# An Example of Engineering Research Center Programs: Design and Implementation of a FMS/CIM Test-bed

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**Abstract**

*A FMS/CIM test-bed, which is called the 'ERC-ACI FMS/CIM Center,' has been designed and implemented at the Engineering Research Center for Advanced Control and Instrumentation (abbreviated as ERC-ACI) at Seoul National University in Seoul, Korea. This paper presents the ERC-ACI FMS/CIM Center, which consists of an FMS model plant and a CIM computer room. Designing and implementing the FMS/CIM Center involved first, integrating major manufacturing processes such as machining, assembly and inspection, second, maintaining extreme flexibility to automatically accommodate any product mix, and finally, solving out the problems which occur during integration of the various automation machines and computing resources from different vendors.*

## 1. Introduction

The model site for Flexible Manufacturing System (FMS) and/or Computer Integrated Manufacturing (CIM) serves as an experimental test-bed for innovative research in manufacturing automation, as well as a reference model and continuing education center for industry. A number of model sites for FMS and/or CIM have been implemented in many universities and research centers, including the CIM system of UMIST [1], the manufacturing cell for gear blanking built at Auburn Univ. [2], the IBM demo centers at Moraine Valley College, Chattanooga State College, and other colleges [3], the Laboratory for CIM at the Pennsylvania State Univ. [4], a flexible manufacturing cell at the Cranfield Institute of Technology [5], *etc.*

However, there are very few full-scaled sites which are designed with both of machining and assembly cells integrated together. Such an FMS/CIM Center has been implemented at the ERC-ACI at Seoul National University in Seoul, Korea. Manufacturing processes such as machining, assembly and inspection are integrated in the FMS model plant of the Center. Also, this FMS plant is linked to a remote CIM computer room for general CIM realization.

The objectives of the ERC-ACI FMS/CIM Center are, first, to develop system integration technologies for the manufacturing cells, the FMS plant and the CIM system, second, to build a test-bed for domestic and international cooperative study, and finally, to transfer automation and systems engineering technologies to the industry through periodic continuing education programs and system engineering consultation.

The project was launched at ERC-ACI in late 1990 when the Phase 1 proposal was accepted by the Ministry of Commerce and Energy Resources (MCER), the Republic of Korea. Phase 1 was to install an integrated FMS model plant by Nov. 1991. Phase 2, which has been completed by Nov. 1992, extended the FMS plant into one of the CIM systems. Phase 2 started in Aug. 1991 with financial support from the MCER and seven industrial companies, including IBM Korea Inc.. Phase 3 then followed Phase 2 and ended in Nov. 1993. Phase 3 enhanced the FMS control structure and embedded a degree of intelligence into the cell levels.

An integrated and multi-departmental team was organized for the project (see Table 1). The team is composed of 11 faculty members, 2 research associates and about 35 graduate students from the Departments of Control and Instrumentation (CE), of Mechanical Design and Production (MD), and of Industrial Engineering (IE).

This paper introduces the FMS/CIM Center implemented so far in the ERC-ACI building. It might be a good example of the interdisciplinary ERC programs. In section 2, the overview of ERC-ACI FMS/CIM Center is briefly introduced. Section 3 presents the integration technologies at the automation cell level.



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**Fig.1. General view of the FMS model plant.**

**Fig.2. General view of the CIM computer room.**

**Table 1. Project team organization.**

| Assigned Job | Faculty (Dept.) | Assigned Job | Faculty (Dept.) |
|---|---|---|---|
| Project Manager | Myoung-Sam Ko (CE) | Machining Cell | Jongwon Kim (MD) |
| Assembly Cell | Bum-Hee Lee (CE) | Inspection Cell | Sang-Wook Lee (CE) |
| AGV System | Kyo-Il Lee (MD) | LAN & AS/RS | Wook-Hyun Kwon (CE) |
| Mobile Robot | Jang-Gyu Lee (CE) | CAD/CAM | Kunwoo Lee (MD) |
| Plant Control | Kyo-Il Lee (MD) | Prod. Planning | Suk-Ho Kang (IE) |
| Database | Sang-Gyun Cha (CE) | Plant Scheduling | Jinwoo Park (IE) |

The FMS/CIM control system is then introduced in section 4. This is the upper layer of the Center. Section 5 describes the current use of the FMS/CIM Center both in educational and research areas. Finally, a short conclusion is drawn in section 6.

## 2. Overview of ERC-ACI FMS/CIM center

Laid out in a 600 $m^2$ area, the FMS model plant is comprised of a machining cell, an assembly cell, an inspection system, an AGV system, an AS/RS, an autonomous mobile robot, two set-up stations and a plant control room (see Fig.1). As a first sample product, three sizes of motor-like units with outer diameters of 50, 65 and 72 mm have been selected. Three sizes of circular end caps and rectangular shaft caps are machined automatically even with an extreme lot-size of one in a random order. In the assembly cell, bearing insertion, rotor assembly into the case unit and bolt fastening are executed. Any product mix is possible.

All the parts are loaded to fixtures at one of two set-up stations. Fixtures are mounted on the pallets. The fixtures for the machining center are fixed on the thick pallets; the others, on the slim pallets. The fixture/pallet assemblies are stored in an AS/RS system. The AGV can accommodate both types of pallets and transport each pallet to the appropriate station. A total of 13 stations is distributed in the plant.

The entire FMS model plant is controlled by a distributed control scheme developed at ERC-ACI. The host computer system installed in the FMS plant control room and each of cell controllers assigned to a machining cell, an assembly cell, an inspection system, set-up stations, an AGV system, and an AS/RS have their own distributed scheduling agents. These scheduling agents are run on a bidding algorithm to result in the dynamic scheduling environment. A backbone local area network (LAN) enables data communication between the host and cell controllers.

The FMS control system is also fully linked to the remote computing resources of the CIM computer room (see Fig.2). This link ensures FMS operation as an integral process within the scheme of CIM system rather than as an island of automation. In the CIM computer room, a production information management system and CAD/CAM facilities are implemented.

## 3. Implementation of automation cells

Figure 3 shows the detail layout drawing of the FMS model plant. The entire plant has been integrated by ERC-ACI members from automation cell levels to FMS plant control level. First, the integration tech-

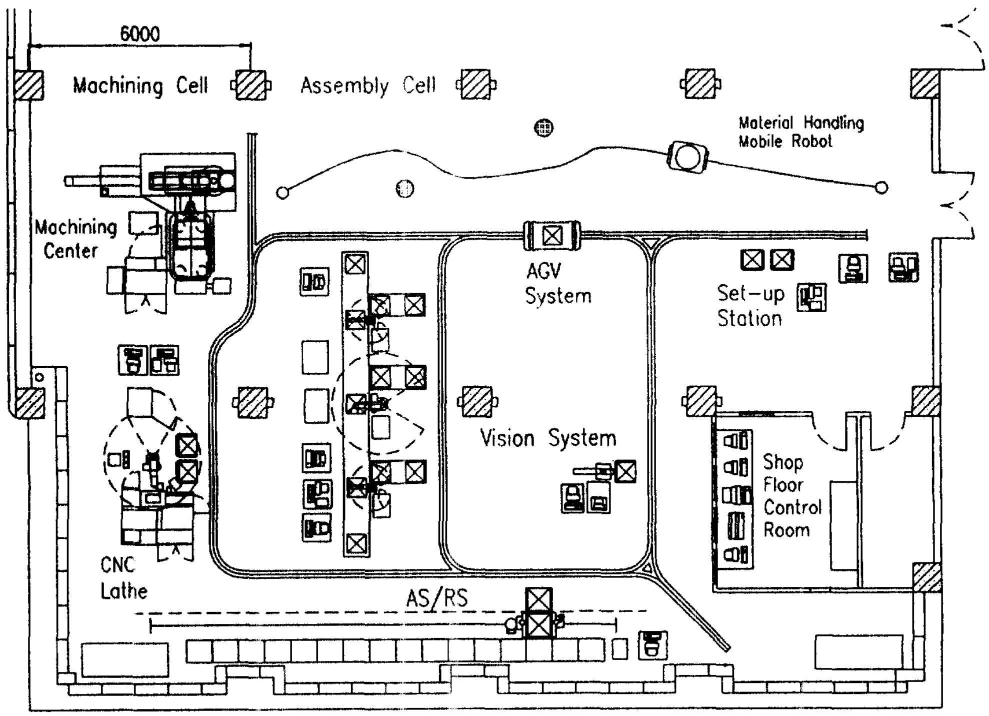


**Fig.3. Layout drawing of the FMS model plant.**

nologies of each cell developed so far are described as follows.

### 3.1 Machining cell

The machining center MCH-10 of the machining cell has been supplied by Seil Heavy Ind.. It is a three-axis, index table, CNC machine tool with an automatic tool changer. It has also an automatic pallet changer (APC) by which each of five thick pallets (size 500 x 500 mm) can be loaded into or unloaded from the machine. The original design of the APC has been changed based on the required specification of ERC-ACI to realize the automatic load/unload function between the machine and the AGV. A pneumatic clamping device is attached to the APC for accurate positioning of the load/unload unit of the AGV within 1 mm. As a CNC system, FANUC 15M has been adopted, and the DNC1 protocol is used for the communication with the machining cell controller.

The CNC lathe PUMA-6J with a CNC system FANUC 0T is combined with a six-axis articulated robot ACRMATE with a control system FANUC R-G2. Daewoo Heavy Ind. manufactures both machines. Since six different parts are machined in the CNC lathe, the robot does the automatic gripper change by selecting one of three gripper units on the gripper stand. The function of automatic soft-jaw change is also very important for ensuring flexibility. In this case, the robot exchanges the set of three soft-jaws of the chucking unit in the CNC lathe with one of those on the soft-jaw stand. Currently six different sets can be changed automatically.

The cell controller is composed of an IBM PC/386 compatible and a FANUC F-D Mate. Both computers are run on the UNIX O/S for multi-tasking operation. Operating software modules developed for machining cell control are divided into three blocks : bidder/manager, command_dispatcher, and status_report modules. The bidder/manager module is installed in the PC/386, and the others in the F-D mate. A local LAN with the DNC1 protocol supplied from FANUC Ltd. is implemented between the cell controller and CNC's of machine tools. Fig.4 shows the partial view of the machining cell with the cell controller located at the front side.

### 3.2 Assembly cell

The main conveyor and three part feeding convey-

**Fig.4. Partial view of the machining cell including the cell controller**

**Fig.5. Partial view of the assembly cell including the robot vision compensator**

ors of the assembly cell have been custom designed by ERC-ACI and manufactured by Goldstar Inst. & Elec. Co.. The Goldstar PLC MASTER K-250 is used for sequence control of the whole conveyor system. The first process consists of inserting a bearing in the rotor shaft, assembling an end cap on the case and fastening four hexagonal socket bolts with a four-axis SCARA robot SM3. This SCARA robot has been developed through cooperation between ERC-ACI and Samsung Elec. Co.. The relative position of assembled parts are compensated on-line by using a robot vision device.

At the second station, the articulated robot AR-CMATE turns over the rotor and case unit, inserts another bearing into the rotor, and then inserts the rotor sub-assembly into the case unit. The final process is to assemble a shaft cap on the other side of the case unit and to fasten four bolts with another SCARA robot SM3.

Each robot has its own gripper stand, where various grippers are located and selected. Since each robot can deal with any size of motor automatically, any product mix is possible. A remote center compliance (RCC) device is attached to the end-effector of each robot to compensate for the relative positioning error between the end-effector and the part on the assembly fixture.

Operating software modules have been developed for IBM PS/55 with OS/2 multi-tasking environment, which serves as the assembly controller. The main function of the cell controller is to control the operation sequence by interlocking the robot controllers and a conveyor PLC system. Fig.5 shows the partial view of the assembly cell.

### 3.3 Inspection system

Two CCD cameras are attached to the X-Y Cartesian robot FT-150 from Yamaha Co. for automatic camera positioning. The images are then transferred to the image processor IP-151 from Imaging Technology Co., which mainly consists of an A/D-D/A module, frame memories, a pipeline processor and an image processing accelerator. The software library ITEX has the capabilities of image frame snapping, grabbing, freezing, and so on.

A SUN SPARC workstation is the main controller for the vision inspection system. Camera calibration, segmentation, edge detection and contour following are done to measure the geometric dimension of each part with a resolution of 0.1mm/50mm. Later these jobs will be shared with a CMM. In addition, the workstation executes external appearance inspection of assembled products, set-up check and the character recognition inspection.

### 3.4 Material handling systems

Materials in the FMS plant are handled by the AGV system MiniCart-350 from Goldstar Inst. & Elec. Co. and a custom designed AS/RS system from Bando Machine Co.. To link the AGV and AS/RS controllers into the backbone LAN, the original source codes of the operating softwares have been updated at ERC-ACI.

On the other hand, an autonomous material handling mobile robot has been developed. It memorizes the environment map off-line by using ultrasonic sensors and calculate the optimal path for arbitrary start and finish points. While moving along the calculated path, it detects obstacles by using ultrasonic and infrared beam sensor arrays and can find a detour on-line. Position compensation is also accomplished by a camera mounted on a two-axis driven fixture.

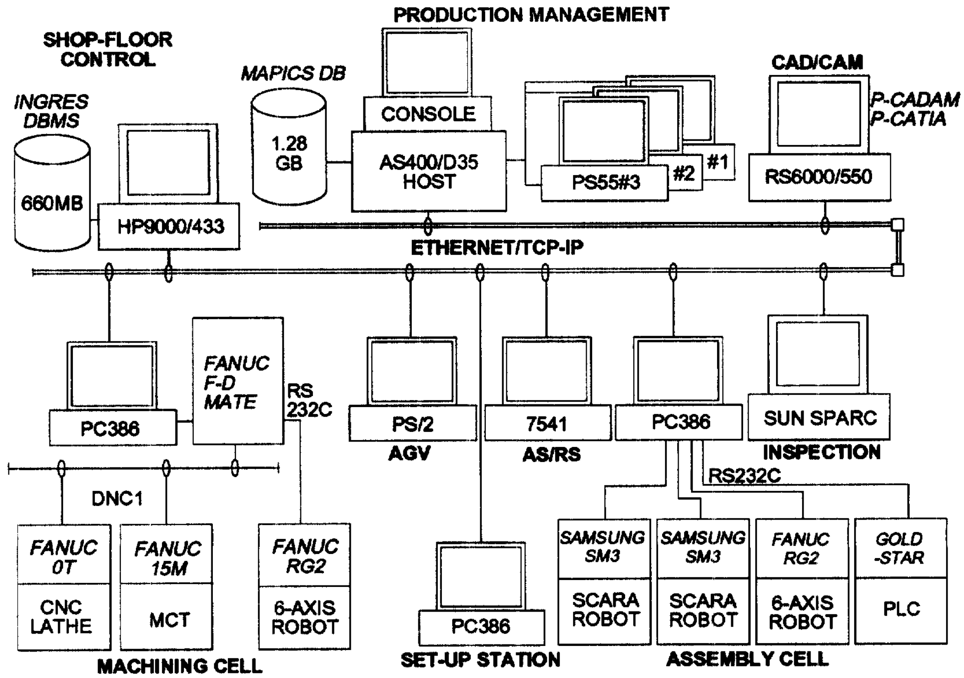


**Fig.6. The Control system configuration of the ERC-ACI FMS/CIM Center**

## 4. FMS/CIM control systems

The whole control system configuration of the ERC-ACI FMS/CIM Center is shown in Fig.6. As seen in the top of the drawing, the control system has an AS400/D35 host computer and a pair of RS6000 workstations, which were supplied by IBM Korea and are located in the CIM computer room on the 3rd floor of ERC-ACI building.

IBM MAPICS/DB software has been installed to the host computer, which has one console and three PS/55 terminals. Each terminal emulates the departments of sales, production planning, procurement and financial control, based on the software modules included in MAPICS/DB such as Master Production Schedule Planning, MRP, CRP, Purchasing, Inventory Management, Order Entry and Invoicing, *etc.* A manufacturing company is assumed to be founded in the Center, and daily production data and activities of the departments in the company are simulated. The production order lists are then transferred to the FMS plant control room.

Two RS6000 workstations are assigned for CAD/CAM integration. P-CADAM and P-CATIA have been installed as CAD/CAM softwares. A parametric design capability has been developed for the automatic design of the components of motor-like units. Also, real-time machining of the arbitrary text strings provided through the keyboard input has been tested and demonstrated using P-CADAM. Further, three and half axis simultaneous machining of a Korean traditional mask has been tested using the modeling and NC programming capabilities of P-CATIA.

The operation control scheme developed for the FMS model plant of the ERC-ACI FMS/CIM Center is one of distributed control schemes. The FMS host computer HP9000/433 and each cell controller have a same structural set of a communication module, a bid-based scheduling server, an command dispatcher module, a monitoring module, and a database.

The bid-based scheduling module enables the on-line dynamic scheduling of the operations at the FMS model plant. Once a job is completed in a cell, then the cell controller becomes a bid manager. It reports the next routed candidate cells that a job is finished and calls for bids on the finished job. The available next cells then make each bid for the next job by sending two informations - an expected finish time and a buffer status - to the bid manager cell. After a fixed time interval, the bid manager cell selects an optimal bid and sends a corresponding win or loss message to each cell which has participated in the bid. In this way, a next operation schedule is determined on-line.

All the computers, workstations and cell controllers are linked through the CSMA/CD bus, baseband, coaxial cable, and Ethernet local area network. TCP/IP has been adopted as a communication protocol. A set of software libraries for the Application Program Interface has been developed to help the many small groups in the project team embed the communication function into their FMS/CIM control software modules. For communication within machining and assembly cells, the CNC's, robot controllers and PLC are connected to the cell controllers through the RS-232C interfaces with different protocols, depending on the machine.

## 5. Current use of the FMS/CIM center

The FMS/CIM Center is being used as educational and research test-bed. The faculty members have developed so far ten continuing educational lecture courses for field engineers in industry as well as for students in campus. The courses are classified at three global levels : Cell Automation Level, FMS Control, and CIM Implementation [6]. The lecture courses have been open to some of industry companies as an one-month continuing educational program for training the middle class engineers. The test-bed can allow the engineers and students to work with the technologies within an integrated system environment, demonstrating how the various areas interact with each other

The faculty members are executing many research activities by using the FMS/CIM center as a test-bed. Especially, it is very adequate for the cooperative projects with industries : to name a few, the development of an object-oriented FMS control software modules within an MS-Window environment, the research on Mini-MAP interfacing technologies, the development of a next-generation CNC, the research activities on robotic controllers and vision inspection technologies for ERC Consortium member companies, *etc.* The verification of the research activities are done on the test-bed for mutual agreement regarding the effectiveness of the projects.

Development of the FMS/CIM Center is continuing : the machining center is being extended to 5-axis simultaneous machining capability, a coordinate measuring machine is being installed. The FMS control software modules are currently being rewritten because the first generation software did not include monitoring and error checking function, and it was not based on the object-oriented structure nor on the user-friendly features. If the malfunction occurs in the system or facility, which is commonly caused by communication errors, man-machine interface is always needed under current control software modules.

## 6. Conclusions

The FMS/CIM Center described so far has been implemented at the ERC-ACI, which is now open to public and industry. This is to encourage the transfer of technical knowledge and to accelerate the improvement of the Center toward an intelligent manufacturing system. The continuing education classes and technical workshops on FMS/CIM are being provided to industry. ERC-ACI also consults for small and medium-sized companies about automation and system integration for technology transfer. In addition to this, it is the future plan of ERC-ACI to pursue the research activities to steadily embed higher-level intelligence into the current FMS/CIM Center.

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