XVIII IMEKO WORLD CONGRESS
Metrology for a Sustainable Development
September, 17 – 22, 2006, Rio de Janeiro, Brazil

INTEGRATION OF PRODUCTION-, QUALITY- AND PROCESS MONITORING FOR AGILE MANUFACTURING

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Abstract: The paper summarizes the main ideas and results for realizing agile manufacturing systems having active disturbance handling approach for real-time manufacturing control. The intelligent integration of information received from production-, quality and process monitoring systems is addressed as the enabler of the approach.

Keywords: agile manufacturing, information integration and processing.

1. INTRODUCTION

The realization of an agile manufacturing system has several important features like flexibility incorporating change and disturbance handling functions [1]. This enables real time production control, its main assignment is to adapt the production system to the changing environment while preserving efficiency with respect to cost, time and quality requirements. This is one of the main issues in the implementation of Intelligent Manufacturing Systems (IMSs).

Considering the traditional hierarchy levels of manufacturing systems [2 and 3] the research is mainly focusing on shop-floor control together with some activities in the connected fields. Most of the change and disturbance handling subsystems of a shop-floor control system are based on the traditional hierarchical infrastructure of the controllers and usually, a key problem is that their reporting schemes do not provide active support for the disturbance handling process.

The work reported on here is focused on active disturbance handling approaches for real-time manufacturing control which not only report the deviations and problems of the manufacturing system, as mainly the state of the art is but suggest possible alternatives to handle them. The regularly (e.g. daily) prepared schedules are the main input of the work. Naturally, it is based on a detailed analysis of this field and the main results include models, methods and tools for handling and preventing changes and disturbances in operative manufacturing execution systems.

The research and the results can be divided into the following, naturally overlapping fields:

- The intelligent integration of information received from production-, quality and process monitoring systems is addressed as the enabler of the approach ensuring the comprehensive database for the applied techniques [4].
- On the base of the current and required states of the system Behavior Based Control (BBC) is applied which uses knowledge-base techniques in its control decisions. The option to apply the BBC techniques in the disturbance handling system is also analysed.
- In the research we integrate discrete event, continuous and hybrid simulation models in the system which runs parallel to the real manufacturing environment. Simulation models like these, act as proactive warning systems informing the user(s) about possible short-term deteriorations [5].
- Parallel to the above mentioned techniques, another issue is to find the unknown relations in an existing production monitoring database which are used for predicting faults and their consequences. A novel submodel exploration method is presented, too, it is used to explore the relations among the integrated database and used e.g. for situation recognition [6].
- A special sub-field of our research activity was to make interesting steps in the field of camera-based supervision of production systems. The main goal is the development of a "smart" camera for process control and fault detection in automation.

2. INTEGRATION OF PRODUCTION-, QUALITY- AND PROCESS MONITORING

The research reported on here has as key element the integration of production-, quality- and process monitoring information and systems. The research is mainly focused on shop-floor control, the regularly (e.g. daily) prepared schedules are the main input of the work. Solutions are developed which affect only the local environment of the system considering as less modification in the initial plans as possible. In order to be able to provide the most efficient disturbance handling solution it is necessary to recognise those situations which endanger the execution of the calculated schedule, moreover, if possible, suggest possible alternative(s) for minimizing the deficit in the manufacturing process. Expectedly, a large set of disturbances will necessitate global rescheduling. One of the main challenges of our work is to find those thresholds in the deviation of production variables (during the execution) above which global intervention is required.

The features provided by the new generation of simulation software facilitate the integration of the simulation models with the production planning and scheduling systems. Additionally, if the simulation system is combined with the production database of the enterprise, it is possible to instantly update the parameters in the model and use the simulation parallel to the real manufacturing system supporting and/or reinforcing the decisions on the shop-floor. The outline of the architecture developed is presented in Fig. 1. The production related data are accessible for both the scheduler and simulation. In our proposed architecture the simulation model replaces a real production environment (Plant), including the model of the real production system, several functions of the Production Monitoring and the Manufacturing Execution Systems. Furthermore, simulation is able to generate internal and external disruptions into the system, while these disruptions are managed by the Decision maker and/or the Scheduler.

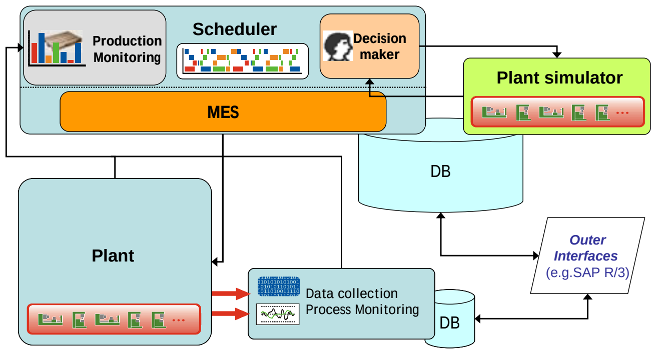

Fig. 1. Architecture for simulation-based evaluation of scheduling and rescheduling strategies, as well as the information flow in the real system

The simulation model is generated from predefined model components by using the production data (e.g., available resources, process-plans used, scheduled jobs, etc.). The scheduler calculates the production schedules to be executed by using the same data base.

The calculated schedule is executed with the simulation. Due to the disturbances occurred, or simply because the rescheduling point is reached, a decision has to be made: whether to continue the execution, repair the schedule, or perform a rescheduling (this procedure is also referred to as control action). The control action, i.e., the process of rescheduling is made by the Decision maker, where his/her decision (e.g., selected rescheduling policy, or threshold) can be supported by simulation based experiments.

The main functions (or operation modes) of the simulator in the proposed architecture are as follows:

- Validation of the calculated schedules, execution validation. Analysis of the schedule feasibility regarding available resources. Evaluate the robustness of (daily) schedules against the uncertainties.
- A-priori recognition of deviations from the planned schedule by running the simulation in advance for short term actions. Support of situation recognition.
- Analysis of the possible actions after a disturbance already occurred and minimisation of the losses. Validation of the selected/applied disturbance handling policy.

This means that the model structure in the simulator is the same for all the three operation modes, however, the granulation (level of modelling detail), time horizon, applied failure models and considered outputs depend on the purpose of the experiments. Moreover, by applying a simulation model instance in operation mode a) replacing the real plant, and additional instances in operation mode b) and/or c) may results in a structure which supports complex decision making in PPS systems, and offers a benchmark platform for the calculated schedules as well as the applied disturbance handling methods.

The schedules provided daily by the new scheduler will be the main input of the simulator. Feasibility test regarding resources and robustness analysis against uncertainty can be performed (operation mode a)). Principally, experiments focus on solutions which affect only the local environment of the system considering as less modification in the initial plans as possible (e.g., resequence the machine affected by a disruption only, reallocate a small set of workers, etc.).

The simulation model is a mirror of the real manufacturing system – or just a part of it – and on the base of the actual status instantly simulates the future processes of the factory for a predefined short period, giving a forecast of possible future states (operation mode b)). A simulation model like this, will act as a proactive warning system informing the Decision maker about possible short-term deteriorations.

To be able to provide the most efficient disturbance handling solution it is necessary to recognise those situations which endanger the execution of the calculated schedule (operation mode b)), moreover, if possible, suggest possible alternative(s) in order to minimise the deficit in the manufacturing process (operation mode c)). Probably, a large set of disturbances will necessitate global rescheduling. One of the main challenges of the work is to find those thresholds in the deviation of production variables – during the execution above – which global intervention is required.

On the base of the current state of the system different possible actions can be taken (e.g. rescheduling, stopping the machine, re-buffering, etc.) Actions like these can be identified in the concept of Behaviour Based Control (BBC) which applies knowledge-base techniques in it control decisions. The option to apply the BBC techniques in the disturbance handling system will be analysed.

2.2. Simulation running parallel to the real production environment

In the research we integrate discrete event, continuous and hybrid simulation models in the system which runs parallel to the real manufacturing environment. These models are mirrors of the real manufacturing system or just a part of it and on the base of the actual status instantly simulate the future processes of the factory for a predefined short period, giving a forecast of possible future states. Simulation models like these, act as proactive warning systems informing the user(s) about possible short-term deteriorations.

In order to satisfy all the requirements for the flexible simulation system the structure presented in Figure 1 has been developed. The simulation uses the same production database as the finite capacity job-shop scheduler.

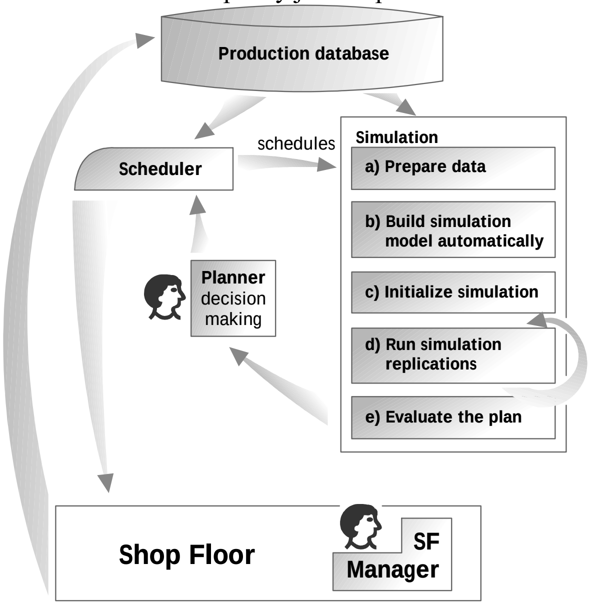

Fig. 2. Architecture and the main process flow in the simulation module

Effects of several disturbance factors on various production performance parameters were analyzed using the above architecture in a concrete, large production system, as shown in the next two pictures.

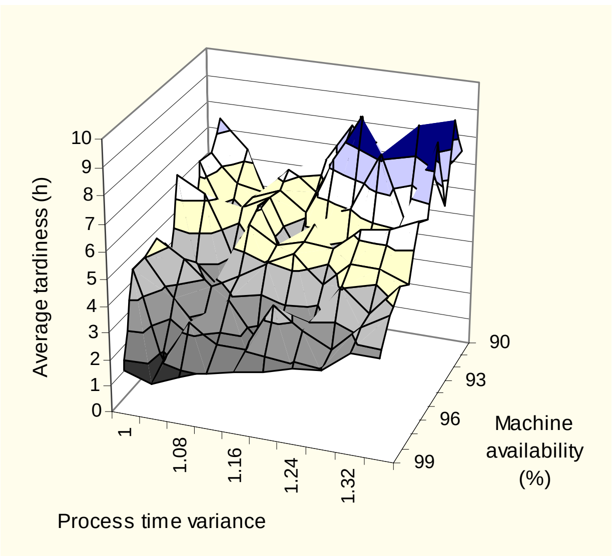

Fig. 3. The dual effect of machine availability and processing time variance on average tardiness

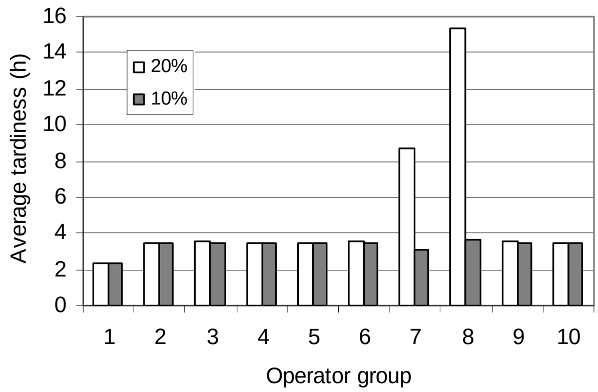

Fig. 4. The effect of missing operators: The dark bars show the results where the number of operators per group was decreased with 10% while the white bars represent the results with 20% less operator per group. The replications were carried out sequentially group by group analysing the effect of only one group at once. The results of the experiment show, that groups 7 and 8 have the main effect on the average tardiness.

2.3. Exploration of unknown dependencies / submodel identification

Another research field is to find the unknown relations in an existing production monitoring database which is used for predicting faults and their consequences. Advanced searching algorithms are developed and applied to find these unknown dependencies between the data in production monitoring data warehouses. A novel submodel exploration method is presented, too, is it used to explore the relations among the integrated database and used e.g. for situation recognition which allows the recognition of critical situations that may result in undesired system states [6]. An excellent analytical analogue to this submodel decomposition and performance evaluation technique is presented in [7].

The following part describes the algorithm from the user's point of view.

The application of the algorithm has two main prerequisites:

- The user has to serve with a set of data describing the analyzed system. This can be satisfied typically with a database table where columns are the description variables and the rows contain their values belonging together. Various settings of these features allow different analysis of the same system.
- A further prerequisite of the application is the setting of allowed, excepted errors or required estimation accuracy for all of the system variables. This requirement is inherited from the ANN based learning technique, it has to be defined when to stop a learning process. Implicitly, the user defines by what level of estimation accuracy, or allowed error can be stated, that a parameter can be estimated based on other ones. This setting can be different for the individual system parameters but it has to be determined before the algorithmic run, consequently, in some respect it is an advantage, but in other respect it is a disadvantage of the

solution. Repeated run with various accuracy requirements can mirror the variety of solutions in respect to this prerequisite. It is worth mentioning also that based on some ideas of the authors this is one of the main domains for further improvement of the method.

Satisfying the above requirement allows to run the developed algorithm. Its result can be grouped into three main parts:

- Net of accepted submodels. They can perform the estimation of their output parameters with the prescribed, individual accuracy. They can have common parameters, so the result is a net of neural networks.
- List of rejected submodels. These models were analysed during the search but they were rejected. A model is accepted if at least one of their parameters can be estimated with the prescribed accuracy, based on the remaining ones.
- Because models are identified through their building up process, the algorithm results also in the concrete neural network models for each of the accepted submodels. This allows the prompt application of the whole, or a part of the net of submodels for solving various assignments.

The algorithm can be applied also when the data set incorporates also incomplete information [8].

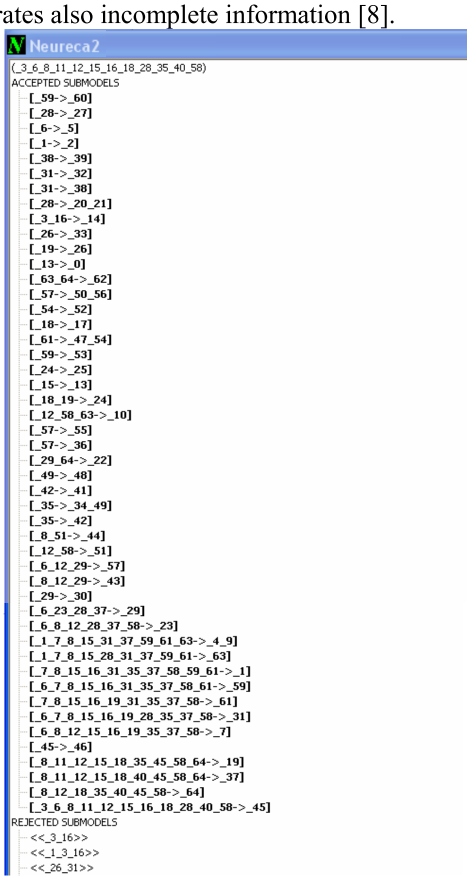

Fig. 5. The explored complexity of dependencies among different parameters (represented as numbers) of machines inside a production line.

The Fig. 5. shows an interesting result representing the complexity of dependencies in a given production line. Sixty-five parameters (represented as numbers) were used for the description of some machines and processes, consequently, only a part of the whole production line was taken into account, and also only a special production aspect was studied, indicating that a comprehensive analysis is an enormously complex and difficult task in the production line level.

This part of the papers aims at positioning the introduced submodel finding algorithm. Various aspects can be enumerated when specifying the place of a modelling and model building technique, only a part, considered important, is mentioned.

- According to the core modelling technique, the solution is mainly based on neural networks. MultiLayer Perceptron (MLP) ANN models are used exclusively, mirroring the position of the technique among the wide range of neural network types. The training algorithm is based on an accelerated back-propagation called SuperSab but it was modified several times.
- According to the last remark in the previous section, the model building method can be considered as a special learning algorithm, too. It does not require predetermining whether a parameter is on the input or output side of the model for building up, consequently, it can be ordered also into the class of unsupervised learning algorithms.
- Modelling of many-valued mapping is solved by the introduced algorithm, too.
- Various approaches can be found in the literature for improving the structure of ANN models also in the case of MLPs, adding and deleting neurons and links are typical steps of this approach. The resulted net of connected neural sub-networks can be considered also as a special solution of a structure determination process of ANNs. The proposed algorithm can result similar outcome than a pruning-learning process combination, so it can be considered as a very special form of pruning solution.
- The applications of ANNs are typically preceded by a feature selection algorithm, especially in the field of manufacturing to surmount their capability restrictions, with respect to the number of parameters and thus, model sizes. It can be found that feature selection and training processes are typically separated. The new, introduced algorithm brakes with this practice; it is a dynamic, integrated combination of these steps. In this aspect, it can be considered as a special feature selection algorithm, or also as a hybrid combination of feature selection and learning based model building, too.

2.4. Camera-based supervision of production systems

This paper of the paper highlights the scientific and practical aspects of a new concept employing cameras as multifunctional sensors for automated processes. The main goal is the development of a “smart” camera for process control, monitoring and fault detection in automation, consequently this technique allows to serve with production-, quality- and process monitoring information in a novel way. Several sensors (optical, inductive etc.), each having limited range of application, will be replaced by a single, flexible camera system with a wide range of applicability and thus substantially reduce the set-up time and costs for machines. The camera should take and extend the role of several sensors and thus substantially reduce the set-up time and costs for machines. In normal operation the camera will analyse the actual process in real-time and compare it to the symbolic description with a high-level decision-making tool.

The fact that e.g. assembly scenarios have considerable structure, permit us to turn difficult detection problems into much simpler verification problems. More precisely, instead of trying to detect what is going on in the viewed scene, we can try to verify that things proceed in the expected, predetermined way. More specifically, our approach is based on what we call Vision Based Logical Sensors (VBLSs). It is assumed that during set-up time, the user of the system may define Regions Of Interest (ROIs) of arbitrary shape in the image acquired by the camera. Moreover, the user may associate specific Image Processing Algorithms (IPAs) and the parameters governing their operation, to each of the ROIs. Typically, IPAs will be change detection algorithms that detect some sort of dynamic change in visual content in the associated ROI. A predicate on the results of an IPA when applied to a ROI at a specific moment in time is considered as a Logical Sensor (LS). Compound Logical Sensors (CLSs) can then be built as predicates involving the values of LSs (or, recursively, other CLSs) at various moments in time. Using these fundamental building blocks, the system may detect important events occurring in the viewed scene.

The Fig. 6 shows an example with the introduced operators.

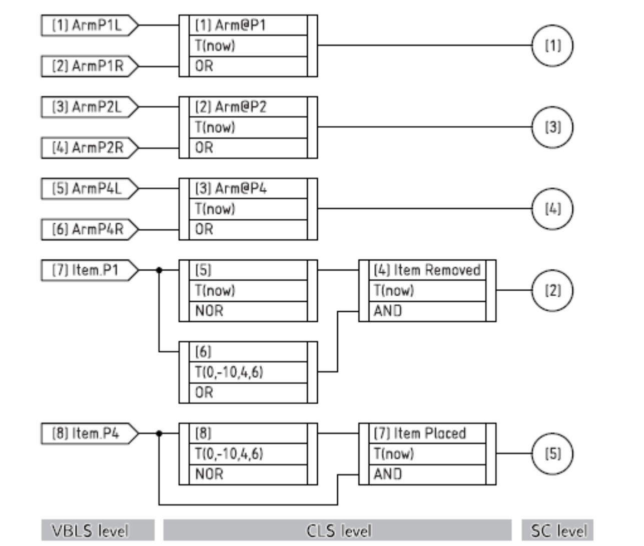

Fig. 6. The hierarchical VBLS/CLS/SC system.

The camera system can be installed and configured either by engineers relying on know-how about the production process(es) analysed, or by a "teaching phase" where an image sequence is recorded and analysed. This involves identifying situations in an image sequence, converting the image sequence to a symbolic description and interpreting the description as far as possible. The teaching means in this concept that having settled on a fixed logical structure, the tool should find a set of timing parameters for CLSs and SC items best fit for distinguishing successful process runs from failures. The timing parameters of these logical objects are similar to the timing parameters of the classical PLC programming required to set-up a production supervision system. The method proposed here is essentially a robust optimisation procedure relying on the main assumption that the underlying logical structure and the values of VBLS parameters are already given by the user and will remain unchanged during the search process. Possible inputs for the search tool could be any of the following three classes:

- one video sequence of a successful process run,
- several successful sequences of identical frame rate,
- successful and unsuccessful sequences of identical frame rate.

In the latter case, the tool would receive, along with the given sequence, an attribute signalising whether or not the process run is considered successful (the method being thus an example of supervised learning).

Since the primary goal of the evaluation of a scenario is to tell successful process runs from unsuccessful ones, this classification ability is the most important property of the VBLS – CLS – SC system and all possible objective functions for the optimisation procedure should give this property the strongest emphasis. One of the most simple ways of expressing classification ability is the ratio of correctly classified cases vs. all cases, i. e., the recognition rate. Experience has shown that for a given set of input sequences, best recognition rate can correspond to a wide area within the optimisation space. However, adding new sequences would show that not all solutions within the search space are equally robust, depending on where the corresponding decision boundaries of the SC items are located. Therefore, secondary criteria expressing decision quality and robustness can be introduced. Multiplying these secondary preferences by weight coefficients much smaller than those of the primary criterion will ensure that the preferences are treated hierarchically.

To solve the timing problem for a test case, a Matlab-based environment was implemented which can handle multiple successful and unsuccessful sequences as well, and can use greedy tabu search for optimisation.

The algorithm finds several optimal solutions this may require the addition of further features (such as expressions for decision quality, robustness and safety) to the target function, but also indicates that a VBLS – CLS – SC network can be quite robust with respect to timing parameters. Observing the behavior of the target function over the iteration steps, it can be seen that the greedy tabu search quickly encounters an optimal or near-to-optimal solution. This property can be an advantage if the optimisation tool is used as an interactive decision support system where a short response time is essential for acceptance by the operating personnel.

The Fig. 7. shows an example of the values the hierarchical composed target function together with the searched timing parameters during the search.

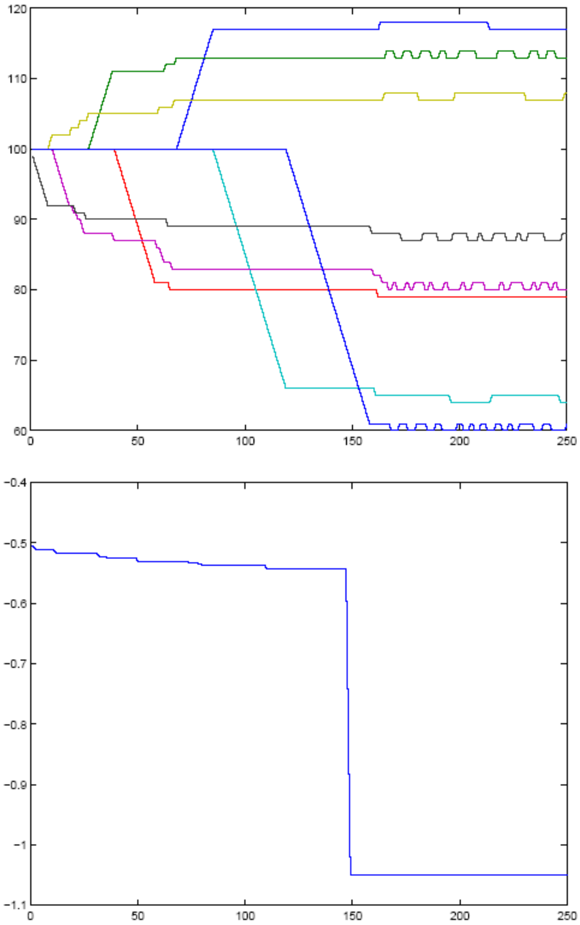

Fig. 7. The searched parameters and the objective function. The example shows that the proposed algorithm can find the optimal solution relative quickly.

3. DISCUSSION

The integration of production-, quality- and process monitoring information is the key enabler of the targeted real time shop-floor control burdened with changes and disturbances. Various techniques are applied to realize this basic feature of an agile manufacturing system. The novel solutions proposed include different techniques working together in a new integrated way [9].

4. CONCLUSION

The paper summarizes the main ideas and results for realizing agile manufacturing systems having active disturbance handling approach for real-time manufacturing control. The intelligent integration of information received from production-, quality and process monitoring systems is addressed as the enabler of the approach. Behavior based control, applied, hybrid simulation solutions, exploration of unknown dependencies and submodel identification, and a special field of camera-based supervision of production systems are the techniques to present a new and efficient solution for real-time manufacturing control.

ACKNOWLEDGMENTS

The research work presented in this paper is in part financed through the EU 6th Framework project No. NMP2-CT-2004-507487 VRL-KCiP –Virtual Research Lab for Knowledge Communities in Production – network of excellence and MultiSens under contract No. 512668, as well as by the projects “Real-time, cooperative enterprises” in the frame of the National Research and Development Programme by the Ministry of Education, Hungary (Grant No. 2/010/2004). A part of the work was covered by the National Research Fund, Hungary, Grant Nos. T046509 and T049486.

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