SIMULATION AND VISUALIZATION OF AUTOMATED GUIDED VEHICLE SYSTEMS IN A REAL PRODUCTION ENVIRONMENT

Axel Hoff, Holger Vogelsang, Uwe Brinkschulte, Oliver Hammerschmidt
Institute for Microcomputers and Automation, University of Karlsruhe
Haid-und-Neu-Str. 7, 76131 Karlsruhe, Germany
E-mail: {ahoff|vogelsang|brinks|hammer}@ira.uka.de

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ABSTRACT

Low-cost Automated Guided Vehicle Systems (AGVS) play an increasing role for the automation of production plants. For complex installations, a simulation of the transport system should be performed during the planning phase in order to check for possible problems and to optimize parameters. During operation of complex AGVS a visualization of the whole system is desirable in order to allow a continuous monitoring. Since most of the relevant tasks have to be performed for simulation and visualization as well, we constructed an integrated tool which is able to deal with both jobs. As an example for operation of the simulation tool, results are presented for the calculation of the number of vehicles for optimal performance of an AGVS given a layout and a transport matrix.

OVERVIEW

As mentioned above, low-cost Automated Guided Vehicle Systems (AGVS) play an increasing role for the automation of production plants since they can be used as a flexible assembly line (Müller 1993). In recent years AGVS prevailed on the market of material flow on the manufacturing floor due to advantages like installation costs, flexibility and the fact, that no extra space is needed in comparison to conventional conveyor systems. There are several ways to avoid collisions between different vehicles. Basically, the track network is divided into blocks as known from railway systems. In order to allow a fexible and cheap re-configuration, block demandal and granting is done by a central “block control unit”, which communicates with the vehicles by radio signals.

Since there is a tendency to use AGVS for more and more complex transportation tasks, a growing need for tools for planning and monitoring the employment of AGVS arises. The first step in planning of a AGVS is the construction of the layout, consisting of tracks, block structure and stations. This task will be performed with an AGVS-editor (Bauer 1997). The resulting layout is stored in a database; it defines the structure of the AGVS. For complex installations, at this point a simulation of the transport system should be performed in order to check for possible problems and to optimize parameters as the track layout or the number of vehicles. This is done with little effort before the final installation of the system is done. When the AGVS is operational one may wish to have a control centre in order to monitor the positions of the vehicles and possible problems like collisions or the battery going low. Since the simulation and monitoring tasks have many subtasks in common, we constructed a tool for performing them simultaneously, i.e. for simulating and visualizing the operation of AGVS.

CONCEPTS

In the area of AGVS different scenarios can be modeled and simulated: the chassis of a single vehicle, the control system of a single vehicle, geometrical dimensions and the envelope of a vehicle to pass stationary obstacles etc. For the plant in question the objective was to find out the number of vehicles for optimal performance of the AGVS given a layout and a transport matrix. A simulation is needed since the layout does not show a simple structure which could be solved algorithmically as in (Schmidt 1989). The following tasks have to be solved for this kind of simulation of the AGVS operation [**S**] and for visualization of the real system [**V**]:

- **(S)** Simulation of a single vehicle (speed, load, battery charge, . . .)
- **(S)** Communication of the simulated vehicles with the block control unit
- **(V)** Determination of position and state of the real vehicles
- **(SV)** Visualization of vehicle position and state
- **(SV)** Evaluation of statistical measures for the system (e.g. waiting times at stations) in order to determine the need for optimization
- **(SV)** Analysis and visualization of problematical track sections (e.g. with frequent blockades due to overload) in order to give hints for optimization

Since most of the relevant tasks have to be performed for simulation and visualization as well, we constructed an integrated tool which is able to deal with both jobs.

Figure 1 shows the structure of the tool and its (optional) embedding into the AGVS control environment. The existing AGVS control environment is shown in grey. It provides the simulation unit with parameters of the real plant, while the simulation unit adds data of virtual vehicles. As can be seen from the figure, it is in principle possible to combine the operation of a AGVS system with a simulation of additional vehicles. This feature can be used for demonstrations of complex systems which can only in part be implemented (e.g. at a fair), but it may also be useful for the conception of extensions of existing AGVS systems.

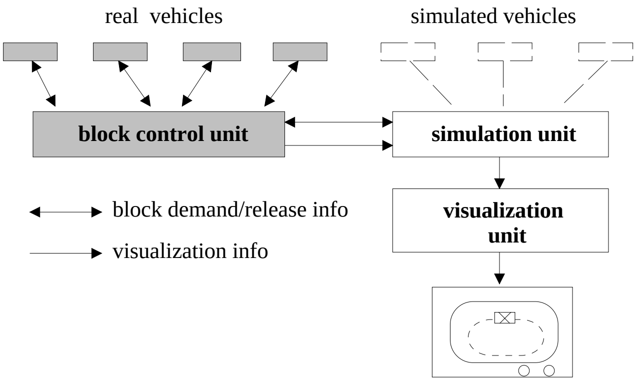

Figure 1: Structure of the AGVS simulation and visualization tool

SIMULATION

The simulation of a single vehicle consists of the description of the physical properties of the vehicle and of its action scheme. The relevant physical properties are position and velocity of the vehicle as well as its current load and battery charge. Both parameters may influence the maximal velocity and the possible acceleration values. Position and velocity are upgraded by a simple Euler integration scheme, which fully suffices for this purpose.

The actions of the vehicle are determined by

- position-dependent signals (as marks for stations or switches), which are provided by the track database,
- information on block occupancies, which are provided by the block control unit,
- inputs of the simulated or real users.

Possible actions of the vehicle are:

- Setting of a new maximal velocity. This will lead to the appropriate acceleration in order to adapt the actual velocity to the demanded one.
- Demanding and releasing blocks.
- Decision which track should be followed at a switch.
- Discharge of the battery.
- Random generation of different types of disorders.

When a vehicle reaches its destination station, it stops and waits for user actions to be done. The defined user actions are:

- Loading or unloading a vehicle with a definite amount of time
- Recharging of the vehicles' battery
- Sending a vehicle to a new destination station
- Requesting a vehicle from another station

These actions may be performed manually by the operator of the simulation, but they will normally be executed by simulated users. A simulated user is present at each station, it consists of a list of actions to be performed on specific conditions. Random elements (e.g. a distribution of waiting times) may be incorporated into the actions of the simulated users in order to get a more realistic simulation and to avoid artefacts. The collection of the simulated users specify the considered production environment, as far as transportation problems are concerned. The vehicle and simulated user actions described suffice to simulate the AGVS operation in the specific environment.

In order to be useful as a planning tool, the simulation program must provide data on the quality of the solution of the transport problem. The most relevant of these data are:

- The mean and maximal time, which the user has to wait for the next vehicle to arrive at each station. Assuming that the main operation at the station consists of processing items stored on the vehicle, this time is a measure for possible delays at the station.
- The time a vehicle has to wait before being allowed to enter each station. This value indicates whether a station is over-equipped with vehicles.
- The time a vehicle has to wait "on the road" due to used blocks. This is an overall measure indicating a possible overload of the track network. If one specifies this value for each block group seperately, one gets hints for possible causes of an overload.

In order to allow an easy inspection of the system, all of these data can be visualized either in the layout scheme or in separate diagrams.

BASIC ELEMENTS

The conception and realization of the simulation and visualization tool is based on a distributed system platform called AK (Schweizer 1995). AK allows an easy construction of platform independent distributed systems.

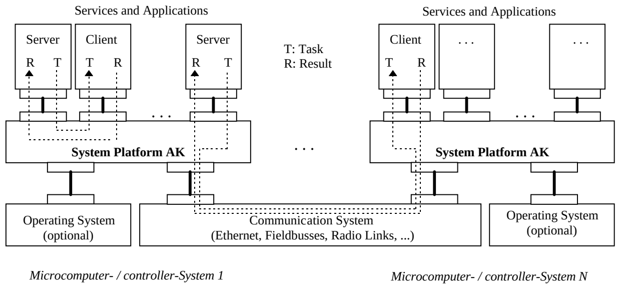

Figure 2: Application example of AK

Services and applications interact by exchanging tasks and results, playing service and client roles. Tasks and results are used for communication, synchronization and the definition of real- time requirements (giving a task a deadline). AK abstracts from the underlying operating system (if any, e.g. on a microcontroller), communication system and hardware. The second prebuilt component is the so called man-machine interface "Fluids". The basic idea of the man machine service *Fluids* (Vogelsang et al 1997) is the introduction of symbols (Brinkschulte et al. 1996b) as state-pictures of structured objects of an application, e.g. process variables of a control unit (Brinkschulte et al. 1996a). The user can flexibly define symbols and their behaviour on events with an interactive tool, the *symbol-editor.* Symbols are composed of base-symbols, such as lines, circles and other user-defined symbols. As a result, symbols may contain a hierarchy of components. These are stored in a configuration database for usage within the application. After the configuration or construction, the symbols are available in the application. To use them, they have to be connected with an object. Changing a value of this object leads to a different graphical representation. Changing the graphical representation (e.g. the user moves a symbol interactive) leads to a different object value. The relations between object values and the resulting images can be defined. This relation is either continuous, where linear or logarithmic functions are provided, or discrete. The construction by using an object- and service-oriented design scheme allows easy switching between simulation, simulation with real parts (a combination of real vehicles and simulated ones) and real operation. Only services have to be substituted or changed in their configuration in order to change the system setup.

An automated guided vehicle comes in many various designs (Premi and Besant 1987), it can be equipped with or without devices for unaided loading/unloading and/or automated coupling of trailers. Moreover, one can choose different principles of guidance (laser, inductive wire, optical markings like tape etc.). Communication with the central block unit can be transmitted by radio, infra-red or via an inductive guidance wire. Different chassis, wheel numbers and steering lead to different velocity and direction controllers.

Since the basic control structure for all this variations of vehicles is the same, the above presented modular concept simplifies the adaptation to different vehicle types (Hammerschmidt and Vogelsang 1996) within a short time frame and reduces costs.

APPLICATION EXAMPLE

As an example, we will give some results of a simulation done for optimizing the AGVS-concept for a German company. The simulated AGVS is now in real operation. Battery-powered vehicles are used which optically recognize and follow a track on the floor (optical guidance was introduced by (Tsumura 1986)). This track is defined e.g. by a coloured adhesive tape. Special optical marks or transponders are used to define relevant points, such as stopping-points or switches. Figure 3 shows the track layout used. The latin numbers indicate the stations, the little dots indicate block borders and switch marks. The vehicles are used to supply the stations with raw products. When new material is needed at a station, a new vehicle will be demanded from station **L**. This vehicle will be loaded there and drive to the demanding station, where it will stay until its content is processed. Afterwards, the vehicle will transport the products to station **V** and return in empty state to station **L**, awaiting a new transport task there. In the described case, the simulation was used primarily to determine the optimal number of vehicles for a given transportation matrix and to identify possible problems related to layout (e.g. avoidable delays).

Figure 4 shows – as a summary of the simulation results – the dependence of mean and maximum waiting time at the operational stations on the number of vehicles used. Each dot indicates the result of a separate simulation, consisting of 240 hours of simulated time. When the plant is operated with few vehicles, the waiting times are high, since the number of vehicles does not suffice to perform all the transportation tasks. With increasing number of vehicles the waiting time decreases until a fixed value is reached. Now, the plant operates at its optimum. The waiting time remaining is due to the block control scheme, which allows the next vehicle to enter a station only when its predecessor has left the corresponding block. This leads to finite minimum waiting times at each station. When the number of vehicles is further increased, the waiting times will finally start to increase again. This is due to an overload of the track network leading to mutual blockades of the vehicles. In this region, the system operates in a chaotic regime and the single waiting times become more and more unpredictable.

Figure 5 shows the probability distribution for the waiting times at a particular station. Such a diagram can be used to find an answer to the question how many vehicles are needed to assure that the waiting time is less than a specified value with a defined minimal probability. Thus, a fine-tuning of the planned AGVS system is possible.

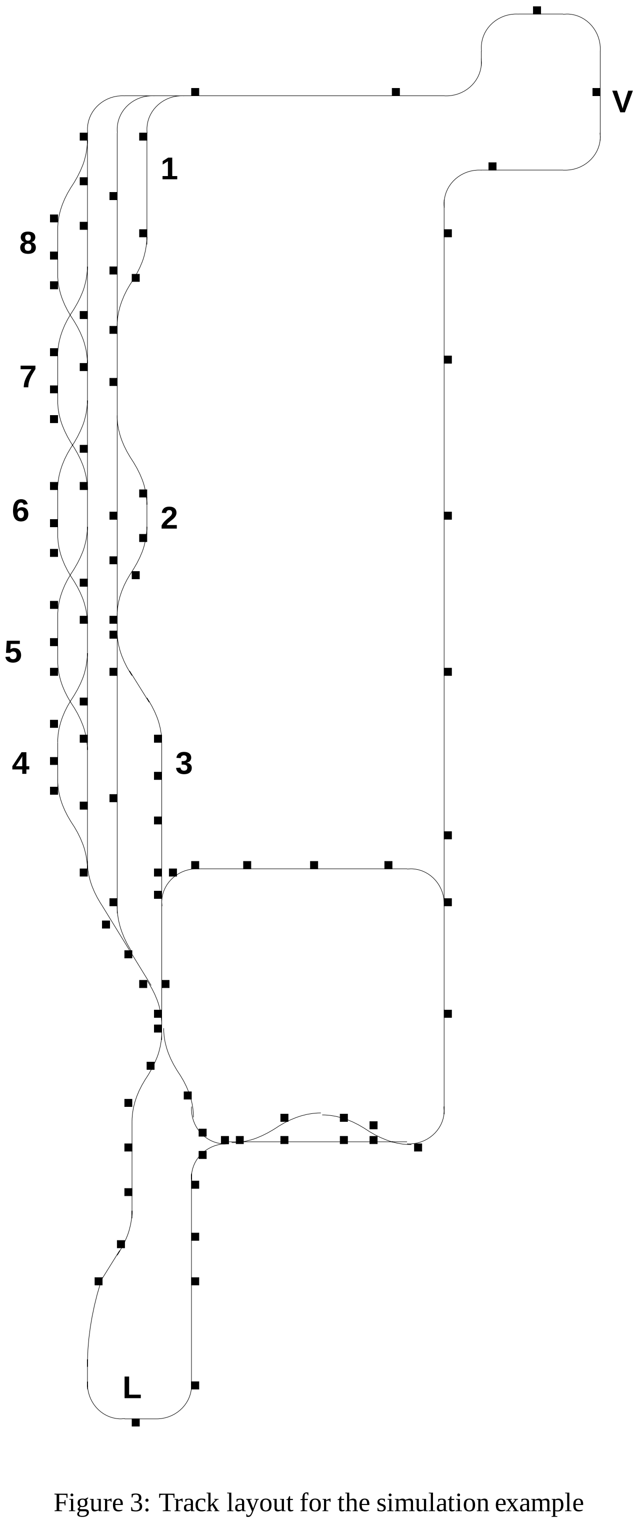

Figure 3: Track layout for the simulation example

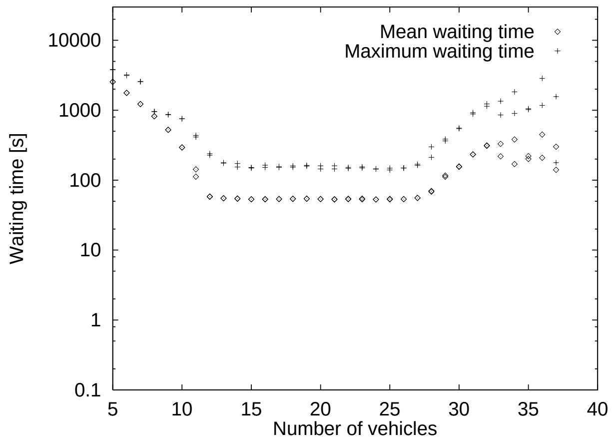

Figure 4: Sample simulation results: Dependence of waiting times on the number of vehicles used

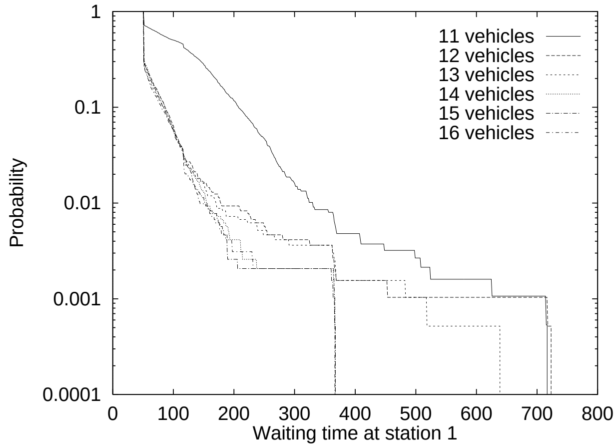

Figure 5: Sample simulation results: Probability distribution of waiting times for different vehicle numbers

CONCLUSIONS

By using the described simulation tool to predict the performance and behaviour of the AGVS an exact planning of the material flow system was possible before vehicle construction, installation and commencement of operation of the whole system. In between the plant is working since several months, and measurements on the plant fit to the simulation results evaluated before. Research is now being continued to extend the simulation by geometrical data in order to allow an automatic track generation of the layout on the factory floor. During operation, a short-time simulation shall be used to optimize control, disposition and placing of transport orders on vehicles and thereby increase the overall performance and avoid superfluous jamming situations.

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