Web-based Real-time Monitoring and Control of a Robot

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ABSTRACT

In order to enhance production in today's uncertain manufacturing environments, real-time monitoring and dynamic control capabilities that are responsive and adaptive to rapid changes of production capability and functionality are vital. Targeting the dynamic issue, this paper presents a virtual production aid, a *Wise-ShopFloor* (Web-based integrated sensor-driven e-ShopFloor) prototype that can integrate Web-based sensor-driven virtual models with a real shop floor.

The Wise-ShopFloor utilizes Java technologies (e.g., Java 3D and Java Servlet) for system implementation which allows the users to monitor and control distant shop floor operations based on runtime information from the shop floor. Particularly, remote monitoring and control of an industrial robot is chosen as a case study to demonstrate the approach towards web-based adaptive manufacturing. It is envisioned that this approach not only can bridge the gap between virtual and real manufacturing but also can largely enhance manufacturing performance and profitability via remote instant assistance.

Keywords: Virtual Manufacturing, Adaptive Manufacturing, Simulation

1. INTRODUCTION

In today's global market, business decentralization and manufacturing outsourcing is often a common reality. To stay competitive at the dynamic global market, effective collaboration is an important variable that must be performed towards perfection. Collaboration, of course, should be an everyday routine among the factories, divisions and groups within a company. But the teamwork must not stop at the gates; it must also involve suppliers, service providers and often even the customers. This leads to a collaborative environment at workplaces across boundaries, both organizational and geographical. Today, the web is widely used for sharing data, information and knowledge, and for supporting collaborative organizations and work groups. It became possible due to the transparency both in its platform and operating system as well as its easy-to-use interface. These properties are therefore used in this research to support engineering organizations in their collaborative work.

This paper is organized as follows. Section 2 provides the background of the research, challenges that modern manufacturing companies are still facing, together with the references to some of our previous research. Section 3 describes the framework of *Wise-ShopFloor.* In Section 4, the results of a case study are reported to validate the performance of the *Wise-ShopFloor* when connected to an ABB industrial robot in university lab environment. Finally, conclusions and our future work are summarized in Section 5.

2. BACKGROUND

The factors that are crucial for achieving a dynamic collaboration in manufacturing are adaptability, flexibility and timeliness. These factors are especially essential when dealing with situations that constantly arise in the complex and distributed manufacturing processes of today. This is obvious at a machining shop floor where a dynamic production has to deal with small batch sizes that come together with a large variety of recurring changed or updated products.

Traditional manufacturing methods are based on offline process data with decisions usually made in advance. The modern dynamic shop floor, however, requires a system with a supporting architecture that enables distributed planning, dynamic scheduling and real-time monitoring and control. It needs to be responsive and adaptive to unpredictable changes in both production capacity and functionality.

One early example of web-based application suitable for collaborative machining is CyberCut [1]. In a recent survey of monitoring research by Teti *et al.* [2], the developments in machining monitoring are reviewed. Grinding process monitoring is reported by Tönshoff *et al.* [3]. Collaborative technologies and architectures that support various manufacturing systems are listed by Cunha *et al.* [4] and Deek *et al.* [5]. Ratchev and Lohse [6] reported a decision support model when formatting assembly workstations using a web-based approach. A web-enabled decision-making environment supporting the design of assembly workstations is described by Lohse *et al.* [7]. The development of methodologies and tools supporting the design process for reconfigurable assembly systems are described by Lohse *et al.* [8] and Hirani [9].

Despite great efforts and various attempts, a shared system that is able to handle real-time monitoring, off-site inspection, enabling collaborative troubleshooting and remote control is still missing from the literature [10]. The research of *Wise-ShopFloor* is targeting this gap and strives to facilitate a collaborative environment for dispersed working groups. It enables team members (managers, engineers, operators etc.) to share real-time information in a cyber-workspace that offers decision support to physical shop floor. No software installation is needed in the team member's computers, except a web browser. The objective of *Wise-ShopFloor* is "*to develop methodology and algorithms for Web-based collaborative planning and control, supported by real-time monitoring for dynamic scheduling*" [11].

3. *Wise-ShopFloor* Framework

The *Wise-ShopFloor* framework [11-12] was designed to provide users with an intuitive sensor-driven web-based environment where distributed process planning, dynamic scheduling, remote control and real-time monitoring can be realized. Within the framework, the individual machines are seen as nodes and valuable resources in the information network. The real-time information from the connected sensors and machine controllers are used to enable continuously monitoring, tracking, comparing and analyzing the production parameters. Instead of using an ordinary camera, which uses large bandwidth and data size, for ongoing monitoring or control of machines or equipment, *Wise-ShopFloor* use Java 3D scene graph models with embedded behavioral control nodes. A user downloads the Java 3D model from the application server the first time when the device is connected to.

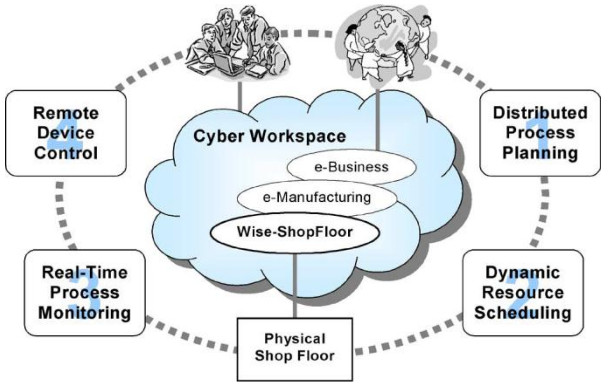

Figure 1. Framework of *Wise-ShopFloor*

The model is rendered locally by the client PC and visualizes the real behavior of the corresponding machine. The 3D model uses Java servlets, applets and pushlets for transmitting data to/from the connected device. Not only motion data but also other condition sensor data like force, temperature and vibration can be transmitted to the 3D model through the network to facilitate the machine's condition monitoring.

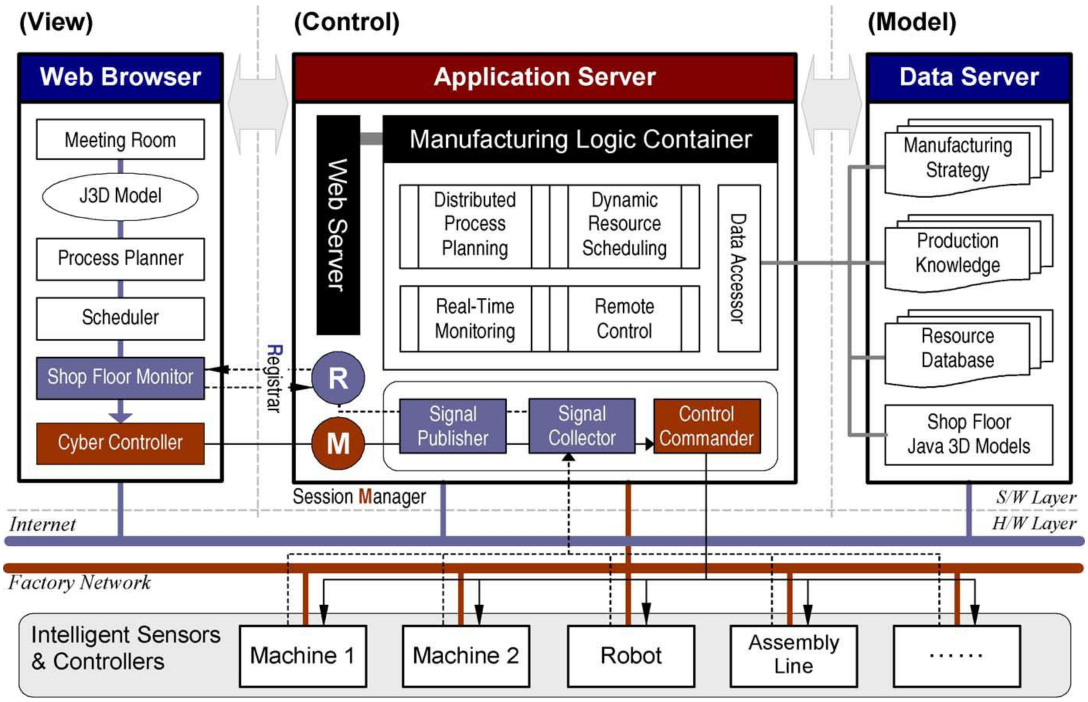

Figure 2. Design of framework for *Wise-ShopFloor*

There is no need for transmitting camera images through the network since the 3D model is sensor-driven and rendered locally at the user's PC. While an uncompressed VGA-image (8-bit depth) needs 307 KB (640×480), a sensor-driven virtual 3D model only needs a data package of 52 bytes for determining one state consisting of multi-axis coordinates (both relative and absolute) for a device. The amount of transferred data is thus decreased by more than 99.9% compared to a VGA-camera. Therefore, *Wise-ShopFloor* enables real-time data sharing over the Internet by eliminating the need of transmitting camera images for monitoring and control. With the largely reduced data transmission, a true real-time monitoring and control becomes practically manageable for dispersed user-groups when connected to a *Cyber Workspace* [13].

The framework makes it possible for project members to make correct decisions ensuring that the shop floor is operating within the defined scope. Enabling planning and control of dynamic shop floor operations in a freely chosen location and at the right time is the aim of the research. The framework of *Wise-ShopFloor* [11] is illustrated in Figure 1.

Being a component in the manufacturing supply chain, *Wise-ShopFloor* links the upper manufacturing systems to physical shop floors. The four major activities shown in Figure 1 are closely linked to e-manufacturing and e-business that are carried out in a collaborative cyber-workspace. A detailed illustration of the interactions between the different system modules is shown in Figure 2 [11]. The framework is designed in browser-server (or B/S) architecture with a built-in mechanism for secure session control.

The application server handles the major security issues like session control and registration, sensor data collection and distribution, planning, scheduling and also manipulation of the connected machines. The *Session Manager* is responsible for user authentication, data logging and session synchronization. All initial communication concerning user access authorization is handled by the Session Manager. Since concurrent users in the multi-client environment offered by *Wise-ShopFloor* may need different sets of data or logic depending on the active tasks, only the required data is transmitted to each user. The publish-subscribe design pattern is used to collect and distribute the right sensor data efficiently to each user at the right time. The *Signal Collector*, found in the application server, is responsible for collection of sensor data from the networked machines. The *Signal Publisher*, also found within the application server, receives the collected data from the Signal Collector and uses applet-servlet communication to re-direct the sensor data to the clients who are the registered subscribers to the data. Which data should be transmitted to which client is decided by a list that is constantly updated by the *Registrar*. This enables the Java 3D-model in a client-side PC to communicate indirectly with the real sensors independently no matter the client is inside or outside of a firewall. The chosen communication protocol for linking server and client is Hypertext Transfer Protocol (HTTP) streaming.

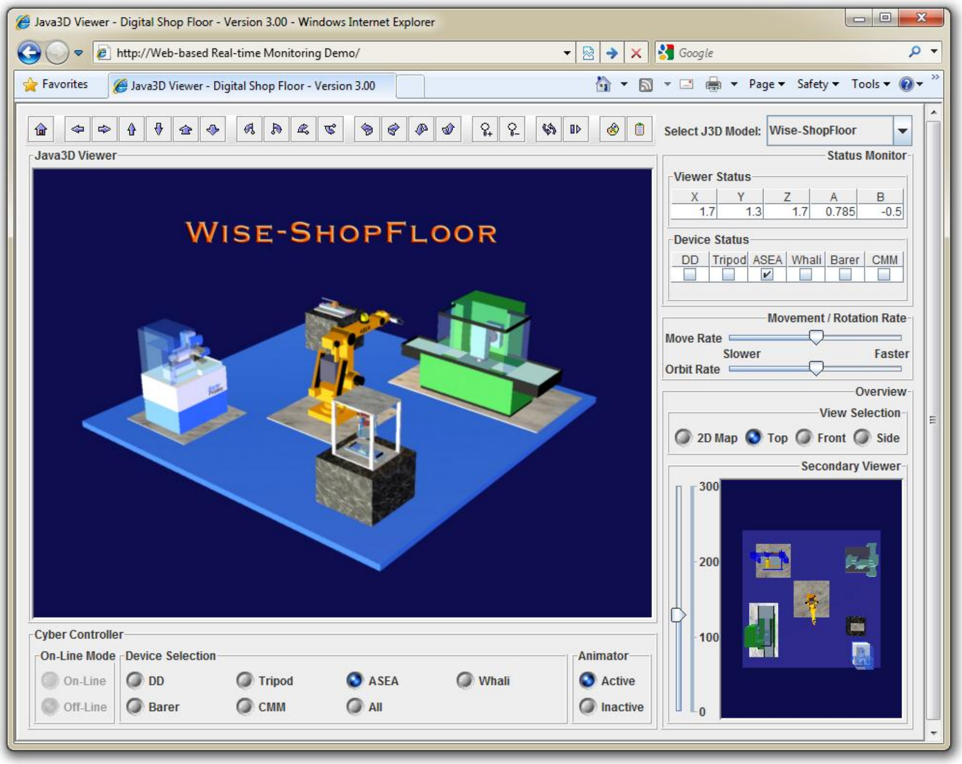

Figure 3. Graphical user interface of *Wise-ShopFloor*

Even though the server is controlling the behavior of a Java 3D model based on the communication of the real-time sensor data, a user can still view the model from different perspectives by zooming, orbiting, panning and tilting the model in the client-PC (Figure 3). The user is able to not only monitor a machine but also control it (if valid authorization is current) through *Wise-ShopFloor.* The application server enables the authorized client to gain control of a machine, send control commands and manipulate it. Although the Java 3D models in *Wise-ShopFloor* provides an alternative to camera-based monitoring, it is possible to use an ordinary web-camera that can easily be switched on remotely to capture any unmodeled and unpredictable scenes for diagnostic purpose. Communication and data sharing between clients and the application server is based on Java. At this level, the real-time constraint is of less importance in contrast to the device level where latency is critical to manufacturing operations.

Machine control and sensor data collection can be programmed using Java but users have the possibility of using any other adequate programming language at the device level for practical implementations. The case study presented in Section 4 uses Java for sensor data collection at the device level. Through the use of *Wise-ShopFloor*, users have a spectrum of programming languages and modules to choose from, as long as the pre-defined data transmission format is preserved.

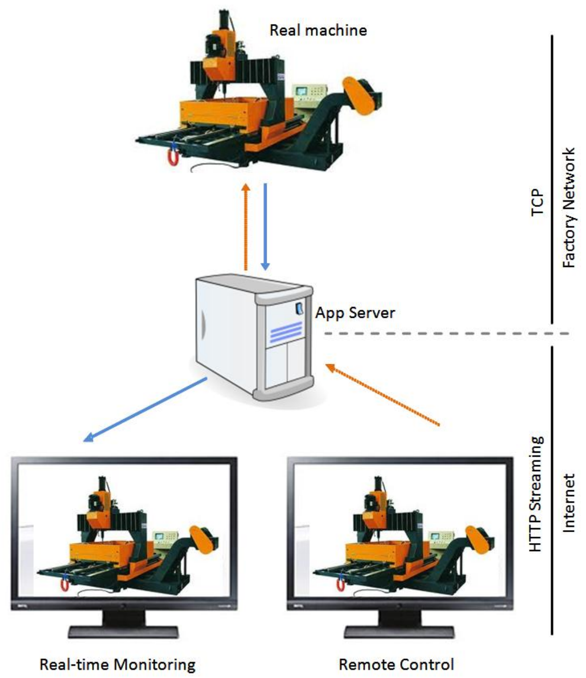

Figure 4. Configuration of *Wise-ShopFloor*

The communication between the real machine and the user interface in real-time monitoring and control is configured as shown in Figure 4. TCP (Transmission Control Protocol) is adopted to achieve a secure connection between the physical machines and the application server. For data distribution between remote users and the application server, HTTP streaming is used. While HTTP streaming is suitable for web-based application given its firewall-transparency, TCP offers a better protection for the hardware via handshaking. As shown in Figure 4, the application server also serves as a gateway between the two networks, the internal factory network and the Internet. By applying the *Wise-ShopFloor* design, a remote user is able to monitor the events and motions of the machine as well as to control it in real time.

4. An ABB Robot Case Study

In our previous research [11-14], various case studies have been carried out to validate the functionality of the *Wise-ShopFloor*, but mainly for machining applications. This section presents the results of a case study where an ABB IRB140 robot is monitored and controlled using *Wise-ShopFloor* with additional functions implemented in the system, such as collision detection, integrated webcam control, etc.

A virtual 3D model of the robot was developed using converted CAD-files and Java 3D. The robot is put on a pedestal and equipped with a pneumatic gripper (Figure 5). Forward kinematics is assigned to the 3D model to achieve realistic movements of the virtual manipulator.

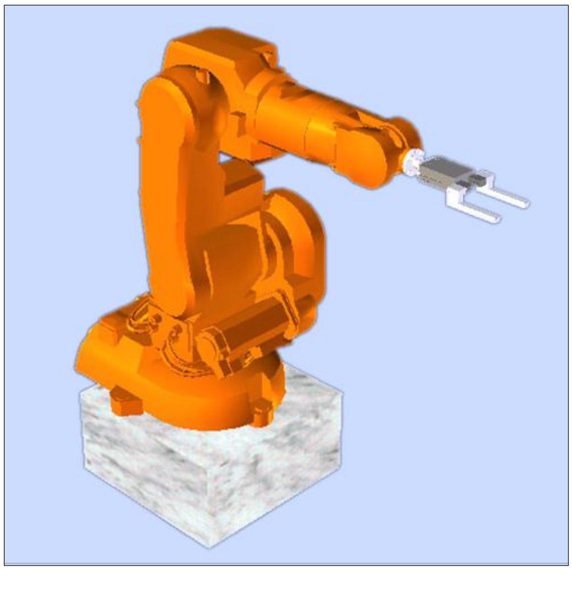

Figure 5. 3D model of the ABB IRB140 robot

A virtual 3D universe (a term used in Java 3D API), with moving machines or robots, needs a system that can detect any collisions between two or more objects to prevent a collision from occurring at the real machines or robots. The collision detection system implemented into the *Wise-ShopFloor* can be used for other moving 3D models as well, not limiting to robots.

When moving the real robot by remote control through the *Wise-ShopFloor* in real time, its Java 3D model is updated constantly with the accurate joint data from the robot controller. The robot controller can also detect movement limitations or a possible collision in three different ways:

1. The controller software knows the boundaries of each joint and stops the movement if a joint exceeds its minimum or maximum range.
2. If the software limits of each joint do not stop the movement, a mechanical limit, when reached, will stop the movement.
3. If a higher torque than expected (a collision) is detected for moving the manipulator, the electric control stops the robot movement.

Since these three conditions are performed through the robot controller, they are not directly applicable to the Java 3D model in offline mode (the client PC with the virtual model not connected to any machine controller). The range of each robot joint is set in the system and cannot be exceeded in off-line mode. The implemented collision detection system in *Wise-ShopFloor* identifies a collision when the bounding boxes of rigid bodies come in contact with each other. In this case study, two "boxes" were applied to the virtual 3D model of the robot, one covering the gripper and the other covering the base of the robot and the pedestal (Figure 6). The boxes can of course be placed at any positions to avoid collision with safety fences or other equipment. The implemented collision detection system is generic and can be applied to new models independent of the types of machines.

The collision detection system in *Wise-ShopFloor* has inbuilt roll-back functionality. When an off-line 3D model is moved and a collision is detected, the virtual model is moved backwards until there is no collision. This is achieved by continuously saving the last 30 poses of the robot. In other words, when a virtual collision occurs the manipulator is moved back to the previous pose. If a collision is still active the preceding pose is chosen until no collision is active and the robot is stopped. The collision detection system is presently only implemented in the offline mode.

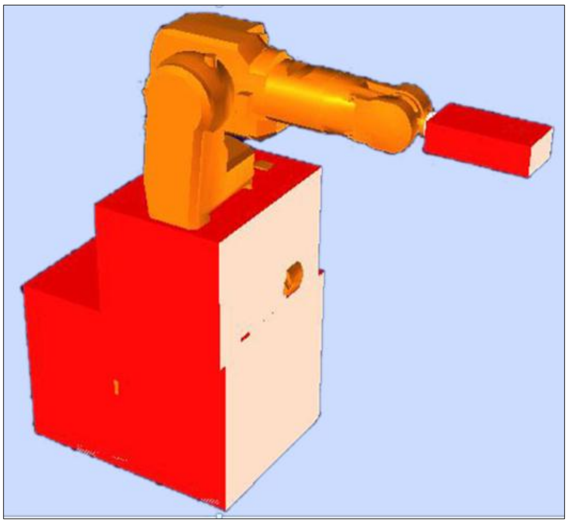

Figure 6. Collision detection system

Previously, no webcam has been incorporated in the *Wise-ShopFloor.* This case study requested a camera that could be remotely controlled including panning, tilting and zooming and it should also have a built-in web server and be IP addressable. A camera PZ7121 from Vivotek was chosen for the case study. It has an HTTP API (Application Programming Interface) for controlling the camera.

The camera control is incorporated in the GUI of *Wise-ShopFloor* as shown in Figure 7 and uses the application server for connecting the camera to the client. The four arrows control the movement of the camera (up-down-left-right) and the "home" button in the middle returns the camera viewpoint back to its default position. The buttons in the corners have the functionality of snapshot, on/off, zoom in and zoom out, respectively. The camera is normally turned off and when in use the operator has to log in with a valid password. A new viewport opens for the camera image besides the virtual 3D model, both active at the same time.

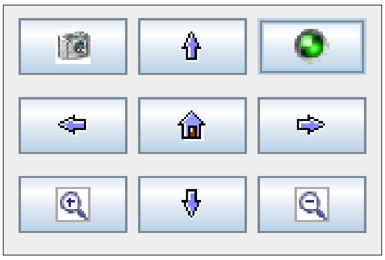

Figure 7. Camera control in *Wise-ShopFloor*

5. CONCLUSIONS

The main contributions of the overall *Wise-ShopFloor* research include:

1. a framework for collaborative manufacturing,
2. an adaptive and distributed process planning,
3. a sensor-driven approach for Web-based real-time monitoring and control, and
4. a dynamic scheduling solution.

This paper, in particular, presents the background and challenges that the R&D in *Wise-ShopFloor* can meet. It focuses mainly on the web-based real-time monitoring and control of an ABB robot. The results of the case study demonstrate and validate the new functions of collision detection, the incorporated camera control, and effective and efficient communication between the robot and its controller. The robot, placed at the University of Skövde, Sweden, has been connected to the *Wise-ShopFloor* and tested from several European countries and the United States. The time delay for the virtual 3D model is not noticeable (about 30 msec.) whilst the camera image suffers from obvious time delay of about 2-3 seconds.

Currently, a robotic assembly cell called "Minicell" is connected to the *Wise-ShopFloor* for testing. The robot shall perform an assembly task which can be remotely monitored and controlled through *Wise-ShopFloor*. The outcomes will be reported separately.

6. ACKNOWLEDGEMENTS

The authors would like to sincerely acknowledge the contributions of following Spanish students who have worked together with us during the case study: Jose Manuel Hurtado de Mendoza Rosas, Emilio Bentabol Muñoz, Enrique Ruiz Zúñiga, Pedro Gonzalez Ruiz and Carlos Bosque Ibañez.

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