Integration of Robots into CIM

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FOREWORD

From its inception in 1983, ESPRIT (the European Strategic Programme for Research and Development in Information Technology) has aimed at improving the competitiveness of European industry and providing it with the technology needed for the 1990s.

Esprit Project 623, on which most of the work presented in this book is based, was one of the key projects in the ESPRIT area, Computer Integrated Manufacturing (CIM). From its beginnings in 1985, it brought together a team of researchers from industry, research institutes and universities to explore and develop a critical stream of advanced manufacturing technology that would be timely and mature for industrial exploitation in a five year time frame. The synergy of cross border collaboration between technology users and vendors has led to results ranging from new and improved products to training courses given at universities.

The subject of Esprit Project 623 was the integration of robots into manufacturing environments. Robots are a vital element in flexible automation and can contribute substantially to manufacturing efficiency. The project had two main themes, off-line programming and robot system planning. Off-line programming enlarges the application area of robots and opens up new possibilities in domains such as laser cutting, and other hazardous operations. Reported benefits obtained from off-line programming include:

- significant cost reductions because re-programming eliminates robot down-time;
- faster production cycles, in some cases time-savings of up to 85% are reported;
- the optimal engineering of products with improved quality.

Moreover, off-line programming techniques protect the operator, who under conventional systems of on-line programming, is at a risk of injury from having to work in the physical proximity of the robot.

The integration of robots in manufacturing cells requires the integration of information concerning product design, plant availability and system layout. Project 623 has achieved this through the use of relational and knowledge databases which lead to large cost savings for vendors providing turnkey systems and users who need fast adaptation to production demands.

The project has been an excellent example of a multi-disciplinary approach, combining the knowhow of mechanical and manufacturing engineers and computer scientists to push forward the frontiers of knowledge in an application domain which is at the leading edge of the major European economies.

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Survey of the project

Chapter 1

Robots in CIM

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Information technology has initiated a structural change in manufacturing industry. Productivity, flexibility, quality, and reliability can now attain a level which could not be realized on the basis of conventional production structures. The very different technological requirements of products has led to increased product variety and shorter product life cycles. These alterations of the market situation demand automation of the highest flexibility and productivity. This can be reached by computer integrated, automated and flexible manufacturing, whereby information techniques take over a key function.

In production technology it was comprehended at a very early stage that computers are important components. Stages of these developments were the NC technique, CNC controls and the development of FMS with robots. In this context it can be stated that robots play an important role as the most flexible automation components. This is also documented by the growing number of robot applications as shown in Fig. 1.1. Specifically remarkable is thereby the big difference between the USA and Europe on the one hand and Japan on the other hand which shows impressively the development potential of the market.

The growth rate shown in Fig. 1.1 has been reached mainly by applying state-of-the-art automation techniques, i.e. without the consideration of the aspect 'robot as CIM component'. But this means that the immanent flexibility of robot systems has been used only to a marginal extent. To use effectively this basic feature, on the one hand powerful, computer-aided tools for planning, programming and simulation must be available. On the other hand, robot controllers must be much improved and enlarged with regard to functionality, open system aspects, user support, communication features and the integration of sensors.

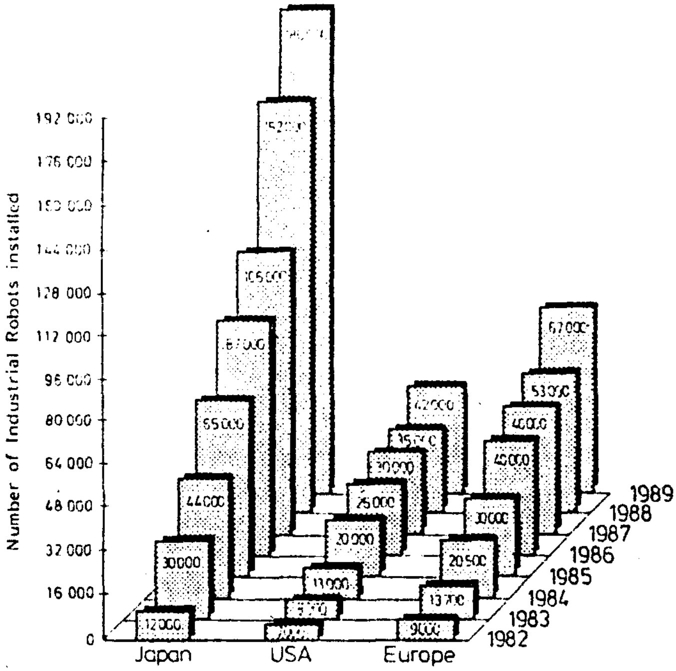

Fig. 1.1 International distribution of robots (IPA Stuttgart).

The first area mentioned above does not only mean that those tools are available to support planning engineers, but also includes that these tools are integrated into an information system which guarantees a continuous information flow from design to the shop floor. This is sometimes called 'information integration' and is probably the most important aspect covered by the term CIM.

The development of such computer-aided tools, their integration and the demonstration of the systems under realistic industrial conditions formed the main objectives of the European research and development project, entitled *Operational Control of Robot System Integration Into CIM*. It was was conducted in the frame of the ESPRIT programme. This book reports on the work done in the project. As can be concluded from the project title, a strong emphasis was put on the component robot. From a general automation point of view, robots are important but still only one among other CIM components which are required for advanced production systems. This means that for efficient automation planning engineers have to be supported by computer-aided tools for the whole of their tasks of planning, programming, testing, installing, operating and maintaining production systems. Furthermore, they must be enabled to re-plan an existing and running manufacturing system at any of the levels mentioned above. Concerning these topics, another R&D project has been launched in the meantime, also within the ESPRIT framework. The title of this project is CIM System Planning Toolbox (CIM-PLATO, ESPRIT Proj. No. 2202).

Both projects turned out to suffer very much from the fact that computer simulation models are not commercially available. This concerns e.g. models of robot controllers, kinematics, etc. To make those models available for the market, a step which substantially enlarges the product range of robot and/or controller manufacturers, strong efforts in the standardization area have to be undertaken. This also formed a work area in the project reported on here. Furthermore, another project has been launched (CIMDATA, ESPRIT) with the objective of realizing a database containing CIM components. The overall idea behind it is to provide planning engineers with all the necessary computer simulation models on the various planning levels which they need to fulfil their entire production system planning task.

Finally it may be mentioned that robots play an important role for automation, but in order to become a real CIM component, they still have to be improved. During the last years, many efforts have been undertaken for the realization of tools to support the planning of robotized systems. This work has to be taken further and enlarged with regard to items such as automated, optimal and intelligent planning functions and procedures.

But for the system robot itself, a lot of R&D work has to be done, too, especially for the development of advanced robot controllers according to the previously mentioned topics which may be summarized under the term 'open system architecture'.

The availability of powerful computer-aided tools which are integrated in a CIM environment ease the task of planning and programming robotized systems. These integrated tools represent advanced automation techniques. But on the other hand the 'real' components such as robot controllers have to be on the same advanced level. Only when this is reached, the system robot will be a true CIM component. The integration of robots into CIM systems as the subject of this book, is based on the R&D work done in the ESPRIT project No. 623. In this first section, the objectives, approaches and benefits gained within this project are described, the project partners are presented, and the overall structure of the book is explained.

Chapter 2

Objectives, approaches and main benefits

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2.1 Introduction

Robots are important components for flexible automation. The enlargement of their application as well as their integration into a CIM environment requires the availability of computer aided means for planning and programming of robotized manufacturing systems. To develop these means, an R&D project in the frame of the European Strategic Program of Research and Development in Information Technology (ESPRIT) was started in 1985 [1,2]. This project entitled

> 'Operational Control for Robot System Integration into CIM, Systems Planning, Implicit and Explicit Programming'

was finished in 1990. Its general goal was to implement industrial prototypes which demonstrate the integration of robot systems into a CIM environment [3]. The critical path of this integration concerns the operational level of CIM, and includes two closely interrelated fields of R&D: the implementation of a computer aided planning system for robotized work cells and of an off-line programming system for robots (Figure 2.1). Both fields were identified and analyzed in detail in the frame of the ESPRIT project 75:

'Design Rules for the Integration of Industrial Robots into CIM Systems'
in which also the main objectives of the project described in this book were determined.

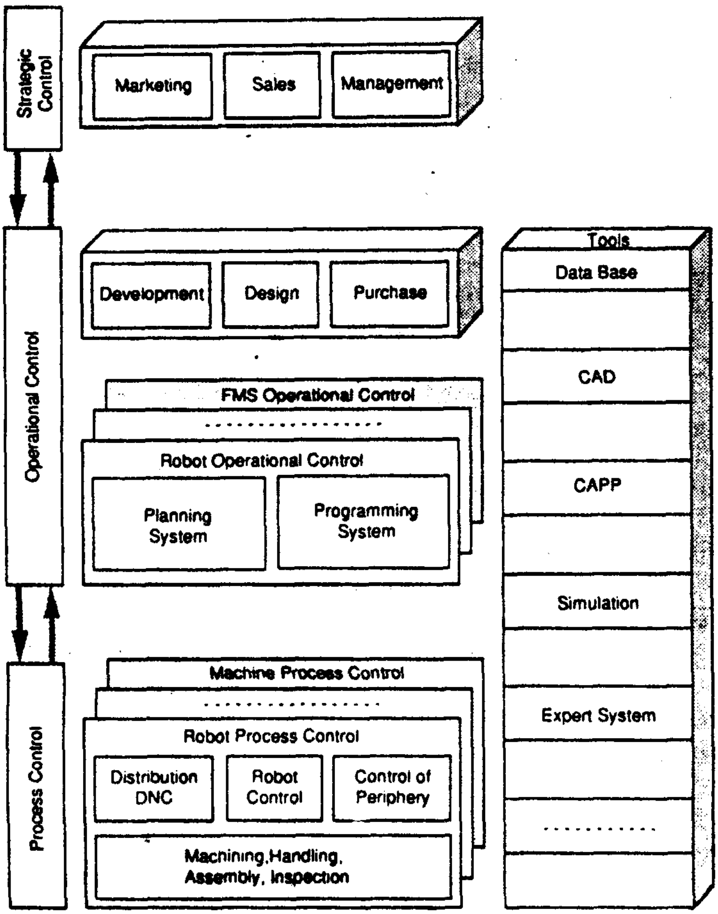

Fig. 2.1 Project reference model.

Based on this reference model, the project objectives are outlined in more detail in the subsequent paragraphs.

2.2 Objectives and approaches

Based on the general goal to implement computer aided planning and off-line programming systems, more detailed objectives were identified.

Planning was understood to be an integrated procedure starting with general project information, requirements list, and work piece data and resulting in optimized layout data of a robotized work cell as well as a formalized description of the task to be executed within this work cell. To explain this in more detail the case of planning robotized assembly cells has been chosen.

The integrated procedure starts with the generation of an assembly sequence plan which includes operation sequence planning, precedence analysis, preselection of robots which are suitable for the different assembly steps and selection of available feeders and grippers. Based on the assembly sequence and the suggested devices, components are selected and roughly arranged. In an interactive and iterative procedure this layout is improved and verified using supporting tools (e.g. for cycle time estimation and material flow simulation). In the next step the generated planning data are transformed into a structure suitable for the off-line programming procedure. In addition to the layout description, the assembly sequence is described by a semiformal representation containing also geometrical, technological and control specific data. The planning phase is completed with a layout optimization procedure considering type variants and locations of robots, tools and peripheral devices, and their influence on important parameters ranging from cycle times to the total cost of the work cell.

The general objective for the development of a planning system was the realization of computer-aided tools to support the procedure explained above. In this context, off-line programming means the detailed planning of the tasks to be executed by the robot(s) before the real work cell is built on the shop floor. (Sometimes in literature the term *execution planning* is used instead of *programming*). This includes the planning of the geometrical path, the determination of motion and technology parameters, the control of interactions with peripherals and the generation of the robot program code (application program). The correctness and executability of the generated application programs have to be tested before they can be transferred to the real robot. Therefore, a process execution simulation has to be an integral part of the programming system.

For this purpose, models and algorithms have to be available which are computer internal representations describing all work cell components with regard to their motion behavior (control models), kinematics, and shapes. In addition to these basic functions of an off-line programming system for robots, three more objectives were identified: trajectory optimization with an eye on cost criteria, minimal stress of joints and/or minimal cycle time, and handling of exceptional cases occurring in the work cell by *a priori* planned procedures.

As far as the concrete work in the project was concerned, it was decided to follow two different approaches for the implementation of off-line programming systems.

The first approach was aimed at realizing an implicit programming system which allows the determination of the robot's task by a task level instead of a robot level specification. Hence the task is described as a sequence of changes in a model of the environment. An action is characterized by its desired effects on objects of the model rather than by its specified motions in order to achieve a task The system then plans these actions and generates a robot level representation of the task [4, 5].

The second approach concerned the development of an explicit programming system based on an interactive procedure. This means that all the necessary actions have to be specified explicitly by the user. A verification of each step in this interactive procedure is enabled by the simulation and test system through visualization capabilities. This allows, for example, a robot independent test of correct task sequences or the visualization of the robots in motion in the production environment [6]. Again, the output of this system is a robot level representation of the task.

One important goal of the project was to specify the task representation at the robot level described above, independent of a specific robot language. This data structure is called *explicit solution representation (ESR)* and contains, at the end of the programming procedure (either explicit or implicit), all necessary information to generate an application program for a specific robot controller.

A further objective was to allow the exchange of modules developed either for the implicit or for the explicit programming system. As a result, robot code generators realized in the explicit area can be used within the implicit system. Another example is the use of implicit modules for trajectory optimization which upgrade the functionality of the explicit programming system. This could be achieved by modular system structures and clearly specified interfaces. In this sense, both approaches are aimed in the same direction. The first one is a top-down approach starting with a specification of the entire implicit off-line programming system in general. However, the realization is adapted and limited to what is practicable today. In this respect it is a more research oriented approach. The second approach is characterized by the practical constraints put forth by industry. It takes into account the limitations during the specifications of modules, but also can interface with the integration of implicit functions. Thus this bottom-up approach in the end will also lead to an implicit programming system by upgrading the explicit programming system through the replacement of interactive functions by automatic ones.

To reach the objective of realizing a flexible system structure which facilitates quick adaption of the system to user needs, a specific working group 'information integration' was installed. These aspects were studied in great detail especially in the second half of the project.

As a summary of the objectives of the first half of the project, the following prototypes were planned:

- a planning system for robotized work cells;
- an explicit or motion oriented programming and simulation system;
- an implicit or task oriented programming system.

Work in the three areas proceeded simultaneously. In all cases, definition and specification of software modules was followed by their realization and application/demonstration in real or simulated industrial environments.

The objective for the second half of the project was the creation of industrial and research prototypes of an integrated planning and programming system for robotized cells. This encompassed on the one hand, the integration of the subsystems mentioned above and on the other hand, the integration of the whole system into a CIM environment.

The first aspect concerns mainly the detailed definition of information interfaces between the planning and the programming system. In Figure 2.2, the main information interfaces of the different subsystems are shown by using the form of an ISAC diagram, in which a block 'translation, robot interface' is added since it was also an objective of the project to generate executable application programs and to transfer them to the real robot.

For simplification, all information needed for the activities characterized by rectangular blocks are marked as 'auxiliary information'. This is not explained in detail, as the diagram should only stress the information interfaces between subsystems. The most important information produced by the planning system are the formal descriptions of the workcell layout and the production task to be executed. By using this information, an explicit solution representation can be produced. The ESR is a system-internal information representation which contains at the end of the programming procedure (either explicit or implicit) all information required for the automatic generation of application programs for robots. Before these programs are transferred to the real robot, they are tested by a simulation system which is an integral part of the programming system. To what extent the generated application programs can be executed in the real work cell depends on the work cell information available during planning and programming. This concerns the absolute positioning accuracy of the robot itself but also the other components and their arrangement in the work cell.