Industrial Cyber-Physical System for Lenses Assembly: Configuration Workstation Scenario

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***Abstract*—The paper presents industrial cyber-physical system for two robots interaction in configuration workstation for lenses assembly. Robots interact with each other through the smart space infrastructure, which is developed based on Smart-M3 information sharing platform. Authors focus on the reference model of proposed system and its implementation for flexible automated assembly line (agile automated assembly line «3AL») accessible in the research laboratory of the ITMO University.**

I. Introduction

The fourth industrial revolution (Industry 4.0) - developing a new paradigm of intelligent manufacturing systems based on Internet of Things, internet services, cyber-physical systems, and cloud technologies. Industry 4.0 has to work together with the people and talk to them directly, using smart devices and human-machine interfaces, not only in the future, but in today's industrial production in real time [1-2]. Evolution from computer integrated manufacturing (CIM) to Industry 4.0 is shown in Fig. 1. This problem has been considered by the authors in [2-6]. Today, many industries are already beginning to apply methods and solutions of Industry 4.0 [7-9].

Internet of Things makes constant sensing and monitoring, which is made on the basis of interpretation of the state of objects, production, produced forecasts, recommendations, plans for real action. Cyber-physical systems provides possibilities of permanent and temporary domain-specific communities self-organization [11]. These systems has heterogeneous nature: biological, cognitive, social and semantic. The number of cyber-physical systems participants can be changed during the system operation. They can use as various communication and mobile intelligent devices for interaction as platforms with regularly updated functions.

Trend towards to small-scale and a large number of variants of products requires the technological processes rapid development of their production on the spot. The components of technological production systems must be able to communicate with each other [12], which is achieved by means of communication technologies of automatic object identification as well as the standards and specifications of FIPA [13].

Modern materials, components, products, process equipment, accessories, tools, containers, packaging, and other often have a built-in system of micro and nano-sensors, chips, and mechatronic micromodules that allow them to be perceived as "smart" intelligent agents. This approach allows to self-organize into unified smart-cells to enhance the intellectual capabilities of the whole technological system. Interaction of the system is carried out, including using different algorithms of artificial intelligence.

In the research laboratory of the ITMO University the prototype of a flexible automated assembly line (agile automated assembly line «3AL», see. Fig. 2) has been developed. It consists of two circuit reconfigurable Montech transport line (Zone *1* and Zone *2*), interconnected by automated warehouse. In Zone *1* operations measurements and initial equipment are performed while in Zone *2* controlling and final product assembly operations are performed. Along the transport line workstations with FESTO[1] and other automated equipment are installed.

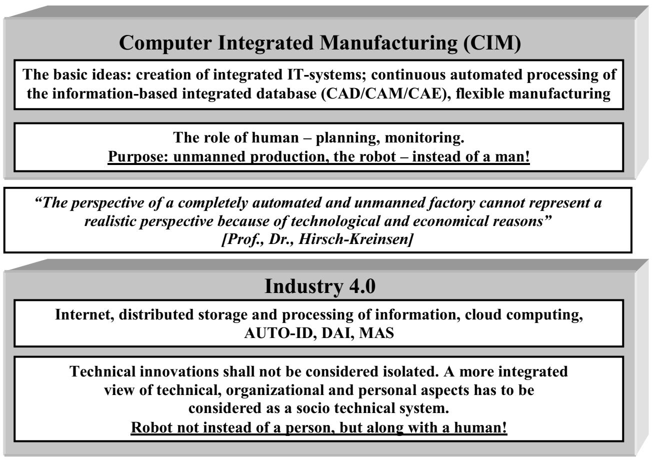

Fig. 1. Evolution: from CIM to Industry 4.0 (adapted from [14])

1 Festo AG & Co. KG, http://www.festo.de

The paper presents a smart space-based cyber-physical system for configuration workstation. The scenario consists of two robots: pick-and-place and assembly. For both robots a controlling software has been developed. For their interaction the Smart-M3 information sharing platform has been used [15]. Platform provides possibilities to organize ontology-based robots interaction that improve their semantic interoperability. The platform makes possible to significantly simplify further development of the system, include new information sources and services, and to make the system highly scalable. The key idea of this platform is that the formed smart space is device, domain, and vendor independent. Smart-M3 assumes that devices and software entities can publish their embedded information for other devices and software entities through simple, shared information brokers. Platform is open source and accessible for download at Sourceforge[2].

The rest of the paper is structured as follows. Section II presents technological process description for lenses assembly. The reference model of proposed Industrial Cyber-Physical System for Lenses Assembly is given in Section III. Implementation is described in Section IV. Main results are summarized in Conclusion.

II. Technological Process

Let us consider of the workstation "Configuration and assembly gluing "the lens in the frame" (Configuration Workstation). Robot *R1* (Fig. 2) receives an order from a warehouse (Fig. 2, Warehouse). There are two containers are accessible in warehouse: container with lenses and container with frames. The robot *R1* takes from warehouse a container with frames and puts it to the self-controlled shuttle located at the *S1* (Fig. 2, *S1*). When the shuttle leaves *S1* the robot *R1* puts to the next shuttle container with lenses. Both shuttles are going to the Configuration Workstation. In this workstation robot *R2* (Fig. 2) transfers containers to the workstation "Packaging arrangement".

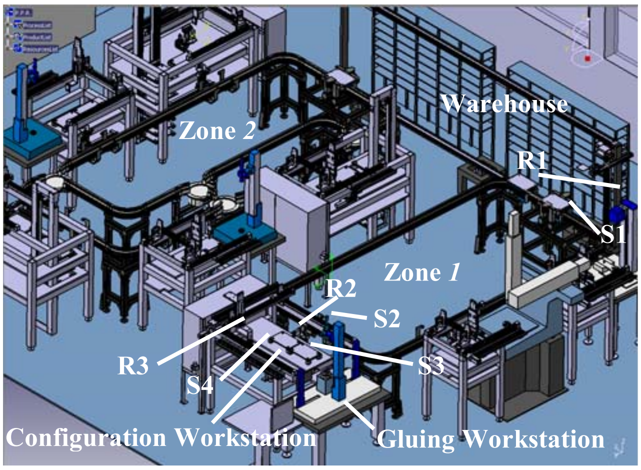

Fig. 2. Automated assembly line «3AL»

[2] Smart-M3 at Sourceforge, URL: http://sourceforge.net/projects/smart-m3

Robot *R3* (Fig. 2) performs assembly manufacturing operations at the workstation. After complete assembly, the container is transferred to the Gluing Workstation (Fig. 2, Gluing Workstation). Then the glued unit (lens in frame) is installed in the container. The algorithm is repeated for all glues. After this operation, the Robot *R2* (Fig. 2) shifts containers on an empty shuttle, located at the workstation. The shuttle is moved to the next workstation.

After completing described operations in Zone *1* shuttle with details is transferred to Zone *2*. In Zone *2* workstations perform other technological operations, up to the final product assembly.

This paper considers the process of *R1* and *R2* robots interaction at the configuration workstation where the equipment units «Lenses in the frames» are produced. Components for these units are the «Lens» and «Frame». Let's consider the process at the workstation.

1) Transport line moves the first shuttle with lenses to the Configuration Workstation.

2) The controller in the Configuration Workstation receives the notification that the first shuttle is located on the position S2. Container with lenses can be found in the shuttle.

3) Container with lenses is moved by the pick-and-place robot (R2) from the first shuttle to the table for the container with lenses (S4).

4) Transport line moves the second shuttle with frames to the Configuration Workstation.

5) The controller in the Configuration Workstation receives the notification that the second shuttle is located on the position S2. Container with frames can be found in the shuttle.

6) Container with frames is moved by the pick-and-place robot (R2) from the second shuttle to the table for the container with lenses (S3).

7) The manipulating robot R3 takes the lens from the lens containers, carries it in a container with frames and inserts the lens in the corresponding frame.

8) If a complete set of nodes is completed, go to step 8.

9) If a lens is missing (but assembly process is not completed) the container with lenses is moved by the pick-and-place robot (R2) to the shuttle. Then the transport line moves the shuttle to the Warehouse (S1) to get a missing lens. After that go to step 1.

10) If a frame is missing (but assembly process is not completed) the container with frames is moved by the pick-and-place robot (R2) to the shuttle. Then the transport line moves the shuttle to the Warehouse (S1) to get a missing frame. After that go to step 1.

11) Move the container with completed units (lens in frame) from the table to the shuttle. The shuttle is moved the container to the next workstation.

12) Set the station to the initial state.

III. Reference Model

Reference model of cyber-physical system for lenses assembly is presented in Fig. 3. The robots are participated in joint scenario for lenses assembly in physical space while they are interact and coordinate their activities in smart space. There are two robots enabled in the scenario: pick-and-place robot (*R2* in Fig. 2) and manipulating robot (*R3* in Fig. 2). Every robot has physical part that implement manipulations in physical space and controller that interacts with the special service through the REST API protocol. Special service is represent the robot in the smart space.

To provide semantic interoperability between robots their interaction in smart space is based on ontology. Every robot uploads its own ontology to the smart space ontology library when connects to the system. The ontology represents the robot model in smart space. It contains information about robot requirements and possibilities. Requirements represent the information that robot has to get for starting it scenario. Possibilities is the information that robots can provide related to the considered system. The ontology library in smart space merges the different ontologies uploaded by the interacted robots.

Implementation of the services has been developed using Java KPI library for Smart-M3 platform. Smart space access protocol (SSAP) is used for providing access for services to the smart space ontology library [15].

Software for robots control consists of a dispatcher module and several executive modules. This software is uploaded to the special controller that implements the robot control. The dispatcher processes control actions and choose related executive module that implements specific technological operations. The smart space service sends control action to controller through the REST API interface. Control action is determined by marker words (see Table I). Current robots's state is displayed into special state flags that have read-access and accessible for the smart space service through the REST API interface. It is accessible for the service by reading the marker words in controller.

Control action has the following structure: *device number*, *program number*, *parameter #1 value*, *parameter #2 value*, and *parameter #3 value*. To implement the *action data flag* should be set to "*1*". Current robot's state can be determined by *execution flag value*. If it is "*1*" then command is finished. If it is "*0*" then command is running. Sequence diagram (Fig. 4) of how marker words values changes are shown in figure.

For the pick-and-place robot the following operations have been developed.

- Move a container from transport line to Position 1.

http://[ip_addr.]/http_in_ci?ci:mmw52=1
http://[ip_addr.]/http_in_ci?ci:mmw53=1
http://[ip_addr.]/http_in_ci?ci:mmw50=1

- Move a container from transport line to Position *2*.

http://[ip_addr.]/http_in_ci?ci:mmw52=1
http://[ip_addr.]/http_in_ci?ci:mmw53=2
http://[ip_addr.]/http_in_ci?ci:mmw50=1

- Move a container from Position *1* to transport line.

http://[ip_addr.]/http_in_ci?ci:mmw52=1
http://[ip_addr.]/http_in_ci?ci:mmw53=3
http://[ip_addr.]/http_in_ci?ci:mmw50=1

- Move a container from Position *2* to transport line.

http://[ip_addr.]/http_in_ci?ci:mmw52=1
http://[ip_addr.]/http_in_ci?ci:mmw53=4
http://[ip_addr.]/http_in_ci?ci:mmw50=1

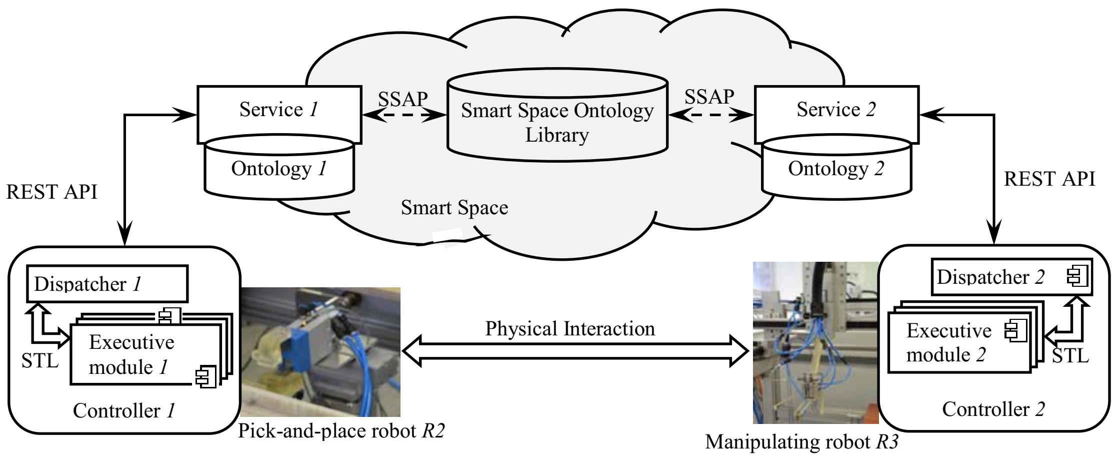

Fig. 3. Robots interaction in the cyber-physical system

Manipulating-robot has independent coordinate systems in horizontal and vertical planes. Position in horizontal plane is described by X and Y coordinates. Coordinates are specified in points. Step between points is 40 millimeters. Position in vertical plane is described by Z coordinate. Step between points in vertical plane is 20 millimeters. Coordinates are passed in control actions through parameters. For this robot the following operations have been developed.

- Move the gripper to horizontal position (X and Y coordinates are specified).

http://[ip_addr.]/http_in_ci?ci:mmw52=2
http://[ip_addr.]/http_in_ci?ci:mmw53=1
http://[ip_addr.]/http_in_ci?ci:mmw54=[X coordinate]
http://[ip_addr.]/http_in_ci?ci:mmw55=[Y coordinate]
http://[ip_addr.]/http_in_ci?ci:mmw50=1

- Move the gripper to vertical position (Z coordinate is specified).

http://[ip_addr.]/http_in_ci?ci:mmw52=2
http://[ip_addr.]/http_in_ci?ci:mmw53=2
http://[ip_addr.]/http_in_ci?ci:mmw54=[Z coordinate]
http://[ip_addr.]/http_in_ci?ci:mmw50=1

- Perform action with manipulator (Close, Open);

http://[ip_addr.]/http_in_ci?ci:mmw52=2
http://[ip_addr.]/http_in_ci?ci:mmw53=3
http://[ip_addr.]/http_in_ci?ci:mmw54=[0 or 1]
http://[ip_addr.]/http_in_ci?ci:mmw50=1

IV. Smart Space-Based Implementation

Considered scenario is a part of presented in the Fig. 2 Automated assembly line «3AL». It includes two robots: pick-and-place robot (Fig. 5 and Fig. 6) and manipulating robot (Fig. 7). The scenario requires 10 lenses and 10 frames. The result is a 10 units (lenses in frames). Operator at warehouse area puts container with 10 lenses on shuttle (see Fig. 8). Operator shares information (RDF triple) with the smart space using his/her mobile phone that the first shuttle (*shuttle_1*) contains lenses (*0* – lenses, *1* – frames):

(“shuttle_1”, “contains_object_type”, 0).

Transport line’s controller receives message, that first shuttle should be moved to configuration workstation. Transport unit moves to configuration workstation. When the shuttle leaves warehouse area, the operator puts

TABLE I. List of marker words for creating control action

Marker word	Name	Meaning
FW50	data flag	shows next command’s preparation state
FW51	execution flag	shows current’s command execution state
FW52	device	device number: 1 – pick-and-place robot 2 – manipulating robot
FW53	program	program number
FW54	parameter 1	parameter #1 value
FW55	parameter 2	parameter #2 value
FW56	parameter 3	parameter #3 value

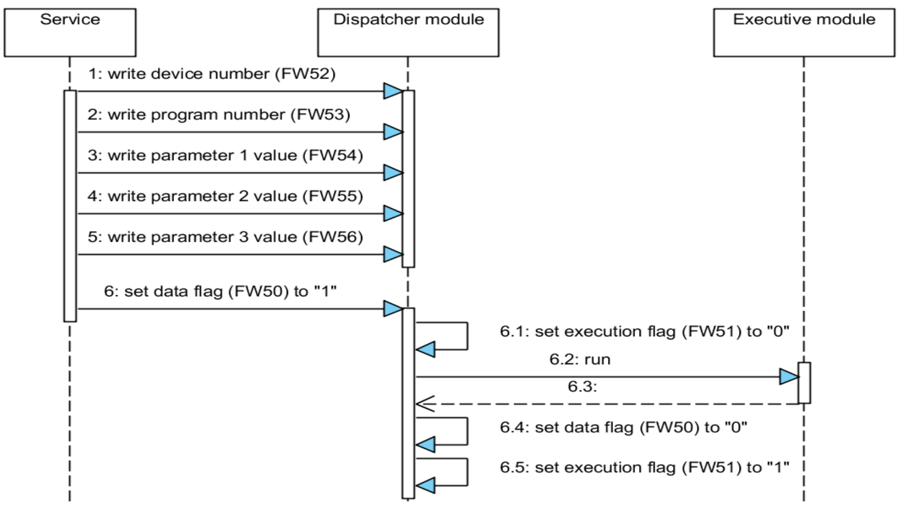

Fig. 4. Service and Control Block Interaction Specification through the REST AIP interface

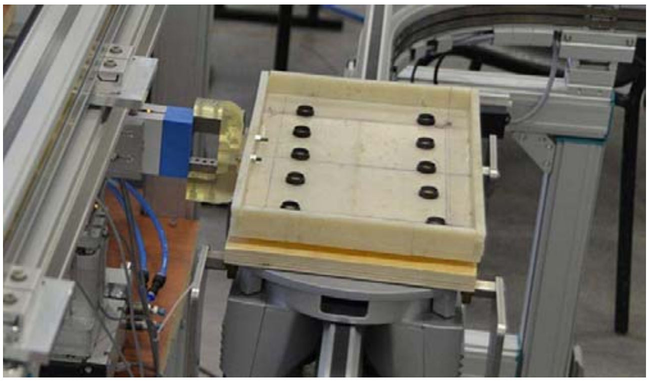

Fig. 5. Scenario: Shuttle at the Position for Pick-and-Place Robot

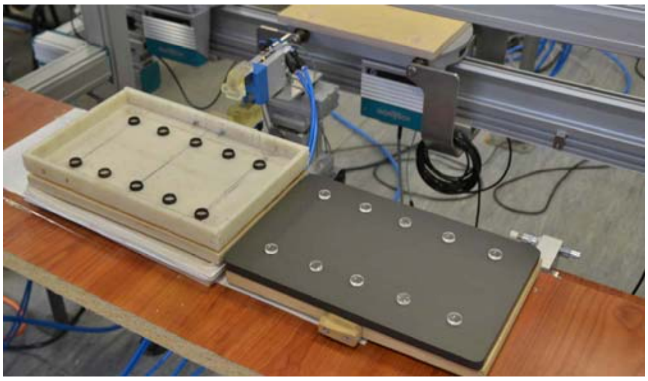

Fig. 6. Scenario: Shuttle at the Position for Manipulating Robot

container with 10 frames to the next shuttle (*shuttle_2*) and shares appropriate information with the smart space:

(“shuttle_2”, “contains_object_type”, 1).

After that, transport line moves the second shuttle to the configuration workstation.

The service of pick-and-place robot subscribes for the following triples:

(None, “reaches_configuration_station”, None),

(None, “assembly_process”, None).

When the transport line moves the first shuttle to the configuration station, it shares with the smart space the appropriate information:

(“shuttle_1”, “reaches_configuration_station”, 1).

The pick-and-place robot service receives notification, that the first shuttle (*shuttle_1*) should be unloaded. The service makes a query for smart space for determine type of object loaded to the shuttle:

(“shuttle_1”, “contains_object_type”, None).

Based on object type information the pick-and-place robot moves the container with lenses to the appropriate position (Position *1*) of Configuration Workstation. Then the service implement the same procedure for the second shuttle (*shuttle_2*) and moves the container with frames from the second shuttle to the Position *2* of Configuration Workstation (see Fig. 5 and Fig. 6). The information that containers are in Position 1 and Position 2 is shared with the smart space by the service of pick-and-place robot:

(“container_1”, “located_in”, “Position_1”),

(“container_2”, “located_in”, “Position_2”).

The service of manipulating robot subscribes for the following triple:

(“None”, “located_in”, “None”).

It receives notifications when the containers appear in Position *1* and Position *2*. When the both positions are occupied the manipulating robot service starts the assembly process. It generates the appropriate control actions for the manipulating robot controller (move to the first lens coordinates, move down, take a lens, move up, move to the first frame coordinates, move down). These manipulations are implemented for all 10 lenses. Then manipulating robot service shares with the smart space information that

Fig. 7. Scenario: Manipulating Robot

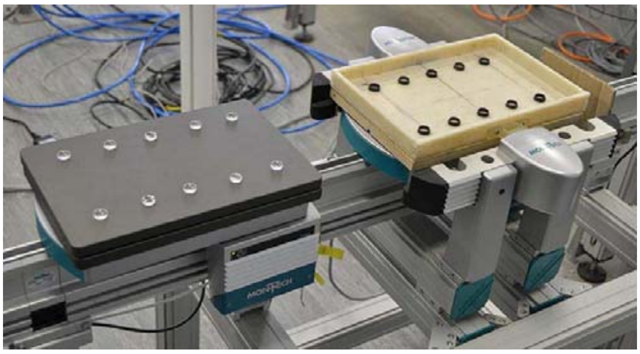

Fig. 8. Scenario: Shuttle at the Warehouse Workstation Position of Transport Line

Fig. 9. Controllers and Valve Terminals for Configuration Workstation

assembly process is completed:

("container_1", "assembly_process", 1)

The service of pick-and-place robot receives notification that the container with units (lens in frame) is ready to be moved to the transport line. Pick-and-place robot moves the container to the transport line.

Scenario has been developed based FESTO[3] equipment controlled by CPX-FEC device (see Fig. 9) that supports easyIP & Modbus protocols and HTTP requests.

V. Conclusion

The paper presents industrial cyber-physical system for two robots interaction in configuration workstation. The systems is based on Industry 4.0 concept that is a new paradigm of intelligent manufacturing systems based on Internet of Things, internet services, cyber-physical systems, and cloud technologies. Robots interact with each other through the smart space infrastructure which is developed based on Smart-M3 information sharing platform. Authors present the reference model of proposed system and its implementation for flexible automated assembly line (agile automated assembly line «3AL» accessible in the research laboratory of the ITMO University). For the implementation the special software for the robot controllers has been developed. This software allows to implement by this robots scenarios based on control actions. Control actions are implemented by the developed smart space services for every robots. The services are interact with each other in smart space and implement robots control in physical space.

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