Robotic Tools and Experiences in Manufacturing Systems

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Abstract: The goal of this contribution is to present the main research lines concerning CIM Systems in the group of Robotic Systems & Robot Programming of the Department of System Engineering, Computers and Control (DISCA), at the Polytechnical University of Valencia (UPV). Our institution has been working for some years on developing and applying several techniques in order to solve common and concrete problems related with CIM environments. These research works are dedicated to five main areas: 1) Robot Control, 2) Auto Guided Vehicles (AGV) & Automatic Transport, 3) Path Planning, 4) Sensing & Artificial Vision and 5) Robotic Systems & Robot Programming, which is the scope of this paper.
Within this area, our Department has been involved in several projects, allowing to improve our know-how about this field by applying techniques that solve robot control problems in robot systems, path planning and control for automated transports, in particular for AGVs; integrate artificial vision systems into CIM environments or model, program and simulate robotic systems.
Robotic Systems & Robot Programming group has a special interest in CIM systems. Given this interest, several tools have been developed in both educational and research fields. The aim of this paper is to explain these results.

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1. Introduction

Developing manufacturing systems, and in general CIM systems, is one of the most important research topics of interest in the *Automation* field. In this area, *robotics* is playing an important role.

Our institution, Department of System Engineering, Computers and Control (DISCA) at the Polytechnical University of Valencia, Spain, has a special interest in this field and, in terms of *manufacturing systems*, this interest is primarily in the integration, programming, control, simulation and management of robot arms and auto-guided-vehicles. Five research groups: *Robot Control*, *Auto-Guided-Vehicles (AGV) & Automatic Transport*, *Path Planning*, *Sensing & Artificial Vision* and *Robotic Systems & Robot Programming*, can be identified.

In this sense, DISCA has been involved in different national and international projects. In these projects, several aspects related to CIM systems have been considered: solving robot control strategies by means of parallel algorithms or using techniques like dynamic or multirate control (Robot Control), developing teleoperation and monitoring techniques for AGVs and testing different software architectures (Auto-Guided-

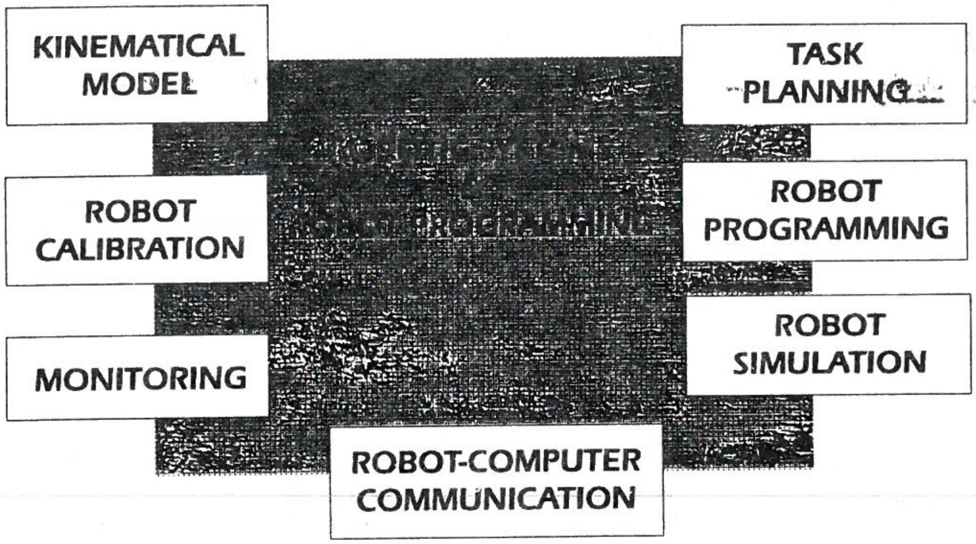

Figure 1. Research areas of interest for the Robotic Systems & Robot Programming group.

Vehicles & Automatic Transport), implementing collision detection and avoidance procedures for both robot arms and AGVs in order to get automatic trajectory generation (Path Planning), and performing automatic visual inspection and pattern recognition through vision systems together with robotic systems (Sensing & Artificial Vision).

The aim of this contribution is to explain in detail some developments carried out by the Robotic Systems & Robot Programming group.

2. Robotic Systems & Robot Programming Group

The *Robotic Systems & Robot Programming* group is one of the groups of our department. Kinematical modelling, robot calibration, monitoring, task planning, robot programming, robot simulation and robot-computer communication are the main aspects to be considered by this group. In these areas, many people have been working on topics related to CIM systems, taking part in different national and international projects, carrying out Ph.D Theses on concrete aspects and developing educational tools in order to introduce the students to this field.

Figure 1 summarizes different areas which this group is involved in.
This group has developed several tools in order to cover aspects related with robotics in general, and to solve current problems met with in CIM environments, in particular. The aim of these tools is to serve as educational platforms to initiate students in the basic concepts of robotics, and to improve our knowledge in this matter.

In order to cover educational aspects, 3 aspects are being considered:

a) Industrial Robotic Systems Modelling and Simulation

Mathematical aspects of spatial relationships using homogeneous transformations are dealt with. These concepts allow for modelling a robotic system or for solving direct and inverse kinematical problems by means of Denavit-Hartenberg technique [1].

b) Introduction to An Industrial Robotic System

The management of an industrial robotic system is referred here. Deep knowledge of typical options available in the Programming Unit of an Industrial Robot is one of the goals. Also, parameters and possibilities involved in the

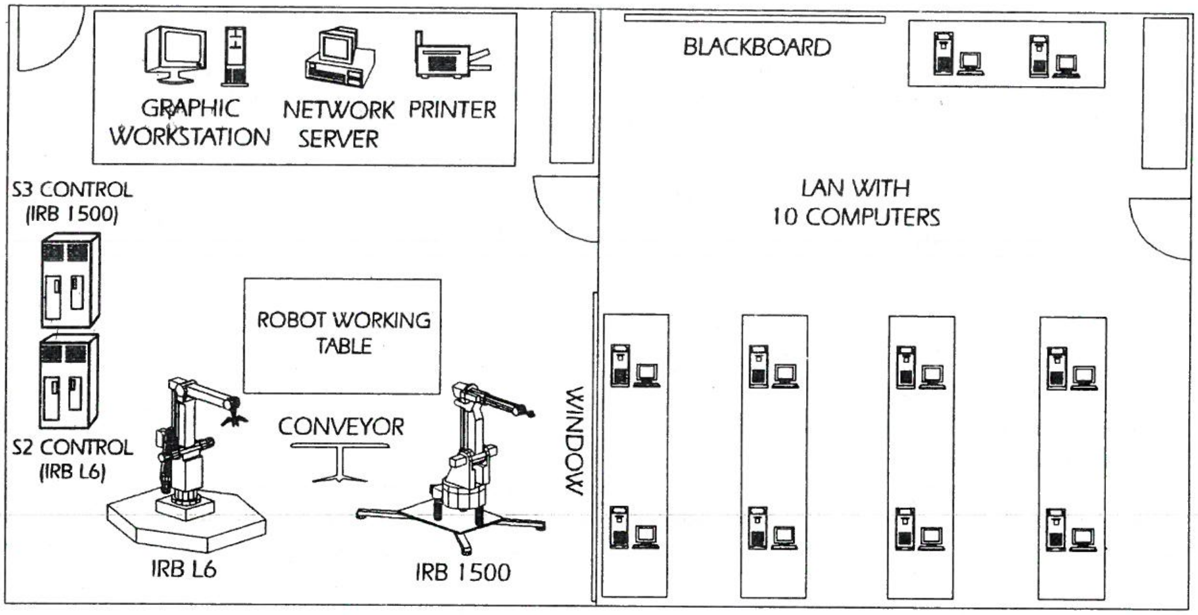

Figure 2. Robotic Systems & Robot Programming Laboratory Layout

movement of a robot-arm are relevant topics to be included here.

c) Industrial Robot Programming

Several aspects must be examined if one wants to know different existing techniques in robot programming: i) industrial robot programming by means of robot oriented textual languages, ii) robot programming by means of a general- purpose language, iii) robot programming using CAD tools, and iv) robot programming starting from a CAD defined trajectory to be followed by the end-effector of the robot.

Related to research advances, our interest is actually focussed on different aspects. Considering standard communication protocols, like ISO Manufacturing Message Specification (MMS) for robots, in order to send programmed actions for a robot in a network by means of a computer server, and improve this integration for using this standard with AGVs, is one of the goals in robot-computer communication area. Automatic robot programming is the main aspect to be considered in task planning, robot programming and simulation areas, using emerging standard languages, intermediate codes and user interfaces in order to translate a geometrical trajectory defined in a CAD environment into real robot actions in a CAM environment. Minimizing the difference between programmed poses for a robot arm or an AGV and reached poses is the most important objective to ponder on in kinematical modelling and robot calibration areas.

These research activities are being developed mainly at *Robotic Systems & Robot Programming Laboratory*, which is equipped with:

- Five axes industrial robot-arm ABB IRB L6 with control system S2.
- Six axes industrial robot-arm ABB IRB 1500 with control system S3E.
- Two fix positions CCD camera vision system ABB IVR 2600.
- A reduced size CCD Pulnix camera in the wrist of ABB IRB L6 robot connected to a PC board.
- An ultrasonic distance sensor in the wrist of ABB IRB L6 robot connected to an A/D PC board.
- A presence detection sensor in the wrist of ABB IRB L6 robot connected to S2 control system.
- Five axes educational robot-arm CRSPLUS A255 with C500 transputer based controller.
- Several storage and transport devices such as conveyors.
- A local-area network with 10 PC-486 and a high graphic performance Pentium.
- Several robot control software explained below.

Figure 2 shows the layout of this laboratory.
Other laboratories used as complementary laboratories and contributing to developing our educational and research activities include *Robot Control and Computer Vision Laboratory*, analysing aspects related with control strategies and vision systems, and *Flexible Manufacturing System Laboratory*, shared with another department and dedicated to educational and research activities in a CIM environment. This laboratory has an AGV (a Robuter-II Mobile vehicle with pallets exchanger and CCD camera) used to test all the characteristics of manufacturing systems.

Next section dwells upon several research aspects and tools.

3. Research Aspects and Tools

Several robot control software packages have been developed, some based on commercial CAD systems and most of them developed in C++ for *Windows* (Borland C++ and/or Visual C++). In [2], these tools are explained in deep for educational purpose. Special interest is taken in topics such as environment integration with vision systems and friendly interfaces development for robot programming. All software has been applied to the ABB robots available in the Laboratory, but it is now adapted for CRSPLUS robots within an industrial co-operation project.

In dealing with *robot* programming and simulation, usually, the first step is to kinematically model the robot arm as well as the whole flexible cell. For this purpose, a specific package for *Windows* environment, called *SIMCEF*, has been developed, which allows that any kind of a robotic system is modelled with dynamic simulation of movements. The system solves automatically the direct and inverse kinematics of any kind of robot. *SIMCEF* has been used for a robotic system selection, simulation and implantation study for FORD company.

The application called *WINARLA* [3 ,[4 consists in an educational system for *Windows* environment which graphically emulates the interface of the Control System S2 and S3 and its Programming Unit for the ABB robotic system.Thus, programmers can use this system on a PC in the same way as the real control system. *WINARLA* has its own robot graphic simulator so that the user can move the robot with a joystick-like interface and see the effects on the screen.

According to this line, another educational tool, INTARLA, has been developed. This tool allows students to introduce an ARLA program for the ABB IRB robots available with the department, to check the syntax of the program and then to simulate programmed actions in a window on the screen. This is a good tool to introduce students to a robot programming language and to do different practices in the field of robot programming, before executing programs on the real robot.

RCAD [4, [5 is a graphic and interactive robot programming system developed for a well-known commercial CAD software, *AutoCAD v12* for *Windows*, that lets the user simulate complete robot work previous to its execution on the real robot. Graphical programming of the robot on a computer spares programmer's time in learning a language syntax, because robot actions are selected by options in menus with a mouse and data required are input through keyboard. This programming tool admits a library with several robot models (previously designed on the CAD system or imported from *SIMCEF*) to be managed. Once selected the robot to be programmed, its model appears on the screen, as well as the menus suitable to the robot type. To program the active robot model, inverse and direct kinematic problem resolution is applied, displaying the movement of the robot on the screen, with simulation and verification of every configuration. The system can be used in two ways: i) step-by-step, by programming movements of the robot, or ii) saving a sequence of movements and actions to form a trajectory or complete robot task, with the possibility of later runnings. The basic function of the former is to check validity of configurations, while the objective of the latter is robot program generation. A program generated by this tool can also be executed on the real robot.

SIPRAC [4 is an application developed for *Windows* environment whose main interface window allows the operator to define a tool trajectory for the robot from *AutoCAD v12* for *Windows* and to feed back programs and data from the robot system to the computer. The system also allows to define and modify a neutral format robot program as well as to send it to the robot system. Finally, there are included six buttons for calling all the other software within this one, so getting an integrated system. The integration of all software applications is reached by means of a neutral format file for robot programs. Every other application will have the same output format to allow its compatibility. This format includes first an initializing head and then different movements and other kinds of action orders which will be executed by the robot.

The tool trajectory generation included in this application is made with the aid of a CAD software. The operator will draw the tool trajectory with all the facilities that this CAD software has, such as lines, polylines, circular arcs, circles, ellipses, Bezier curves,..., saving a trajectory as a DXF file. This file is interpreted and digitalized in such a way that complex curves are converted into a set of polylines according to an accuracy parameter. For each polyline, movement parameters should be chosen, such as speed, kind of movement (free, straight lines,...), accuracy parameters, and so on. An important question here is to define the tool orientation which is not included in the drawing obtained in the DXF file. Also at the end of each movement, the operator can specify different actions such as gripper actions, wait some time, wait until an input digital signal is activated/disactivated or activate/disactivate an output digital signal.

Another robotic application under development is a pattern recognizer according to sensor information which allows to generate the robot program from a pattern and store this program in the neutral format robot program (explained above) in order to repeat execution. This application is important in activities where a robot must go over a surface on which an operator has marked a trajectory to follow. Examples are arc welding, glue processes and so on.

In this respect, it is possible to use the sensor information that comes from the vision camera, the distance sensor and mainly the presence detection sensor. With this sensor information, parts of an assembly can also be recognized in such a way that a robot programmer can give high order commands to a robot, such as *pick this part and place it on the other one*. This is the aim of another project now in progress at our department, that includes a graphic *Windows* based interface.

Communication between PC and robot is an important part of all the software explained above, in such a way that actions on the computer are followed by robot actions. In this way a PC-Robot communication library developed for *Windows* and based on ABB Robot Computer Link Protocol, *CTOOLWIN*, is used in all the software. To allow each PC on the local-area network to communicate with one of the robots, a robotic system manager, *ASIROB*, has been developed for both sharing the robots to the PCs including waiting queue treatment and monitoring the robotic system state (moving, stop, in process,...) at any moment with a visual interface.

The use of an international standard in communication is very interesting in order to establish a correct and efficient robot-computer link. In this line, an on-going project involves robot communication from a computer using the ISO/DIS 9506, MMS Companion Standard for Robots. The idea is to provide an environment that allows us to make a computer communicate with a robot, while executing robot programs and reading the state of the robot each moment by means of a computer server in a network. This computer server has defined a virtual robot that receives the actions to be executed by the robot in the above mentioned standard, and translates these actions to the corresponding robot.

Our future interest in robot programming focusses on robot languages standardization using IRL (Industrial Robot Languages) as a high-level language, and ICR (Intermediate Code for Robots) as a lower-level code. For this purpose, after the study stay of a member of the research staff at the Institute for Systems Engineering and Informatics at Joint Research Centre in Ispra (Italy) in 1994, several translators from languages such as ARLA or VAL-II to ICR are being developed. Included in this point, improving IRL so as to consider task and object oriented properties, is one of our goals. The design and development of man-machine interfaces for monitoring and calibration, including a wide range of sensor information is also a current topic of research. A Ph.D thesis is being prepared on these topics.

Last but not least, another interesting field to consider is that of security problems with CIM systems, and with robotic systems (both robot arms and AGVs) in particular. In this respect, there is a network proposal about "Training and Mobility of Researchers" with several European institutions, which is called ENSuRE IT (European Network on Safety and Risk Evaluation for Information Technology). Concerning this network, our department is going to propose and develop different techniques for getting safety software to run with robotic systems. This fact is very important mainly in telerobotic environments and, in general, in off-line programming.

For all these research areas related to robotic systems and robot programming, several co-operations within European projects have been carried out. Consequently, a member of our department was in Hungary last year, to participate in a workshop in the frame of a TEMPUS project, and several foreign ERASMUS students were hosted to carry out final works in order to obtain their degree.

4. Conclusions

Integration in Manufacturing Systems is one of the most important research areas at DISCA, and specifically at the Robotic Systems & Robot Programming Group. In this paper research lines have been presented as grouped in 7 areas, referring different aspects involved in this field. Collaboration of academic members and departments is an important aspect to improve Research & Development in our institution, the Polytechnical University of Valencia. In this sense, our institution encourages its members in establishing links with other entities both in the country and abroad.

Due to this, several national and international projects have been carried out on all these research lines, and some of them are under way, allowing that contacts with national and international institutions are established. Another interesting result is the fact that several members of our department spent research stays at centres outside the country. These research stays make us keep developing research works, and in some cases, get the Ph.D degree for members of our department. On the other hand, during the last years, several foreign researchers came to collaborate with our department.

Nowadays, our group is open to establishing more contacts with institutions interested in CIM systems or even in concrete aspects of automation such as control techniques applied to CIM systems, developments in artificial vision or robotic systems.

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