time equivalent), for choosing the overall setup and working on preparation and supervision of Step b)
- one engineer (with master in MST, MSE or ESE, 25%), for working on the preparation and supervision of Step c)
- three job students of each 40 hours per month, that help setting up the system and supervising the first group of students.

Overall, the hardware investment is expected to amount to about 12.804 Euro and the personnel investment to about 59.151 Euro. The outcome would be new and worldwide unique Embedded Control Project with a multitude of small student designed controlled systems that can help to further increase the visibility of the Master in Embedded Systems Engineering and introduce our students in an innovative way to modern control system development.

Hardware Investment	**Costs**
5 x dSPACE MEDKit à 1071 €	5355 €
1 x Software licenses for all dSPACE MEDKits (TargetLink Base Suite and Target Link Simulation Module)	3249 €
5 x Hardware equipment for the projects (600 € per project)	3000 €
1 x Furuta pendulum and 1 x levitating magnetic ball setup	1200 €
Sum	12.804 €

Personal Investment	**Costs**
1 x PhD student or post-doc (25% for 12 months)	21.250 €
1 x engineer with master (25% for 12 months)	16.100 €
3 x job students (40 hours / month for 12 months)	21.810 €
Sum	59.151 €

FUTURE DEVELOPMENT: CONTROL PROJECT FOR EXTERNAL STUDENTS

After the initial development, the ECP shall be offered each year once or twice as project course with 5 ECTS to ESE master students, supervised by tutors funded by the chair "Systemtheorie". A spin-off of the ECP in the second year could be a conventional control project that builds on the hardware of the most successful ECP implementations and thus only comprises Step b). This would allow non-ESE students to work exclusively in a MATLAB/Simulink environment and still gain real-world control experience. Such a more conventional control project could be offered to master students of Microsystems Engineering (MSE/MST), Sustainable Systems Engineering (SSE), Renewable Energy Engineering and Management (REM), as well as to interested students from Applied Physics, Mathematics, and Computer Science.