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Advanced Machine Service Support using Internet-enabled 3-D based Virtual Engineering

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Abstract

In the era of globalisation, one of the key factors for manufacturing machine builders/suppliers to remain competitive is their capability to provide cost-effective and comprehensive machine service and maintenance for their clients at anytime anywhere. Previous research has highlighted the role of virtual engineering tools in the design and development lifecycle of manufacturing machinery systems. Virtual engineering models created during the development phase can potentially be used to provide valuable functions for many other tasks during the operational phase, including service and maintenance support. This paper introduces an innovative Internet-enabled three-dimensional (3-D) based virtual engineering framework that can be used for such purposes. Specifically, it addresses a system architecture that is designed to facilitate the tight integration between virtual engineering tools and a set of Internet-based re-configurable modular maintenance supporting tools. This system architecture has been verified by implementations using different toolsets atop of various Internet technologies (e.g. XML Web services and LabView's Datasocket). Implementation details and successful industrial-based test cases are also provided in this paper.

Keywords:

Machine service support, Internet-based monitoring, virtual engineering

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1. Introduction

Machine service and maintenance is by nature an intricate specialist task. Often, machine builders have to provide worldwide service at short notice. Machine builders would benefit enormously from the possibility to monitor and diagnose equipment operating at distant locations – both for condition-based preventive maintenance and for diagnostic purposes before flying in qualified maintenance personnel and spare parts. Even within a single plant, the possibility to monitor manufacturing equipment from a central service and maintenance office has obvious benefits. In the past, cyclically or sporadically occurring faults, which could not be identified automatically and monitored directly by fault messages of the controllers, had to be detected by visual observation (Groll 2001). In the era of globalisation, this is not desirable if the service and maintenance support have to be provided continuously in a worldwide basis. It is also not applicable to machine failures for which the error symptoms could not be repeated for observation. Video diagnosis systems and corresponding fast off-line video transmission technologies can be seen as an enhancement to provide visual information to improve the analysis capability (Wolfram and Isermann 2002). However, this incorporates high additional cost in installing and running the video systems; transferring the video data over the network is also very costly in terms of the bandwidth requirements and network traffic. Furthermore, monitoring by video can only be applied to observe a very limited number of perspectives of an individual machine so that it falls short of the applicability for monitoring the complex machine system as a whole, where faults may occur with different components at different locations. Because of these reasons, the idea of using three-dimensional (3-D) graphical visualisation models has been proposed by many researchers, largely based on VRML and Java. Such 3-D models are very useful in providing users with highly visualised and easily comprehensible information. They provide users with increased flexibility and functions such as walkthrough and fly around that are impossible by using stationary video cameras (Wang et al. 2004). Nevertheless, the disadvantage of using VRML or Java is that it requires significant efforts of the users to devise and then codify the kinematics models for the machines being monitored, which is often not justified in an industrial context, especially if the models are built only for some specific purposes.

It has been noticed that the advanced kinematics modelling and realistic animation features that are nowadays commonly supported by many advanced virtual engineering systems have offered a highly promising alternate solution to these visualisation models. The approach of extending virtual engineering tools is considered to be also highly cost-effective if the same set of simulation models, developed incrementally during the machine design and development lifecycle, can be continuously reused. As a matter of fact, our previous research conducted in the ESPRIT project VIR-ENG (Adolfsson et al. 2000, VIR-ENG 2001, Moore et al. 2003), has

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3 proposed and successfully demonstrated the use of virtual engineering to support the entire development
4 lifecycle of modular manufacturing machine systems, from conceptual design during negotiation and
5 quotation stage, to the final machine commissioning phase. It has been envisaged that the graphical simulation
6 models developed incrementally during the machine development stage can be effectively applied to the
7 operational monitoring and maintenance phase as well. In addition to the modelling capability and validity of
8 the simulation models, the applicability and effectiveness of such an approach rely also heavily on a
9 framework that tightly integrates virtual engineering tools (machine system simulations) with a set of Internet-
10 based re-configurable modular maintenance supporting tools.
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12 The aim of this paper is to introduce the novel approach of using a 3-D-based virtual environment as an
13 integration platform for improving the capability of machine builders/system integrators in providing more
14 cost-effective and comprehensive machine service support in the global market. Feasibility and applicability
15 of this new approach is verified by the implementations carried out in our research groups collaboratively
16 using different state-of-the-art Internet technologies on a number of industrial-based test-beds. The rest of
17 this paper is organised as follows: Section 2 provides an overview of applications of 3-D virtual technology in
18 current machine service support that can be found in commercial solutions and research outcomes. Section 3
19 introduces the important modelling concepts and techniques when using virtual engineering tools for
20 manufacturing machine system lifecycles. Section 4 reveals our proposed integration system architecture.
21 Section 5 addresses the implementation details and industrial-based test-beds. Conclusions are given in
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42 **2. Related Work**

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44 This section presents a literature review of current developments and applications of 3D virtual technology in
45 the area of machine service support that can be found in commercial solutions and research outcomes. It
46 focuses on applications in two main areas: (1) on-site maintenance support and (2) remote monitoring and
47 collaborative maintenance support.
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2.1 On-site Maintenance Support

On-site maintenance support is an area where 3D virtual technology has been used extensively and there are now a number of commercial solutions that are available. In these solutions, a 3D visualization tool is typically integrated with various data/information sources (databases) and asset/maintenance management application modules. Examples of such commercial solutions are: Cadmatic Maintenance software (Cadmatic, 2005), myShipVi (Intergraph, 2005), Virtual Mill (Pöyry, 2005), Walkinside (Walkinside, 2005), ProcessLife (ProcessLife, 2005) etc. The integration allows users to access equipment data/ information and maintenance management tools via an interactive 3D-based user interface (instead of the traditional 2D-based user interface). This allows maintenance personnel to retrieve and correlate equipment operational and maintenance data/information, identify/locate specific components and to manage maintenance operations. Some commercial products provide tools for facilitating integration with equipment data acquisition systems, allowing access to low level equipment operational/parameter data such as that associated with energy consumption, volume, temperature, pressure, etc. An example of such systems is the Visualisation Decision Support System (VDSS) (Jiang, et al., 2003). The VDSS was developed for the condition monitoring of Hydro-electric Generation Units (HGU). It consists of a 3D-based visualisation system integrated with the equipment control system and maintenance support systems (e.g. SCADA systems and machine expert systems), in a network environment. The developed 3D-based visualisation environment showed how the complex structures of HGU could be visualized effectively. It also showed how a 3D virtual environment could be used to efficiently locate sources of equipment faults/failures. The field evaluation of a prototype of the support system has demonstrated the benefits and feasibility of integrating 3D virtual technology with machine control and maintenance support systems for improving condition monitoring for complex equipment systems.

Another category of on-site maintenance applications using 3-D virtual technology is called augmented reality. A typical augmented reality system is created by overlaying a 3D virtual view (in conjunction with 2D graphics/text and additional 3D views) onto a human real world view either through a transparent screen or displayed on a computer monitor screen. In these applications, an augmented reality-based maintenance assistance tool is designed to be portable in such a way that it could be used for providing additional data/information in real-time. Such kind of tool allows the maintenance personnel to focus on his/her work with assistance provided, as appropriate, by the tool. Data/information provided by the tool may consist of one or more of the following: camera views, 2D/3D virtual models, maps, component details (such as

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3 identification details, specifications, manufacturer details etc) and maintenance instructions/recommendations.
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5 One of the main limitations of the earlier versions of prototypes was that they were typically bulky, making
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7 them unsuitable for real life applications. Latterly, several research efforts have been made (and some
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9 ongoing) towards minimizing the physical size and to improve the capabilities of such tools. Some prominent
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11 examples of such research projects are STARMATE (Laval 2002, Schwald and Laval 2003) and ULTRA
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13 (Makri, et al., 2005).

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16 In the above-reviewed applications, most tools have been designed specifically for the machine user (i.e. the
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18 plant/equipment owner) as a plant operation and maintenance management tool particularly for large
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20 plants/equipment. In general, the potential of extending the functionality of such 3D-based visualization tools
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22 for the machine builder/supplier, for supporting remote machine service support activities, has not been
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24 sufficiently explored. Even though some of the tools allow the machine user to access low level
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26 plant/equipment operational data, they are generally insufficient, for them to be used by the machine builder,
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28 for providing service support for complex manufacturing systems. There is also a lack of integration of the
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30 visualization tools with automated/intelligent maintenance-support-tools. In addition, the visualization aspect
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32 of the tools needs to be improved for more efficient visualization of complex mechatronics systems.

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34 With regard to the applications using augmented reality, the tools are generally based on pre-generated
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36 data/information stored in a database. In certain cases, such as when pre-generated maintenance instructions
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38 are insufficient or inaccurate, support from remote experts or engineers would be required. In such cases, it
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40 may be beneficial to integrate the portable maintenance assistance tool with a remote maintenance support
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42 system in such a way that it allows real-time bi-directional communication and data/information sharing
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44 between the maintenance personnel and the remote expert. This has the potential for improving the cost-
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46 effectiveness and efficiency of a remote machine service support strategy.

47 48 49 **2.2 Remote Monitoring and Collaborative Maintenance**

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52 In general, this is an application area where the potential of 3D virtual technology has not been extensively
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54 exploited. It has been found that most existing commercial remote monitoring and collaborative maintenance
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56 support systems are still based mainly on 2D-based visualization tools. Even though there have been several
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58 research efforts attempting to promote the use of 3D-based visualization tools for applications in remote
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3 machine maintenance support, most proposed solutions were based on the integration of 3D-based
4 visualisation technology with remote video technologies and Internet technologies. There have been various
5 3D-based remote/web-based monitoring and control strategies/systems proposed and demonstrated by a
6 number of researchers (Meggiolaro et al. 1999, Pasek et al. 2002; Wang et al. 2002). Most research was
7 focused on optimizing the real-time performance of the remote control and monitoring system. Machine
8 feedback data (such as axis position, speed etc) was typically acquired via remote sensors, which was used to
9 update, in real-time (or near real-time), an animated 3D virtual model (viewed via a web browser)
10 representing a real machine system. Generally, such systems did not consider the various aspects essential to
11 machine service support. Meanwhile, several researchers have attempted to explore how web-based 3D
12 visualisation technologies could be used for improving remote machine maintenance support strategies/tools.
13 Among others, an augmented reality-based remote maintenance support system was first proposed by Panu
14 (Panu et al. 1999). For remote visualisation purposes, the system consisted of cameras located at the machine
15 site coupled with a PC-based remote visualisation tool located at the machine expert's site. The remote
16 visualisation tool was based on an augmented reality system where a 3D-based model (and other 2D graphics
17 and additional 3D-models) is overlaid onto the video view on a PC monitor. The system allows maintenance
18 work to be performed without requiring a remote expert to be present at the machine site. It also provides
19 tools to allow remote experts to acquire and visualize selected equipment process data, which was transferred
20 in real-time. It should however be noted that the proposed strategy did not take full advantage of
21 intelligent/automated maintenance-support-tools for supporting various maintenance support functions. It
22 served mainly as a communication tool to allow remote experts to communicate instructions to and obtain
23 feedback from onsite maintenance personnel. In other words, remote experts had to rely on the assistance
24 provided by onsite maintenance personnel for most support activities including troubleshooting/diagnostics.
25 Subsequently, a similar strategy was proposed by Bellamine (Bellamine et al. 2002). The main difference
26 between the strategy proposed by Bellamine and that proposed by Panu was the use of a remotely controlled
27 robotics arm, instead of a human operator, for the acquisition of equipment operational data.

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49 In an effort to minimize the requirements for network communication bandwidth, (Mile and Mehboob 2002)
50 proposed and demonstrated a JAVA3D web-based remote machine monitoring system. The system was
51 proposed to facilitate real-time collaboration between maintenance personnel present at different locations. It
52 allows maintenance personnel to remotely monitor machine operations via a JAVA3D-based virtual
53 environment embedded in a web browser, without requiring a real-time video link. Equipment operational
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3 data was acquired directly from equipment controllers via a special purpose server component, which then
4 transferred the acquired data over the Internet to remote clients. On the client side, the received data was used
5 to update an animated 3D virtual model displayed in a JAVA3D-based virtual environment. In general, the
6 work has demonstrated how a 3D-based virtual environment, when integrated with Internet/network
7 technologies, could be used to create a remote virtual maintenance collaborative environment.
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14 The literature review has revealed various unexplored potential of 3D virtual technology. In particular, as we
15 pointed out in Section 1, the potential of integrating existing 3-D-based virtual engineering tools that are used
16 typically for machine design and development lifecycle with a set of Internet-based remote modular
17 maintenance supporting tools is, to our knowledge, virtually unexplored. This leads us to propose an extended
18 system architecture for further improving the cost-effectiveness and efficiency of existing remote machine
19 service support for new generation manufacturing systems, based on our previous efforts in VIR-ENG (Moore
20 et al. 2003).
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29 **3. Virtual Engineering for Manufacturing Machine System Life Cycle**

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32 The virtual engineering tools considered in this paper can be classified into Discrete Event Simulation (DES)
33 and Computer Aided Robotics (CAR). DES tools are normally used to study production flow, although their
34 use can be extended to other areas than manufacturing system analysis. CAR tools are normally used to study
35 movements of industrial robots, customised machinery, etc. with collision avoidance and off-line
36 programming as important applications. Ergonomic simulation, for instance posture analysis for workplace
37 design, is a technology related to CAR.
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42 Other than the advanced kinematics modelling and realistic 3-D animation feature provided by virtually all
43 CAR systems and some of the available DES systems, the capability of using these virtual engineering tools
44 for the modelling of machine system logic as well as the system dynamics required for both system
45 development and maintenance purposes should not be underestimated. The core concept behind the new
46 approach proposed here is the separation of a simulation model into a number of sub-models including
47 machine/environment logic models and the machine dynamics models. These sub-models can then readily be
48 linked to the logic control models and/or real/simulated machine controllers using hardware-in-the-loop (HIL)
49 techniques for testing and verification. Figure 1 illustrates this concept and proposes some suitable modelling
50 formalisms for different types of models.
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Figure 1. Modelling techniques for manufacturing machine system lifecycles.

A machine/environment logic model is a logic model that mimics the logical behaviour of the machine or process as well as part of the surrounding environment (e.g. auxiliary devices or human operators) in response to the commands sent from the logic control models/machine controllers. In return, based on the interaction of the logic model and the machine dynamics models, inputs to the logic control models/machine controllers are changed to imitate the events/signals from the feedback devices and any observable state variables of the machine system. In other words, the machine/environment logic model behaves as the virtual actuators and sensors of the controlled process. Hence, the interface for the connection to a logic control model is called virtual I/O (VIO).

After the logic control models has been fully tested and verified, control components that control the physical machines can be generated seamlessly using the VIR-ENG approach (Moore et al. 2003) or transferred to real machine controllers such as programmable logic controllers (PLCs). It is also possible to carry out tests with the real controllers against the virtual machines by replacing the virtual sensors and actuator interfaces (i.e. VIO) with the physical I/O devices, normally in a piecewise basis. It has been noticed that an identical concept has been proposed as the methodology for using the emerging IEC 61499 function blocks modelling standard to develop next-generation state-machine controllers (Lewis 2001).

The above-said approach has been partially demonstrated to shorten the machine system development time significantly based on the experience from an industrial test-bed (VIR-ENG 2001) in which simulation models have been developed using CAR system IGRIP, DES system QUEST supplied by DELMIA (2003). The approach proposed in this paper builds upon the tools and techniques from the VIR-ENG project and continued research. A key element in this approach is the seamless integration between simulation model (which is a hybrid DES/CAR model) and physical equipment. This integration makes it possible for instance to:

- Study failure modes and their effects during machine system design through simulations in which certain disturbances/faults are emulated.
- Monitor the operation of the machinery system on-line, which facilitates both supervision by humans and data-acquisition.

- In the case of breakdowns, retrieve control code execution, sensor information from a temporal database and carry out a 'replay' of the machinery systems recent history in the simulation model.
- Develop, test and upload temporary control code in the case of temporary reconfiguration due to machine service activities (either preventive or corrective maintenance).

To extend the model for valid and robust fault detection further, an accurate machine dynamics model is paramount. With an observation that accurate machine dynamics is difficult to model by using physical principles, especially during the system development stage, applying system identification techniques is proposed. Linear models (Ljung 1999) or non-linear models, e.g. using neural network (Nelles 2001) can be identified using observed input-output data pairs acquired during the machine commissioning or initial operational stage. These models can then be embedded into the machine simulation and link to a machine/environment logic model that governs which dynamics model should be invoked based on the predetermined logical structure. In a remote monitoring setting, these dynamics models act as the reference models to generate the nominal dynamic response of the system with the input data from the sampled data acquired remotely and allow comparison to actual output from the real system using residual analysis. The residual signal is useful for fault detection, as well as to isolate and assist diagnostic tasks when tracing the root cause of the fault using various residual evaluation techniques – an approach that is commonly known as model-based fault detection. While significant efforts have already been paid to address model-based fault detection and isolation (FDI), particularly for the process industry (Chen and Patton 1999, Isermann and Ballé 1997), the focus of this paper is to contribute a new virtual engineering framework so that existing generic or machine-specific FDI algorithms or schemes, can be tightly integrated with 3-D based graphical simulations to provide an unique service and maintenance environment for builders of discrete manufacturing machine systems.

Figure 2. The five main MSSS use cases.

4. Machine service support system

The above-said concepts are being realised through the design and implementation of a virtual engineering framework called MSSS (Machine Service Support System), as an extended part of the machine design and

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3 control environments developed in VIR-ENG. As illustrated in Figure 3, the MSSS framework is designed
4 based on a three-tier client-server architecture in which the MSSS remote components that reside at the
5 machine system user's computer acts as a "thin" server that performs functions like data acquisition, data
6 logging and transmission. Main advanced machine service support functions like continuous data monitoring
7 and analysis, fault detection, simulation, control system verification are performed by the MSSS system
8 components. Users such as maintenance engineers or support engineers of the machine builder can use an
9 integrated Graphical User Interface (GUI) to interact with all MSSS components. Functionalities that are
10 provided by MSSS can be collectively represented by the Unified Modelling Languages (UML) use case
11 diagram shown in Figure 2. Detailed description on these MSSS functionalities are given in the following sub-
12 sections.
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21 **4.1 Data acquisition and transmission**

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24 MSSS is essentially a remote data acquisition and analysis system. Therefore, it is obvious to see that an
25 advanced data acquisition, pre-processing and management framework is the foundation for all other
26 functions. The OLE for Process Control (OPC) technology (OPC Foundation 2003) is being used for
27 collecting discrete-event data and continuous data with low sampling rate (<100Hz) from the PLCs/soft-logic
28 controllers or directly from the fieldbus. As the de-facto standard for application interface to control devices
29 in the industrial automation sector, OPC is nowadays supported by almost all automation suppliers and
30 therefore offers seamless data access solution without the need of developing customised software drivers.
31 Nevertheless, dedicated sensory and high-speed data-acquisition devices might be required if high sampling
32 rate is required for collecting continuous data such as electric current. The data acquisition system can be
33 remotely configured so that specified parameters, machine process variables, discrete-event signals can be
34 acquired in prescribed time intervals and sampling rates. Configurations for routine periodic data logging can
35 also be selected for day-to-day monitoring. All configurations to the data acquisition components are done
36 through the services provided by the MSSS remote components through the user interface functions provided
37 by Scenario Manager (see Section 4.4). Implicitly, the term "Internet/Intranet" in the system architecture
38 implies that a single solution can be applied readily into both on-site and off-site machine service scenarios as
39 illustrated in Figure 4. This also facilitates a common user interface for local and remote monitoring, day-to-
40 day and "on-demand" specialist maintenance. An Internet-related security scheme has to be enforced to
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3 disallow unauthorised access to services provided and data stored by the MSSS remote components. State-of-
4 the-art technologies for the implementation of such services are reported in Section 5.
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10 Figure 3. System architecture of MSSS.
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14 **4.2 Model-based monitoring and fault detection**

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17 For continuous visual monitoring or in the case of a machine failure (breakdown), MSSS users can use the
18 historical data saved in the database to carry out “playbacks” to investigate the recent history of the machine
19 system and current status using the corresponding simulation models. In these cases, animations are driven by
20 the historical data acquired, but simultaneously, the reference dynamics models are used to generate the
21 nominal response of the system with the input data from the historical data. The output data generated by the
22 simulator and from the collected historical data can be visualised and compared using various data analysis
23 and residual analysis techniques. The data visualisation features accomplish the 3-D animation for presenting
24 useful “non-animated” data like electric current and voltage produced both from the simulator and the
25 collected data as an additional means for assisting any monitoring and diagnostic tasks. A fault alarm is
26 generated, for instance, if a residual signal is evaluated to exceed a certain threshold; but more advanced fault
27 detection algorithms can be easily incorporated into MSSS.
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40 Figure 4. On-site and remote use scenarios of MSSS.
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43 **4.3 Control System Verification**

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46 Control system verification is a desirable feature that the simulation models can be used to verify the control
47 programs for testing and verification during the machine system design, development, commissioning or re-
48 configuration stage. While this functionality has been explored in-depth during the VIR-ENG project, the
49 focus of MASSIVE is to extend the research outcomes from VIR-ENG to support verification of control
50 programs that are developed/modified to cope with maintenance service tasks (see Figure 6). Remote
51 download of control code that has been verified in a virtual environment is particularly helpful for the
52 following situations:
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- Develop, test and upload temporary control code in the case of temporary reconfiguration due to machine service activities (either preventive or corrective maintenance).
- Remote download of new/modified control code to include additional functions requested by the machine users during the operational phase, e.g. to enhance the performance of the machine or to cope with slight changes in production.

MSSS provides control system verification with two different types of configuration:

- Verification of logic control models and then the logic control code is generated, compiled and subsequently downloaded to the target controller hardware. Verification, testing and simulation are therefore carried out in a pure software environment.
- Verification of the actual control logic hardware and software.

The first configuration type has been developed and demonstrated successfully using languages defined in IEC 61131-3 (1993), in particular Sequential Function Chart (SFC) as the logic control modelling language.

Figure 5. Virtual verification and generation of control logic components.

An important research area that has recently been identified is to extend the concept and implementation to incorporate the function block standard defined in IEC 61499 (Lewis 2001). The integration of real and simulated machine controllers with a simulated model of the machine system in order to test the system's behaviour, has been identified to be one of the "hot topics" and technology trends of virtual manufacturing (Dépincé et al. 2003). With today's industrial automation equipment, this integration can be achieved by connecting the simulated machine/environment logic model directly to the machine controller via the OPC client/server-based data access technology. This integration technique has been successfully demonstrated by embedding OPC client functions into a simulation system (Sundberg et al. 2003) using the interfacing technique described in (Ng et al. 2004).

4.4 Scenarios Manager

Excluding the tools used to develop the simulation models, fault-detection algorithms, PLC programming, etc., there will be only one single application that the final users use to interact with the MSSS components – Scenarios Manager. Scenarios Manager is actually the configuration environment for users to define/create different scenarios (e.g. monitoring scenario, tentative failure or “what if” scenario for diagnosis) when carrying out different use cases described previously in section 4.3. Therefore, instead of being called as Configuration Manager, the name Scenarios Manager is introduced. The UML use case diagram shown in Figure 6 denotes the use cases that MSSS supports and all these use cases are executed through the Scenarios Manager.

Figure 6. Use cases for MSSS Scenarios Manager.

5. Implementation Details and Test-beds

While XML-based Web services can provide a flexible and portable solution for implementing the framework. It has been noticed that the framework can be readily implemented using other available technologies, based on a number of commercially available solutions and communication middleware. At the University of Skövde, implementation techniques based on a combination of National Instrument’s Datasocket technology and RTI’s Network Data Distribution Services middleware (NDDS) (Pardo-Castellote 1999), extended with a number of in-house developed software modules, have been applied to develop an environment for the monitoring and diagnosis of a number of industrial-based equipment. This includes a gantry robot for loading/unloading automotive engine blocks which is located in Euromation and multi-press lines built by AP&T, both companies have headquarters in Sweden.

In order to acquire real-time data in a remote basis, the OPC technology and LabView DataSocket Internet programming technology are being used together for collecting discrete-event data and continuous data with low sampling rate from the PLCs/soft-logic controllers or directly from the fieldbus. By using the LabView

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3 DataSocket Internet programming technology, it is possible to pass live measurement data at a high rate over
4 the Internet to multiple remote clients concurrently. The DataSocket architecture is a programming interface
5 (API) for connecting to data from a number of sources such as local files on FTP or Web servers and items on
6 OPC servers. A DataSocket application specifies the data location by using the URL networking standard.
7 Just as a Web browser uses an URL to connect to a Web page, a DataSocket application uses the URL to
8 connect to a data source. By using the industry-standard URL, data can be brought or shared from DataSocket
9 applications. In addition, the DataSocket Transfer Protocol connects a DataSocket application to live data by
10 specifying a connection to a DataSocket Server. The DataSocket Server is a stand-alone component that
11 simplifies network (TCP/IP) programming by automatically managing connections to clients and
12 automatically converting the measurement data to and from the stream of bytes sent across the network.

13
14 In the test case conducted with Euromation, the goal was to provide remote control and remote monitoring of
15 a gantry robot for loading and unloading automobile engine blocks. In this test case LabView DataSocket has
16 been used for both data exchange and remote control. In order to get hold of the data from the gantry robot, a
17 DataSocket writer is placed on a PC at the factory site. This DataSocket writer, acts as an integrated data
18 acquisition and data provider application, is composed of several Virtual Instrument (VIs) that are specially
19 built for MSSS. The period during which data acquisition from the machine control system should be
20 performed can be configured remotely by the users of the application. Data is logged to an on-site database for
21 the purpose of data analysis and driving 3-D animation that shows the movement of the machines when a
22 remote reader VI is connected to the DataSocket server exposed by this data provider application. Several
23 remote reader VIs can connect to the same URL simultaneously and using either the live data or data logged
24 in the database sent from the DataSocket server and then save the data into a local database as indicated in the
25 MSSS architecture. Figure 7 shows the client applications that run remotely logging data from the actual
26 gantry robot at Euromation with help from the DataSocket Server VIs and then plotting and 3-D animation of
27 the Euromation manufacturing cell in MSSS. Since the simulation models for this gantry robot were built in
28 previous research, it provides a very suitable test-bed for proving the concept of re-using and extending VE
29 models for the purposes of service and maintenance support.
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53 Figure 7. Online monitoring of the gantry robot in Euromation using MSSS.
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3 In the AP&T test-bed, one of their multi-press lines is used to test the motion playback and diagnostic
4 capability of MSSS. This type of multi-press lines, which AP&T sells in a world-wide basis, is fully
5 automatic with a high grade of complexity. Since their main service support team is situated at their
6 headquarter in Blidsberg, Sweden, where most of the lines are designed and built, the remote service and
7 support functions of MSSS can thereby plays a significant role for providing satisfactory services to their
8 distant customers. With MSSS, the service support personnel at the head office can conduct a discussion
9 about what and where the problem within the press line is situated with the customer or the technician on-site
10 through the MSSS “motion playback” function. Motion playback allows the simultaneously running of a 3D
11 virtual machine together with data plotting from control signals data that are saved in the database. The option
12 to run the simulation and data plotting of all important control signals at the same time in a slower pace than
13 real time with multiple repetitions would give much greater opportunities for expert personnel to identify, for
14 example, synchronisation errors in signal exchanges between robots and press machines in the multi-press line
15 (see Figure 8).
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28 MSSS also allows users to perform query on the database for searching specific extreme values. This feature
29 is of enormous value when trying to identify errors that occur stochastically, but must be used carefully as
30 otherwise abundant data would be logged repeatedly. Therefore, the possibility for users to remotely
31 configure that data logging of MSSS over the internet is a crucial function for AP&T’s expert personnel who
32 are searching for or performing analysis on peak values as well as specifying different types of fault-
33 localizing scenarios. To be able to configure what data to be logged over the Internet is exceptionally
34 important as the complexity and size of the manufacturing system increase.
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42 Figure 8. Online monitoring and I/O signal synchronisation of a multi-press line.
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45 Based on all these advantages that MSSS can bring along, AP&T is considering the possibility of including
46 MSSS as an add-on service for their multi-press line machine control systems. This will facilitate them to
47 provide better and quicker services to their customers, in terms of remotely diagnose problems and test
48 solutions without first sending specialist staff to site.
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6. Conclusions

While 3-D visualisation is an appealing feature commonly found in commercial solutions and research approaches for machine monitoring and diagnostics, the possibility of extending existing 3-D based virtual engineering tools, commonly used in robot simulation or DES, for remote service support of discrete manufacturing machine systems is relatively unexplored. This paper has presented such an approach that is based on our previous work on virtual engineering. The proposed approach is considered to be highly cost-effective if the same set of simulation models, developed incrementally during the machine design and development lifecycle, can be continuously reused. In addition to the modelling capability and validity of the virtual engineering models, it has been pointed out the applicability and effectiveness of such an approach rely heavily on a framework that tightly integrates machine system simulations with a set of Internet-based re-configurable modular maintenance supporting tools. The core concept behind this framework is the separation of a virtual machine (simulation model) into a number of sub-models including logic control models, machine/environment logic models and machine dynamics models. This separation facilitates many useful advanced functions to be developed, including control system verification, HIL testing, monitoring by “playback” and model-based fault detection, etc. This framework is realised through the implementation of a software environment called MSSS that has been applied in two industrial-scale test-beds. Initial results have demonstrated the high potential of MSSS for machine builders/system integrators to offer improved service to their customers through immediate response with precision in a distant basis.

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References

- Adolfsson, J., Ng, A.H.C. and Moore, P.R., 2000, Modular machine system design using graphical simulation. In *Proceedings of the 33rd CIRP International Seminar on Manufacturing Systems*, 5-7 June, 2000, Stockholm, Sweden, pp. 335-340.
- Bellamine M., Abe N., Tanaka K. and Taki H., 2002, Remote Machinery Maintenance System with the use of Virtual Reality, *Proceedings of the First International Symposium on 3D Data Processing Visualization and Transmission (3DPVT '02)*, pp. 38-43.
- Cadmatic, OY, 2005, <http://www.cadmatic.com> (accessed January 2005).
- Chen, J. and Patton, R. J., 1999, *Robust model-based fault diagnosis for dynamic systems*, Kluwer Academic Publishers, Dordrecht.
- DELMIA, 2003, *IGRIP/Envision & QUEST D5 Release 12*, Dassault Systemes, <http://www.delmia.com>.
- Dépincé, P., Peer-Oliver, W. and Michael, Z., 2003, *Virtual Manufacturing*, MANTYS - Thematic Technology Trend Report.
- Groll, F., 2002, Process visualization and optimization with modern software tools. In *Proceedings of the International Symposium on Robotics*, 7-11 October, Stockholm, Sweden, pp. 193-197.
- IEC 61131-3, 1993, *Programmable controllers - Part 3: programming languages*, International Electrotechnical Commission.
- Intergraph Corporation, 2005. <http://solutions.intergraph.com> (accessed February 2005).
- Isermann, R. and Ballé, P., 1997, Trends in the application of model-based fault detection and diagnosis of technical process, *Control Engineering Practice*, 5 (5), pp. 709-719.

- 1
2
3 Jiang, G., Zhaohui, L. and Yitao, C., 2003, Visualisation of a Hydroelectric Generating Unit and Its
4 Applications, *Proceedings of the IEEE International Conference on Systems, Man and*
5 *Cybernetics*, Vol. 3, pp. 2354-2359.
6
7
8
9
10 Laval, B.D., 2002, STARMATE – SysTEM using Augmented Reality for Maintenance, Assembly,
11 Training and Education, Public Report v2.0, October 2002. [http://vr.c-](http://vr.c-s.fr/starmate/downloads.htm)
12 [s.fr/starmate/downloads.htm](http://vr.c-s.fr/starmate/downloads.htm) (accessed July 2005).
13
14
15
16
17 Lewis, R., 2001 *Modelling control systems using IEC 61499*, The Institution of Electrical Engineers
18 (IEE), London, United Kingdom.
19
20
21
22
23 Ljung, L., 1999, *System identification: Theory for the user*, Prentice-Hall, New Jersey.
24
25
26 Makri, A., Weidenhausen, J., Eschler, P., Stricker, D., Machui, O., Fernandes, C., Maria, S., Voss,
27 G., Ioannidis, N., 2005, <http://www.ist-ultra.org/pictures/ultra.pdf> (accessed July 2005).
28
29
30
31
32 Meggiolaro, M.A., Jaffe, P.C.L., Iagnemma, K. and Dubowsky, S. 1999, A Force-Updated
33 Kinematics Virtual Viewing System with Application to Nuclear Power Plant Maintenance,
34 *Proceedings of the 10th World Congress on the Theory of Machine and Mechanisms*, Oulu,
35 Finland, http://robots.mit.edu/publications/papers/1999_06_Meg_Jaf_Iag_Dub.pdf (accessed July
36 2006)
37
38
39
40
41
42 Mile, O. and Mehboob, K. 2002, Remote Diagnosis And Collaborative Maintenance Over The
43 Internet, *Proceedings of the 5th International Conference on Managing Innovations in*
44 *Manufacturing*, Milwaukee, WI, USA, 9-11 September, pp. 382-387.
45
46
47
48
49 Moore, P. R., Pu, J., Ng, A. H. C., Wong, C. B., Chong, S. K., Adolfsson, J., Olofsgård, P. and
50 Lundgren, J.-O., 2003 Virtual Engineering: An integrated approach to agile manufacturing
51 machinery design and control, *Journal of Mechatronics*, 13, pp. 1105-1121.
52
53
54
55
56 Nelles, O., 2001 *Nonlinear system identification*, Springer-Verlag, Berlin, Heidelberg.
57
58
59
60

1
2
3
4
5 Ng, A. H. C., De Vin, L.J., Sundberg, M., Oldefors, F., Moore, P.R. and Yeo, S.H. (2004), An
6 integrated environment for machine system simulation, remote monitoring and fault detection,
7 *Proceedings of the 1st International Conference on Informatics in Control, Automation and*
8 *Robotics*, August 25-28, Setúbal, Portugal, Volume 2, pp. 150-157.

13
14 OPC Foundation, 2003, <http://www.opcfoundation.org>.

15
16
17 Panu, H., Aarne, H., Petri, V., Matias, H. and Hannu, P., 1999, Virtual Reality Assisted Tele-
18 presence System for Remote Maintenance, <http://www.automation.hut.fi/~etala/> (accessed July
19 2005).

21
22
23 Pardo-Castellote, G., Schneider, S. and Hamilton, M., 1999, *NDDS: The real-time publish-subscribe*
24 *middleware*, Real-Time Innovations whitepaper, <http://www.rti.com> (accessed July 2005).

25
26
27 Pasek, Z.J., Min, B.K., Marker, S., Husted, F., 2002, Web-enabled monitoring and control of
28 manufacturing systems, *Advances in Manufacturing Science and Technology*, 26(1), pp. 5-16.

29
30
31 ProcessLife, 2005, VRcontext, http://www.vrcontext.com/products/virtual_reality_products.htm,
32 <http://www.processlife.com> (accessed March 2005).

33
34
35 Pöyry Forest Industry, 2005, <http://forestindustry.poyry.com> (accessed January, 2005).

36
37
38
39
40
41
42
43
44 Schwald, B. and Laval, B.D., 2003. An Augmented Reality System for Training and Assistance to
45 Maintenance in the Industrial Context, *Proceedings of the 11th International Conference in Central*
46 *Europe on Computer Graphics, Visualization and Computer Vision (WSCG2003)*, Czech
47 Republic, February 3rd-7th, 2003, pp. 425-432.

48
49
50
51
52
53 Sundberg, M., Ng, A. H. C. and de Vin, L. J., 2003, Distributed modular logic controllers for modular
54 conveyor systems. In *Proceedings of the 20th International Manufacturing Conference*, Cork,
55 Ireland, pp. 493-500.

- 1
2
3
4
5 VIR-ENG, 2001, *Integrated design, simulation and distributed control of agile modular*
6 *manufacturing machinery (VIR-ENG)* ESPRIT Framework IV 25444, final report, June 2001.
7
8
9
10 Walkinside, 2005, VRcontext, http://www.vrcontext.com/products/virtual_reality_products.htm,
11 <http://www.walkinside.com> (accessed January, 2005)
12
13
14
15 Wang, L.H., Shen, W.M. and Lang, S., 2002, Wise-ShopFloor: a web-based and sensor-driven shop
16 floor environment," *Proceedings of the 7th International Conference on Computer Supported*
17 *Cooperative Work in Design*, September 25th-27th, 2002, pp. 413-418.
18
19
20
21
22
23 Wang, L., Orban, P., Cunningham, A. and Lang, S., 2004, Remote real-time CNC machining for
24 web-based manufacturing, *Robotics and Computer-Integrated Manufacturing*, Vol. 20, Issue 6,
25 pp. 471-601.
26
27
28
29
30 Wolfram, A. and Isermann, R., 2002, Component based tele-diagnosis approach to a textile
31 machine, *Control Engineering Practice*, 10, pp. 1251-1257.
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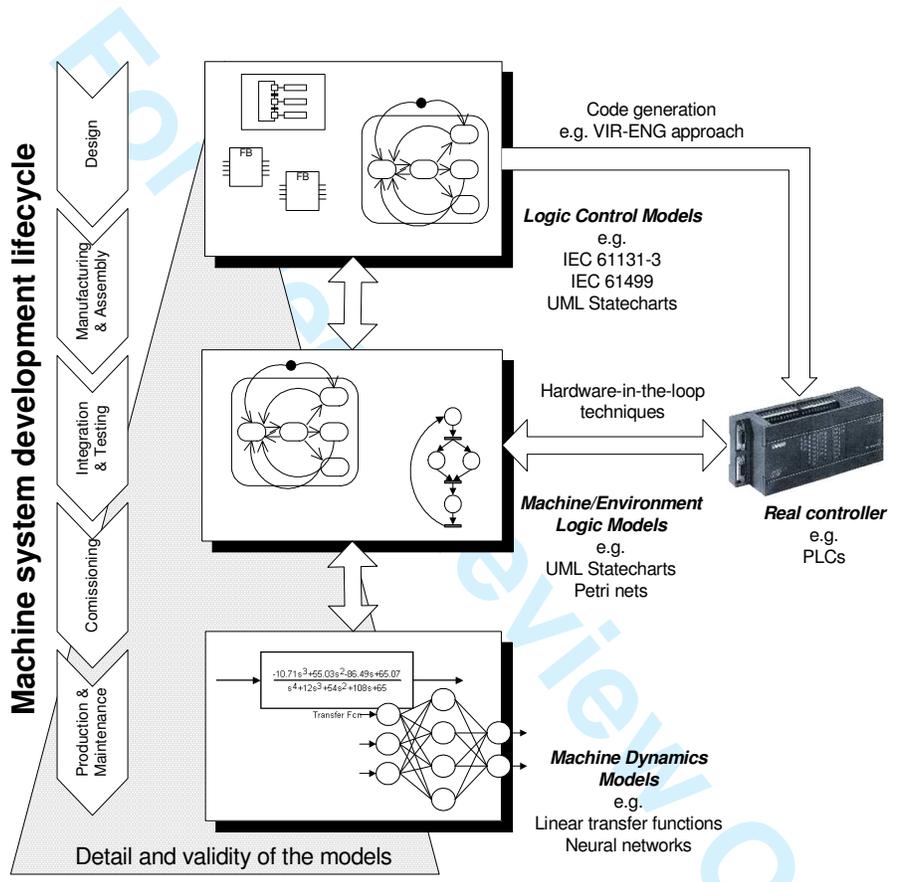
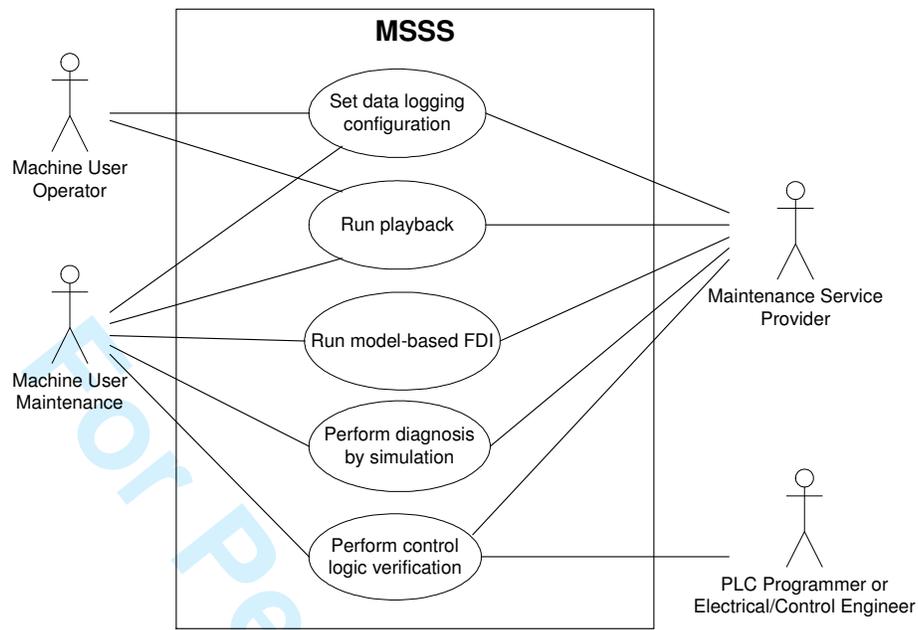


Figure 1. Modelling techniques for manufacturing machine system lifecycles.



27 Figure 2. The five main MSSS use cases.

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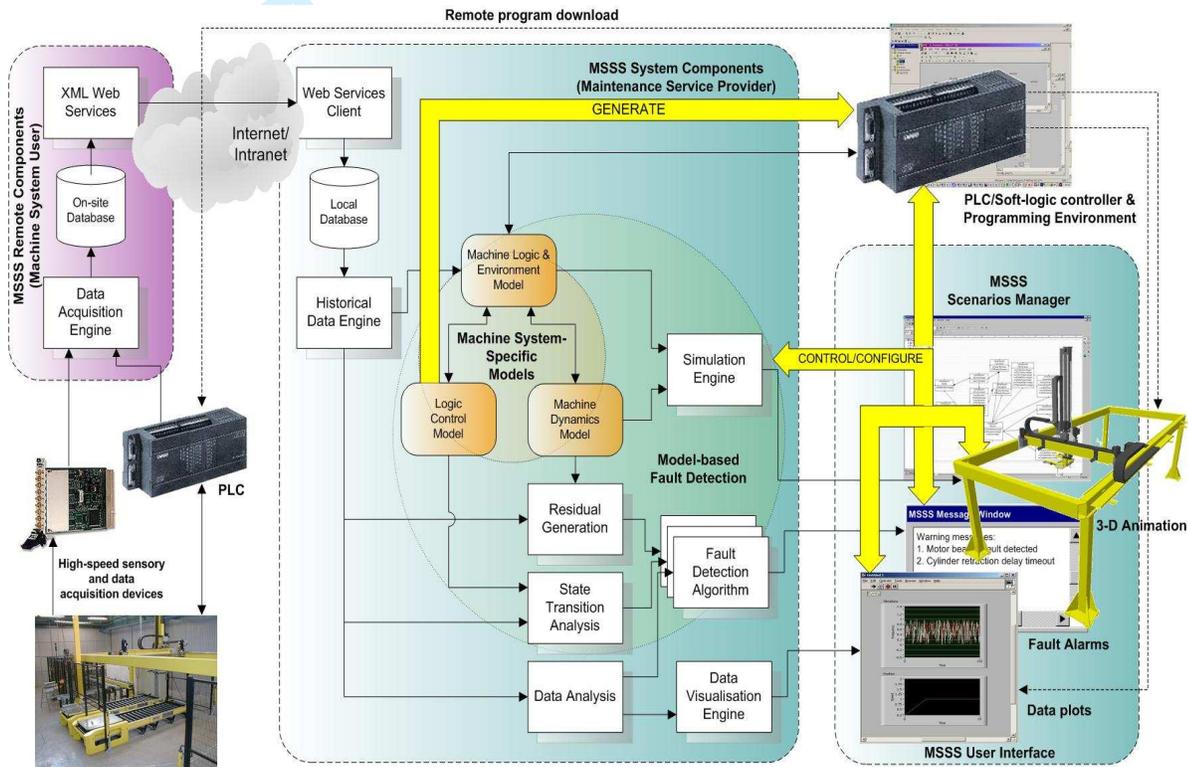


Figure 3. System architecture of MSSS.

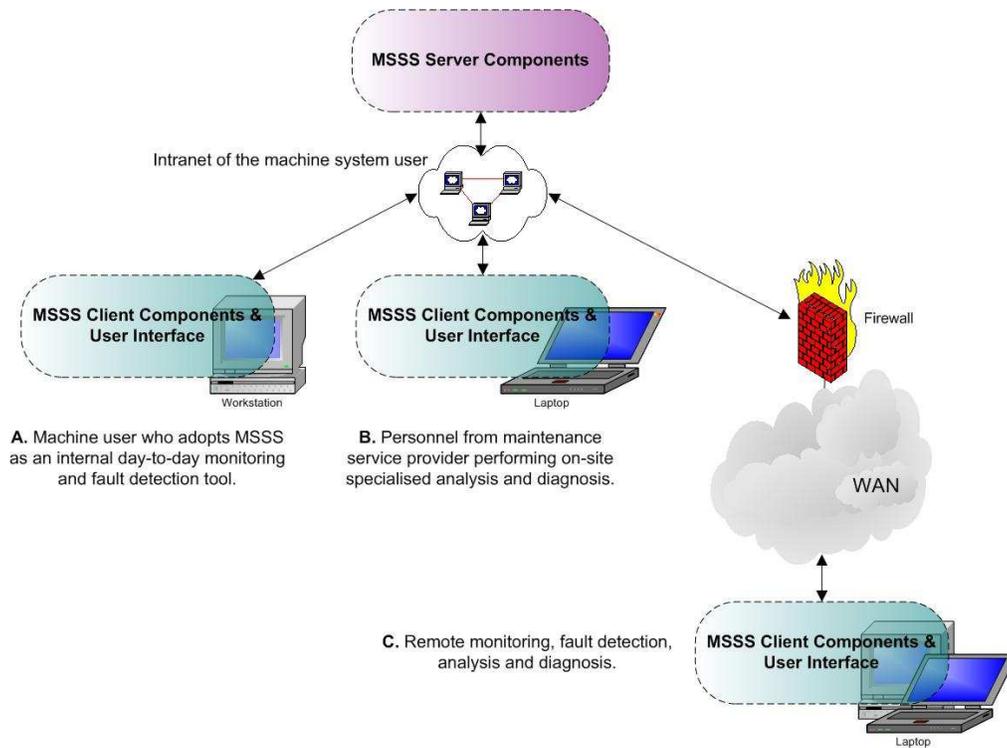


Figure 4. On-site and remote use scenarios of MSSS.

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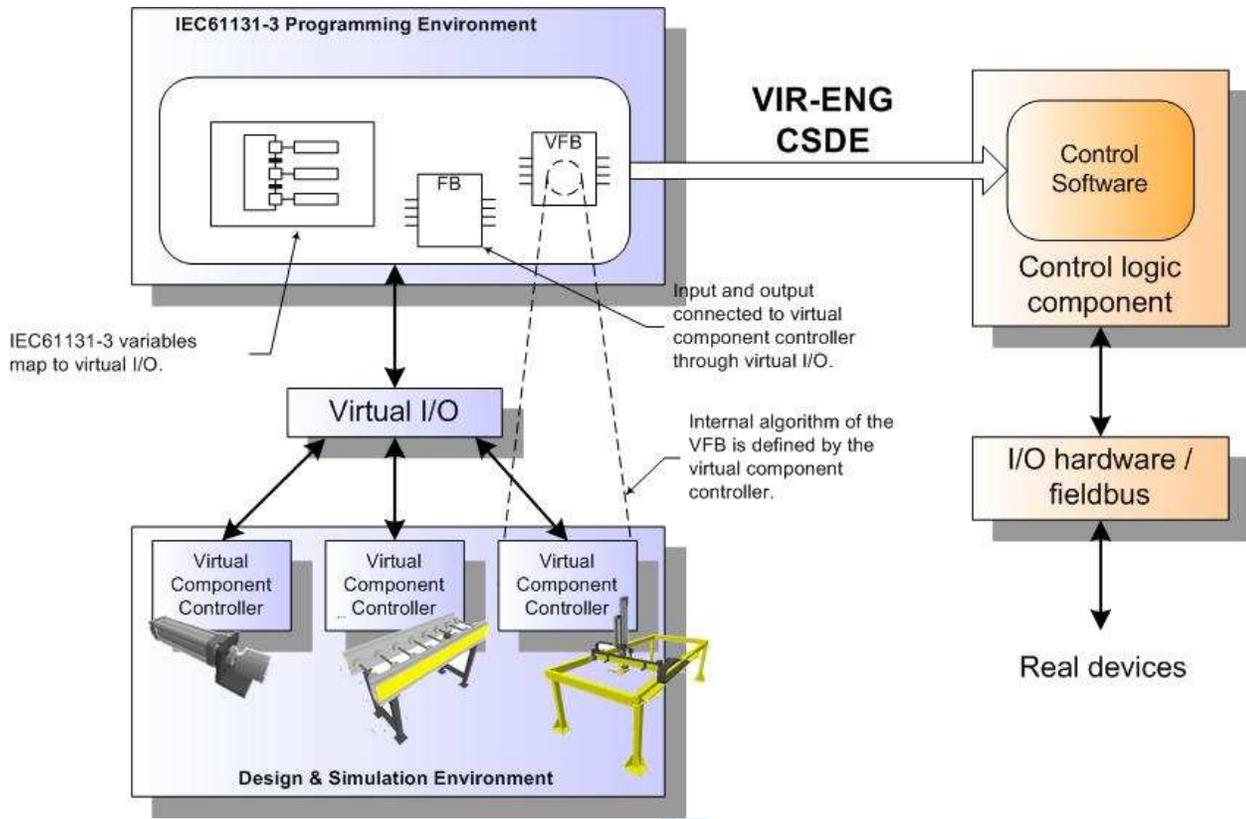


Figure 5. Virtual verification and generation of control logic components.

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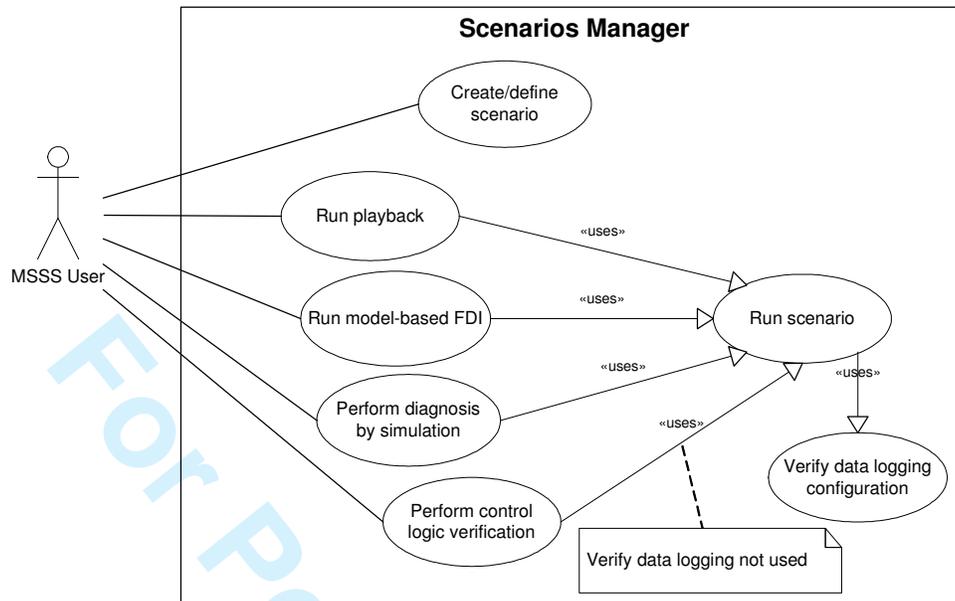


Figure 6. Use cases for MSSS Scenarios Manager.

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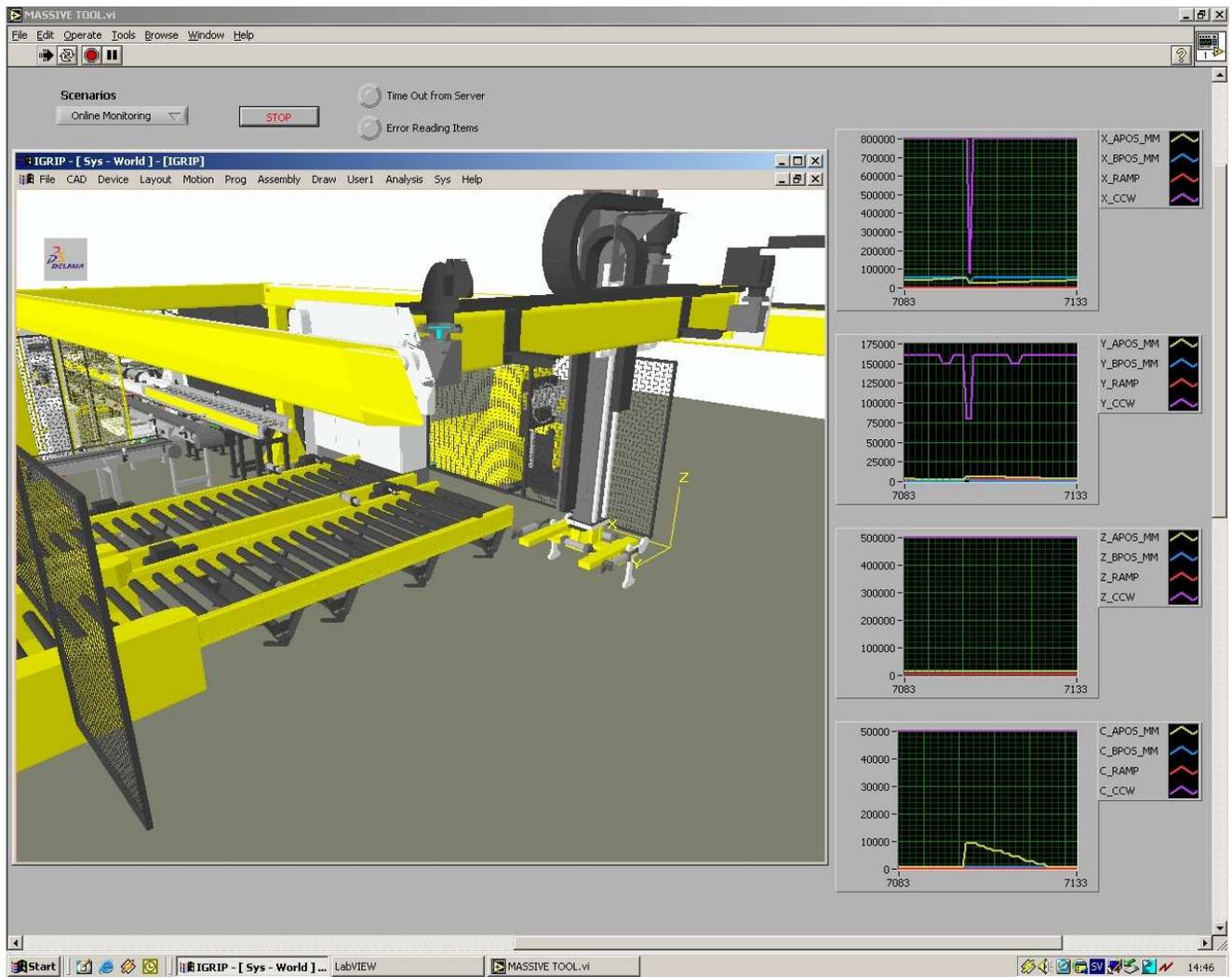


Figure 7. Online monitoring of the gantry robot in Euromation using MSSS.

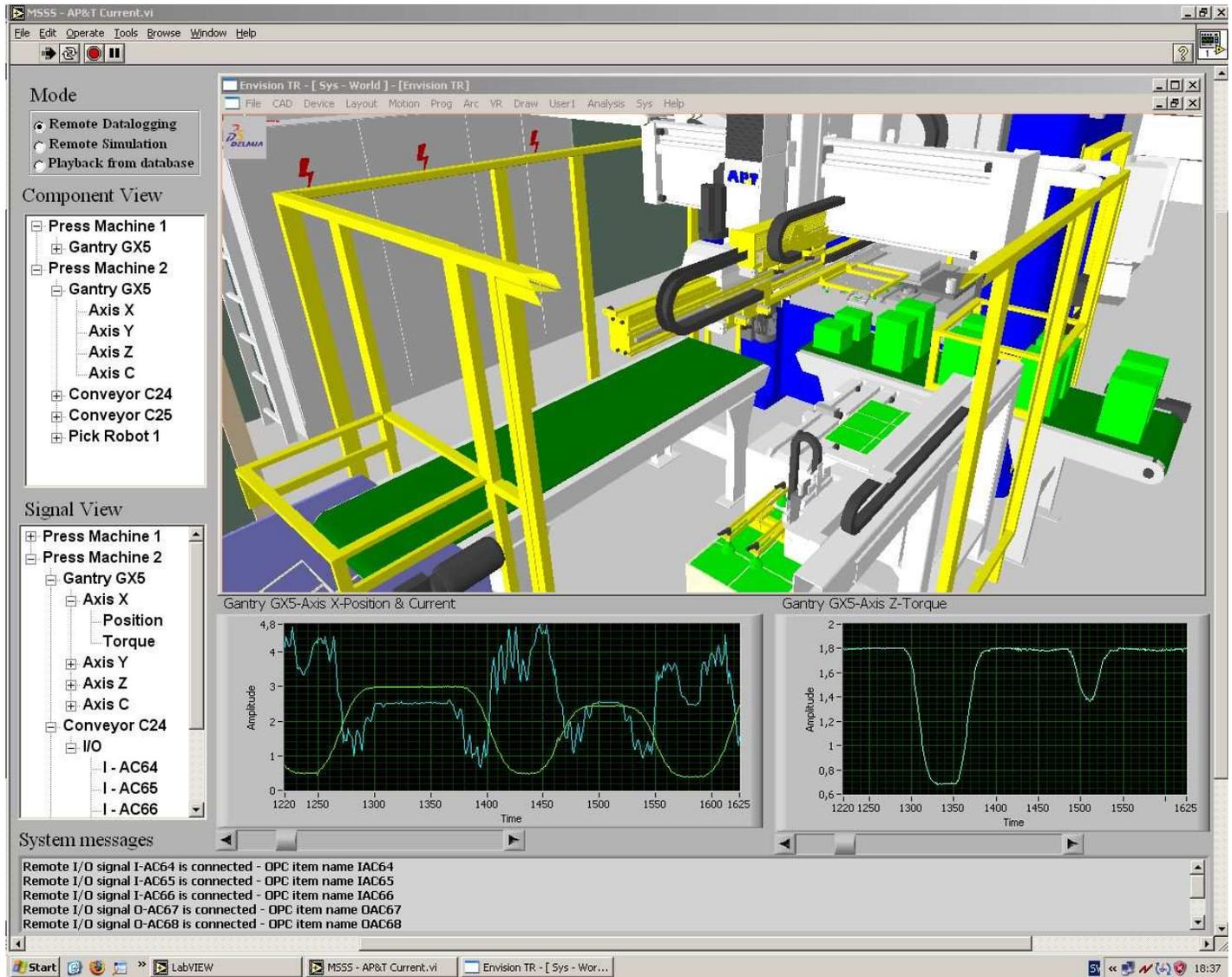


Figure 8. Online monitoring and I/O signal synchronisation of a multi-press line.