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DESIGN AND CONTROL OF MULTI-AGV SYSTEMS
REUSE OF SIMULATION SOFTWARE

Jaap. A. Ottjes * and Frank. P. A. Hogedoorn **
* Delft University of Technology, Faculty of Mechanical Engineering
and Marine Technology, P.O. Box 5034,
2600 GA Delft, the Netherlands
E-mail: J.A.Ottjes@wbmt.tudelft. nl
** Preussag Noell Benelux B.V., P.O. Box 1194
3220 BD Hellevoetsluis, the Netherlands

ABSTRACT

Working in cooperation, Preussag Noell Benelux B.V. and the Delft University of Technology have developed a method for the integrated design and control of multi-AGV (automated guided vehicle) systems of up to ten vehicles. With the aid of simulations of the user-environment, termed the client system, the number of vehicles required and the logistic control strategies are determined and optimised. The simulation software which is derived is then used for the real-time control of the entire system. Advantages of this approach include a low-cost control system, a short design phase, adequate attuning of the AGV system to the client system, opportunities for the use of advanced specific control strategies and rapid, low-error implementation. A prototype simulation environment has been developed and tested including the real time control of an AGV.

INTRODUCTION

With the current far reaching automation of industrial processes it is often necessary to integrate the transport function in the total logistics of the process. To provide this transport function, increasing use is made of Automated Guided Vehicles. This is one of the consequences of the fact that there have been major developments in the fields of navigation and sensor techniques. Until a few years ago an AGV system was usually controlled on the induction principle, a rigid system that was prone to malfunction and that made heavy demands on the adaptation of the work floor. The new generation of AGV systems, the most important feature of which is the application of free navigation, provides new prospects for logistic optimisation with a minimum of necessary floor adaptations and a large degree of flexibility with regard to route changes and also high reliability.

The performance of an AGV system is largely determined by the control system, certainly when a number of vehicles work together in a system and interact with each other.

On the basis of practical experience and questions from the market, it was found that there is a growing need for control systems within the category of multi-AGV-systems up to around ten vehicles. The functions of this type of control system involve:

- A low-cost control system, based on a standard PC and conventional software.
- Advanced control facilities in the form of user-selectable logistic strategies, for example, order and vehicle allocation.
- Graphical display of the system under control, which means the provision of monitoring facilities.
- The acquisition of statistical data relating to the system under control, for the purposes of performance analysis and cost calculation.
- Ease of operation through the use of a menu driven environment and the option to take over manual control of the system.

A project has been set up to develop a design strategy for the control of multi-AGV systems up to ten vehicles. The technical basis is formed by the existing free-ranging AGV program of Preussag Noell Benelux B.V.

THE CONCEPT

The control of Automated Transport Systems (ATS) is complex, especially when a number of AGVs are working together and this exerts a big influence on their performance. For this reason a flexible advanced design environment is needed. This means that there should be opportunities for the design and testing of what are often industry-specific control systems. Testing at on-site industrial locations is either very expensive, bears too great a risk in relation to the continuity of the production process of the client system, or is entirely impossible. The decision was therefore made to test the control with the aid of a realistic simulation model of the total system. This simulation model was later used as a basis for the real-time control of the AGV system and for monitoring purposes, as a result of which the model acquired a double function. This approach was proposed for discrete industrial systems earlier (Overwater 1987) , (Gustafsson 1995). First a general configurable simulation model for the ATS will be discussed, after which the reuse of this model, with minimal modifications, will be considered.

THE SIMULATION MODEL

The simulation model that has been developed for the ATS must be able to determine how many vehicles are needed for complex transport functions and to carry out optimisations relating to vehicle routing and product/vehicle allocation strategies. Owing to the requirements that the model should be generally applicable it has been designed modular. Three classes of modules are distinguished: the vehicles, the central control and the resources. The simulation model works according to the process description method (Zeigler 1976). The various components contain the data structure of the component and, in the case of an active component, also the process description of the component. The tool we used is the Must simulation package, based on object Pascal (Must 1992).

The vehicles are modelled relatively rigidly and form the core of the model. They carry out their tasks according to autonomous commands to follow programmed routes. The order to follow a route or a combination of routes is transmitted to the vehicle by the control system.

The modelled central control directs selected transport orders to the vehicles in the system, For this both logistic strategies for the selection of a transport order itself, various product priority rules and strategies for the direction of a vehicle to this transport order (shortest route, shortest travel time, lowest rate of occupation, lowest chance of blockage, etc.) are available. These strategies can be selected and tested by the designer and also changed or extended as required.

With the exception of only the AGVs, the term resource covers all logistic components such as abstract product generators, machines, buffers and other possible means of transport. Resources create the transport orders in the model. With the aid of these resources the client system can be modelled. The designer can incorporate the resources in the model to simulate the client system and thus make possible the testing and optimisation of the ATS in a realistic work environment. The use of object oriented programming technique permits the easy addition of new types of resources without the need to make radical changes in the model.

The client system, modelled in the form of resources, generates a list with planned and scheduled actions which are translated into transport orders. Making use of the available information in the model, and on the basis of various strategies, transport orders are allocated to AGVs. Both the actual AGV status (position within the system) and the future status (planned arrival time at a destination) are taken into consideration. Because the control system has information from all the components in the system at its disposal it is relatively easy to programme advanced allocation strategies for transport orders. In this way the control system provides the AGVs with transport orders to serve the client system.

Experimenting with the simulation model, the performance of the system can be determined as a function of the system parameters such as the number of AGVs, allocation strategies for transport orders and AGVs, route optimisation and the path planning algorithms. Insight is obtained about occupation rate of vehicles, waiting and throughput times of the transport units in the system and service levels with respect to the client system. In this way the number of AGVs required can be determined and various layouts and controls can be tested, so that a good working total system with known performances can be designed. With this concept building blocks are obtained that can be used afresh for each new project.

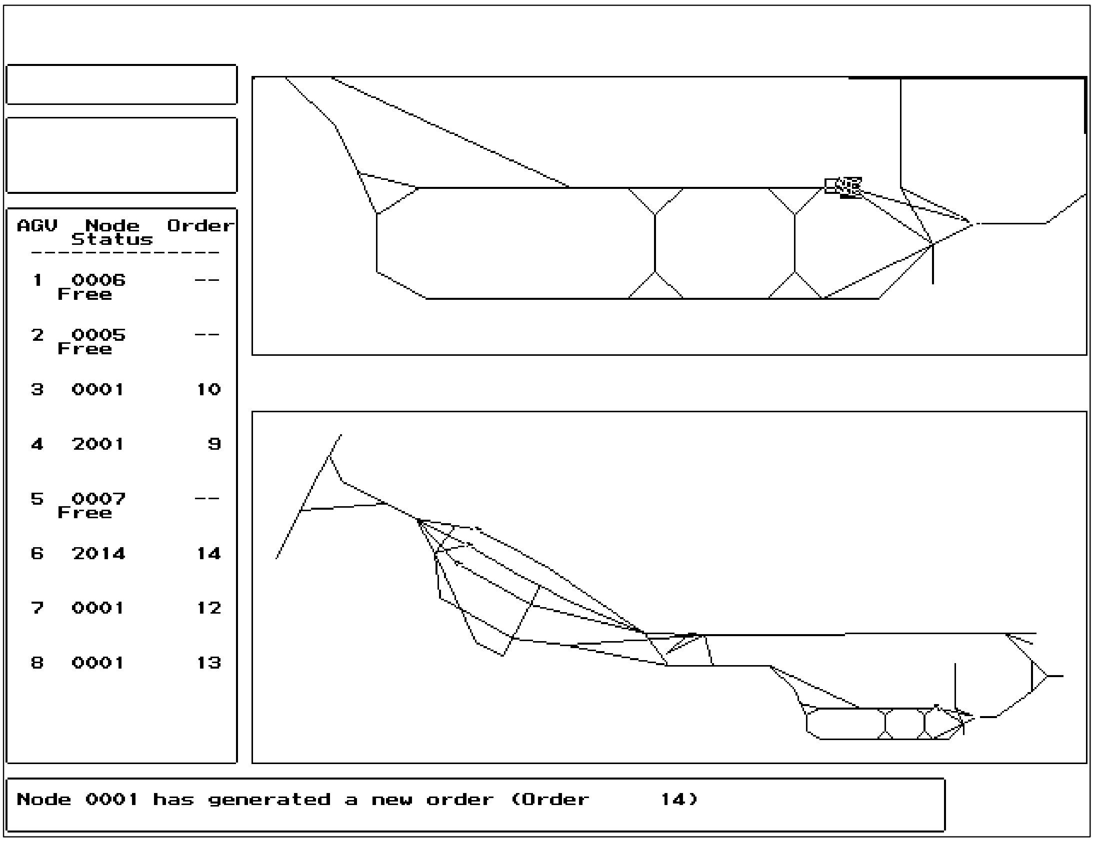

Figure 1: Capture of the simulation screen of an AGV system. The lay out and routing are designed using a CAD tool called the Route Editor, the results of which are directly used for the simulation lay out and for the AGV guiding. The upper part of the picture shows a magnified section of the lower part.

REAL TIME CONTROL BASED ON THE SIMULATION MODEL

If the simulation is to be used only in the design phase usually at the moment when the real system is implemented a completely new control system analogous to the simulation control system is programmed, often with the real system as test environment and this is usually time consuming. In addition, advanced control algorithms, that have already been implemented and tested in the simulation software will need to be developed anew, often by using software that is less suitable for this purpose. The simulation model however already contains all the components of the system to be designed however. This contains both representations of the physical components such as transport systems (AGVs) and means of production (machines), and the control software. Naturally it will be necessary to implement the interfaces to the real physical components, but the control software has already been developed and validated in the simulation model. A working error-free control system already exists, be it that it is written in simulation software. This double work can be avoided by using the simulation system, with minimal modifications directly for the real-time application. This train of thought brings the following advantages:

– It is not necessary to design a real-time control system.
– When programming the control system it is necessary to add only the missing real-time functions to the simulation model. Usually these functions relate to the exchange of data with the real system, i.e. the interface with the physical components in the system must be added. Verification, validation and the correction of errors is only necessary for the newly added functions.
– The facilities of the simulation language used, which are often extensive, can be employed. The implementation of advanced control rules and logistic strategies is relatively uncomplicated, in particular because it is possible to use parallel processes. Owing to the presence of all the simulation components, the system behaviour can anticipate future events and, on the basis of this, can allocate the transport orders to the vehicles.
– The acquisition of statistical data relating to the real system measured by the simulation system, for example the occupation rates, waiting times and throughput times. On the basis of this statistical information the performance of the

system can be assessed and, if necessary, adjusted by using different allocation strategies from the "simulation library".

- Monitoring of the real system with the aid of animation which is already available in the simulation model. (figure 1)
- User friendly interface between the control system and the user.
- Relatively inexpensive hardware and software.

To convert the simulation model to the real-time model it was necessary to make the following adaptations : (figure 2)

- The simulation model must function in real-time. For this the simulation clock must be synchronised with the true time so the simulation mechanism is slowed down to such a degree that the model runs are indeed synchronised with the actual time.
- The orders transmitted from the control module to the simulated AGVs must **also** be given to the real AGVs. This requires that there is an interface between this module and the AGVs. This communication function may be integrated in the control system, but is usually accomplished by an application at a lower level. This application takes care of the traffic regulation and the transmission, filtering and translation of information passing between the control system and the AGVs.
- The system information of the simulated AGV-system is replaced by that of the real AGVs, so the real AGVs are now controlled by the control modules of the simulation model.
- So far the transport orders are still generated by the model of the client system. The system obtained can be tested by using the simulated AGVs as a shadow system working parallel to the real AGVs. The control system has all the actual information from the real AGVs and all the data that are known to the simulation model. In practice some inaccuracies will occur. For example a real AGV may arrive at the destination later than its simulated counterpart. The simulated AGV should therefore be synchronised with its physical counterpart at specific time intervals.
- The real client system is substituted for the simulated client system so that the transport demand is now generated by the real system. For this too, an interface with the real client system is needed, for example, machines that report that a pallet with a product that is ready must be moved away by an AGV. In the client system this interface function will usually be fulfilled by a PLC. Just as in the case of the AGV interface, here too the interface may be coupled directly to the control system or be accomplished by means of an application at a lower level, which can handle defined processes and transmit information between both systems.

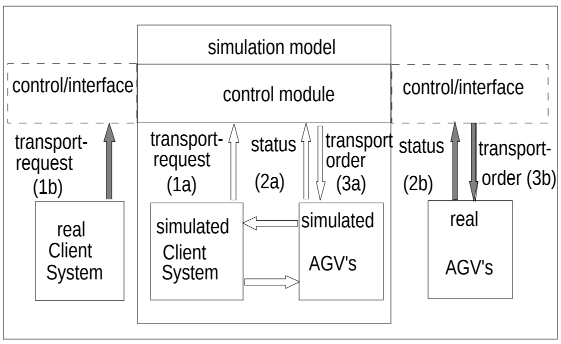

Figure 2: The simulation model working real time, controlling the AGV system. Real transport requests (1b) are now substituted for simulated transport requests (1a), transport orders are now going to both real AGVs (3b) and simulated AGVs (3a) and the simulated status is updated by the real status

The simulation model has been only very slightly modified. The control module has been expanded by the addition of a number of real-time functions to provide for synchronisation, robustness and the interface with the client system. The transport demands are now generated by the actual client system and managed by the control module, Each physical component has a simulated counterpart in the original model, the behaviour of which is directly linked to that of the physical component. The advantage of this is that within the real-time control system all the possibilities that were already provided by the simulation model can be used to process the data of the real control system. The AGV movements can be monitored on the simulation screen as shown in figure 1.

RESULTS AND CONCLUSIONS

A prototype of a generic simulation model for multi-AGV systems is developed the control module of which can be reused for real time control of the real system. The interactions with the client system can be modelled into detail, so that dimensioning and optimising activities can be carried out in the simulation phase. In order to successfully apply this way of working the following requirements have to be fulfilled:

- The necessary interfaces must be created. The interface between the control module and the AGV system is standard. The interface between control module and client system depends strongly on the client system. Some practical problems that may occurred are caused by differences in parameters in the simulation model and the real values, such as the pick up time of a pallet and the exact velocity of the AGVs. The model is therefore synchronised regularly with the real system.

– The required reaction time of the control system must be large in relation to the calculation time required by the control-PC. If critical response times are required this may cause delays, although this does not apply usually to models at this hierarchical level. It is estimated that it will be possible to control systems with up to ten AGVs in this way.

The ideas that had been worked out were put to the proof in a test situation in which the control system ran on two PCs. The real control system which was based on the simulation ran on one PC, while the second PC served as interface between the control system and the AGVs. Communication with the AGVs was via radio, while a local network was used for the communication with the control system. The previously mentioned advantage of having a short design phase, which resulted from the reuse of existing software, appeared to be very real in practice.

Based on practical experience, the described prototype model has been developed into a commercial product which is used and sold by Preussag Noell Benelux B.V. as the standard AGV-control system. Beside the real time application it is also used as a simulation tool to give demonstrations to customers, to calculate the number of vehicles needed in new projects and to help developers testing software changes. The described concept of multi functional software that can be used in different project phases from sales to a real time application has proven to be an effective method to save time and costs.

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