15th Triennial World Congress, Barcelona, Spain

COST REDUCTION VIA ACCURATE CONTROLLER SIMULATION

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Abstract: Accurate simulation provides a significant means for cost reduction during planning and operation of manufacturing installations. Within the projects Realistic Robot Simulation the standards Robot Controller Simulation (RCS) Interface and Virtual Robot Controller (VRC) Interface were defined by international consortia of leading car makers, robot and simulator manufacturers and line builders, with Fraunhofer IPK, Berlin as project manager. For enabling accurate simulation of complete manufacturing lines, a new project entitled Virtual Programmable Logic Controller (VPLC) is planned. The article outlines the resulting potential of cost reduction throughout the life-time of an installation and gives an overview on the application of the standards for cost reduction. *Copyright © 2002 IFAC*

Keywords: Realistic, Robot, Simulation, Simulators, Accuracy, Industrial, Standard, Virtual Reality, Planning, Commissioning, Manufacturing, Maintenance

1 INTRODUCTION

Accurate simulation of manufacturing installations provides a virtual model of a real installation that can be used for several purposes. In particular, it enables the prediction of an installation's behavior without having to access the real one. Therefore, simulation bears a considerable potential for cost reduction.

During the pre-productive phase of an installation's life time (i.e. planning, construction and commissioning), simulation allows for shortening product times-to-market by concurrent and more goal oriented work. Furthermore faults, that would be costly when detected later, can be detected and avoided early. For the productive phase, simulation provides a model of an installation that can be used for preparing work which would, if executed at the real installation, hamper production or may even lead to damage.

A prerequisite for a successful cost reduction via simulation is the capacity of a simulation model to predict. Therefore simulation aims at modeling reality relevant aspects of reality with high accuracy.

A consortium of automotive companies, line builders and robot and simulator manufacturers gained considerable experience in the area of robot controller simulation during more than a decade of cooperation. A major result of this cooperation are two standards: the Robot Controller Simulation (RCS) Interface and the Virtual Robot Controller (VRC) Interface. Based on these standards, a variety of products have been developed and extended, while efficient working procedures for cost reduction have been elaborated.

The following section "Manufacturing Simulation as a Means for Cost Reduction" gives an overview on several applications of simulation for cost reduction throughout the entire life-time of installations. The next section "Improvement of Accuracy in Controller Simulation" describes how the several steps that were undertaken to achieve the high accuracy that is possible today in simulating robot controllers. The subsequent section outlines how and where the developed technology can be applied to further aspects of simulation. The final section gives a summary.

2 MANUFACTURING SIMULATION AS A MEANS FOR COST REDUCTION

Simulation can be used during the pre-productive and productive life-cycle phases of an installation in order to fulfill several purposes (Baumgartner A., Bernhardt R., Schreck G., Willnow C, 2001). Each of the purposes, in turn, leads to certain cost reduction effects. An overview is given in figure 1.

2.1 Cost Reduction during the Pre-productive Phase

During the planning of an installation (i.e. during mechanical design), the major benefit of simulation arises from 'running' a virtual model of the line to be designed and from a graphical animation of the model. As a result, the designer can see the installation moving in action. Furthermore, the simulator can derive various performance data.

Potential for cost reduction results from early detection of possible problems that would otherwise arise during commissioning. These problems would then be more costly to repair, caused by the involved hardware equipment, effects on the over-all design and the time pressure of the approaching acceptance date.

Further cost reduction results from deeper analysis of the behavior of the future installation and a more profound evaluation of design variations. For example, the simulation can supply the designer with estimations of cycle-times and of the use of components. Through this, bottlenecks can be detected and avoided, components can be optimized or even saved. The final product becomes less costly and the relation of cost to performance is improved.

During the mechanical and electrical construction of an installation, simulation can be used for starting programming earlier. Here the time saved in the pre-productive phase becomes most obvious. While programming without simulation requires the availability of the installation, simulation allows for performing both tasks concurrently. Furthermore, programming tasks that require the access to the same components can be performed simultaneously on 'copies' of the same simulation scenario.

Additionally, programming at simulation contributes to risk reduction. While programming errors at the real installation may cause mechanical damage and may endanger personnel, simulations are forgiving. A crash in a simulation may, in the worst case, require the re-starting of the simulation. For this reason, before programs are commissioned at the real installation, they can be thoroughly tested in simulation.

For the commissioning, simulation provides a virtual version of the installation which can be used for finding solutions to problems arising at the real installation without interfering in the work. This includes tasks reaching from analyzing and solving mechanical problems to program debugging.

However, the major benefits in the commissioning phase arise from the earlier uses of the simulation. Since design errors were detected earlier, they will not lengthen the time of commissioning. Also, programs that were thoroughly tested during the construction can be commissioned faster.

A major problem with the use of simulation arises during the commissioning phase. At this point, simulation and reality may start to diverge seriously. Modifications at the real line, that are now often

Life-time Phases		Use of Simulation	Cost Reduction Effect
Pre -productive Phase	Planning	- Verification with animation - Optimization with animation	- Less late repair of faults - Optimized layout
	Construction	- Programming in parallel - Program test in simulation	- Reduced time consumption - Risk reduction
	Commissioning	- Program test, analyses	- Verified design - Reduced time consumption - Availability of equipment - Risk reduction
Productive Phase	Optimization	- Analysis of the installation - Verification of modifications - Re-programming and test	- Improved performance - Maintaining production - Risk reduction
	Change in Product	- Feasibility verification - Program preparation and test	- Risk reduction - Maintaining production
	Redesign	- Combinations of the above	- Combinations of the above

Figure 1: Phases during the life-time of an installation, related usages of simulation and resulting cost reduction effects.

performed hastily in order to meet dead lines, may now become inconsistent with the simulation models. If the differences become too large, the simulation may become unsuitable for efficient use during the productive phase.

2.2 Cost Reduction during the Productive Phase

Optimization of a running installation is often prevented by the fact that the installation is not productive while the optimization work takes place. Furthermore, modifications in the installation always bear a certain risk of damage. This may lead to additional losses in productivity. For these reasons, the benefits of improvement often have a lower priority than that of keeping the production running.

Simulation allows to cope with both obstacles. Planned optimizations can be prepared in simulation without hampering production. Modifications can be thoroughly tested before being implemented in the installation.

In addition, simulation provides efficient means for analyzing an installation for optimization potential and for verifying in advance the effect that a planned improvement will actually have. In this sense, simulation plays a role in quality control. Of course, the accuracy of the predictions given by the simulation depend directly on the accuracy of the simulation.

Modifications in an installation for a change in the product can be prepared cost efficiently in simulation as well. For example, this may be the case when introducing a new product variant that requires program changes and possibly mechanical modifications. Simulation can also be used in the everyday operation of commissioning the installation for producing pieces with small batch sizes, as it is typical e.g. for applications in ship yards.

Once again, the major source of cost reduction is that the installation remains productive while the modification is being prepared. Furthermore, commissioning times are reduced, since programs are verified in simulation before being applied to reality.

The redesign of an existing installation, though similar to the smaller modifications described above, denotes more extensive modifications that consume a longer time span. A good example is the redesign of a body-in-white-line in automotive industries when introducing a new car model into the line. Of course, the redesign work hampers the production of the already introduced car models and is therefore preferably performed during company holidays.

In order to interrupt production for a minimum of time, all the above described applications for simulation can be used: Verifying the re-design, analyzing design variants, preparing programs, optimizing the line and testing it in simulation.

3 IMPROVEMENT OF ACCURACY IN CONTROLLER SIMULATION

A successful and promising approach for accurate simulation of controllers was started in the early 1990s with the projects Realistic Robot Simulation (RRS). The core of the approach consists in defining standards. Around the standards simulation product are built. The major steps in the development occurred as follows:

3.1 The Robot Controller Simulation (RCS) Interface

The need for accurate simulation models for robot controllers became urgent at the end of the 1980s (Bernhardt R., Schreck G., Willnow C., 1995). At this time, the most prominent obstacle for successful application of robot simulation was formed by deviations in the robots' motion behavior during simulation as compared to reality as illustrated. An example of such deviations is given in figure 2. After several attempts to re-model robot behavior, it turned out that the controller software is to complex for such an approach. The only successful approach consists in using the original controller software.

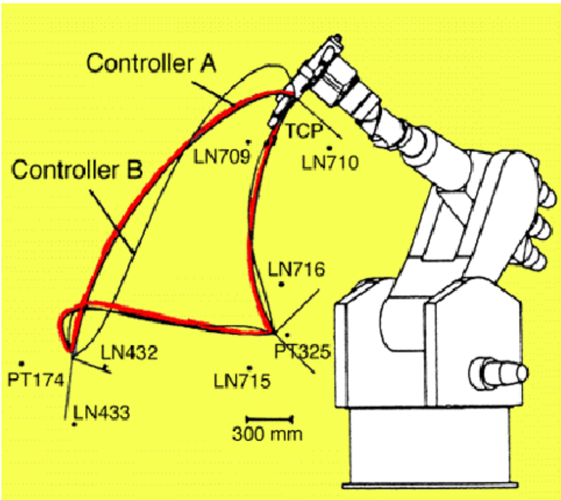

Figure 2: Deviations in robot motion behavior in the late 1980s

For the integration of the real controller software into simulators, however, it turned out that this work had to be done again and again for each robot controller and simulator pair. In order to simplify this work, the concept of defining a standard interface was born. Via this interface, any robot controller software can be coupled with any simulation system.

In 1992, the project Realistic Robot Simulation (RRS) was started by a number of automotive companies and the required interface was developed by leading robot and simulator manufacturers. The project management was performed by Fraunhofer IPK, Berlin.

In order to keep the technical risk at a reasonable level, the partners agreed to restrict the extent of controller software to the motion system. The resulting Robot Controller Simulation (RCS) Interface allows for creating instances of robot motion controllers, passing motion targets to them and obtaining the interpolated motion steps. In addition, several groups of supplementary functionality are provided, including motion specification, event and machine data handling.

The RCS-Interface was published in 1994 (RRS-Owners, 1997). Soon several compliant products appeared on the market and were applied. Today the RCS-Interface forms the world-wide de-facto standard for precise simulation of robot motion behavior.

3.2 The Virtual Robot Controller (VRC) Interface

After the success of the RCS-Interface as a solution for the most prominent problems, needs for further improvements came up. In particular, application languages, technology control and I/Os still had to be emulated by the simulation systems. In order to achieve an even higher simulation accuracy for robot controllers, a further standardization project was started in 1998, with a consortium extended to include line builders and measurement system manufacturers (see figure 3).

Since the goal was an interface that gives all robot controllers a uniform appearance, it was called the Virtual Robot Controller (VRC) Interface (VRC-Specification Owners, 2001). In 1999, the draft version of the VRC-Interface was published in the consortium. While the RCS-Interface defines more or less a procedural interface for accessing a library of robot motion mathematics, the VRC-Interface, requires a much looser coupling since it has to almost completely cover the controller software, including the operating system. This is achieved by exchanging commands, responses and events by asynchronous calls.

The calls provided by the VRC-Interface can be grouped into three categories which are for modeling interfaces of real controllers and into three categories which are required for running VRCs in simulation. These categories are illustrated in figure 4.

Figure 3: The consortium consisting of automotive companies, robot and simulator manufacturers, line builders and measurement system manufacturers

Categories that model interfaces of real controllers are as follows:

- <u>I/O</u>**:** Transferring I/O signals between virtual controller and simulator software
- <u>File System</u>: Transferring programs, machine data, etc. between controller and simulator
- <u>User Interface</u>: Functionality for loading, starting, stopping programs, evoking editors, etc.

<u>Categories for simulation purposes are as follows</u>:

- <u>Base Commands</u>: Creating and managing instances of virtual controllers
- <u>Virtual Time Management</u>: Controlling and synchronizing simulation progress of virtual controllers
- <u>Simulator Support</u>: Providing controller internal algorithms (e.g. transformations) and events to simulators.

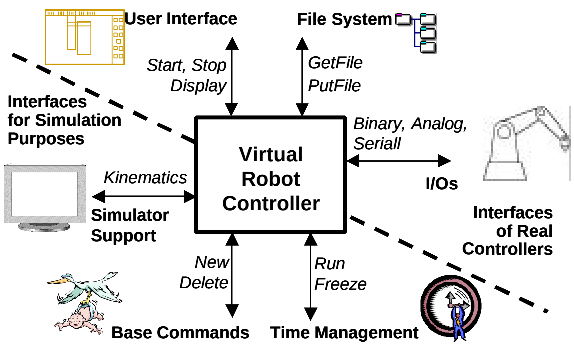

Figure 4: The categories of interface calls that give VRCs a uniform appearance

The draft version of the VRC-Interface was encouraging. The extent of the interface promised a high level of precision and the simplicity and soundness of the interface concepts promised a successful implementation. Soon thereafter, a first controller/simulator coupling, based on the draft version, appeared on the market.

With this technical challenge as good as solved, further demands arose.

3.3 The Extended VRC-Interface

Besides the accuracy of a controller model, its integration into the over-all development process plays an important role. This especially concerns the above described steps during the pre-productive and productive phases of an installation.

Already during the early planning stage, the use of original software is important. The design personnel, that are normally not controller specialists, have to rely on correct controller behavior. Furthermore the labeling of signals, positions, etc. begins in this early phase. Procedural data like operation sequences, that are generated during design, form the core of program skeletons that are worked out in detail later-on. Efficient work procedures require that this data is re-used during the following steps of programming and commissioning.

Furthermore, a consistent backwards-flow of data is important for transferring modifications performed at the real line flawlessly back to simulation and even to tools of the design phase. This is already required during commissioning, but becomes crucial for all simulation activities during the productive phase.

In order to standardize the required, controller specific support, the project was extended for these aspects in 1999. The major additional functionality comprises:

- Robot Native Language Program Generation (Code Generation)
- Upwards and downwards Data Consistency Mechanisms
- Controller Specific User Interface integration into simulators, i.e. Native Language Program Editors.

The resulting continuous data flow from mechanical design, via detail programming in simulation, to the shop floor and vice versa is illustrated in figure 5

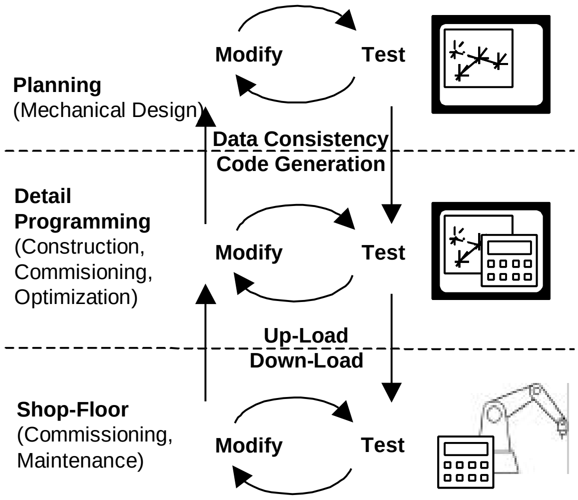

Figure 5: Continuous Data Flow from early planning phases via Native Language Programming in simulation down to the shop floor and vice versa

The first public version of the VRC-Interface, including controller simulation and integration into the over-all data flow, was published in 2001.

4 FURTHER GOALS

The achievements of the RRS-projects form a solid base for further developments and for extending the success of this technology. In addition to obtaining an extremely high simulation accuracy, based on the experience of more than one decade of a successful application of simulation, a tight integration into the over-all data flow is realized. Both form an efficient means for cost reduction during the development and operation of manufacturing installations with robots.

Further goals consist in transferring the developed methodology to further controller types and processes in the vicinity of robots. This will not only extend the success to other technological areas that can profit from the gained experience. It will also contribute to keeping the simulation world consistent. For example, accuracy losses arising from the coupling of inconsistent procedures and data formats will be avoided (Willnow C., 2001). Furthermore, the use cases and the proceeding during application of simulation will be kept consistent.

For the first steps, it is planned to transfer the developed technology to Programmable Logic Controllers (Virtual PLCs) as well as to end effectors and processes (Bernhardt R., Schreck G., Willnow C., 2001).

5 SUMMARY

Simulating manufacturing installations provides a considerable potential for cost reduction throughout the whole life-cycle of an installation. This starts with the pre-productive activities of design, construction and commissioning. Here, the major source for cost reduction consists in keeping the pre-productive phase short. As a result, customer demands can be satisfied earlier, amortization is earlier, installations are optimized for costs and performance, and decisions are verified before involving costly hardware.

Optimizations, product modifications and redesigns of the installation can be prepared during the productive phase without hampering production. Down-times of the installation can be reduced and the performance and security of the installation can be enhanced.

A prerequisite for an efficient use of simulation is a reliable predictability that allow a transfer of simulation results into reality. This can only be achieved through a high accuracy in the simulation.. With the result of the latest Realistic Robot Simulation project, the Virtual Robot Controller (VRC), a highly accurate simulation technology for robot controllers has been achieved. Furthermore a flawless integration of controller models into the over-all data flow and into the work procedures during the application of simulation throughout the whole life-cycle of an installation has been developed.

For the future, it is planned to transfer the experience gained over more than a decade into other areas. Projects are planned for Programmable Logic Controllers (Virtual PLC) and effectors and processes.

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