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# Implementation of robot welding cells using modular approach

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**Abstract.** During recent years the automation of production processes in small and medium enterprises (SME-s) has been a subject of growing interest. The economy of scale and increased volume of production can be achieved by selecting the right strategy for the automation. The automation systems are as a rule complex and their implementation is resource consuming for SME-s. In the present paper we study implementation of robot welding cells in several enterprises. It is shown that introducing robot welding cells in SME-s is a difficult task because of the limited resources and lack of the needed competence in SME-s. For successful realization of automation projects the complex systems must be divided into smaller and simpler parts using modular approach. The success of the project can be achieved through suitable definition of the modules. This makes it possible to implement the project steps in parallel by involving the needed resources.

**Key words:** automation systems, modularization, agents, robot welding cell.

## 1. INTRODUCTION

### 1.1. Trends in robotics

The implementation of industrial robots has been an increasing trend in the world during the last decade. In 2006, about 951 000 robots were installed in the production industry worldwide. During the year 2012 the estimation of robot installations is about 1 057 000 units [[1]]. The implementation of robots exceeded the number of 100 000 installations per year in 2004 and the trend is increasing.

The robots were introduced also in areas where the implementation was considered not profitable or impossible before (construction industry, logistics operations). The development of technological possibilities of robots has been rapid. In the three-dimensional virtual robot environment the on-line and off-line programming is more process-oriented and enables faster product implementation.

Robots have been applied for a long period mainly in mass production. The majority of tasks done with robots are repetitive and do not change during the long period of time.

To stay competitive in the world market, the manufacturing of cost efficient and client-oriented products is important for SME-s. The nowadays trend is the implementation of robots in SME-s. The availability, competitive prices and plain programming made it possible and feasible.

Implementing robots in SME-s has special features. Not only short cycle times are needed when producing small batches, but the rapid set-up and introduction of new products have significance in this case. Applying robots and manipulators for producing small batches and great variety of products is the main direction of development.

## 1.2. Research background

SME can achieve great advantage by implementing welding robot cells. Introducing robot welding cells in SME-s is difficult because of the complexity of the system and quite often of the lack of competence and lack of the appropriate methodology in companies. To be faster, the complex system must be divided into smaller and simpler parts using modular approach. This approach gives an integral overview of the system and makes the tuning precise and effective to each part of the system.

A lot of authors has analysed the robot implementation. Their approaches include several subjects and focus on concrete areas like welding, calibration, programming etc. The areas covered are the following:

- general trends in the world (field of use, robotization volume) [1],
- programming of robots (programming systems, optimizing programs, off-line programming) [2],
- coordination, calibration (using cameras and sensors) [3],
- welding processes (MIG/MAG, laser + MIG, quality assurance) [4],
- scheduling of operations, workload [5],
- criterions for robot selection, modelling system, (modular architecture, product family) [6],
- kinematics and singularity [7],
- production process (reuse of process knowledge, cycle time, bottlenecks) [8],
- monitoring, controlling of the system [9].

Although these articles do not support the implementation of whole (complex) systems, they can be used for the analysis of such systems.

Thus an extensive study about robots suitability for using them in SME-s has been done. A fundamental research has been carried out also by other researchers on developing robots suitable for SME-s, under the European 6th Framework called “SMErobot” [10].

## 2. METHODOLOGY

### 2.1. Definitions

Main areas considered in this research are:

- systems theory – complex systems,
- modularization – methodology and division of systems,
- information technology – agents, virtual environment,
- system implementation.

Frequently used terms are explained below.

International Council on Systems Engineering (INCOSE) defines a system as follows: "A system is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce system-level results. The results include system-level qualities, properties, characteristics, functions, behaviour and performance. The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are interconnected" [[11]].

Systems theory has long been concerned with the study of complex systems. Complex systems are of high dimensions, non-linear and hard to model. The need for systems engineering arose with the increase in complexity of systems and projects. When speaking in this context, complexity incorporates not only engineering systems, but also human organizations. At the same time, a system can become more complex due to an increase in size as well as with an increase in the amount of data, variables, or the number of fields that are involved. Systems engineering encourages the use of tools and methods to better understand and manage complex systems.

Various informal descriptions for complex systems have been defined, and these may give some insight into their main properties:

- a complex system is one that by design or function or both is difficult to understand and verify,
- a complex system is one in which there are multiple interactions between many different components.

Main properties of complex systems that can be highlighted are:

- highly structured system with variations,
- sensitive to small perturbations,
- difficult to understand and verify,
- constant evolution over time,
- multiple interactions between components.

Systems engineering proposes to divide complex systems into appropriate parts. One of the approaches can be modularization of the system.

The term "module" in this research is used for physical (product) or virtual (program) modules. For the definition of modules, different approaches can be used (DSM matrix, functional decomposition). Modules are used in this research for simplifying the description of the system (by dividing the system into manageable parts or subassemblies).

A module is a structurally independent building block of a larger system with well-defined interfaces. A module is fairly loosely connected to the rest of the system allowing an independent development of the module as long as the interconnections at the interfaces are well thought of [12,13]. By dividing a complex system by using modularization, shorter implementation process can be achieved.

In this article the implementation refers to actions from system selection, technology description up to the introduction of a real product. The system is defined in such a way that it is possible to develop it further during the time (that needs definition of the model and interconnections).

During the implementation process the software agents are introduced, which enable communication (links) between different system parts or modules. For the purpose of this study, we use "agent" as "an entity that performs a specific activity in an environment of which it is aware and that can respond to changes" [14].

### 2.2. System decomposition

The complexity of the systems causes problems, such as:

- integration of the system with real factory,
- implementing production technology for robot production,
- lack of competence in enterprise,
- development of jigs,
- economic and return of investments (ROI) calculations.

Complex system decomposition (system implementation) is possible by using different approaches. One of them is by dividing the system into layers by using related domains (for example: product technology, production system). The formation of different domain layers is then possible. As the layers include different information and knowledge it is feasible to use modularization. Modularization enables one to form different modules (product, process, program), which makes the system more manageable.

To form interconnections between different system layers two approaches can be used: 1) modularization and modules (information shared between modules in different layers), 2) agents (information and decisions shared between layers and their agents). For example, product module information can be shared for formation of program modules and an agent in product analysing layer can share information with the next layer or make decision about the product feasibility.

Each level of the system includes a different implementation process and it is possible to move between different layers and fill them with different information and connections. By splitting the implementation process to smaller, better manageable parts means that the introduction of complex systems will get more feasible for SME.

## 3. RESEARCH

### 3.1. Scope of the studies

During the research, three different system implementations are presented. These case studies include:

1) robot welding cell for mini-loaders (case 1), used for welding of mini-loaders base-frames, tools and lifting beams;
2) robot welding cell for cylinders (case 2), used for welding of cylinder tubes and cylindrical rods;
3) robot welding cell for the bed frame (case 3), used for welding of bed base frame components.

These systems are treated as complex systems. The main properties of the systems are shown in Table 1 (based on layers).

### 3.2. Definition of system layers

By dividing the system, three main directions must be considered: 1) physical world (real things and parts), 2) virtual world (3D models, policies), 3) information world (informational models, which connect the real and virtual world). Taking into consideration the implementation process, the system can be divided into parts using the main domains which arise during implementation. Each layer is determined by a concrete issue such as:

- process (what products are produced, how products are produced?),
- system configuration (what hardware is used for production?),
- installation (what steps are to be made for set-up?),
- variables, modules (which variables influence the system most?),
- program (how the production has to be set up?),
- simulation (can the system be implemented in real world?).

The division of the robot welding cells can be made based on this approach. The main features of the systems are shown in Table 1.

During the system implementation the following layers of the system can be defined.

1. Product analysing layer (technology charting). An example of the technology chart configuration is shown in Fig. 1. This layer includes information about modules, virtual reality models, agents and database modules.
2. System configuration layer (based on the technology analysis the system hardware can be selected). The virtual system configuration can be represented as shown in Fig. 2. This layer includes information about modules, virtual reality models, agents and functional diagram.
3. Simulation layer – testing the feasibility of the system and product by using virtual reality software (CAD, RobotStudio). This layer includes information about modules, virtual reality models, agents, functional diagram and technological modules.

**Table 1.** Robot welding cells and system properties

| Layer | Case 1 | Case 2 | Case 3 |
|---|---|---|---|
| Product technology (policies) | Lot of products, different requirements | Lot of products, similar requirements | Product family, similar requirements |
| System (hardware) | Big and complex system, flexible | Big system, flexible | Small system, less flexibility |
| Facility (virtual testing) | RobotStudio, CAD, Rapid, Omron | RobotStudio, CAD, Rapid, Omron | RobotStudio, CAD, Rapid, Logo! |
| Installation (facility) | Additional set-up in factory | Additional set-up in factory | Additional set-up in factory |
| Jig (hardware) | New product, additional jig | New product, jig upgrade | New product, new jig |
| Program (software, policy) | Lot of movements, sophisticated programs | Little movements, sophisticated programs | Lot of movements, simple program |
| Production (facility, policy) | Welding process complex, parameters | Special requirements for process | Mild requirements for process |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Drawing | 663237 | | | Welding parameters | v | w | I |
| | | | | | mm/s | m/min | A |
| Name ① | adapter | | | wld250v8sh11 ② | 8 | 7.5 | 250 |
| Module number | M_105.mod | | | wld100v2sh12 | 2 | 8 | 100 |
| Workstation | Station 2 | STN2 | | wld250v6sh11 | 6 | 7.5 | 250 |
| Workobject | Wobj663237 | | | wld250v10sh11 | 10 | 7.5 | 250 |
| Programming time | 700 | min | | wld200v6sh14 | 6 | 12 | 200 |
| ROBOT TIME | | min | | wld100v4sh16 | 4 | 8 | 100 |
| Welding time | 13 | min | | wld150v9sh15 | 9 | 9 | 150 |
| Positioning time | 5 | min | | weld100v6sh16 | 6 | 8 | 100 |
| Maintenance | 4 | min | | wld150v9sh15 | 9 | 9 | 150 |
| OVERALL TIME 1 | 22 | min | | wld200v8sh14 | 8 | 12 | 200 |
| Leadtime | | | | wld200v14sh14 | 14 | 12 | 200 |
| Jig setting time | 15 | min | | wld70v6sh19 | 6 | 10 | 70 |
| Loading time | 7 | min | | wld50w6u4 | 6 | 6 | 50 |
| OVERALL TIME 2 | 22 | min | | wld100v8sh16 | 8 | 8 | 100 |

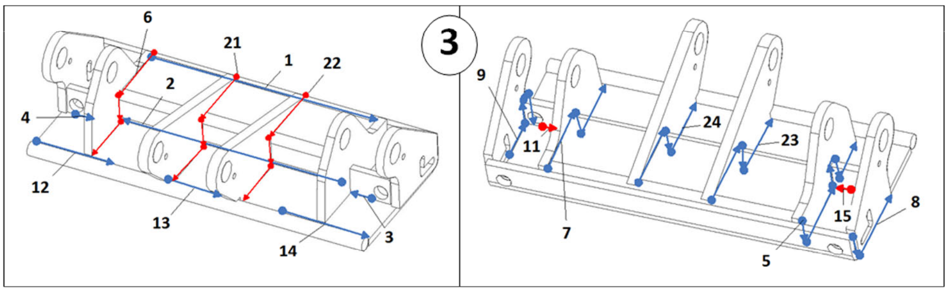


**Fig. 1.** Technology chart in robot welding cell in case 1 (area 1 – program parameters, area 2 – welding parameters, area 3 – welding directions and sequence).

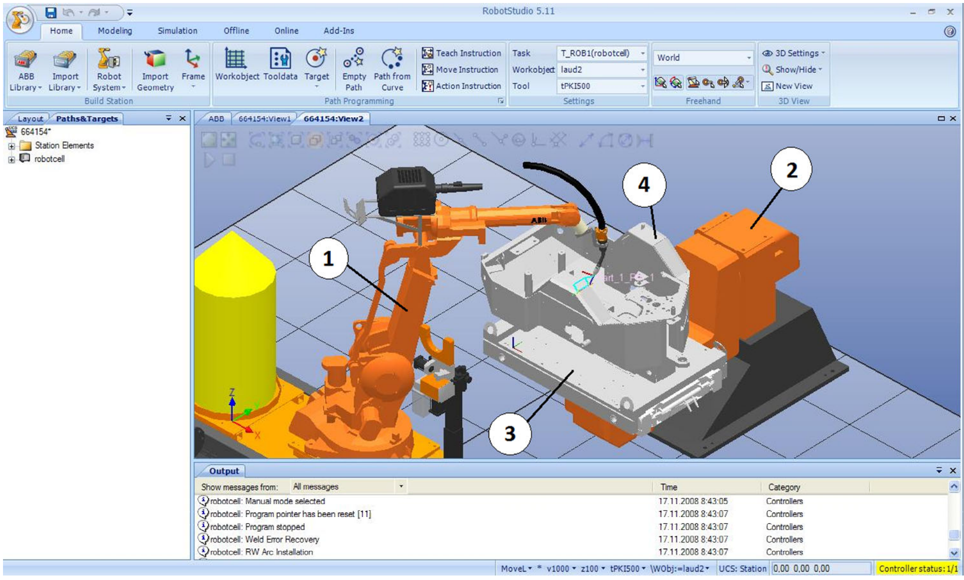


**Fig. 2.** Virtual environment for system and product testing in case 1: 1 – robot; 2 – manipulator; 3 – jig; 4 – product.

4. Facility layer – real system installation in factory. Also the CAD and virtual reality information can be updated. This layer includes information about agents and the functional diagram.
5. Installation layer – including all information and policies for support of the system installation in real factory. In Fig. 3 the topics included during installation are shown.
6. Jig layer – to connect the system and product with each other. This layer includes information about modules, virtual reality models and agents.
7. Program layer – includes program modules, welding positions and additional modules.

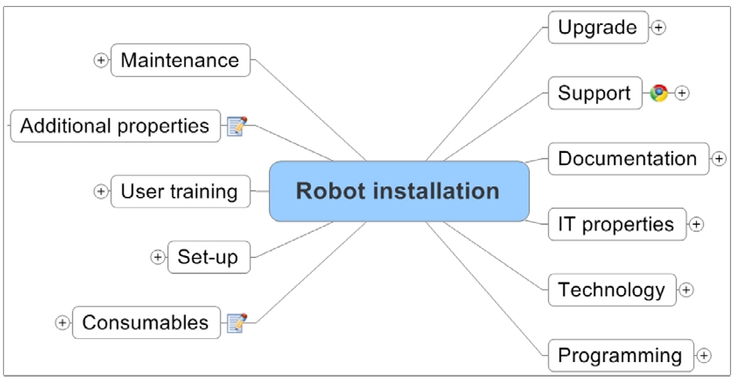


**Fig. 3.** System installation layer in the robot welding cell, case 3.

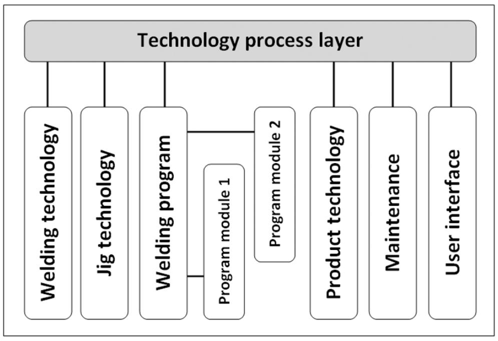


**Fig. 4.** Technology process layer.

8. Layer for the technology process – production in real world, welding parameters. In Fig. 4 the main issues concerning this layer are shown. This layer includes information about policies, modules and agents.

Modules can be associated with every layer where it is neccessary. Modules (product, process, program) represent the important data about the products or processes and help to share information between layers. For example, product technology module information can be used for production program modularization or for jig modules definition.

The next level of sharing information and decisions between layers is by use of agents. Their use can be helpful for making decisions about product suitability for production in robot welding cell or about jig suitability for concrete product production.

### 3.3. Virtual room integration for the complex system

By defining layers of the complex system, the visualization of information (knowledge) is helpful. The information extracted from system layers has to be clearly arranged. An arranged information model of a complex system is proposed. The proposed information model has a layered structure. Different levels of system layers information (hardware, software, policies) can be inserted into it. This information (knowledge) can be extracted during system implementation at different stages of the process. The proposed model is named “virtual information room”, acting as a carrier of the information (knowledge). The model can have as many layers as needed depending on the system complexity. The proposed virtual model is shown in Fig. 5.

This model can be filled with system information and process knowledge during the system creation phase. By having layered structure it is easier to grasp system properties and move between layers to understand interconnections between different parts of the system. Each layer can be suitably detailed. Also it is possible to move between these layers and to update them with additional information (knowledge).

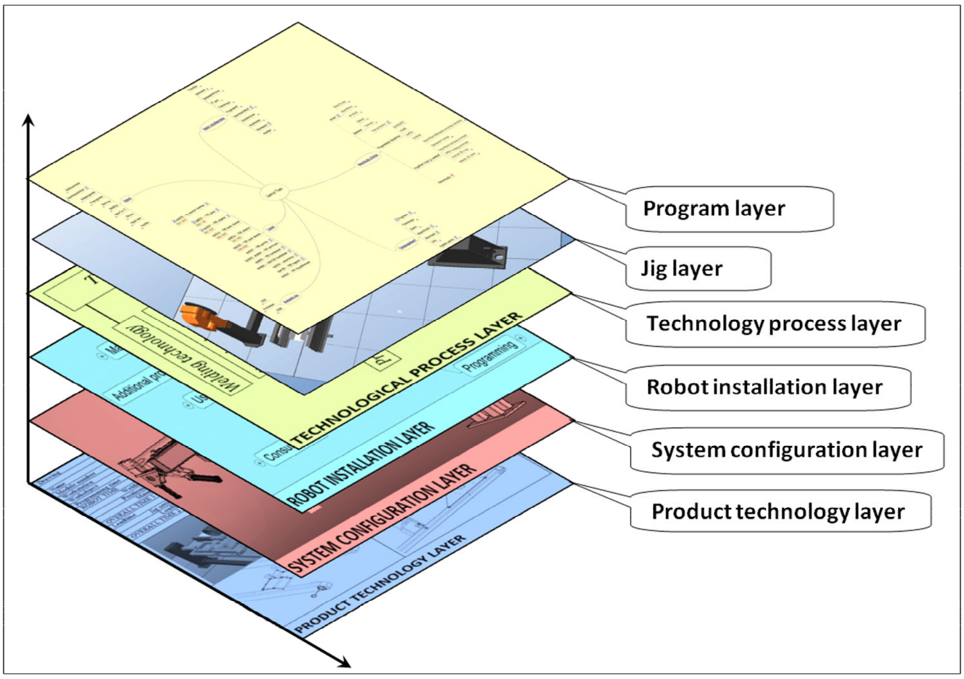


**Fig. 5.** Layered virtual room for complex system implementation.

By dividing the complex system into layers and by connecting layers with modules it is possible to use software agents, which enables the communication between layers. Information and decision sharing is shown in Fig. 6, where modules share information between layers and agents share decisions. Decisions by the agents are made based on several criterions, which are defined in the layer. For example, product suitability decision for robot welding is a multicriterion problem, where product dimensions, welding length, number of welds etc play important role on decision making. Because this is outside the scope of this paper, it is mentioned only briefly.

## 4. CONCLUSIONS AND RECOMMENDATIONS

The implementation of welding robot cells in SME-s is an increasing trend. The proposed system decomposition methodology, illustrated by case studies, may be advantageous for SME-s. The conclusions and recommendations based on this study are the following.

1. Implementation of systems using division of tasks enables one to introduce complex technologies in SME-s.
2. This study gives an approach how to share actions between different layers and to manage complex systems implementation.

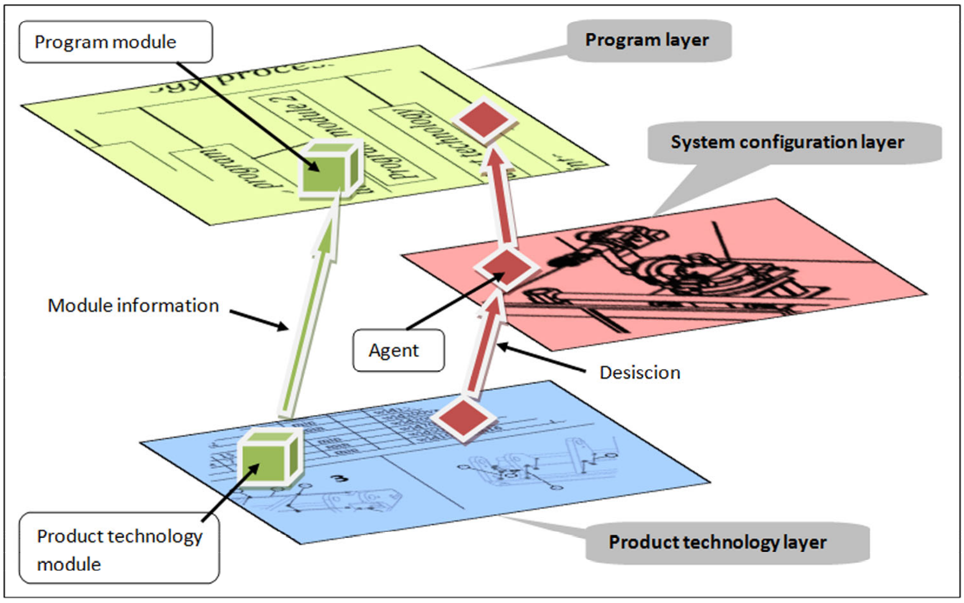


**Fig. 6.** Sharing information between modules and decisions between agents.

3. Layered approach helps to prevent problems during the system composition and boosts its implementation.
4. It is important to have good insight of integrated hardware module interface properties (robot, manipulator, jig, PLC, welding equipment).
5. Layered approach gives a better overview of the system and processes and the scale economy can be achieved.

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## Robotiseeritud keevituskompleksi juurutamine modulaarset lähenemist kasutades

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On käsitletud robotiseeritud keevituskompleksi juurutamist väikeseeria-tootmises, kasutades modulaarset lähenemist. Kuna taolised süsteemid on keerukad, siis tuleb nende juurutamisel kasutada lähenemist, mis võimaldab süsteemi hallatavateks osadeks jagada. Üheks selliseks meetodiks on süsteemi kirjeldamine, kasutades erinevaid kihte ja neis asetsevaid mooduleid. Lisaks on kasutusele võetud agentide mõiste, mis võimaldab mooduleid ja kihte omavahel siduda. Kasutatud lähenemise eeliseks on see, et süsteemi on võimalik aja jooksul täiendada (peenhäälestada), lisades vajalikke seoseid ja agente. Meetodit on testitud kolme erineva robotiseeritud keevituskompleksi juurutamisel.