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A Concept for Isles of Automation: Ubiquitous Robot Cell for Flexible Manufacturing

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Abstract: In this paper, we present a concept for short series production using industrial robots and advanced control systems. We call and define this system as "isles of automation". The concept is beyond the current robot workcells by the properties of flexibility, reconfigurability, context awareness and programmability. In the concept, there are modules defined for programming, sensing, material handling and flow as well as communication. The overall architecture defines how these modules are working together. In this paper, we present these modules and illustrate the operation in the pilot case.

Keywords: Robot programming, CAD, path generation, offline programming, short series manufacturing, flexible manufacturing.

1. INTRODUCTION

At the same time when modern production is facing tougher price competition, the requirements for flexibility are increasing. Product life cycles are getting shorter, the variety of products is increasing, and production costs should be decreased at the same time when there is no technical solution on the market to answer to this. With well-established technologies this is getting increasingly difficult. Although robotic systems are classified as a flexible production technology, in practice the robotic implementations are concentrated to high volume production [5]. Only a few solutions have been installed for short and single series production. The main obstacle in installing robots for short series production is the amount of product-specific costs [6]. Each work phase and process for each product has to be programmed, and the function of auxiliary equipment is usually based on part-specific geometry. If the product volumes are low, the effective utilization of a robot assumes that it is applied to a large variety of parts, or to a large amount of different work phases, to bring the robot utilization rate to a decent level typical of the SME industry. In addition, parts to be processed in the production environment have complicated forms which makes manipulation more challenging. Task level control is quite common topic in the literature [9][10] but vertical approach presented in this paper is a novel solution. Architecture of a holonic manufacturing system [11] is close the approach presented in this paper. Automation island is similarly autonomous but not cooperative by default as holons are.

This paper has been organized as follows. In chapter 2 we introduce and define the concept of the isle of automation, in chapter 3 we introduce the architecture of production cells and in chapter 4 components of the isles of automation. Demonstration is shown in chapter 5 following the ideas of our concept. Finally conclusions are drawn in chapter 6.

2. CONCEPT FOR ISLES OF AUTOMATION

The concept of isles of automation for short series production has a modular structure and realizes highly flexible and controllable robotized system. It exploits the features of ubiquitous technology including flexibility, adaptivity, context awareness and reactivity, which are beyond the current automation solutions. The production system easily adapts to new products or product variants and to deviation in work pieces. In addition, data acquisition presents new possibilities, when open interfaces are offered down to the sensor level. This means sensors offer services and are visible to the whole control system. Sensors can be used for on-line purposes such as control but also off-line monitoring such as quality control and prognosis of the maintenance of the machines. This kind of features can not be found in the current systems such as presented in [4].

The development of manufacturing systems has had two main approaches: Flexible Manufacturing Systems (FMS) and Reconfigurable Manufacturing Systems (RMS) [1]; the concept presented in this paper has adapted features from both. The basic element of the automation island is an industrial robot equipped with different kinds of external sensors and auxiliary devices combining mechanics, sensor technology and software together with an intelligence in a form of control and decision making system. This gives high level flexibility in terms of programmability, reusability and price. The operation of the automation island is managed by control software, "isle manager", which is controlling the execution of tasks. It also manages the sensing and reactions to non-expected situations in the robot cell. The work is carried out by communicating with distributed modules and providing the ways to carry out the tasks. "Isle manager" locates in application layer in the production cell and communicates within a production call and workflow manager in the engineering resources.

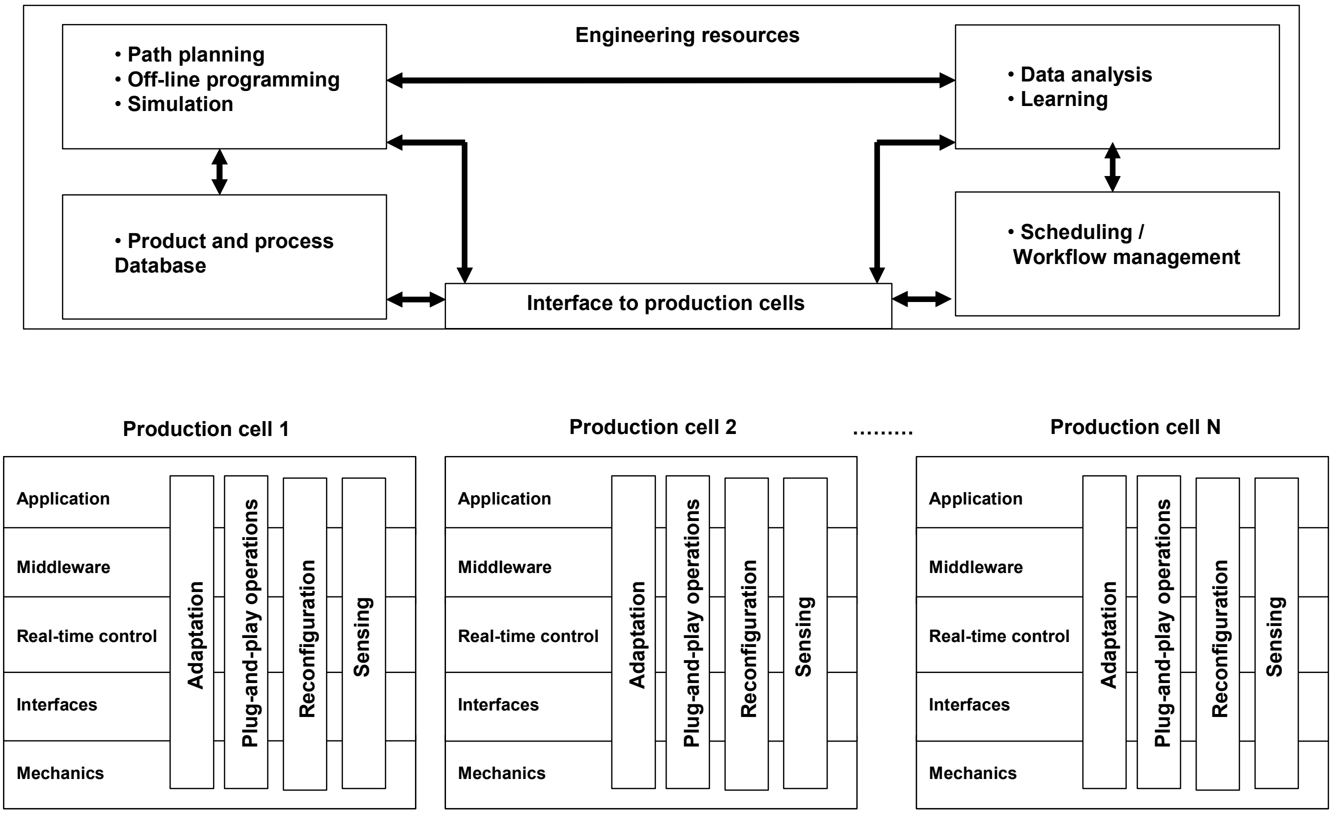

Fig. 1 The conceptual structure of isles of automation

2.1. Description of the concept: production cell

The concept of the automation island is described in the figure 1. The main parts of the system are robot cell(s) and engineering resources. Interaction between production cells and engineering resources is very active. If the factory contains a large number of production cells, there can be a pool of engineering resources which gives services for productions cells. Another possibility is that each cell has its own engineering resource which means they are operating autonomously like separate islands. This is typical case when there are one or two production cells in the factory. In that case engineering resources are embedded in the production cell. In principle, an engineering resource of one production cell can offer services to other production cells as well.

The decision making is distributed in the automation island. There is a high level controller, which takes care of the high level production management. Flexibility in production also sets requirements to the managing and controlling of the island. To use hardware efficiently, flexible, modular and reconfigurable software must be used at every level to manage the whole system. Modular structure and software flexibility means that operations and functions can easily be configured and used on-line. This approach has several features of Service Oriented Architecture approach presented in production environment [7].

The monitoring and management of the production island in the high level is carried out in the workflow manager. Basically this manager is responsible for everything running smoothly and accordingly to the plan.

The control concept has a layered structure for different response levels. These layers include hardware, interfaces, real-time control, middleware and application layers. The key-functions in the island are adaptation, reconfiguration, sensing and plug-and-play operations. These functions are operating vertically in the cell, see figure 1. Depending on the requirements of the applications, the properties, operation and status level of these key-functions are defined. They are explained more detailed in chapter 3.2.

2.2. Description of the concept: engineering resources

The engineering resources are working as an automation backround system and operating mainly off-line. It consists of pre-processing and post-prosessing functions depending on the time of operation. For operation of the robot and auxiliary devices, pre-processing functions include planning, off-line programming and simulation modules. To

support the process, there is a database for product information and process execution. It also may have a connection to other factory databases. For post-prosessing functions, there are data analysis and learning modules as well as workflow management for overall management of the cell operation, see figure 1.
Communication between the cells and engineering resources is carried out through a production interface mainly between the application layer and modules of the background system, see figure 1. Data exchange is not time critical and common formats are defined.
There can be several production cells in the system as illustrated in the figure 1. They can exchange and share information and resources such as sensors, devices, tools etc. Flexibility of production means also that a product can be manufactured in any of the cells and they can negotiate which will carry out the task.

3. ARCHITECHTURE OF THE PRODUCTION CELLS

3.1. Layer structure

Layers of the production cell are described in the figure 2. All the units of the cell (e.g. robot manipulator, controller and device controller) will contain the same layered structure starting from mechanics to application layer. If a new unit is connected, the layer structure has to be the same or at least interfaces must be compatible. Depending on the requirements of the each unit, different layers will be built. Communication between the layers is carried out using interfaces suitable for each device. Communication is recommended to carry out between same layers to enable synchronization of the communication. In the higher layers (application, middleware and real-time control) communication is carried out using textual structures, e.g. XML.

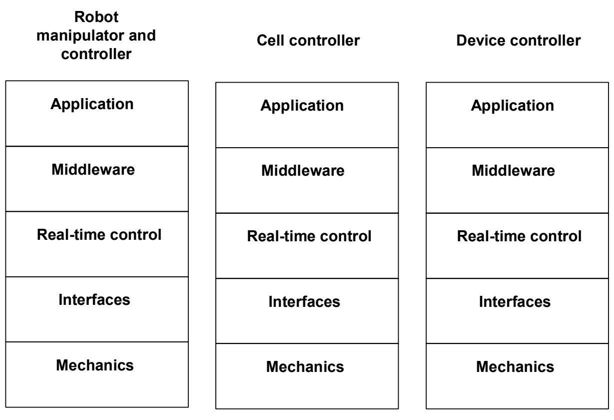

Fig. 2. Layer structure of the units of the production cell

In a time critical layer such as real-time control, interfaces and communication can be carried out using special real-time standards such as industrial Ethernet or digital or analog I/O or industrial buses if very fast communication is required.
An exemplary content of each layer is described in table 1. In the application layer, there can be application or robot application program running in the cell computer or in a robot controller. The common property is that programs are not time-critical compared with programs in real-time control layer. In the middleware layer, there are services for different layers. Most of the services are built such that they are invisible to user. The basis for key functions are in the middleware layer. Real-time control layer contains both operations of real-time operating system as well as users functions operating in real-time. In the robot controller, all the kinematic calculation and motion control is carried out in this layer. Interface layer has interfaces to devices and communication networks and mechanics layer has physical devices, cards and tools.

3.2. Key functions

There are services available in the production island going through the layers as described in figure 3. Multi-layer operation means that they can support each layer depending on the requirements. We call these key-functions and they provide services for flexibility of the isle of automation. Key functions are adaptation, plug-and-play operations, reconfiguration and sensing. All of these services do not necessary have to exist in every cell and different cells can get these services from other cells. Key functions have also cross-dependencies, i.e. they support each other. The purpose of the key-functions is to provide the ubiquitous operations to automation island. Adaptation is on-line or off-line reaction to changes of product or production. It utilizes sensing –key-function to achieve the measurement data for the basis of the operation.

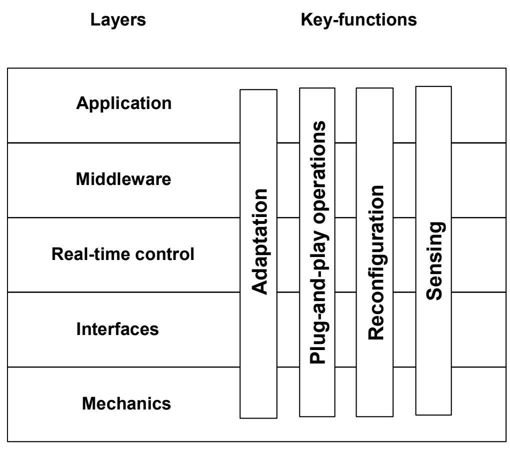

Fig. 3. Key functions in the layer structure

Plug-and-play operations enable easy connectivity of new sensors which can be used in the adaptation of the production system to new, different size of workobjects. In general, plug-and-play operations enable an easy way to connect and disconnect components such as sensors, actuators, tools and devices between production islands. Reconfiguration function enables making of structural changes in the production cell. The changes are carried out such that all the required properties of the island will be achieved. Reconfiguration is also supported by plug-and-play operations. Sensing provides different kind of sensing / measurement services for other functions and layers. It will utilize plug-and-play operations to easily change sensors between production cells.

Table 1 The content of the layers

Layer	Example of operation
Application	Application program, robot program
Middleware	Services for upper and lower layers including key functions
Real-time control / OS	RTOS: RTLinux, linux, e mbedded windows
Interfaces	Analog, digital, ethernet, device drivers
Mechanics	Manipulators, grippers, feeders, tools, sensors

4. COMPONENTS OF THE ISLE OF AUTOMATION

Here we briefly introduce technologies, add methods and visions that correspond to the required features. These are in line with the architectural description given in chapters 2 and 3. Based on analyses of the current stage of the technology, technologies and methods are selected for the concept [2][3]. The essential components of the automation island are 1) programming, 2) robot and external sensors, 3) material handling devices (e.g., grippers, feeders), 4) control system and 5) communication system. Information flow of these is also described in figure 4. Programming tools include both off-line programming tools and on-line programming which is required in on-line reactivity. Robot and external sensors include robot manipulator and sensors like force, vision and laser rangefinders to observe the environment. The selection of these sensors depends on the requirements of the application. Material handling devices will make sure that robot has pieces in the right position to be manipulated. Grippers and such kind of tools are specially designed or selected to manage flexible operations. Workflow management software is above all and controls operations in the task level, e.g. how different phases of the workobject are carried out in the work flow. New tools and devices can be connected in a plug-and-play manner without parameter configuration. Communication and control system defines the information flow in the isle of the automation, where communication defines the protocols of the communication. All these components are designed to be built up using both commercial components available from the market as well as components built by ourselves.

Modularity is a key element in achieving the desired flexibility and reconfigurability features. The modularity is spread out from the factory level down to the smallest functional units of devices. It affects the physical structure, control devices, data transfer solutions and sensor utilization. The concept includes necessary modules for various purposes. The modularization also serves the aims of standardization and quality.

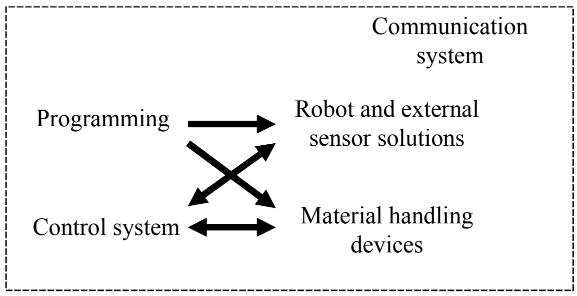

Fig. 4. The information flow between the main components of the isles of automation

5. DEMONSTRATION

The proposed concept was demonstrated in a pilot case, which considered implementation of different parts of the concept , i.e., the production cell and engineering resources. The goal of the demonstration task was to deburr bevels of a workobject. As a source information, there was a 2D drawing of the workobject and information about the bevels.

In the engineering resources, programming of the robot motion paths is based on 2D CAD drawings. Also sensing planning can be carried out for the localization measurements of the workobject. For robot programming, a converter was developed to transform the 2D CAD data into 3D format. In the demonstration the task related tool tags were automatically generated to the surface of the CAD model, after which they were transformed to paths for the robot. This phase was supported by a robot motion path planner which calculated the paths for robot motion such that all points are reachable in a same joint configuration (for more information, see [8]).

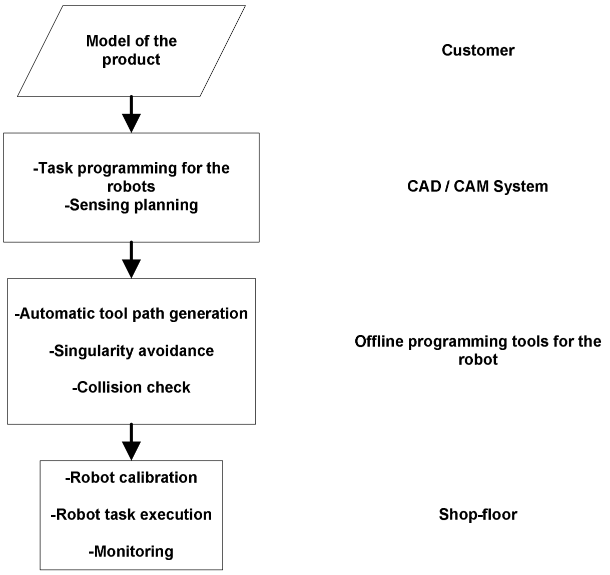

Fig. 5. Workflow in demonstration case

The workflow of the demonstration task is illustrated in figure 5. In the workflow, first three operations are carried out by the engineering resources and the last one by the production cell. Scheduling / Workflow management is carried out manually by the shop floor operators. Engineering resources will generate programs to application layer in the production cell.

This robot programming demonstration has been carried out in the VTT laboratory. We used the ENVISION off-line programming tool by Delmia for visualizing the virtual robot cell and transformation of workobject from 2D to 3D data. As a robot we used KUKA KR150-L110 industrial robot and deburring of the bevelling were done by a simple tool emulator. In the demonstration, we were content to show that the interfacing between the different parts of the system could be done easily. Also generation of motion paths from 2D data was successful. We did not consider any further process related issues such as tools and quality of the bevelling.

6. CONCLUSIONS

In this paper, we presented a concept for short series manufacturing. The concept defines a system structure composed of engineering resources and production cells. We described the content of these in detail and illustrated a demonstration case in laboratory where selected parts of the concept were implemented into a robot cell.

The demonstration gave very promising results about the usability of the concept. The overall idea behind it is to be able to respond very challenging manufacturing problems to automatically process complicated objects and carry out reconfigurations between the products.

In the future, the concept will be implemented into several demonstration cases also in different application areas. From additional tests we can achieve feedback about the usability of the concept and iteratively improve it. The purpose of the concept in the future is also to be a tool for design engineers to support the design of new flexible robot systems.

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