A HOLONIC FAULT TOLERANT MANUFACTURING PLATFORM WITH MULTIPLE ROBOTS

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Abstract: To be competitive, manufacturing should adapt to changing conditions existing in the market. Manufacturing firms also need to adapt to newly developed technologies and to rapidly changing environmental protection regulations. Modern automated manufacturing systems need *robotized material-conditioning system*s capable of moving materials efficiently throughout the entire production area. This involves not only moving and storing materials, but also *identifying*, *locating*, *qualifying*, *controlling* and *measuring* them during processing and transportation. The objective of the proposed project is the design, implementing, testing and validation of a *holonic*, *fault-tolerant* manufacturing control platform integrating *multiple robots* with visual guidance for *on demand* material conditioning and automated visual inspection.

1 INTRODUCTION

In general robotic systems are composed by a multitude of software and hardware components which are susceptible to faults, such component faults can lead to an unexpected behaviour of those systems and also to loosing the supplied services.

Some systems are designed to be fault tolerant which means that in case of malfunction of a component, the system will present a well known behaviour or will "hide" from the user the malfunction of those components.

The paper describes a system which can be used to unify, control and observe the cell's devices (in particular each robot-vision system) from a remote location, e.g. the CAM/CAQC server linked to other design and planning compartments.

1.1 Traditional Manufacturing

The literature to date in the area of manufacturing and material-handling control considers four basic types of control architectures (CAs).

(CA1) In the *centralized system*, there is a single control unit that produces all decisions about the flow of materials in the system.

(CA2) The *hierarchical architecture* is based on a top-down, master-slave approach, where the flow of commands comes strictly from the higher-level controllers to the lower-level controllers assuming a deterministic behaviour of the system.

(CA3) The *hybrid architecture* is mainly derived from the hierarchical architecture, yet it allows cooperation and sharing of information between lower-level controllers.

(CA4) The *heterarchical architecture* is formed by a group of independent entities called *agents* that bid for orders based on their status and future workload.

1.2 The Manufacturing Holonic Area

To compensate for the deficiencies of both hierarchical and heterarchical control systems, in recent years the research community introduced several new concepts for the design of manufacturing systems such as *Fractal Factory*, *Bionic Manufacturing*, and *Holonic Manufacturing Systems* (Van Brussel, 1998). Each concept attempts to model a manufacturing system based on some analogies with other existing theoretical, natural or social organization systems.

The **holonic** concept describe a basic unit of organization in biological and social systems (Koestler, 1968). Two important properties of holons make the holonic concept a suitable

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modelling tool for use in the design of both manufacturing and material-handling systems. First, autonomy grants holons the right to make decisions without consulting any supervising entity. Second, cooperation permits holons to communicate with other peer holons to develop mutually acceptable plans and execute them.

Research to date in the holonic manufacturing systems has no focused specifically on the material-handling function. Machine vision systems are more often used to guide the motion of robots and to inspect materials for geometry and surface status. Consequently, vision systems may provide both the function: **Guidance Vision for Robots** - GVR and **Automated Visual Inspection** – AVI. The taxonomy of guidance vision systems for robotic GVR tasks has included in recent years two important architectures: *Look-and-Move* and *Visual Servoing*, each one being able to use position or image feedback information (Hutchinson, 1996).

2 THE FAULT TOLERANT SOFTWARE PARADIGM

Fault tolerance in any system implies a redundancy form. There are two kinds of redundancy in time and space. Redundancy in time means that the activity (computation) of a defected server is launched again on the same processor (after the malfunction cause has been eliminated) or on another and repeated after is completed with success. Redundancy in space implies simultaneous execution of server activities on several processors in parallel, then by voting the final result is chosen.

The most important paradigms for the proposed objectives are:

- Transactions: software structuring mechanism for applications which access shared data (typically for data bases).
- Check pointing: mechanism which, in case of malfunction, the activity (computation) can be restarted from a coherent state preceding the malfunction.
- Replicated State Machine: the provided service is executed in parallel on few processors (collection of duplicated servers).
- Passive replication: a service is implemented on few processors but only one is active (primary) and treat the clients requests.

3 THE SYSTEM STRUCTURE

The physical layout of the multiple robot development platform controlled according to the holonic manufacturing concept is shown in Figure 1.

The platform contains four robots (of vertical- and horizontal articulated type) accessing a double-path, closed loop conveyor for part transportation. Part diverting from the inner ring belt to the outer ring belt of the conveyor is performed under the control of a Programmable Logic Controller (PLC) directly accessible for program editing and

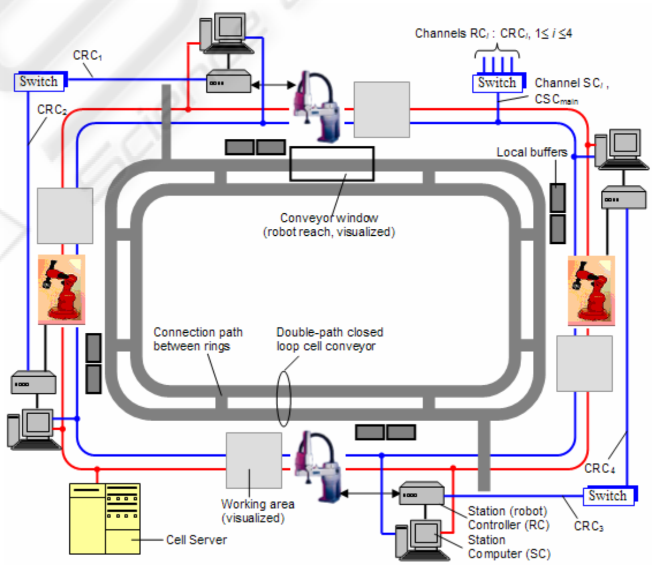

Figure 1: The layout of the manufacturing platform with multiple robots, vision and holonic control.

download from a IBM PC-type computer.

Robot controllers (RC) have master positions over the four workstations, communicate between them and are connected in a fault-tolerant multi-network with Station Controllers of IBM PC-type.

The following issues are foreseen, deriving from the objectives proposed above:

1. *Process and system analysis*, leading to the design and configuring of a generic manufacturing cell platform with four robot-vision stations, multiple stationary and mobile matrix cameras covering various fields of view including conveyor belt windows; the backbone of the manufacturing is a double-path, closed loop conveyor accessed by the robots. The layout of the cell resources will allow running different production scenarios under holonic control at batch level.
2. *Design and implementing of a fault-tolerant communication system* between station controllers and computers (robot systems, conveyor control) and the central cell server, both at controller level and computer level.
3. *Methodology, control solution and algorithms for the material-conditioning problem in multi-agent production structures, applying the holonic manufacturing concept*. There will be designed the layered holonic control architecture (Global Scheduler, Order Holon layer, Material-Conditioning layer, System Monitoring and Database) and implemented in a parallel processing, multi tasking software architecture.
4. *Design and implementing the Robot – Vision cooperation mechanisms* for merged tasks: Guidance Vision of Robots (GVR) and Automated Visual Inspection (AVI) of materials. The solution
5. is based on: (i) the description of material flows by means of sets of specific features extracted from images; (ii) configuring the operating parameters of the vision environment by virtual cameras; (iii) scene-, robot-, object-, and gripper's fingerprint modelling; (iv) the utilization of a powerful set of vision tools allowing user definable measurements and evaluation of parts.

Related to the thematic area **Integration of technologies**, advanced information technologies (IT) will be integrated in the holonic production control system: robot control with visual servoing, intelligent image processing, feature-based material description, object orientation, multi processing, flexible manufacturing control.

The objectve of providing on demand qualities for the production scheduling and manufacturing control is representative for the thematic area **ICT supporting businesses and industry**.

The holonic concept, transferred and tailored to flexible manufacturing based on intelligent robots guided by artificial vision, corresponds to the thematic area **Future and emerging technologies**.

A significant scientific contribution will consist in adding fault-tolerance to the cell's communication system. A fault-tolerant communication architecture is proposed in Figure 2, providing redundancy at both the Station Controller level, and at the Station Computer level. The Global Scheduler (GS) will be implemented by a IBM xSeries Server, which transfers the recommendations of job scheduling to the cluster of Order Holons implemented in the IBM PC-type Station Computers (SCs) via a GS server-SC client Direct Network (Ethernet). This holonic control layer is *hierarchical*.

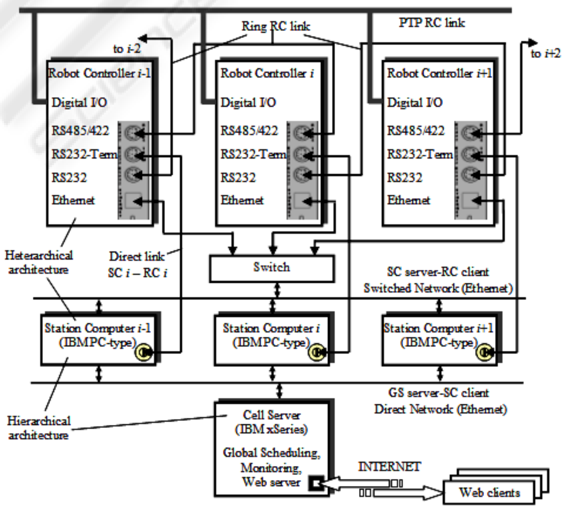

Figure 2: Fault-tolerant communication architecture for the multiple-robot platform with holonic production control.

The cluster of SCs implementing the Order Holon (OH) and Material Handling Holon (MHH) holonic control layers is interconnected to the process devices (Robot Controllers) via a SC server – RC client Switched Ethernet Network, creating a heterarchical fault-tolerant architecture:

- the failure of a Station Controller is detected by continuous monitoring via the direct serial links SC_i – RC_i and determines in consequence the rescheduling of jobs for the (n – 1) remaining valid Robot Controllers j, $1 \leq j \leq n, j \neq i$.;
- if one of the Station Computers is down, its role is taken over by the remaining (n – 1) workstations, as each SC data base is replicated and updated on line in all the other (n – 1) ones;
- if the switch is down, the heterachical communication between the SC and the RC clusters still operates via the direct links SC_i – RC_i and the Ring RC link.

The vital inter-operational conditioning between device tasks (mutual exclusion, synchronization) is provided by a cross connection I/O network.

4 THE FAULT TOLERANT COMMUNICATION LEVEL

The communication level represents the key element of the management systems and command integrated with robot controllers of FMC.

A critical aspect in designing a communication level is the building, partitioning and the on-line/off-line data bases transfer, fact that involve the multiplication of the communication links insuring the a global fault tolerant behaviour. So, it must deal the interoperability on the dynamic aspect, allowing the modules connected to the communication system to cooperate between them. The features announced above belong to a communication level which must combine the reliability and the performance of an industrial network with the building simplicity of a communication system used for parallel applications executed on multiprocessor machines.

In a normal way, each controller is connected to the communication network. If in the setup stage of the manufacturing or during the manufacturing, a controller is malfunctioning, another controller will take the tasks. To make this possible we need to make available the data bases on each controller, and also a commutation of the informational routes with the help of the network. The availability is assured by software redundancy which involve keeping at least one replica of each data base.

4.1 Network Reconfiguration

Rebuilding the communication route in the network represent the last step required to restart the normal behave of the FMC control system.

In case of malfunction of the communication network the following important cases can appear:

1. if the connection between Switch and the Supervisor PC is down the remote control will be lost, but the FMC will reconfigure: the RC will use the ethernet network for communication, and the RC with the first IP from the class will take the functions of the Supervisor PC. If the connexion is re-established the Supervisor PC makes a query finds the replacing controller, transfer the databases and restart the normal behave.
2. if the switch is not functioning, all the Ethernet connexions are lost, but the controllers will use the serial "network". The behave is like in the first case only that the web users can view the status from the Supervisor PC, including the images acquired by the observation cameras.
3. if a controller lose the Ethernet connexion he will use one of the two serial lines to reach the Supervisor PC depending on the cpu time of the neighbours.

5 CONCLUSION

The project is under construction; most of the Server Application's functions are already implemented and tested on a pilot platform in the Laboratory of 'Robotics and AI' of the University Politehnica of Bucharest. The research project will provide a portal solution for linking the existing fault tolerant pilot platform with multiple V+ industrial robot-vision controllers from Adept Technology located in University Labs from various countries. The SA module is basically finished and successfully tested. Currently, the eCAs are under construction.

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