FLEXIBLE ROBOT CONTROL FOR THE BUILDING INDUSTRY

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ABSTRACT

In the building industry, individually-tailored mechanical systems still dominate the field of construction work on bridges, factory halls, and buildings, as well as preventive maintenance work and repairs in various applications. Recently a strong demand to develop and integrate new robot controllers and mechanical systems for the building industry can be observed. AEG developed a new control system for such highly flexible handling systems. Those systems can consist of mobile or stationary robots, small machines with few axis or manipulators with up to 12 axis, large reach and payload. Many software functions are integrated in the robot controller to increase flexibility and performance for the end user. The first projects of computerized manipulators and handling systems have already been successfully completed in an interdisciplinary cooperation with the leading companies and institutes in this field.

1. INTRODUCTION

In the wide field of the building industry manufacturers of robot controllers are confronted with many new and non-standard demands. Common to such applications compared with manufacturing in the automotive field is a more or less unstructured environment. There are inhouse and outdoor applications with specific demands for a controller regarding installation technics, maintainance, safety- and diagnostic-functions.

Starting to bring robotics into the production automation in the past ment to develop a new generation of machines with motion axis and motion controllers. To introduce robots in the building industry is quite a different matter, because there are already a lot of special machines with motion axis but manually operated in most cases. To roboterize these systems means to integrate a robot controller to an existing handling machine. The operator of such machines is not yet used to handle and program automatically controlled systems. Therefore the task to set up an user-friendly operating device with optimized data visualization was done very carefully. The interfaces to drive- and measurement-systems are very important for an accurate adaptation of a controller too. The controller consists of a high computation capability as well as many standard control functions. Combined with the possibility to develop and implement software functions which are specific for a machine, a technology or a customer, the AEG controller is a basic system which can be adapted to various robot systems in the wide field of the building industry.

2. ROBOTS AND TECHNOLOGY IN THE BUILDING INDUSTRY

A systematical analysis of the application of a robot control in the building industry leads to three different but important criteria:

- the machine,
- the technology or handling task and
- the operational environment.

To combine and fulfill the control aspects of these three criteria is the task for a flexible robot control.

Machines

Many machines with singular or coordinated motion axis are already introduced to the market. To offer new concepts and developments for complex handling systems is only possible with the help of more efficient control technics. The classification of a machine can be given by answering the following checklist:

- inhouse or outdoor application
- stationary or mobile system
- reach and workspace
- payload
- number of axis
- kinematic structure
  (degrees of freedom and number of redundant axis)
- stiffness or flexibility of the armstructure
- servo drives (electric or hydraulic system).

For example a mobile concrete pump is a standard machine. It has a reach from 20 - 65 m. The kinematic structure consists of up to six redundant rotational axis. The mechanical structure of the booms is very flexible. Because of the mobile system and the required power, servo-hydraulic drives are used /1/.

Technology and handling task

The robot system is a so called technology carrier for several applications such as

- material handling,
- painting,
- cleaning (sandblasting, rotational brushes, laitance cleaning),
- manufacturing (mounting, masonry tasking, cutting, drilling, etc.)
- inspection and automatic diagnosis,
- pumping i.e. wet concrete,
- carrying a working platform etc.

To make the controller not to complicated and cost intensive, special macros for a given technology have been developed and implemented to realize a robot system for the application specified /2,3/.

Operational environment

Especially for the building industry there is a wide range of different fields where robot systems will be involved to realize new technological solutions in the near future:

- building (inside or outside, house, factory, power plant),
- wall,
- street,
- bridge,
- tunnel,

- sewer and
- emergency and rescue missions.

A carefull analysis of the influence of temperature, humidity, vibrations etc. has to be carried out for all such operational environments.

3. FLEXIBLE ROBOT CONTROL

To realize a robot system for the above mentioned applications a robot control with high flexibility is needed. This means, that a standard robot control will have to be extended or adapted either in hardware components or by means of software modules.

The crucial components of a robot controller are

- hardware,
- man-machine-interface (MMI),
- interface to a cell controller,
- interfaces to drives and sensor systems, and
- control functions.

The most important aspects for these components related to the building industry are now explained in more details.

Hardware of a robot control

The hardware is configurated with standard components, this complies for all AEG robot controllers. Here a few examples:

- housing,
- power supply,
- central processor unit,
- servo control and sensor processing unit and
- interface boards (s. fig. 1).

An important aspect for the integration of the hardware into a machine, expecially for outdoor applications, is the right cabinet for the controller. It has to fulfill all the requirements for temperature range, humidity and compensating external vibrations etc. Also the size of the needed cabinet is not to be neglected for the installation i.e. in a truck or an excavator.

Man-machine-interface (MMI)

To set up a well excepted operating device in hardware and software is a big challenge. In the past robot control was introduced into the factory automation. The automation process there is characterised by well defined tasks. After programming the robots automatically repeat their task for a long working period with only few changes and virtually no interruption by an operator.

For most applications in the building industry the requirements are unfortunately the other way around. Several tasks are not well defined and the requirements given by the surrounding conditions often change rapidly. The priority to operate machines in the building industry is not to run the machine by a program but to manipulate it by the help of an intelligent controller. Therefore the control is not used to replace the operator but to support him in an efficient way and to ease the task. Nevertheless it is quite possible to set up programs for repeatable jobs.

To fulfill these constraints the MMI of the robot control consits of the following components:

- interface (hardware),
- processor- and display-unit,
- housing with keyset, emergency switches and joystick,

- basic operating software functions and data visualization,
- special operating menu and display functions.

The AEG teach panel has a display with 16 lines, each with 20 characters. This high performance is very helpfull to give all the actual and necessary information to the operator. In the building industry the operator is not used and not trained to handle computer controlled machines. Therefore especially the housing, keyset, switches and the special operating menu should only be specified together with the end user.

For the manipulation of the machine axis it is possible to use switches or a three dimensional joystick. The standard functionality of the joystick is to give a position demand to the single axes or the combined axis movement for a trajectory. To manipulate the movement i.e. of the booms of a concrete pump the displacement of the joystick is proportional to a required velocity. So the movement is under full control of the operator, because it stops immediately when the joystick is set back in the initial position.

The software of the system level of the AEG robot control covers all the main items of standard functions for operating and programming a machine. This includes the editing of programms. The user is supported by function keys and a user friendly menu technic. With the clear structure of the menu the operator is guided to the various functions

- commissioning of machine parameters,
- set up main- and subprogramms,
- set up PLC-programms,
- teaching of points and trajectories,
- testing programs,
- automatic mode and
- archiving.

In addition to these functions all important informations, data and failure messages are displayed. Important are the actual mode of the robot control, the coordinates in which the machine is running (joint, world or tool) and data of the actual position. Failure messages for example are informations about the servo control such as tracking error, errors in the position measurement or disturbances in the communication.

These basic functions have to be analysed and newly configurated for special applications, because it is not helpfull to give all the possibilities of manipulation to the operator. Parallel to the special hardware lay-out of the device the menu- and display-functions must be optimized for the application. This can be realized by the use of the basic operating functions of the robot control. An adapted operating level can be achieved with less software effort by a special masking of the standard menu. This masking software prepares the operating and display functions in a specified manner.

Interface to a cell controller and CIM-level

Every modern robot control must contain an interface to another computer which may be a PC, a PLC or a cell controller. For a PC the following software modules exist:

- archiving,
- offline programming and
- DNC-interface.

Archiving includes programs for trajectories and PLC-functions as well as machine parameters. It is also possible to connect a plotter to the controller via this interface.

The offline programming system enables the user to set up programs independed from an uncomfortable environment, the availability of the machine and without interuption of the production process. The software is based on window-technics. The several commands are chosen via a mouse, so that no errors can occur by editing programs. Many help functions with a detailed description are included to support the user in every system level of programming.

The software modules of the DNC-interface include the basic functions of a telegram handling for a communication with a cell controller. This is a necessary step to integrate the robot control into a factory automation on a CIM-level. For the many inhouse application also in the building industry the CIM integration is an important factor for future robot systems.

Control functions

The performance of a robot control is mainly given by the level of control functions. They are realized in the basic software of the system and servo level.

The standard control functions also describe the possibilities for the customer how to use a robot system (fig. 2):

- operation functions,
- program interpreter,
- motion planning,
- interpolation,
- logic unit, internal PLC,
- sensorsignal processing,
- servo control,
- diagnostic functions,
- handling of machine parameters and
- data-, program-, and interface-management.

With the well organized operation functions the user can handle a robot or a special machine like a manipulator. This means, that the movement and other functions of the machine are completly under the control of the operator. Nevertheless the operator is supported by the computer control, because of the running diagnostic functions and the actual data visualization. The operator can handle the machine in JOINT-, WORLD- and TOOL - coordinates in this mode and he is able to set or activate the several PLC-functions.

The programming language DOROB of the AEG robot control is a userfriendly tool to define the demanded task in a number of programs. After the start of a program the robot system runs in the automatic mode. It is possible to set up up to 100 main- and subprograms. A program may include all information for a trajectory and logic functions.

In addition to a simple point to point movement the powerfull interpolation procedure allows to realize a linear, circular or a parabolic path. The calculation of the motion planner assures that the several PLC- and sensor-functions are exactly activated at the demanded position. Via the diagnostic functions the operator is informed about the actual state of the machine. The data include the operating mode, actual program, position in the chosen coordinates, tracking error and informations concerning servo- and measurement-systems. With the help of these information an increase in safety of the machine operating can be achieved by a robot control.

To offer a flexible robot control means that it is possible to implement machine specific control functions such as (fig. 2):

- coordinate transformation,

- compensation of deformation,
- collision avoidance,
- macro functions for technology, and
- nonlinear control for servo-hydraulics.

The coordinate transformation algorithms enable the operator to manipulate a machine with up to 12 axis and a complex kinematic structure in WORLD- and TOOL - coordinates. This relieves the operator of a complicated handling of serveral joy sticks and he can concentrate on the handling task. To increase accuracy the robot control may include a software module for deformation compensation. With this function the static deformation caused by the elasticity of the arm is compensated. This is an important feature expecially for large machines with less stiffness of the machanical structure.

Important for passive safety of the whole system is the collision avoidance. The operator can progam a plane, i.e. a ceiling or a wall, or a solid as it is necessary for his specific environement of the handling task. During the operation the computer online controls the movement depending on these programmed obstacles. This function also ensures, that no collision between the several robot axis can occur, which is important especially for machines with a complex kinematic structure. Together with additional sensor information this module can be extended to an active operator guidance. For example to manipulate the arms of a concrete pump between two ceilings or several pillars this is a very helpfull support for the operator.

Most of the machines used in building industry are equipped with hydraulic drives. This drive concept can not be changed when the machine is extended to a real robot system. Therefore the control part has to ensure a optimized automatic control for those drives. In the AEG robot control an nonlinear servo control is implemented. This includes a closed positon loop with adaptive gains, a velocity and/or pressure feedback and several additional functions to react on the nonlinear behaviour of valves and drives.

As a so called technology carrier a robot system needs several specific functions for example for painting, sandblasting or pumping of concrete. Such functions are implemented in special macros in the AEG robot control. These macros are integrated in the overall system software. They can be handled by the user as a robot program. The parameters for such a macro can be set up with the operating device.

4. ROBOT CONTROL FOR THE BUILDING INDUSTRY - ACTUAL PROJECTS

With the above mentioned flexible robot control AEG is involved in serveral projects for the building industry. The most important projects are

- a computer controlled concrete pump,
- a robot system for renewing brick sewers and
- a large manipulator for handling tasks.

All these projects are preliminary discussed and finaly worked out together with several partners of industry and institutes.

Computer controlled concrete pump

The concrete pump is a mobile system with 5 rotational arms and hydraulic drives /1/. The arm structure is a redundant kinematic system and the transfer gears in the links between the arms are highly nonlinear. All these items are covered in the coordinate

transformation of the robot control to achieve a good and accurate behaviour for motion tasks. The arms of the machine are very flexible. This influence is compensated by an additional calculation of a deformation model which takes into account the specific construction and parameters of the machine. Optional the declivity of the truck at a construction site can be compensated with the robot control, using a special sensor input. Depending on the relative postion of the boom to the working site, for example a building in the real environment, an additional frame system can be teached. With this coordinate system the relative deviation between the programmed task and the given positions of the real task can be compensated automatically. Together with a procedure for collision avoidance other special control functions are implemented which increase the safety of the robot system and support the operator to fulfill his task of pumping concrete in a more efficient manner.

For the task of servo control absolute encoders were mounted at each link. On the servo- and sensor-board of the robot control a nonlinear automatic control for the servo-hydraulic drive system is implemented. It uses position and pressure feedback with adaptive gains. The gains are adapted depending on the variable parameters and states of each arm. Because of the nonlinearities of the hydraulic system and the large reach of the arms this is an important aspect for the dynamic behaviour of the machine.

To introduce a computer controlled concrete pump to the customer means a big challenge for a good man-machine-interface, because the operator is well trained to handle the conventional version. A special operating device with a wireless remote control was set up. This enables the operator to control the machine independant from the installation of the robot system. With the interface from the operating level of the system software to the software of the operating device an optimized version expecially for the technology of concrete pumps is realized.

Robot system for renewing of brick sewers

Today for nearly all cities it has become necessary to renew many kilometers of brick sewers. The reason is the corosion of the material in the joints between the bricks. So the joints have to be cleaned by milling and the sewer wall has to be pointed up again. Because this is a tedious, dangerous and therefore expensive job a new robot system was developed to achieve a remote controlled execution of this task.

The robot is a 5 axis system with a kinematic structure comparable to industrial robots. It includes a special stepping mechanism to move forward automatically /4/.

The system is equipped with the AEG robot control. The coordinate transformation includes functions for an optimal motion along the special geometric profile of the sewer. A sensor ball or a joy stick is used for manipulation tasks and to override programmed trajectories.

The remote control is realized by a special operating software and programming procedures on an external PC. The connection of the PC to the robot control is set up with the DNC-interface and the DNC-software function of the system level. As an example this project proves, that a flexible robot control can be integrated and adapted to a system with a new man-machine-interface and a new technological environment /4/.

Large manipulator for handling tasks

Together with other partners and companies AEG is involved in the ESPRIT II project 2280 called LAMA (LArge, MAnipulator). The manipulator has a redundant kinematic structure with 9 axis and 6 degress of freedom. The reach of this stationary machine is about 20 m. The hydraulic drive system consits of servo valves and hydraulic cylinders. The several work packages include research, development and testing of the mechanical part, the servo hydraulics, sensor systems, software and hardware of robot control. Taking into account recent developments in communication technics in this project the SERCOS interface is adapted to hydraulic drives. SERCOS is a serial bus with a fibre optic ring and a special communication software. This ring connects the decentralised intelligent drive systems of a machine to a central controller /5/. Such a large manipulator will handle heavy loads for a large reach in future applications.

5. SUMMARY

Handling systems, in particular robots, have profited from the technical progress made in the field of sensor and control systems in recent years. As a result automated manufacturing and assembly in the automotive field has become a standard. In many instances, physically strenuous, monotonous and dangerous jobs are today performed by flexible handling systems, such as industrial robots. They relieve the strain on human workers, increase productivity of the company and improve safety and reliability in the production cycle. In addition, they make an important contribution towards humanization of the working environment.

The mentioned projects prove that a flexible control is an important factor to set up robot systems with a given industrial machine as well as it is possible to open the way to complete new applications. Such a high demanding task i.e. is the cleaning of aeroplanes in the project SKYWASH with a flexible robot system /3/.

6. REFERENCES

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AEG

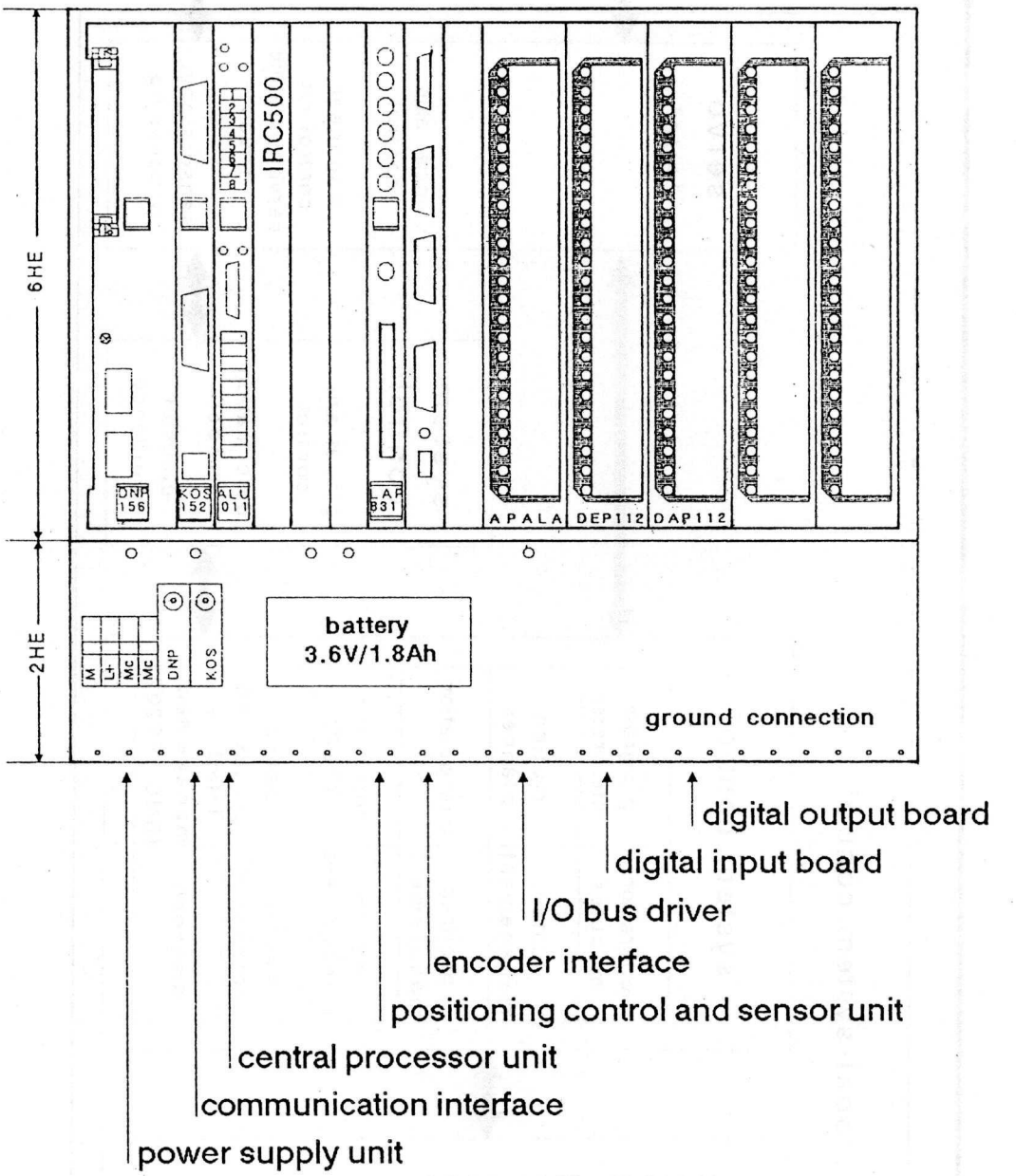

Figure 1: Overall design of AEG robot control hardware

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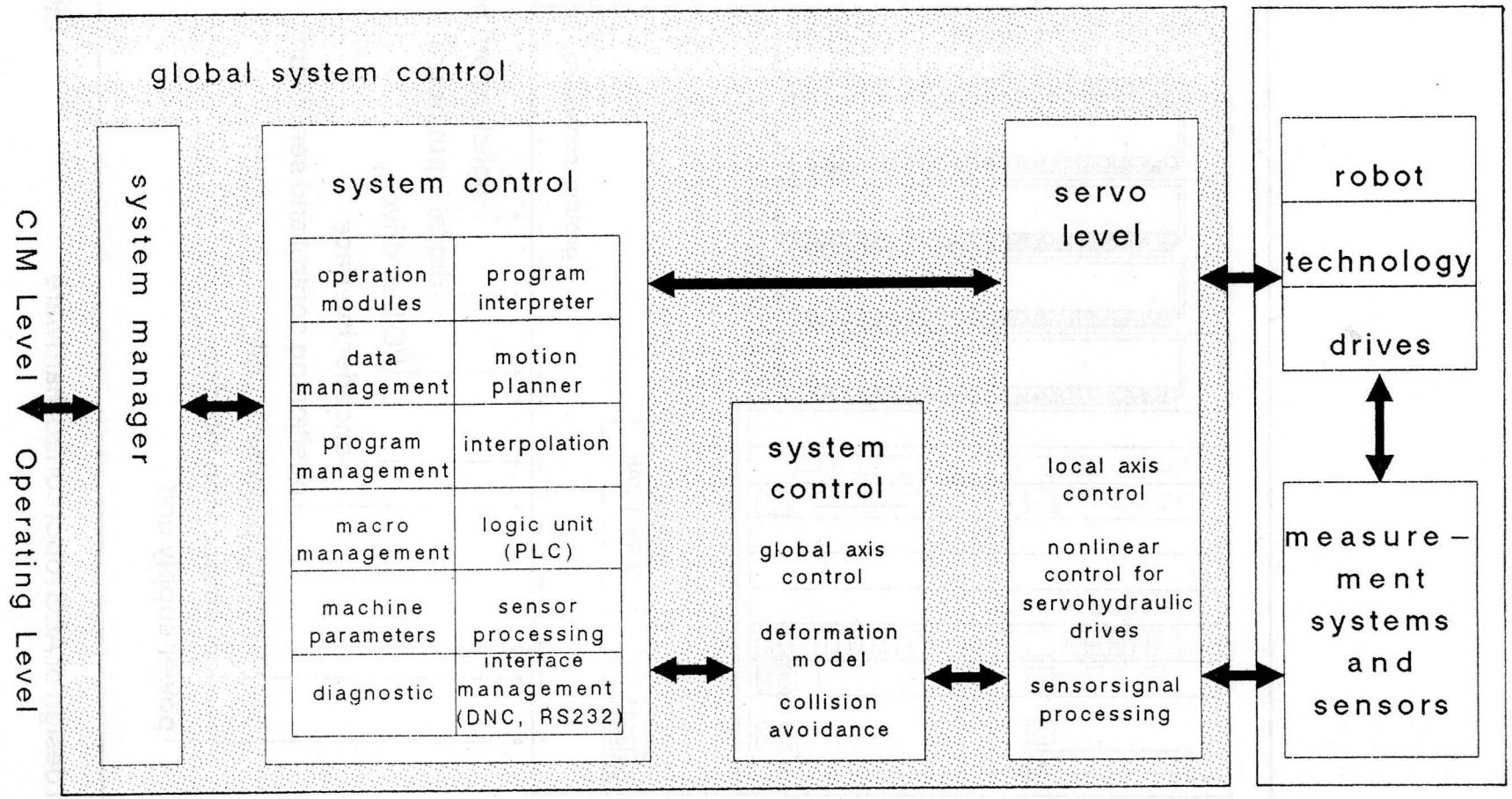

Figure 2: System software of AEG robot control

GeAmatics