LABORATORY 2.0
Towards an Integrated Research Environment for Engineering Mechanics

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Abstract: Cooperation Support Systems, respectively CSCW-Systems, increasingly offer standardized interfaces to allow their integration into university-wide IT infrastructures. However, several disciplines (e.g. engineering and medical science) require the use and seamless integration of additional applications to meet researchers' requirements and support collaboration in a sustainable manner. This articles outlines the possibilities to integrate high-tech laboratories into existing IT infrastructures to strengthen the exchange of information among teaching, research, and industry. Since, laboratory components are usually characterized by proprietary interfaces, we replaced these manufacturer-specific interfaces and protocols by a service-oriented architecture for laboratories. Therefore, functionalities of laboratory components will be encapsulated as a service and made accessible by Linux Field-Bus Couplers. The modularization of the laboratory allows the connection to the world of e-learning documents. This article highlights the symbiosis between research in engineering and teaching at universities. The authors explain in the article that not only the research can take a significant influence on teaching, but also vice versa, the teaching is a part of the later researches in laboratories.

1 HIGH-TECH LABORATORIES: INACCESSIBLE KNOWLEDGE?

In many academic disciplines the transfer of knowledge between top level research and teachings in universities is sluggish and unacceptable for modern research institutes (see (Nahar et al., 2001) and (Potocnik J., 2007)). Particularly, research facilities that use complex and expensive testing equipment are often reserved for a small number of researchers. Hence, costly acquired research results are slowly disseminated and the transfer of current research results to lectures is barely given. A second challenge are proper backup and archiving solutions for test results as well as the related experimental parameters. Yet, the knowledge about the relation between test evaluations and additional parameters of the test set-up is fundamental for the later re-use of obtained results.

In the area of materials engineering, components are subjected to cyclic thermo-mechanical stress (Mahnken, 2008). Thermal shock is an extreme form of thermo-mechanical stress of components, which occurs particularly in components of mechanical engineering. These highly specialized laboratories usually consist of many components from different manufacturers. Most of today's laboratory components provide only proprietary and vendor-specific interfaces. Hence, the laboratory does not provide enough flexibility in terms of adjustments and reorganizations (see (Nahar et al., 2001) and (Potocnik J., 2007)). Furthermore, this entails media breaks, which prevent the transfer of research results to teaching as well as to cooperation partners from industry.

In this article we present a service-oriented approach for laboratory architectures. The objective is a modularized thermal shock laboratory, allowing more flexibility in respect to the test set-up and easy data exchange among the laboratory and existing applications of an university-wide infrastructure. Standardized interfaces are necessary for easy processing and re-use of test results. A laboratory component can be addressed in a much more flexible way by encapsulating its functionality as a service and making it accessible by using Linux Field-Bus Coupler. This mod-

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ularization of the laboratory and the standardization of the interfaces allow a seamless integration of the laboratory into the existing university infrastructure. Knowledge creation and knowledge transfer should no longer be considered separately, since they influence each other. For us high-tech laboratories play a central role for university teaching, they are a source of knowledge. New learning and teaching opportunities will arise by the close coupling of knowledge creation and knowledge transfer. To guarantee efficient access to latest research results in the context of courses, high-tech laboratories have to be consistently integrated into university-wide infrastructures.

This article is organized as follows. In section 2 a service-oriented architecture for laboratories will be explained. As an example field of application the implementation is realized for a thermal shock laboratory. Thereto, we first refer to the service encapsulation of laboratory components (section 2.1) and then the use of Linux Field-Bus Coupler[1] for the modularization of the laboratory network will be discussed. The section 2.3 deals with safety aspects in the laboratory environment. Section 3 tries to answer the question how to facilitate and accelerate the transfer between research and teaching. Afterwards section 3.1 introduces a framework for building collaborative learning and working environments. Furthermore, the framework supports in integrating existing heterogeneous systems into complete networks to consolidate system convergence. Section 4 presents LTM-SOLA, a service-oriented laboratory application. This application is a browser-based graphical user interface to plan, prepare, control, and coordinate thermal shock experiments. Finally, we discuss our results in section 5 and give a short outlook to further work.

2 A SERVICE-ORIENTED LAB ARCHITECTURE

The intention to develop a service-oriented laboratory architecture has two main reasons. On the one hand to arrange laboratory components in a flexible way by modularization of the control software. This allows researchers to adjust the laboratory regarding the actual needs as well as replacing existing and adding new devices to the laboratory's integrated network. On the other hand the service-oriented architecture intends to enable a simple and sustainable integration of laboratories into existing information infrastructures. Thereby the knowledge flow between research in laboratories and teaching in courses can be sustainable improved.

2.1 Service Encapsulation of Laboratory Equipment

The objective is to avoid media breaks between different systems to allow a continuous information flow. Although it is impossible to reduce every media break, e.g. those that occur when shifting from digital to analog media and vice versa. However, media breaks have to be reduced in order to ensure system convergences (Keil-Slawik, 2005).

In order to consistently reduce media breaks and to ensure an integrated system network, which includes the laboratory, unified interfaces have to be developed for all laboratory devices. The issue is that laboratory devices are typically equipped with proprietary protocols. Uniform interfaces, or even a consistent API to control the devices do not exists. Thus, the idea to develop a service-oriented architecture for laboratories may be a suitable approach. Thereby, functions of the laboratory components will be encapsulated as a service. In (Ferber et al., 2008) the authors describe a possibility to make laboratory components accessible using web services. For this purpose Java classes have been developed that make the laboratory device's functionalities accessible via modern web services and encapsulate proprietary protocols. This concept with uniform interfaces and protocols makes laboratory components accessible from "any" application (like e-learning, CSCW applications or digital libraries).

Nevertheless, the disadvantage of the presented approach is that communication between Java-based services and the laboratory components still require a central master computer. This master computer is responsible for the entire interaction and is a single point of failure. In addition the performance and response time of the control software is an important factor when using laboratory services in real experimental execution. Hence, it is valuable to modify the concept of web services by replace the central master computer with a service-oriented application, that is modularized and thus very flexible. To make laboratory components more independent how the web services have made it, the LFBC infrastructure will be introduced. The company WAGO[2] provides industry standard Field-Bus Couplers that are suitable for our purpose due to its network interface and an embedded Linux as operating system. This

[1] Linux Field-Bus Coupler (LFBC) – a 32-bit ARM processor system with an embedded Linux operating system.

[2] WAGO® is a German company for electrical interconnections and automation (`http://www.wago.com`).

approach is unique, because the most laboratories use the PLC technology. WAGO provide a wide range of field bus modules for any devices. So only one manufacturer is involved, the system is extensible and easily programmable in C. The LFBC coupling the manufacturer-specific interfaces and protocols of the laboratory devices in blocks that are run cyclically to update the signal states. So any device is equipped with a field bus modules and the specific functionality that is embedded in a building block and running in the execution cycle of the LFBC. These functionality is accessible from the local network by bidirectional inter-process communication flow, called network socket.

2.2 Intelligent Laboratory Components

In section 2 the advantages of a service-oriented architecture for laboratories are emphasized. Beside it scientists wants to focus on their core tasks such as planning, setting up, the actual execution, and later on the evaluation of thermal shock experiments. The former laboratory architecture had the fundamental disadvantage that an experiment is non-exclusively influenced by the control software. Instead, the execution is affected by external conditions (a central master computer and a Siemens PLC[3]).

The solution presented in this article breaks the rigid link between the central master computer and laboratory devices by using LFBCs (see section 2.1). This allows completely new experiment scenarios, for example, to determine the PID[4] control parameter prior to the actual experiment execution. The PID controller calculation (algorithm) involves three separate parameters, and is accordingly sometimes called three-term control. The PID parameters are usually determined once for a specific control system. However, the conditions in the thermal shock laboratory are continuously changing, because scientists experiment with various samples that differ in their material composition and therefore require specific PID parameters. Thus, the PID definition has to be adjusted individually for each test set-up.

Figure 1 shows a comparison between a standard 2-point control and the advanced PID control. The blue and the black lines stand for the desired values. The purple line represents the actual values using PID controller and the yellow line constitutes the actual

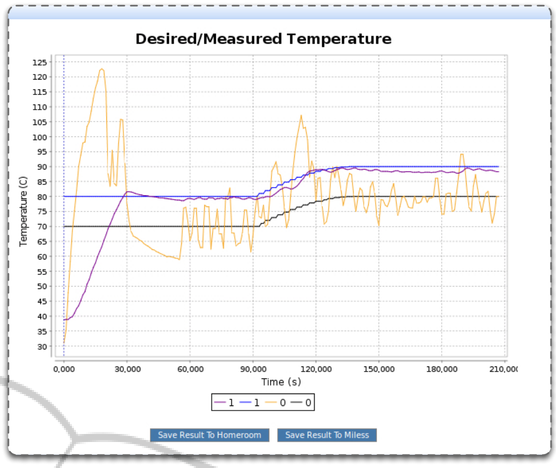

Figure 1: Comparison Between 2-Point Control and Automatic PID Control.

values using 2-point control. Obviously, the PID-based parameters significantly improve the automatic control.

Conditioned by the encapsulation of laboratory devices as services, associated with the use of LFBC infrastructure, the calculation of appropriate PID parameter was made possible. Thus, the induction heating can be adjusted to the current test set-up for an efficient automatic control. The presented functionality is only a fraction of what opportunities the system offers for integration of building blocks.

2.3 Safety Aspects of the New Laboratory Architecture

In laboratories often heavy and dangerous devices are used, hence a faulty test set-up and inappropriate use may lead to fatal accidents. In addition, failures may imply huge financial losses. To avoid this kind of inappropriate use a major task of the Siemens PLC was to ensure the safe execution of thermal shock experiments. For example, the safety door of the test chamber must be closed before the induction heating can be switched on. This precaution is implemented on the PLC. In the new laboratory architecture the Linux Field-Bus Coupler has to take over this task and thereby ensure the safe experiment execution. In a LFBC the input and output signals are presented as a process image. To facilitate the access to this relatively complicated process image, a program was developed which provide a high-level access to the process image. The access on a high-level is done by a program called "*iocontrol*", which works like an operating system and implements the PLC functionality for a LFBC. This allows to call the modules cycli-

[3]The PLC is a memory-programmable control unit.

[4]A proportional-integral-derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems – a PID is the most commonly used feedback controller. (Further information: `http://mhf-e.desy.de/e638/e1770/`).

cally that are responsible for controlling one or more devices.

3 KNOWLEDGE CREATION AND KNOWLEDGE TRANSFER

There exist numerous approaches to sophisticated implementations of virtual laboratories that can support students to learn practical work without the risks in real laboratories (Ramat and Preux, 2003). Nevertheless, it is insufficient for the universities to educate their students only in virtual laboratories. Rather there is the requirement to prepare students as good as possible by practical scenarios and assistance in real laboratories for the industry's needs. Furthermore, high-tech facilities cooperate in many ways with the industry and especially with medium-sized companies, for those who cannot afford an own test bench. Experiments that are performed in the high-tech laboratory such as the thermal shock laboratory represent the information demand of many engineering companies.

In addition the authors follow this approach to keep the delay between the knowledge creation and knowledge transfer in teaching as low as possible. Hence, the integration of the new laboratory architecture into existing infrastructures is essential. The presented laboratory infrastructure in section 2 not only enhances the flexibility regarding the arrangement of laboratory devices, but also allows simplifies the integration of the laboratory into existing information infrastructures. This includes in particular digital libraries, in which experiment results and experiment parameters can be stored permanently and centrally. Since, digital libraries are used as knowledge bases for teaching and e-learning platforms in many ways, the connection between the laboratory and digital libraries is very important. Through the direct link media breaks are eliminated and experiment results can be directly or after a appropriate preparation used for teaching. Before give an idea of how to use the results in teaching we will introduce you in the WasabiBeans Framework, which provide a wide range of rights and user management, important for give accessibility to the corresponding results.

3.1 System Integration with the WasabiBeans Framework

To reach a direct link between different systems or even across system classes they must be conform connected to an integration layer or a message-bus[5] (Schmidt et al., 2005). Only in this way a complex exchange of information between these systems can be effected. One possibility to find adequate support here is the WasabiBeans framework (Schulte et al., 2008). WasabiBeans is a framework for building collaborative learning and working environments and the integration of heterogeneous systems into a system group. This framework relies on a JBoss Application Server[6] platform and therefore allows the use of many existing standards such as JAAS or JCR with that the flexibility in the directory- and persistence layer can be ensured.

Figure 2 shows the new laboratory architecture that can be connected with arbitrary applications using WasabiBeans as a service-oriented platform for system integration. The decision for the use of WasabiBeans framework has to be justified, in particular, that the fast transfer of information, without a break in media should be ensured between research and teaching. To use the collaboration between scientists in the laboratory on the one hand and the user group, which will benefit form the experimental results, should be effectively enhanced by the development of an integrated infrastructure. The data model of WasabiWeans implements the concept of virtual knowledge spaces (Hampel et al., 2004). Therefore, the framework is ideally suited to structure and organize information as well as collaborative work with documents. An essential function is the management of experiment results and teaching materials for courses. Thus, there are novel teaching and research possibilities by having flexible capabilities of storage as well as the fine tuned rights and user management.

3.2 Bundling of Laboratory Services as WasabiBeans-Module

In section 2.1 we discusses the advantages of encapsulating laboratory components and make them accessible as services. To access the individual services better, they are grouped together as a module and added to the WasabiBeans framework. Due to the generation of a WasabiBeans module it is possible to let the services run on the same JBoss AS, which had deployed the WasabiBeans framework. This has the great advantage that all calls to services of other modules, such as a service for storing documents in

[5] A message-bus denoted in the information technology a class of software solutions that support the integration of distributed services.

[6] The JBoss Application Server (JBoss AS) is the world's most widely used Java application server. Available online at: http://www.jboss.org/jbossas.

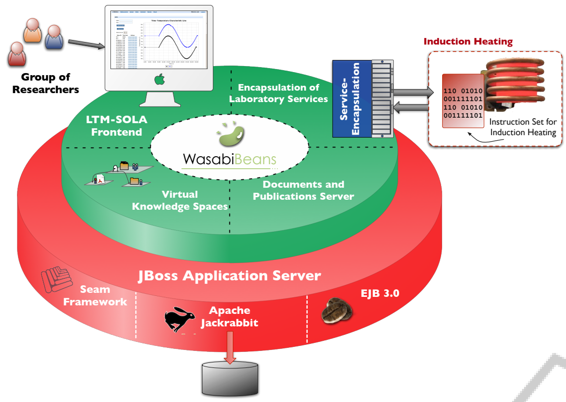

Figure 2: Serivce-Oriented Laboratory Architecture Based on LFBC.

a digital library, to be carried out only local. This means in particular that no RMI calls or web service calls are necessary. Performance measurements have shown that this is a speed increase by a factor of up to 1000 is possible. Another reason for the creation of a module is the easier use of the new lab services from existing applications. This concerns not only those who already use the WasabiBeans framework, but also the applications of a university-wide infrastructure that have not yet been fully integrated into the system group. The WasabiBeans framework offers a variety of cooperative support services and therefore facilitates the interface to existing applications. The developer has a high degree of flexibility through the use of the framework. For example, events can be triggered by the completion of an experiment, that imply actions required in other applications.

4 LTM-SOLA - SERVICE-ORIENTED LABORATORY APPLICATION

The developed application LTM SOLA[7] is a key figure to forward the modularization of the laboratory and creates a large degree of flexibility with the service-oriented approach concerning to prepare of thermal shock experiments and archiving the results. Through the provision of web services is set to technical standards and standard interfaces are offered. By internal structure of the business logic as JavaBean classes, the bundling of the provided services is possible. Access to each service is coordinated with the specified interfaces and allows the use of business objects.

[7]Lehrstuhl fuer Technische Mechanik Serviceorientierte Laborapplikation

LTM-SOLA provides services, which take over the planning, preparation, control and coordination of thermal shock experiments. In the Editor view (see Figure 3), temperature profiles in form of a temperature curves can be created that is used to control the induction heating or the cooling device. Also various configuration options are available in the Scheduler view that are essential for the execution of the thermal shock experiments. Here, for example, the number of heating and cooling cycles can be defined, or the selection of the temperature curves are created in the editor can be done. In selecting the method of heating the user can choose between the *Standard* method with a temperature curve, the *TwoLines* method for controlling the temperature gradient or the *SelfLearn* method for determining the PID parameters. During an experimental, the processes in the monitor view will be followed in real time. In a chart, the actual and set temperatures are reviewed alongside the experiment.

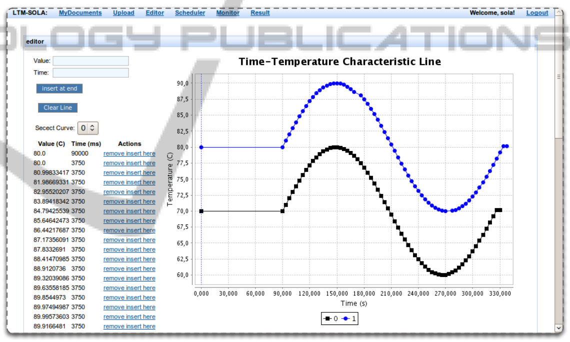

Figure 3: Editor-View of LTM-SOLA.

LTM-SOLA was designed based on the new requirements and can be used to control laboratory components, but it was particularly concerned to interoperability with other systems and a great value where placed on the cooperative experimental execution. In LTM SOLA it is possible to define roles for each individual page views, so that not every user can do the actual control of the laboratory equipment. With a login cooperation partner and another university member get access to the editor's view in order to create a heating profile for the experiment. The heating profile can be then saved in the system and later loaded from a scientist on the ground to execute this experiment. Through the use of WasabiBeans frameworks, the storage of experiment results in different repositories is possible. LTM SOLA for example, can store the experiment results form the Result view in the digital document and publication server *Miless* for permanent archiving. More information about Miles are (Gollan et al., 1999). Miles is in turn integrated into various systems such as an e-learning system, as a source of knowledge. In this way, experiment results can be accessed from different systems without media breaks to bring teaching and research closer together.

5 CONCLUSIONS

High-tech institutions cooperate in many ways with the industry and especially with medium-sized enterprises that are not able to operate their own laboratory due to the high costs. Furthermore, universities try to educate their student in a professional way. On the one hand by involving students in current research projects and on the other hand by taking the necessities of the industry into account. The cooperation process between academics, industry partners and students was interrupted by the lack of standardized interfaces. Figure 4 shows the thermal shock laboratory as an integral part of a university-wide system infrastructure. The systems are not isolated anymore, but linked by a service-oriented approach to an integrated systems network for scientific research and work processes.

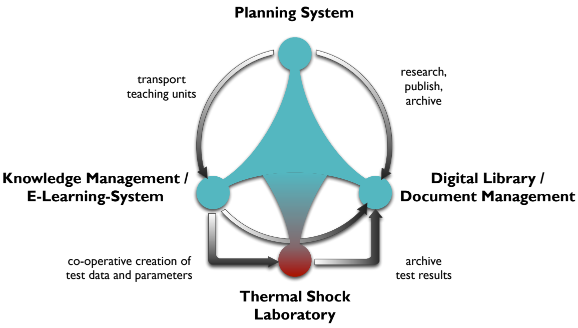

Figure 4: An University IT-Infrastructure that Includes the Thermal Shock Laboratory.

The service-oriented architecture for laboratories that bases on LFBCs has been proven in daily work. Firstly, this concept made it possible to rearrange the laboratory for different purposes and needs. Second, the interaction and information exchange between the laboratory itself and other existing applications is a lot easier than before. In particular, the laboratory became a fully integrated part of a complex university-wide IT infrastructure. The LFBC infrastructure seems to have a promising future, thus current activities focus on refining LTM-SOLA. We try to offer a complete scientists work place to plan and prepare experiments, but also to edit test results and structure all information that are collected during the test execution. We are working on expand the co-operative work aspects and provide an infrastructure that allows to integrate various repositories to a transparent storage unit. In this age where the technology behaves very dynamic and ever-increasing complexity, this approach meets the requirements of flexibility, extensibility and reusability.

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