HOLONIC FAULT-TOLERANT CONTROL OF NETWORKED ROBOT-VISION ASSEMBLY STATIONS

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Abstract: The paper describes a networked fault-tolerant assembly system of job shop type containing multiple robotized stations operating under visual control. During the assembly process, the products are identified, located, qualified, and controlled by analyzing images from virtual cameras associated to stationary- and arm-mounted cameras. The holonic control architecture is formed by the following types of entities: a Global Assembly Scheduler generating Order Holons, a dual layer of Material Handling (Robot) Holons and Sensory Holons, and a System Monitoring & Database entity. These elements are embedded in a 3-layer computing & control structure, and interconnected by a 4-fold fault-tolerant communication network keeping track of assembly job execution. Implementing issues and experimental results are reported.

Keywords: assembly robots, intelligent knowledge-based systems, fault-tolerant systems, scheduling algorithms, robot control, robot vision.

1. INTRODUCTION

A *networked robotized assembly structure* is composed by a number or robotic resources, linked between them by a closed-loop transportation system (conveyor). The final product results by executing a number of mounting, joining and fixing operations by one or several of the networked robots. The set of specific assembling operations is extended to on-line part conditioning (locating, tracking, qualifying) and checking of relative positioning of components and geometry features. These functional extensions may be supported by artificial vision either integrated with motion control (Guiding Vision for Robots - GVR) or as stand alone, computer vision (Automated Visual Inspection – AVI). In both cases, vision is used on line to check for proper geometry features and presentation of assembly components in view of robotized mounting, and for inspecting the assembly in its intermediate and final execution stage – positioning, component alignment, completeness (Borangiu, 2004).

Traditional networked assembly structures have either a *hybrid* or *heterarchical* architecture. The first one, derived from the hierarchical architecture, allows cooperation and sharing of information between lower-level (robot) controllers; a supervisor initiates all the activities and then the subordinates cooperate to perform them. The second is formed by a group of independent entities called *agents* that bid for orders based on their status and future workload. There is no master-slave relationship; all the agents including the manager of a particular order are bidding for it. Due to the decentralized architecture, the agents have full local autonomy and the system can react promptly to any change made to the system. However, because the behaviour of an order depends on the number and characteristics of other orders, it is impossible to seek global batch optimization and the system's performance is unpredictable. In order to face resource break-downs, networked assembly structures should use robot controllers with multiple-network communication facilities allowing for fault-tolerance: targeted data saving and task redistribution.

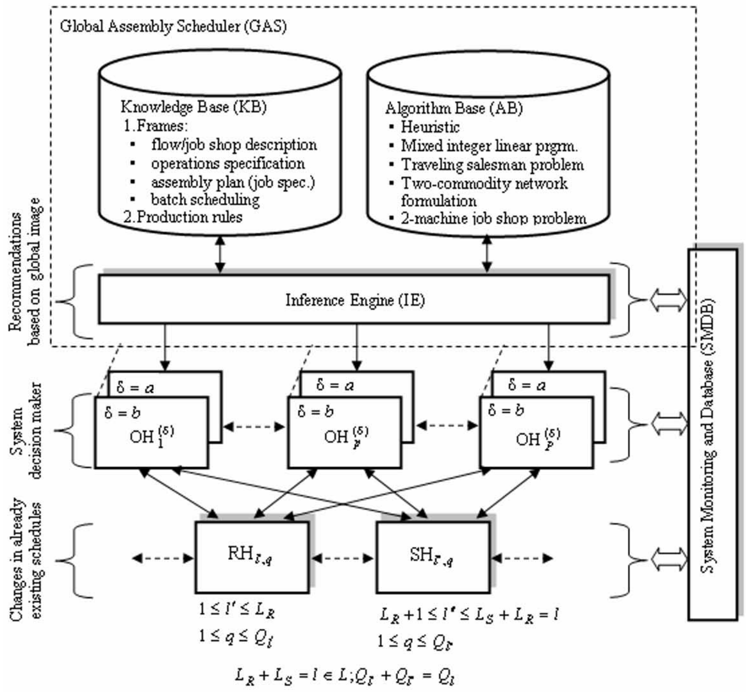

Fig. 1. Knowledge-based holonic architecture for job shop robotized assembly.

2. THE HOLONIC KNOWLEDGE-BASED NETWORKED ASSEMBLY STRUCTURE

To compensate for the deficiencies of hierarchical and heterarchical manufacturing control systems, the concept of *Holonic Manufacturing Systems* was chosen for designing and implementing a networked robotized assembly system, featuring intelligence, product tracking and fault-tolerance.

The holonic concept is used as modelling tool in the design of the control system of a networked robot assembly structure. The basic elements of the control systems – the holons *cooperate* (to develop mutual acceptable assemble plans and execute them) but are *autonomous* (are granted the right to make decisions without consulting any supervising entity). Inspired from the PROSA reference architecture (Van Brussel 1998), the architecture includes three holon types (Order, Resource and Product) each responsible for an assembly control layer: technological planning, resource capabilities and product traceability, respectively. The architecture in Fig. 1 is considered to control the multiple-robot assembly system.

The flow of information between control units is always bi-directional due to the decentralized nature of the architecture and the application of the holonic concept of cooperation. This assembly structure has four types of entities (Babiceanu, *et al.*, 2004):

1. A layer of *Order Holons* ($\mathrm{OH}_p^{(\delta)}, 1 \le p \le P$) of variable depth, corresponding to assembly plans computed off line for the P final products.
2. Two types of Resource Holons:
   - *Robot* (or Material Assembly) *Holons* ($\mathrm{RH}_{l',q}$), formed by all robot manipulators, grippers and tools together with their controllers, responsible for mounting and fastening assembling parts, and for moving their arm-mounted cameras in points where products are visually inspected.
   - *Sensory* (Material Tracking & Checking) *Holons* ($\mathrm{SH}_{l'',q}$), formed by all machine vision systems and magnetic code RD/WR devices respectively used for component / subassembly position and geometry control and product tracking on pallets.
3. A *System Monitoring and Database* (SMDB) entity, responsible for monitoring the number of jobs and availability of resources in the system, and for keeping track of the already executed operations and assembly jobs.
4. A *Global Assembly Scheduler* (GAS), generating basic and alternate assembly plans for all batch products in the form of OH. An algorithm base is embedded into a knowledge-based system (KBS). An inference engine in the KBS controls, through a forward chaining strategy, the procedures of: triggering production rules, switch to algorithmic schedule generation, and holonic task allocation.

In the holonic system, an OH represents an *assembly job* and all its associated information embedded in a Cell Server (CSv) and replicated in the IBM PC-type Station Computers (SCo) while the RH and SH are respectively represented by robot assembly resources (with Station Controllers SCn – the robot controllers) and monitoring devices (vision, magnetic code R/W).

In the proposed architecture, the GAS is basically a control unit that delivers (optimal) schedules for the material assembly and conditioning equipment when the system is operating under normal conditions. The main GAS computing occurs off-line: a set of jobs (assemblies) is to be executed by a set of robot-vision resources (processors), eventually minimizing an imposed performance function. An assembly job (product) may consist of a number of operations. All assembly parameters are known a priori; each