Intelligent Manufacturing Systems: Robotization of a Factory Warehouse

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Abstract. The paper first discusses the Intelligent Manufacturing System (IMS) concept, viewing it as an Artificial Intelligence (AI) learning system, particularly in regards to reinforcement learning. Then the paper describes the role of material storage in an IMS. Viewing a material warehouse as an IMS memory chip, the paper describes an application by which a classical factory high bay storage is robotized, by converting a stacker crane vehicle into a warehouse robot.

Keywords: Intelligent Manufacturing Systems, Machine Learning, IMS Material Memory Chip, Robotization of an Industrial Warehouse, Microcontroller.

1 Introduction

Manufacturing is an important human activity by which a new product is obtained using previous basic materials and products. A classical manufacturing process is related to a concept of a manufacturing plant [1], such as the one shown in Fig. 1.

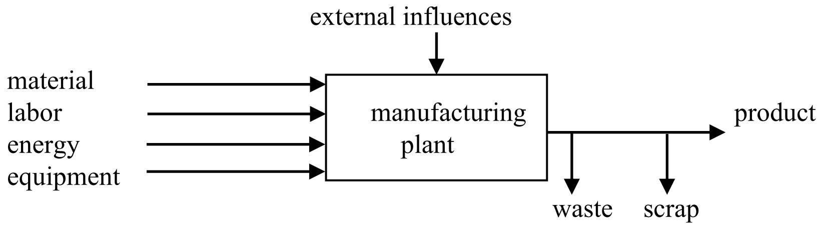

Fig. 1. A basic concept of a manufacturing plant

As can be seen in Fig. 1, classical manufacturing considers a manufacturing plant, which receives needed resources and produces a desired product. It also produces waste and scrap. External disturbances are considered to be integral to the production process as well.

Manufacturing technology has passed a long way until arriving to the modern concept of intelligent manufacturing systems [2. 3]. Here is a list of some of the crucial steps in manufacturing methods development.

- *Hand crafting*. Usually a single person produced a product;
- *Mass production*. An automated system of several people, using machines to produce a product in high volume;
- *Group technology*. Material parts are encoded and information processing is involved in the manufacturing;
- *Computer integrated manufacturing*. Computers and networks are highly integrated in the manufacturing process.
- *Just-in-Time (JIT) manufacturing*. A supply chain is considered vital to efficient manufacturing. An attempt is made that each material be always present at the time of need;
- *Flexible manufacturing*. Manufacturing based on software, which can change the production rapidly according to needs;
- *Intelligent manufacturing*. Manufacturing systems that can learn from the environment and adapt to it. The system includes Artificial Intelligence at various levels of its functioning.

A segment of the research on modern manufacturing is focused on biological systems manufacturing, where biological processes of protein synthesis in terms of flexible manufacturing are researched [4].

There are various aspects of intelligent manufacturing and this paper will address three of them. First, a theoretical discussion about intelligent manufacturing as a reinforcement learning system will be considered. Then the memory chip metaphor is described. Then the issue of transition of a classical factory high bay storage towards a robotized warehouse will be addressed. For that part of the paper, a practical solution in a real-time, real-place factory will be presented.

2 Intelligent Manufacturing Systems

An Intelligent Manufacturing System (IMS) is ultimately viewed as a factory without people, i.e., as an autonomous system of Artificial Intelligence [5]. An IMS assumes that it is capable of functioning using some kind of previous experience in the decision making process. In addition to this definition, there are other views towards what an IMS is, one of them being that Intelligent Manufacturing Systems are those performing the manufacturing functions as if the human operators are doing the job [6]. Thus, the general idea is that the IMS will gradually replace people's labors, using various implementations of Artificial Intelligence and Robotics.

This idea of an Intelligent Manufacturing System can be viewed from various viewpoints and here it will be discussed from the Machine Learning viewpoint. Fig. 2 shows a general scheme of a reinforcement learning system [7].

In reinforcement learning, an agent performs an action in a particular input (situation, state), after which the environment evaluates the agent's action with a signal interpreted as reinforcement (i.e., reward, punishment, etc). Using that signal as performance evaluation, the agent can learn in time to improve its behavior in the considered environment.

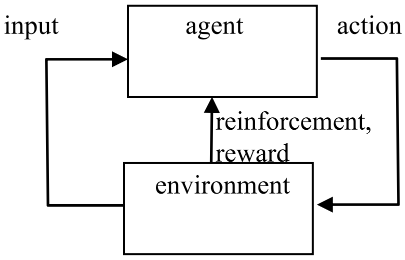

Fig. 2. A reinforcement learning system.

Here we point out that an intelligent manufacturing system can be viewed as a reinforcement learning system. The view is shown in Fig. 3.

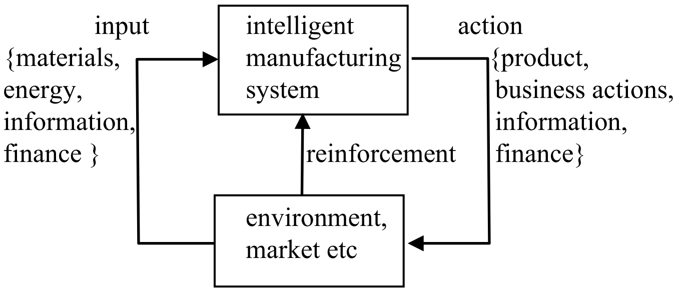

Fig. 3. Intelligent manufacturing system viewed as a reinforcement learning system.

As Fig 3. shows, an IMS is always considered to be in an interaction with its environment. From the environment it receives a special signal which is recognized as a performance evaluation (reinforcement) signal, using which an intelligent system can improve its performance. Because reinforcement does not arrive at each action, the learning regime therefore represents a delayed reinforcement learning process [8].

3 A Material Memory Chip of an IMS Motherboard

The IMS architecture can be of various types. An important decision in the building of an IMS is the type of material storage. It might be distributed or centralized. Fig. 4 shows a layout of an IMS in case of a centralized warehouse where all materials, by-products and products are stored.

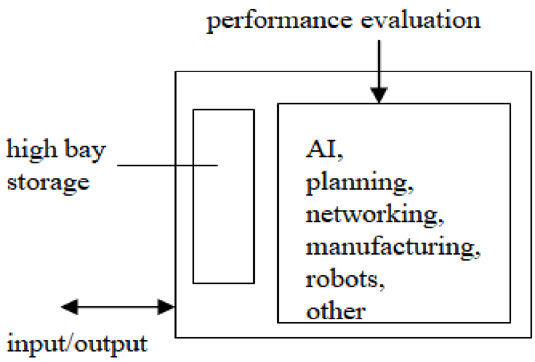

Fig. 4. Layout of an IMS, as a motherboard with a memory chip

Fig. 4 can be viewed as a motherboard of an IMS, containing a memory chip for material storage and retrieval. The memory chip is usually a high bay storage (e.g., [9, 10]), having a stacker crane as a storage/retrieval system.

Fig. 5 shows a schematic of a high bay storage with a stacker crane.

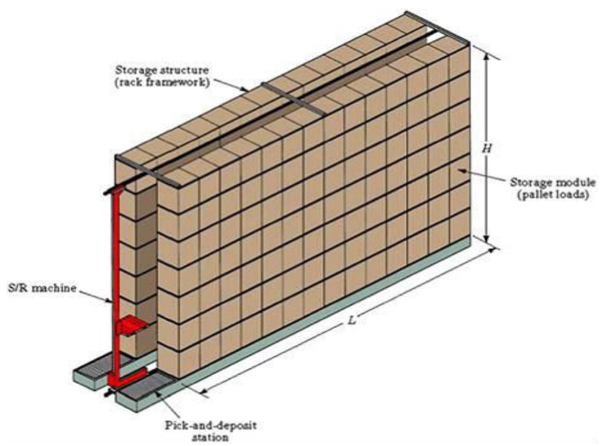

Fig. 5. A high bay storage with a stacker crane [11].

As Fig 5. shows, the high bay storage is a system of memory (storage) cells in which material is stored and retrieved by a machine called a storage/retrieval machine (S/R machine) or a stacker crane. The crane moves in an aisle and has access to all the cells of the storage. The cells are usually filled with standard size boxes (palettes) designed to be handled by the stacker crane. The crane moves in a Cartesian system x-y-z, so that each cell can be described by (x, y, z, s/r) where s/r stands for store or retrieve, i.e., the action performed on that cell. The x and y variables are positive and numerical, while z is binary {left, right}, pointing that the action is on the left or the right cell relative to the stacker crane. The z variable is represented by a telescopic joint (linear gripper) that moves left or right. Thus, the entire crane system can be viewed as a 3DOF robot in Cartesian coordinates with translational joints.

An advanced high bay storage may contain cells that are more complex. Some of the cells can have processing capabilities. That type of a material memory system is a processing-in-the-memory type of intelligent manufacturing.

4 A Challenge of Robotization of a High Bay Storage

In today's state of technology, it is usual that a vendor of high bay storages would offer a robotized system for its control. Some factories, however, have high bay storages which are not robotized, where the stacker crane is operated by a human driver. Thus, there is a need for robotizing such a high bay storage, by replacing the human driver with a controller. That way, the human driven vehicle is converted into an unmanned vehicle.

Here such a challenge will be described, alongside a solution that has been implemented. Considered is a high bay storage in the Rade Končar factory in Skopje, Macedonia, with a stacker crane which was initially operated by a human driver. After robotizing the stacker crane, a robotized factory warehouse was obtained.

The initial analysis of the stacker crane of the factory Rade Končar is given in Fig. 6.

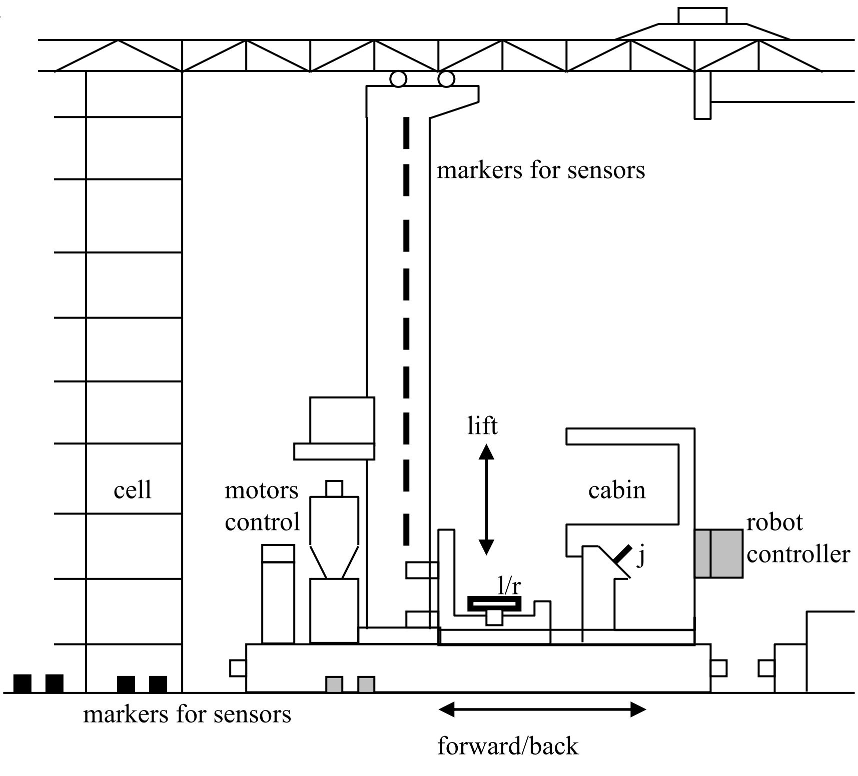

Fig. 6. Schematic of a considered stacker crane in a high bay storage.

As Fig. 6 shows, the considered stacker crane has a cabin, inside which a human is placed, and the human controls the crane using two joysticks (j). The crane moves horizontally $\pm$ x (forwards/backwards). The cabin along with the left/right (l/r) telescopic joint (drawn in bold) moves vertically $\pm$ y. The vertical movement is implemented in such a way that the cabin and the joint are placed on a lift and can move to the needed height. At a particular (x, y) cell in the crane aisle, the telescopic joint extends to either left or right, so as to store or retrieve a box at that cell. The aisle contains sensory markers for the x positions of the crane, while the crane contains sensory markers for the y positioning of the lift. On the crane there are motors that move the entire crane construct. The crane contains a control panel where the electrical wiring is performed.

After this analysis, the task was to replace the human driver in the cabin, and add a computer controller to the crane (shown in gray in Fig. 6), so that the crane would become an unmanned vehicle, i.e., a warehouse robot.

5 The Solution: Developing a Robot Controller

First the joystick commands and the wiring of motors and sensors were studied. There were commands for horizontal movement (forward, back, fast), for vertical movement (up, down, fast) and left/right movement (right, center, left). The sensor signals were for horizontal movement (front, rear), for vertical movement (y, store, retrieve), and for the telescopic joint movement (right, left, center). The wires from the Terminal Panel were collected in a D37 connector. The wires for power lines were also collected. Thus, the interface from the crane to the controller was the D37 connector.

Once the crane controller interface was chosen, a controller to human interface was designed. The design of the controller is shown in Fig. 7. As it shows, the robot controller contains a human-controller interface and a controller-crane interface. The human-controller interface contains a 7-inch screen and a numeric keyboard, as well as a USB connector. The USB connection is used for uploading programs and other communication needs.

The controller-to-crane interface contains a board of 10 relays (10VDC/2A) for motor control and 14 optocouplers (16-28VDC) for sensor readings. It is a galvanically isolated interface. The D37 connector connects the controller box to the crane terminal panel.

The power is obtained from the AC power of the crane. An AC/DC converter converts 230VAC into 5VDC/10A.

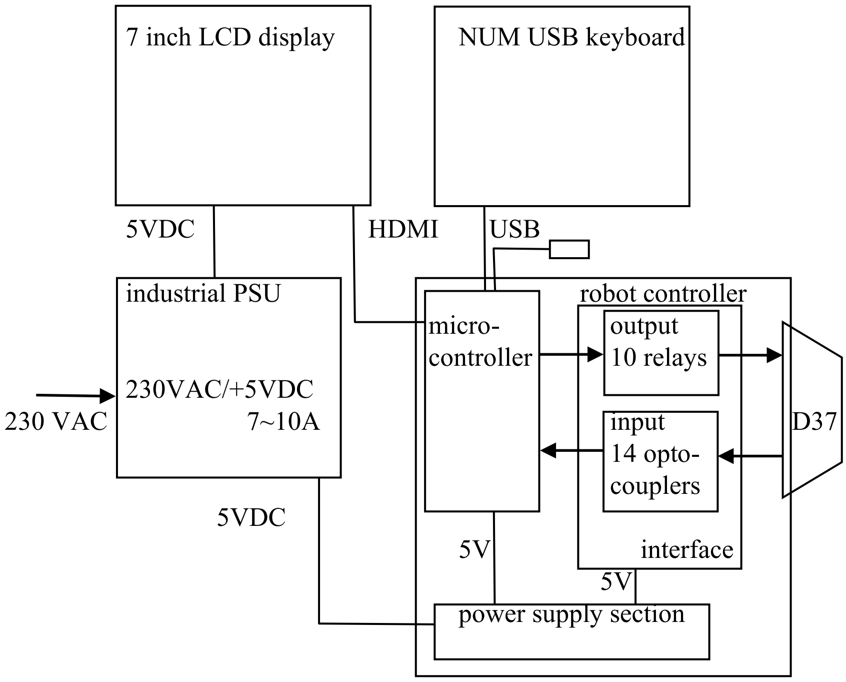

Fig. 7. The design of the robot controller.

The microcontroller used is a Raspberry Pi [12, 13], shown in Fig. 8. More details about the microcontroller are given in [14]. It is a microcontroller that potentially enables an extension to networked manufacturing systems, e.g., [2].

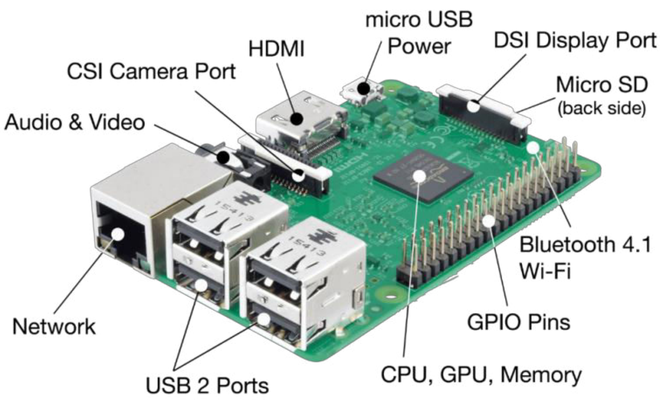

Fig. 8. The microcontroller used.

6 The Realized Controller and the Warehouse Robot

Fig. 9 shows the front panel of the realized robot controller, mounted on the rear side of the crane.

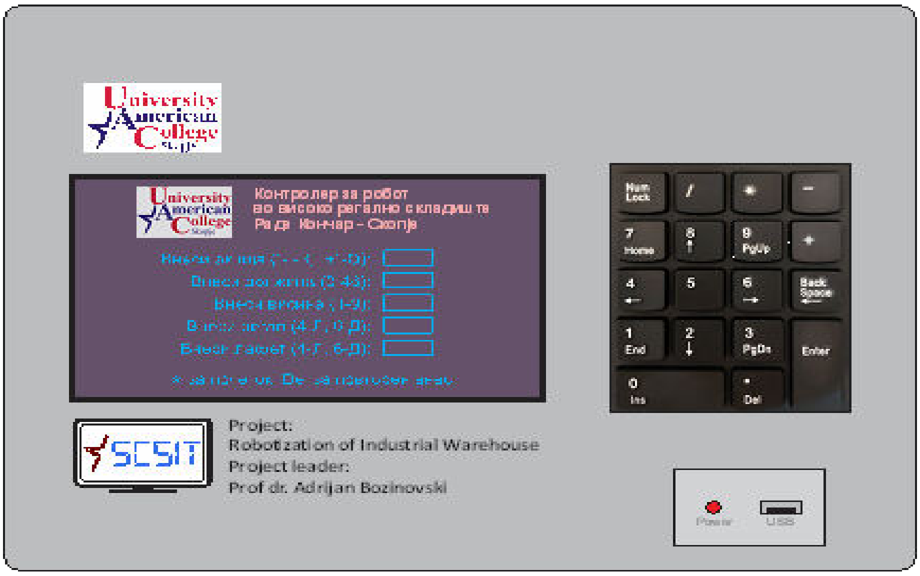

Fig. 9. The robot controller mounted on the rear side of the stacker crane.

The front panel of the controller box contains the logos of the university and university department which carried out the project. The robot controller has a screen with a command menu in the Macedonian language. It also has a numerical keyboard related to the commands on the screen. The controller box also contains a USB port for program loading, as well as an LED for power-on indication. A power-off button is placed on a side panel of the controller box, so as to immediately stop the controller-based crane operation in a case if emergency. An antenna for wireless communication is mounted on the controller box, so that a human operator might give commands without the need for being physically close to it.

Fig. 10 shows the robotized stacker crane at work (real-time, real place), in the Rade Končar factory's high bay storage [15]. It is shown during a store /retrieval operation, inside the warehouse aisle. The controller from Fig. 9 is shown mounted at the back of the crane, whereas the crane's cabin is empty, meaning that it is not operated by a human driver. The robot is positioned such that it operates on a box on the third level. The view in Fig. 10 is from the entrance of the aisle where the robot operates.

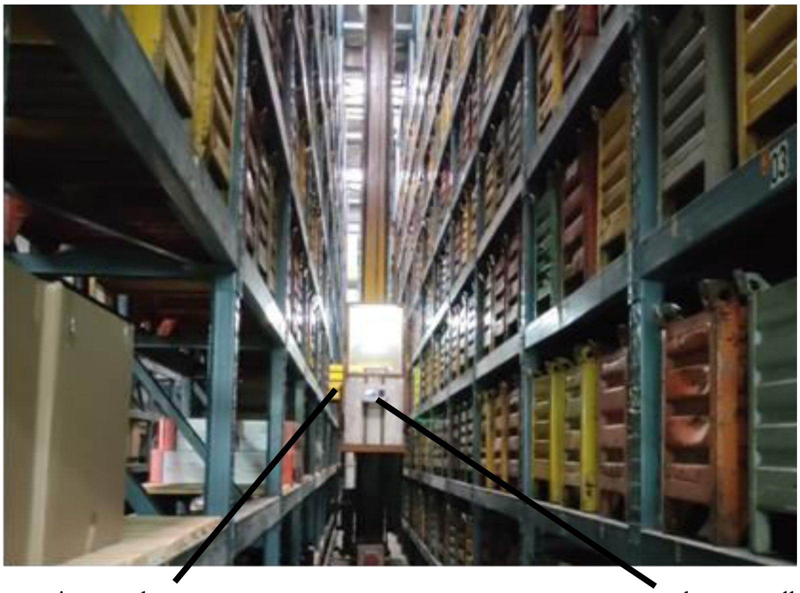

Fig. 10. The robotized stacker crane at work in Rade Končar factory.

The operator who types in the robot commands in the controller stays outside the aisle space. The commands can be given either by typing them via the controller keyboard, or via a wireless command assignment. The principal form of a command is (action {fetch, put}, coordinate (x, y, z)). Before stored to or retrieved from a cell in the storage, crates (boxes) are placed on two placement bays, one on each side of the crane, when it is parked in its starting position.

7 Conclusion

The paper discusses both the theoretical and practical issues in relation to Intelligent Manufacturing Systems. The theoretical issue considered is the relation between Intelligent Manufacturing Systems and Reinforcement Learning in Artificial Intelligence. The practical issue considered is how a classical high bay storage in an existing factory can be converted into a robotized storage, thus fostering Intelligent Manufacturing.

The theoretical contribution of the paper is the relation between Intelligent Manufacturing and Reinforcement Learning. It shows how an Intelligent Manufacturing System can be viewed as a learning system in a Reinforcement Learning regime.

Part of the theoretical view toward IMS is a view that a warehouse can be viewed as a memory chip on a IMS motherboard. That view is implemented in this paper and is a relation between the theoretical part and the application part of the paper.

The practical contribution of the paper is a solution to a worldwide problem, where there is a factory with a classical high bay storage, which wants to move towards a robotized factory warehouse. A solution is given for such intent, by building a robotized warehouse with an unmanned stacker crane, as a step towards developing an Intelligent Manufacturing System. A controller was built and was placed on a stacker crane, thus converting the crane into a warehouse robot. To the best of the author's knowledge, such a solution, using a modern microcontroller, has not been provided in the literature outside this work.

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