Virtual commissioning of a robotized production cell with use of mechatronic features

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Abstract. In the work the way of the virtual commissioning of the robotized production cell with use of the mechatronic features (MOE) was presented. The preparation of a machine model or a production line for virtual commissioning can be divided into two basic stages. The first stage consists in creating a geometric form of the modeled system (Modeling and Assemblies modules). The second stage consists in preparing the created model for its analysis in the control context. This approach makes the described modeling process very time-consuming. In order to improve this process, it is proposed to use the mechatronic features method for modeling technical means in the context of their virtual commissioning. The mechatronics feature was defined as the set of: the functional features (FOE), the conjugation relations between FOE (RSF), the sensor features (SEOE), the signal features (SOE), the conjugation relations between FOE and SEOE (RSFSE), the conjugation relations between FOE and SOE (RSFS), the conjugation relations between MOE and the geometrical form of a cooperating subsystem with the control subsystem (RSMPG), and the transformation relation (RPM). The elaborated method of preparation of the virtual model of the mechatronic system allows to improve the process of the virtual commissioning.

1. Introduction
The continuous development of computer-aided systems of machines design and technological lines allows testing the operation of virtual mechatronic systems in the control context. The virtual commissioning of a mechatronic system model can take place with the application of a real or virtual control system. The virtual model of the technical mean and the program describing the operation of the future system are created in various programming environments. Ensuring correct data exchange between the model and the control system requires the use of an integrator. The method of integration depends on the capabilities of individual programming environments. The most popular means of communication between systems can include: the use of dynamic data exchange (DDE), the ActiveX technique and the use of an OPC server. In the Institute of Technological Processes Automation and Integrated Manufacturing System, numerous research works are carried out related to the control of automated and robotized systems [1-8] with particular emphasis on the safety system and diagnostics of technical means [9-13]. There are also works in the field of integration of programming environments with the use of dynamic data exchange, ActiveX technique and the OPC server [14-23], where the virtual model of the actuator system of the control one of the given machine with is subject to integration with the virtual control system. The paper presents an example of virtual operating of a robotized manufacturing workcell in the context of its control. The OPC server is an integrating element of the
virtual manufacturing workcell model with a virtual control system. On the other hand, the model of the control system is presented in the description form basing on mechatronic elementary objects.

2. The object of the virtual operation
The modular automated production workcell consists of (figure 1): the robot with the welding system (1), the rotary table with the set of electrical clamps (2), the cooling system (3), the control system (4) and the modular system of floor plates (5). The main goal of operation of the robotized manufacturing workcell is the permanent joining of elements using the welding process. The process of elements joining using welding technology can be presented in the following steps:

- opening of the gate securing access to the workcell during its operation,
- placing of the connected elements, by the operator, in the handles of the rotary table,
- closing the security gate,
- gripping of connected elements by means of clamps,
- rotation of the table with gripped elements,
- starting the robot and performing the press welding process,
- moving away of the robot to a safe position,
- rotation of the table with a ready element,
- opening of the clamps,
- opening the safety gate,
- removing of the welded part.

![Figure 1. The robotized production cell.](image)

One of the main design tasks in relation to the robotized manufacturing workcell was to develop the modular system of floor plates. This system allows the robot to be correctly positioned, relative to the rotary table with installed clamps and mounted elements that should be connected. To develop the described system, the design methods based on knowledge and experience as well as features method were used [24-25].

3. Definition of the mechatronic feature
In order to speed up the works associated with the preparation of the model of the robotized manufacturing workcell for virtual operation, analyzed in this paper, the method of mechatronic features (MOE) was used. The mechatronic feature refers to a single drive along with its logic of operation
(figure 2) and consists of:

- functional features (FOE), which represent the geometric form of MOE components and fulfill a specific function in its area,
- coupling relationships (RSF) between FOE objects that determine their way of behavior,
- sensory features (SEOE), which determine the state of MOE by determining the positioning of FOE objects,
- coupling relationships between FOE and SEOE objects that arise from the way of coupling between SEOE and FOE objects,
- signal features (SOE), which on the basis of RSFSE provide information on the MOE status to the integrator,
- transformation relation RPM associated with the given MOE,
- coupling relations between MOE (RSMF),
- coupling relations between MOE and the geometric form of the entire system (RSMPG).

**Figure 2.** The scheme of description of the mechatronic feature.

The definition of a mechatronic feature as a set of FOE, RSF, SEOE, RSFSE, SOE, RSMF, RSMPG and RPM shows the dependence 1.

\[
MOE^{PUS}_{i} = \left\{ \begin{array}{l}
(FOE_{1}^{i}, FOE_{2}^{i}, ..., FOE_{n}^{i}) \\
(RSF_{1,2}^{i}, RSF_{2,3}^{i}, ..., RSF_{n-1,n}^{i}) \\
(SEOE_{1}^{i}, SEOE_{2}^{i}, ..., SEOE_{m}^{i}) \\
(RSFSE_{1,1}^{i}, RSFSE_{1,2}^{i}, ..., RSFSE_{n-1,n}^{i}) \\
(SOE_{1}^{i}, SOE_{2}^{i}, ..., SOE_{m}^{i}) \\
(RSMF_{1,2}^{i}, RSMF_{1,3}^{i}, ..., RSMF_{n,1}^{i}) \\
(RSMPG_{1,2}^{i}, RSMPG_{1,3}^{i}, ..., RSMPG_{m,n}^{i}) \\
RPM^{i}
\end{array} \right\}
\]

where:
\[ MOE_{i}^{PUS} \] – mechatronics feature \( i \) included in the control sub-system \( PUS \),
\[ FOE_{j}^{l} \] – functional feature \( l \) included in the mechatronics feature \( i \),
\[ RSF_{n,i}^{l} \] – coupling relation between functional features \( n \) \( i \) \( l \), included in the mechatronics feature \( i \),
\[ SEOE_{p}^{i} \] – sensory feature \( p \) included in the mechatronics feature \( i \),
\[ RSFSE_{i,t}^{FOE,SEO} \] – coupling relation within the mechatronic feature \( i \) with the number \( t \), in relation to the functional feature \( foo_{j}^{l} \) and sensory feature \( seo_{j}^{l} \),
\[ SOE_{m}^{i} \] – signal feature \( m \) included in the mechatronics feature \( i \),
\[ RSMF_{i,k}^{FOE,FOE} \] – coupling relation between mechatronic features \( i \) and \( k \), in relation to the functional features \( foo_{j}^{l} \) and \( foo_{j}^{l} \),
\[ RSMG_{i,r}^{FOE,PG} \] – coupling relation between the mechatronic feature \( I \) and the geometric form of the entire system \( U \) with the number \( r \), in relation to the functional feature \( foo_{j}^{l} \) and the geometric form of the entire system \( p_{g}^{w} \),
\[ RPM_{i,j}^{l} \] – transformation relation associated with the mechatronic feature \( i \),
\[ i,j,k,l,m,n,p,r,t,u,w = 1,2,...; s \in N. \]

4. Virtual operation of the robotized production cell using mechatronic features and the virtual controller

The 3D model of considered system was prepared in the Mechatronics Concept Designer module of the PLM Siemens NX software. The program which describes the operation of the virtual model was implemented in the Automation Studio software of the B&R company. In order to integrate both programming environments the server OPC BR.OPC.Server_3.0_V1.14.19 was used. The server allows exchanging the information between the Mechatronics Concept Designer module of the PLM Siemens NX software and the virtual controller.

Preparing the model of a robotized manufacturing workcell for integration with a virtual control system consisted in defining objects corresponding to the functions of individual sets of MOE objects. The following groups of objects have been defined in the model (figure 3):

- “Basic physics” – these objects include geometric forms of the components of the robotized workcell in relation to which physical properties are assigned (e.g.: piston rods of the actuators). One object can contain any number of elements that do not change their position with each other during the movement. These objects are represented in the structure of the model description using MOE concept as a FOE set.
- „Joints and constraints” – these objects define the path and range of movements with respect to the objects of the “basic physics” type. These objects are represented in the structure of the model description using MOE concept as a set of RSF and RSMF and RSMG.
- „Sensors and actuators” – objects of the “sensors” type determine the system state resulting from the changing position of the moving objects of the “basic physics” type. These objects are represented in the structure of the model description using MOE concept as the SEOE set. On the other hand, the “actuators” type devices determine motion parameters (velocity, displacement) of “basic physics” objects in accordance with the dependencies defined in “joints and constraints” type of objects. These objects are represented in the structure of the model description using MOE concept as RPM.
- "Signals"—these objects are the carrier of information about the state of the system obtained from objects of the “sensors” type and determine its operation. These objects are represented in the structure of the model description using MOE concept as SOE file.
- "Signals adapter"—these objects are used to exchange information between the virtual 3D model of the executive system and the integrator.

![Figure 3](image)

**Figure 3.** The model of the actuator prepared to the integration.

The SEOE features, created in the 3D model of the robotized manufacturing workcell, determine its current state and transmit it via SOE features and integrator (OPC server) to the virtual control system. The state of the system is understood as the position of its individual elements (FOE) during its operation. In the system being considered the displacement may be related with: clamps that are driven by linear motion electric motors, the rotary table which is driven by an electric motor of rotary motion, a safety gate that is driven by an electric motor of rotary motion, robot arms that are driven by electric motors of rotational movement and electrode of the press welding head, which is driven by a linear motion electric drive.

Therefore, within the robotized manufacturing workcell, three groups of SEOE can be distinguished. The first group is associated with the registration of the positions of electric drives, the second - with the registration of the position of elements associated with moving elements of drives, the third - with the registration of the position of the joined elements. On the basis of the information about the system state, the virtual control system “makes” the decision on the behavior way of the drives (RPM) of the manufacturing workcell and the program performed by the robot and transmits it to the executive system model via the integrator and SOE features.

In the work it is assumed that the virtual PLC controller has a superior function in relation to the executive components of the manufacturing workcell, including the industrial robot. The robot's readiness for operation is signaled by the control lamp. Only in this mode it is possible to activate the manufacturing workcell operation from the level of the virtual control system. In addition, the prepared robot control panel is used for initial verification of the robot's location in the area of the workcell. Controlling the robot is in this case is intuitive, as it is in the case of the actual control panel in terms of movements in the robot's internal system (JOINT). Virtual operation is possible thanks to the integration of both environments (figure 4).

The control program, created in the virtual controller with regard to the listed drives of the manufacturing workcell and control panel, was written in the “Structured text” programming language.
5. Conclusion

The use of mechatronic features method to describe the 3D model of the robotized manufacturing workcell allows preparing the model for its activation in the context of control.

The created industrial robot control panel, using the Automotion Studio software, enables the initial verification of the robot foundation in the area of the manufacturing workcell taking into consideration the possibility of reaching by the head with the gun welder to the specific position.

In order to speed up the work related to the preparation of the model of the executive system for virtual operation, it is necessary to develop the database of mechatronic features.

The application of the integrator, in the form of the OPC server, and SOE objects enables the exchange of signals between the 3D virtual model of the robotized production cell and the virtual controller.

The described way of the integration of the 3D virtual model of a robotized production cell with a virtual controller enables on minimize the risk of incorrect working of the real system.

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