AN ARCHITECTURE FOR HEAVY DUTY MACHINE CONTROLLERS -FORESEEING AUTOMATED ROAD CONSTRUCTION ENVIRONMENTS

An architecture for machine controllers

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Abstract

Considering the architecture designed for the overall incorporation of information technologies (IT) on road construction environments, this paper focuses on the development of automated machine controllers, and on the underlying requisites of machines to use these controllers. Special attention is paid to the modules that compose the machine controller. This work was developed within European Project ESPRIT III 6660 RoadRobot (Operator Assisted Mobile Road Robot For Heavy Duty Civil Engineering Applications).

Keywords: Integration, interoperability, positioning systems, communication, controller.

1 Introduction

The integration of Information Technology (IT) into the Building and Construction (B&C) industry has not yet achieved a satisfactory degree of implementation. This industrial sector is still in strong need of IT, especially when considering major areas of the building industry, such as the outdoor construction of dams, roads, airfields and other large construction projects.

The results of the incorporation of state-of-the-art technologies into the building industry (especially when IT is considered) are still very poor. Most established developments are concentrated on the Computer-Aided Design (CAD), drafting, scheduling control of tasks, and automation of certain pre-fabrication processes.

No special attention has been given to the automatic data flow of planning and control information, or advocating about the business needs to the seamless flow of scheduling, resource, materials, and cost information between firms. For practitioners in these industrial environments, very often time and material planning are done in a manual process at the construction site in a standalone basis, most of the time assisted by data received on phone calls or paper support (Pimentão et al. 1994).

Even considering the research work, most of what has been undertaken regarding the development of overall control architectures for outdoor building sites is not noticeable, whereas the development of such control architectures for other industrial sectors has advanced significantly during the last years. The question is now, whether the results of the past developments can be transferred to the demands of the building and construction industry. The evaluation and improvement of architectures and modules coming from other industrial areas (Camarinha-Matos and Osório 1992) seems to be necessary.

For that reason, to learn from existing architectures and modules from other industrial areas, according the special requirements of the building industry, can help to find new ways towards fully or partly automated and integrated construction processes (Sousa et al. 1998).

Future developments have to focus on the integration of IT into the building industry (Bradley 1991). Besides the low-level automation of overall planning and control systems, the task-level programming of complete building sites has to be achieved. The main interest of future works lies in the development and elaboration of a generic architecture for standardised integrated indoor and outdoor construction sites. Therefore, further work should also be concentrated on the automation of specific heavy-duty machines (Ulrich 1991; Leidinger 1991) in order to obtain a manpower reduced building site, with computer integrated time scheduling and material planning possibilities.

The adoption of standards in modelling, using a specific data protocol to support the integration and flow of information using a unique data exchange format, to be adopted by the various activities in B&C environments is, for sure, a key factor where proposals are now starting coming out. Examples are the work being developed by STEP within ISO TC184/SC4 Building and Construction Working Group (STEP 1998), by International Alliance for Interoperability throughout its Industrial Foundation Classes (IAI/IFC).

2 The Road Robot's architecture

The purpose of the European ESPRIT 6660 RoadRobot (Operator assisted Mobile Road Robot for Heavy Duty Civil Engineering Applications) project was the definition of a flexible control architecture suitable for outdoor heavy-duty construction applications, towards an automated construction site involving mobile equipment, concerning the building industry requirements.

A flexible architecture for information flow and road construction management has been implemented, considering four logical levels: Site, Cell, Machine and Tool (Pimentão et al. 1993), as depicted in Fig. 1.

The process of road construction managing starts by loading into the RoadRobot Information System (IS) the information produced by a CAE system (in this case the InRoads from Intergraph), using a tool that we called "Project Development". Information is then decomposed and processed in order to produce the tasks.

Task decomposition is performed in a semi-automatic way with the aid of a

Decision Support System (DSS). Regarding a road section, the DSS looks at the geometrical and geological information and, based on a set of rules supplied by the experts (e.g. two-lane road produce a task per lane), and on equipment restrictions such as excavator arm length, to produce the tasks.

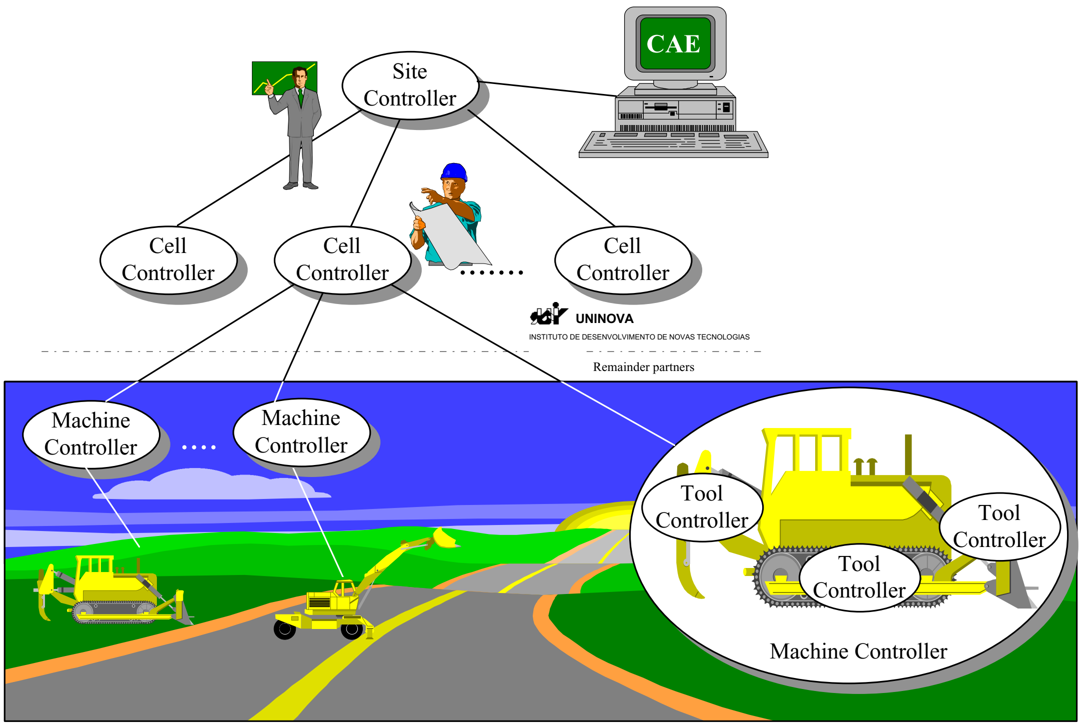

Fig. 1: Road Robot's architecture

Once task specification is accomplished, each task is then assigned to a given construction cell-type. Each task is set in the proper sequence, based on the knowledge of the road construction processes, with the aid of a “Planning tool” that assists the user on the sequencing and possible paralleling of tasks.

Cell types are based on the characteristics of the set of equipment that composes it (e.g. paving cell). Task scheduling follows it with the assignment of existing equipment to each cell and effective time scheduling. At due time, the Site Operator is supplied with the information needed for setting up the given Cell, and once the Cell reports its operational status, it is fed with the task information.

The process of planning and scheduling of tasks at the Cell level is performed in a similar manner, where each task is, in due time send to the machine controller for execution.

It is worth noticing the fact that at the Site and Cell levels, all tools have been integrated using the developed Road Model (RoadRobots’ improvement over TNO’s Road Model Kernel), which is an ISO 10303 - STEP model for representing information relevant for road construction processes. Also relevant is the fact that all communication among controllers (task assignment, control and execution status) has been included in the Road Model, which makes it (although subject to a strong revision) a model for the full construction process.

2.1 The Machine Controller

When considering an overall system to control the process of a given machine, the state of the art was, by that time, the fact that just some tools were regulated by means of control loops with complete lack of auto co-ordination. The settings for these tool controllers were not derived from the tasks to be performed, but set by machine operators using their expertise. This scenario kept the quality of the road very dependent on the experience and co-operation of the crew on and around the machines. Therefore, in order to change this situation an application independent part of the machine controller was defined in order to perform:

- Reception of tasks from the Cell Controller,
- Execution of commands from the Cell Controller and the machine operator,
- Controlling the process by monitoring and adjusting the process parameters when necessary,
- Signaling the machine operator and the Cell Controller when tasks are completed, aborted etc. and when any kind of problems occur.

This machine independent part interacts with the machine dependent, which is responsible by decomposing the given task in operations to be assigned to the tool controllers.

2.1.1 The Machine Controller's Architecture

The machine controller has been devised in two parts: machine dependent and machine independent. The following modules compose the later, depicted in Fig. 2:

- *Cell-Machine Interface*: the interface that allows the machine controller to receive task information and commands from the cell controller and manage the respective feedback;
- *Machine-Tool Interface*: the interface to the tool managers;
- *Knowledge based system*: the "heart" of the machine controller which, based on the machine dependent knowledge, processes information from a given task and translates it into tool parameters. It also has the ability to control the tool controllers on the performance of their assigned tasks;
- *Navigation System*: a module that supplies the machine controller with the machine's position and orientation;
- *User Interface*: an interface to the machine operator, mainly used to supply information, but that can be used also to control the machine in case of lack of communication to the cell controller.

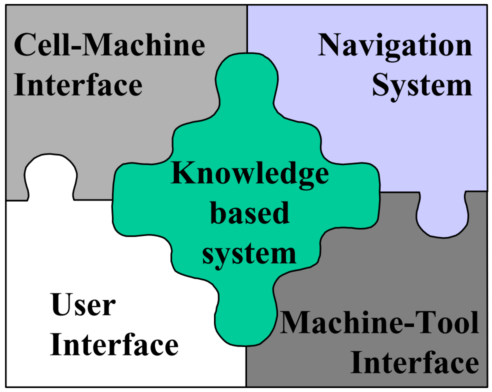

Fig. 2: The modules of the machine controller

2.1.2 A controllable machine

In order to implement the RoadRobot concept, the selected machines have to abide to some requirements (e.g. electrically driven tool controllers, sensors). For the Project one machine was chosen to demonstrate the concept in a real construction site – a paver machine from RoadRobots project leader, the German paver manufacturer VÖGELE, AG.

When considering the automatic control of a road paver the Joseph Vögele company began, in 1990, to investigate alternative concepts to hydraulic drives for translation movements and rotary movements in order to achieve a more flexible and less expensive solution.

Even in the tough environment of a construction site and under extreme environmental conditions (temperature, humidity, dirt, corrosion), electric drives have been found to offer the following substantial technical advantages compared with hydraulic drives:

- Electric drives can be dimensioned according to output and torque.
- The variable speed range at constant output is so wide that the need for traction and shifting can be dispensed with.
- Even at a high driving torque its uniform motion at speeds close to zero is ensured.
- Electric drives have capability of temporary overload.
- Electric drives offer low-cost solutions for increased automation.

In conclusion and as result of these technical features the first completely electrical paver was produced under the scope of the RoadRobot project.

2.1.3 The Navigation system

The primary objective of the Navigation Module is to provide a rugged system that can determine the position of a mobile vehicle in five degrees of freedom (x, y, pitch, roll and yaw). The RoadRobot navigation system must be able to localise the vehicle to achieve accuracy over a large and unlimited operational envelope. Localisation of roll, pitch and yaw of the vehicle is required to a high accuracy.

A summary of the primary requirements identified for the Navigation

Module is listed below. These objectives were deemed to range from highly desirable to absolutely essential for construction vehicles in general.

- *High Static and Dynamic Accuracies*: the objective of the system is to locate the vehicle to a positional accuracy of <1cm or better in the translation parameters and 0.02 radians in the rotation parameters. These accuracies should be maintained for the vehicle moving with a velocity of 0.1 m/s in translation and 0.1 radians/s.
- *Robust, Capable of all-weather operation* without loss in performance and capable of working in a wide range of environments (built- up, in tunnels)
- *Applicable to a wide range of vehicles*. In order to capture the widest possible market, the Navigation Module should be applicable to other type of vehicles. In order to meet these requirement features such as: Low-cost, compact size, low-maintenance, weather-proof are all factors.

There were a large number of navigation systems available on the market (CTS, GPS, radio-based navigation and laser-based positioning systems), however none closely matched the RoadRobot's navigation system requirements.

Laser-based systems have been a viable proposition in relatively low cost mobile robotics for some time now. Most of these sensors use a laser to find the absolute bearing of a bar code in the environment, however some use retro reflective material attached to beacons to determine their relative bearing. A small number of these sensors provide both range and bearing to the retro reflective beacons One disadvantage with using beacons is that they need to be placed at regular locations in the environment before vehicles can operate.

As a result a number of sensors with radically differing modalities, including a laser-based scanner, were identified as having combined potential to meet the requirements of the objectives, provided they could be made to work together as a complete system. The decision was made to develop a system using existing sensors whose information was pooled together using well understood State Estimation principles. State estimators provide a mechanism for integrating various forms of sensor data, which only provides indirect information on the state that is being estimated, and refining the state or position of the vehicle. The system produced can take data from a variety of low-cost sensors and can, using smart algorithms, generate information that is of significantly higher quality than that provided by individual sensors.

The resulting system includes a combination of single ended GPS, laser-based beaconing systems and a low cost inertial sensor and it is controlled by and provides navigational information to the Machine Controller via a serial communications link.

The produced system technical specifications are presented in Table 1.

The specification achieved is quite acceptable for the construction site vehicles in general.

The Navigation Module is mounted on top of the RoadRobot vehicle where it has a clear line of sight to fixed retro-reflective beacons that have been placed in the surrounding environment.

Table 1: Technical specifications of the navigation system

Parameter	Value
Positional Accuracy	1 cm
Orientation Accuracy	20 mrads
Max- Vehicle Rotation Rate	0.1 rads/s
Max. Vehicle Velocity	0.1 m/s
Mm. Navigation Update Rate	10 Hz
Max, Laser Sensor Range to Beacon	30m

Once the beacons have been placed in an acceptable layout their positions need to be determined. After placement, the positions of the beacons need to be determined accurately, this is done using a theodolite and traditional surveying techniques. These positions are then given to the navigation system.

A minimum of three beacons is required to maintain the stated accuracies. Ideally, the operator would configure the beacons so that the vehicle could always see the maximum amount of beacons that are equally spaced around the vehicle. It is also better to have the beacons well spread, rather than in clusters.

2.1.4 The knowledge based system

It was decided that, at machine controller level, the application of AI-techniques for processes that are not totally understood.

Process knowledge must be acquired from the operators, and by modelling the processes themselves and their interactions. Several techniques were developed for knowledge engineering, which gained an increased level of importance.

A recent application field for expert systems is the use in real-time control applications. To this purpose it was necessary to combine of rule-based systems, fuzzy logic and neural networks. Fuzzy logic and neural networks were used to control the real-time aspects of applications, while the rule based systems were used for the high-level control of an application.

The knowledge about the control of the process is kept as rules, which can be updated without having to re-organize the entire software.

2.1.5 User interface

The available graphical user interfaces provided standard control and outlook of PC applications. Problems arose with the realisation of dedicated graphical representation of the machine tasks and statistics. These have been solved by the use of a flexible, graphical user-interface programming environment.

The Local User Interface realised in the RoadRobot project represents a flexible, high performance state-of-the-art graphical interface. It allows controlling and monitoring the machine operating process in a very user-friendly way.

The Local User Interface is an integrated part of the Machine and Tool Controllers and provides, as such, the opportunity to enter markets such as machine control integrated with shop floor information systems. The real-time visualisation of the physical process, together with the user-friendly interaction with the operator supported by the use of a touch screen system, optimises the interface between operator and machine. This combination gives added value to a standard graphical user interface.

2.1.6 Communication infrastructure
The machine controller has two types of interfaces: one with the Cell Controller and the other with the Tool controllers.

a) Cell-machine interface

The main problem that arose was the communication between cell controller and the machine controller, given that the former was supposed to be positioned in a fixed location whereas the later is moving around with the machine.

For the physical communication problem a Radio Frequency (RF) solution was selected, nearly without consequences for the software application. The only restriction is on long distance communication, where the quality of the signal is poor, limiting the baud-rate. However, for short distance communication, up to l00m, it can deliver a baud-rate up to 1 Mbit/sec.

At the logical communication level TCP/IP protocol family was selected, which allows for an overall communication infrastructure from the Site Controller down to the Machine Controller.

b) Machine-tool interface

The existing control systems implied that a change of the type of machine or parts of the equipment always required a lot of implementation work. To this end, more flexible process control was requested by the end-user of the machines. The development of an architecture, which follows the principle of distributed intelligence for a group of automated functions, helps to reduce the work in this area. Due to the fact that now an independent working processor controlled one process group, a whole process group can be added or eliminated just as required. This development was enabled by the use of a fieldbus system that allows the exchange of the process control parameters and the flexible composition of several process modules.

The objective to reduce the repair costs in case of malfunction has been considered by the identical hardware construction of the process modules. They could be easily exchanged. The specific working program is then transferred via the fleldbus system and adapts the module to the process specific working.

3 Conclusions and acknowledgements

At the start of the Road Robot project, the quality of the road was largely dependent on the know-how of the persons involved. If the teamwork did not work efficiently, large amounts of money had to be spent in order to correct the failures. That was the reason for the requirement of automated system, which should provide a constant quality.

The developed architecture and the data integration achieved has proved to be a requirement for substituting and improving, with reliability and performance, the manual and/or repetitive procedures.

This project had a major challenge, based on the need of applying and sometimes developing technology (applications, communications and hardware) towards the full automation of tasks that are usually performed/controlled by humans.

The use of standards in the modelling process helped to proceed towards automated and integrated construction sites, by integrating the actors in the different levels of participation, both exchanging data among applications and sending messages for control of the process. Standards like STEP, IAI/IFC are examples of those that can contribute positively for the intent. The results achieved during the RoadRobot project stress these conclusions, based on experiences executed under real conditions. (Gonçalves et al. 1996).

Based on the results of RoadRobot, the consortium designed a world-wide new road paver concept, which was used to pave the first road without direct human intervention.

We would like to thank, without exception, all the partners working in the Road Robot projects' consortium and, in particular, we acknowledge the European Commission by the financed budget and its support and trust in our ideas and developments.

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