Hybrid Automated Line Workstations Interaction Scenario for Optical Devices Assembly

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Abstract—**The paper propose a scenario for interaction of workstations in the hybrid automated assembly line. Presented scenario is a part of optical devices assembly process. For the interaction of workstations an ontology-based publish / subscribe self-organizing mechanism is used. For the scenario implementation, an appropriate 3D model has been developed with help of DELMIA modelling system. For modelling workstation interaction the services have been developed based on Smart-M3 information sharing platform that provides possibilities for information sharing and ontology-based publish / subscribe mechanism between different services in a common space.**

I. INTRODUCTION

Optical devices assembly contains a list of operations that have to be implemented sequentially for every optical device (lens) by set of workstations. The task looks like simple for automation; however, the processing time for every workstation can be different and depends on lens type. In this case, to reduce workstations downtime and increase assembly process it is proposed to implement control by automated assembly line based on workstations self-organization in according with current situation in the assembly. Self-organization is the mechanism or the process enabling a system to change its organization without explicit external command during its execution time [1]. Workstation self-organization referred to a fourth industrial revolution (Industry 4.0) that aims at developing new paradigm of intelligent manufacturing systems based on Internet of Things, internet services, cyber-physical systems using smart devices that have to interact with each other for joint activities [2-3]. Today, many industries are already beginning to apply methods and solutions of Industry 4.0 [4]. For the workstations self-organization in the considered scenario publish / subscribe mechanism is used. Workstations are interacting in the smart space that allows them to organize joint ontology-based access to information and knowledge.

Scenario implementation has been implemented using 3D model of optical device assembly process. 3D model can be used for different purposes on every step of product's life cycle. For example, 3d model of an object can be used to find best design solution, and 3d model of a plant can help to find out best technological process order. If 3d model of a plant connected to external control systems it is possible to debug controlling algorithms.

DELMIA modelling system [5] is used for 3D model implementation. DELMIA with its "Assembly process simulation" module was used as a modelling system. It is possible to build a 3d model of an object and make this model "alive" by adding information about it activities. "Assembly process simulation" module can make kinematics modelling of assembly technological processes. As the results of this modelling general process complete time is calculated and also all possible collisions are revealed.

The developed model consists of set of workstations that processes the lenses and assembly line that delivers lenses from one workstation to another. For monitoring workstations and controlling assembly line a special services have been implemented. The services have been developed using python language. For interaction of these services, the Smart-M3 information sharing platform is used [6]. 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 [7].

The rest of the paper is structured as follows. Optical device assembly process is presented in Section II. Section III describes a 3D model for base micro lens assembly. Section IV presents smart space-based assembly line control implementation based on Smart-M3 information sharing platform. The results are summarized in Conclusion.

II. OPTICAL DEVICES ASSEMBLY PROCESS

Optical device assembly process has been considered on the example of base micro lens assembly (see Fig. 1, adapted from [8]). The base micro lens design consists of a base unified patterns of well-known design solutions, using basic optical details with known properties and aberrations to determine optimum performance and quality of the image formed with this lens.

ISSN 2305-7254

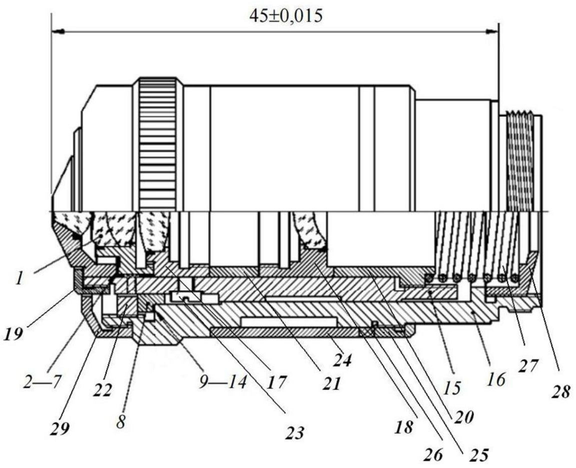

Fig. 1. The basic design of the base micro lens

The main distinguishing feature of this base micro lens is that all internal units (optical elements frames) have the same outer diameter and are installed in a domestic cup (pos. 15, Fig. 1), which can be moved and rotated in the body of the base micro lens (pos. 16, Fig. 1).

Technological processes of base micro lens assembling are logically divided into the integrated stages (see [9]). Stage 1 – assembling of the domestic cup, Stage 2 – domestic cup assembly control, Stage 3 - assembling the case, Stage 4 - control the case, Stage 5 - final assembly.

A. Stage 1. Assembling of the domestic cup (pos. 15, Fig. 1)

At this stage, all details are assembling in the domestic cup (pos. 15, Fig. 1). For this purpose, the following details are used:

- units «lens in the frame» (pos. 1, 17, 18, Fig. 1);
- seating rings (pos. 2-7,20, Fig. 1);
- screw-nut (pos. 19, Fig. 1);
- bushing (pos. 21, Fig. 1).

Internal units assembling for the domestic cup of the base micro lens (pos. 15, Fig. 1) can be carried out on one or another side of the domestic cup. To compensate the effect of details decentering in case of manual assembly the cup is provided with a holes for changing the position of the units «lens in the frame» (pos. 1, Fig. 1). In case of the automated assembly each internal unit is set with the rotation (around the base inner axis of the domestic cup) on certain angles. These angles are calculated by mathematical models of virtual assembly [8]. As a result correction seating rings is selected (pos. 2-7, 20, Fig. 1) that removes the spherical aberration.

Domestic cup assembling is implemented as follows. The seating ring (pos. 20, Fig. 1) is installed to the special device with a chuck and clamped. Then the domestic cup (pos. 15, Fig. 1) is twisted into the ring (not to the rest). Conmponents are put on the assembly stand taking into account their «virtual orientation» - the units «lens in the frame» (pos. 17 and pos. 18, Fig. 1), the bushing (pos. 21, Fig. 1). Then the stand is installed in the device with a chuck. After that, assembling details are gradually installed into the domestic cup (step by step).

B. Stage 2. Domestic cup assembly control

At this stage, the internal control of the domestic cup assembly is implemented. Assembly quality is determined by the quality of a control image got by special equipment. The control image quality of the domestic cup is carried out on the stand by measuring the image diffraction of a point and scattering function. If the energy concentration in the center (circle Erie) more than 80%, the domestic cup is assembled correctly and does not require any adjustment.

C. Stage 3. Assembling the case

All base micro lens details are collected in a single case. Assembling is performed taking into account actual values characteristics of units obtained by measurements and given by virtual assembly model, and with certain details orientation. Assembly units are adjusted to achieve a desired height of the base micro lens and the internal centering domestic cup. To build the case the following details are used (kit):

- domestic cup of the base micro lens (pos. 15, Fig. 1);
- body of the base micro lens (pos. 16, Fig. 1);
- seating rings for height (pos. 9 - 14, Fig. 1);
- rings (pos. 8, 22, Fig. 1);
- screw (pos. 23, Fig. 1).
- unit domestic cup is set to the special assembly device;
- in the domestic cup assembling unit two rings (pos. 19, 20, Fig. 1) are fixed;
- the screw (pos. 23, Fig. 1) is screwed in the assembling unit domestic cup;
- assembled domestic cup is removed from the device;
- the body (pos. 16, Fig. 1) is set to the assembly device;
- outer diameter of the body is lubricated;
- the assembled domestic cup is taken and installed in the case;
- seating rings (pos. 9 - 14, Fig. 1) are set in the case;
- the ring (pos. 8, Fig. 1) set it in the case;
- the ring (pos. 22, Fig. 1) in the local stock screwed it to the domestic cup.

D. Stage 4. Control the case

At this stage, height control of the base micro lens is implemented. Height of the base micro lens is depended of correctional seating rings (pos. 9-14, Fig. 1). A virtual assembly determines the dimensions of the ring. Height control is carried out with special measuring equipment. Measuring equipment compares the pattern image obtained from the reference base with pattern obtained from the assembled base micro lens. If the resulting image has valid values of blur then seating rings for height (pos. 9-14, Fig. 1) are matched correctly. If the error is greater than alignment tolerance then case turning is implemented to reach an acceptable value of error.

E. Stage 5. Final Assembly

For the final assembly of the base micro lens the following details are used:

- assembled base micro lens case;
- engraved ring (pos. 24, Fig. 1);
- ring (pos. 25, Fig. 1);
- colored ring (pos. 29, Fig. 1);
- lens hood (pos. 28, Fig. 1);
- spring (pos. 27, Fig. 1);
- nonmetallic ring (pos. 26, Fig. 1).

The following processes are implemented. The base micro lens case is set in the assembling device. The ring (pos. 22, Fig. 1) is fixed to the end in assembling the base micro lens case. The case is pulled out from the assembling device, turned over and set to the assembling device. Then the spring (pos. 27, Fig. 1) is installed in the case. After that the lens hood (pos. 28, Fig. 1) is screwed into the case. Then the gliding properties of domestic cup in the case is checking. Then the end of the lens hood is enameled. The engraved ring (pos. 24, Fig. 1) is mounted on the case (pos. 16, Fig. 1). After that the nonmetallic ring (pos. 26, Fig. 1) is mounted on the case. Moreover, the ring (pos. 25, Fig. 1) is screwed to the end. Then the engraved ring rotation checking is implemented (pos. 24, Fig. 1) and the ring (pos. 25, Fig. 1) is enameled. After that, the case is turned over and the other side is set at the assembly device. Then the colored ring (pos. 29, Fig. 1) is screwed to the case and enameled.

III. 3D MODEL FOR OPTICAL DEVICES ASSEMBLY PROCESS

3D model of optical device assembly process has been developed in DELMIA modelling system and consists of final assembly case assembly workstation model, workstation model, transport line model, warehouse model, base micro lens model (product), detail models, and models of other supply equipment. These models consist of standard models prepared by equipment manufacturer and models, which are specially constructed for this project. Isometric view of the flexible assembly line module is presented in Fig. 2. Unused parts are hidden and removed. Model of flexible assembly line consist of three components: processes, products and resources. Processes consist of all operations from modelled technological process. Products consist of products, details and supply tools. Resources consist of assembly workstations and technological equipment.

Operations from modelled technological process are located in process list (see Fig. 3). Every operation consists of group of simple activities. These activities are performed on objects connected with operation. These activities can perform position and location changes for objects (standard DELMIA activities), or can perform actions predefined by the user. These activities determine how model is changed during execution of the operation.

Products part collects all objects which are used as input and output for technological operations. Products, details and supply tools are placed here. For flexible assembly line model this part has shuttle model, container model, product and details models.

Resources part collects all objects that are used as technological equipment in operations. For flexible assembly line model, this part has case assembly workstation model, final assembly workstation model, warehouse model and transport line model.

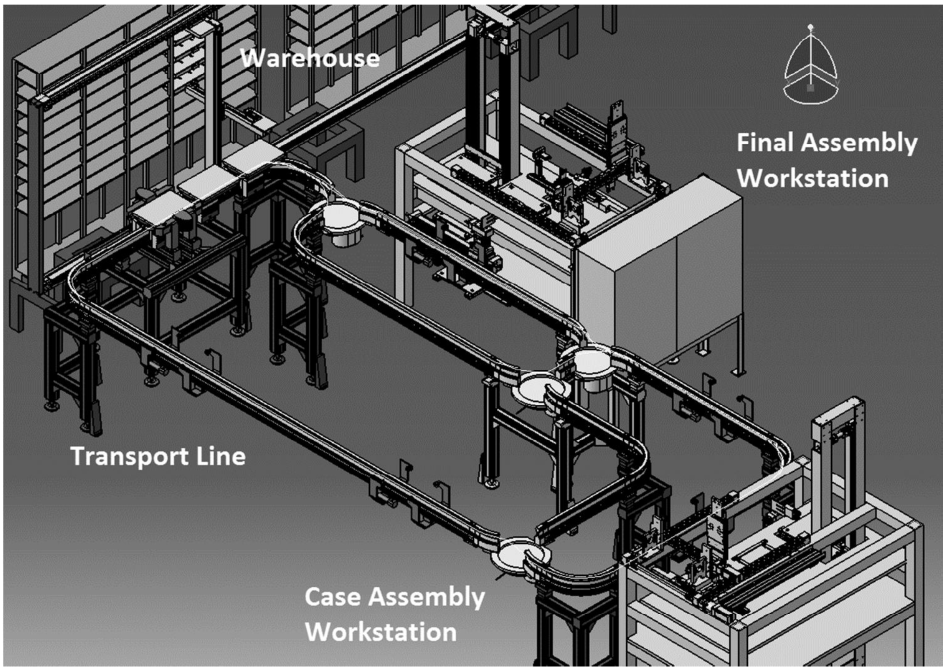

Fig. 2. Isometric view of the assembly plant

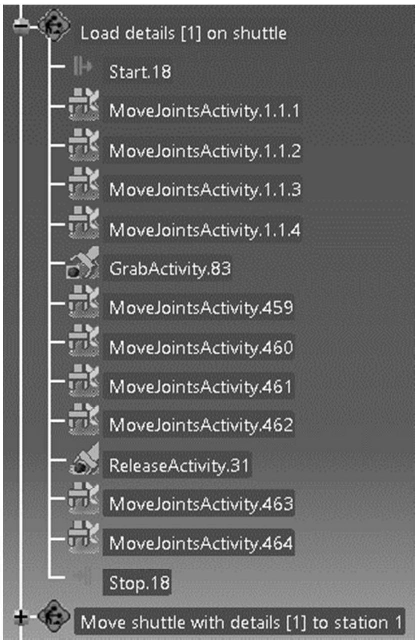

Fig. 3. Process list of operations from modelled technological process

Sequence of operations for technological process is determined on Fig. 4. To build this diagram, first all operations for technological process have been identified than they have been linked with each other. It is supposed that operation can start its execution only if all previous operations are completed.

Scenario uses four technological objects: warehouse, transport line, case assembly workstation (stages 1–4 from Section II), and final assembly workstation (stage 5 from Section II). Warehouse is used to store details (on stage 3 from Section II), units (on stage 5 from Section II) and products (base micro lens). Case assembly workstation (Workstation 1) is used to assemble units from details. Final assembly workstation (Workstation 2) is used to assemble products from units. Transport line is used to move objects between stations and warehouse. It is considered that time to assemble products from units is greater than time to assemble units from details, but time to move shuttles between stations and warehouse is the same.

In the presented scenario three products from three detail kits is assembled. Scenario starts when box with first detail kit is set on shuttle at warehouse (step 1). Transport line moves shuttle with first detail kit to station 1 (step 2). Station 1 assembles first unit kit from details; simultaneously, box with second detail kit is set on shuttle at warehouse (step 3). Transport line moves shuttle with first unit kit to station 2 and shuttle with second detail kit to station 1 (step 4). Station 2 assembles first product kit from units; station 1 assembles second unit kit from details; simultaneously box with third detail kit is set on shuttle at warehouse (step 5). As assemble operations on station 2 take more time than on station 1, station 1 finishes assembling earlier than station 2, so transport line moves shuttle with second unit kit to warehouse and shuttle with third detail kit to station 1 (step 6). Station 1 assembles third unit kit from details; simultaneously, box with second unit kit is removed from shuttle at warehouse (step 7). Transport line moves shuttle with first product kit to warehouse and shuttle with third unit kit to station 2 (step 8). Station 2 assembles third product kit from units; simultaneously box with first product kit is removed from shuttle at warehouse (step 9). Box with second unit kit is set on shuttle at warehouse (step 10). Transport line moves shuttle with third product kit to warehouse and shuttle with second unit kit to station 2 (step 11). Box with third product kit is removed from shuttle at warehouse; simultaneously station 2 assembles second product kit from units (step 12). Transport line moves shuttle with second product kit to warehouse (step 13). Box with second product kit is removed from shuttle at warehouse (step 14). This scenario is shown on Fig. 5.

IV. SMART SPACE-BASED ASSEMBLY LINE CONTROL IMPLEMENTATION

Implementation of the considered scenario has been done based on Smart-M3 information sharing platform. For every workstation a Smart-M3-based service has been developed that represents the workstation in smart space and implements communication with other workstation services. Services have been implemented using Python language.

A. Reference model of workstations interaction in smart space

For the assembly line control interaction between two services has to be supported. Interaction has been implemented

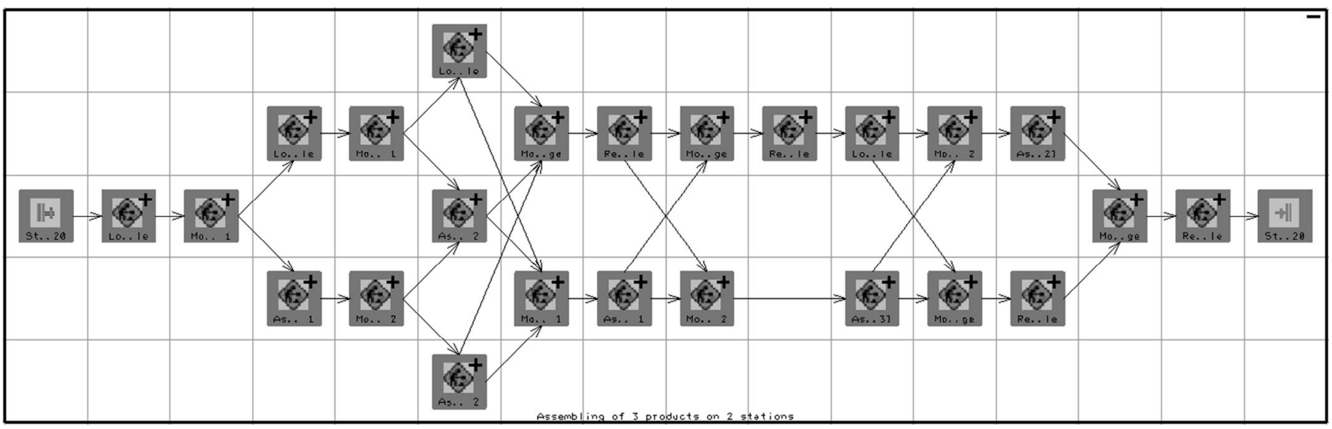

Fig. 4. Network PERT chart

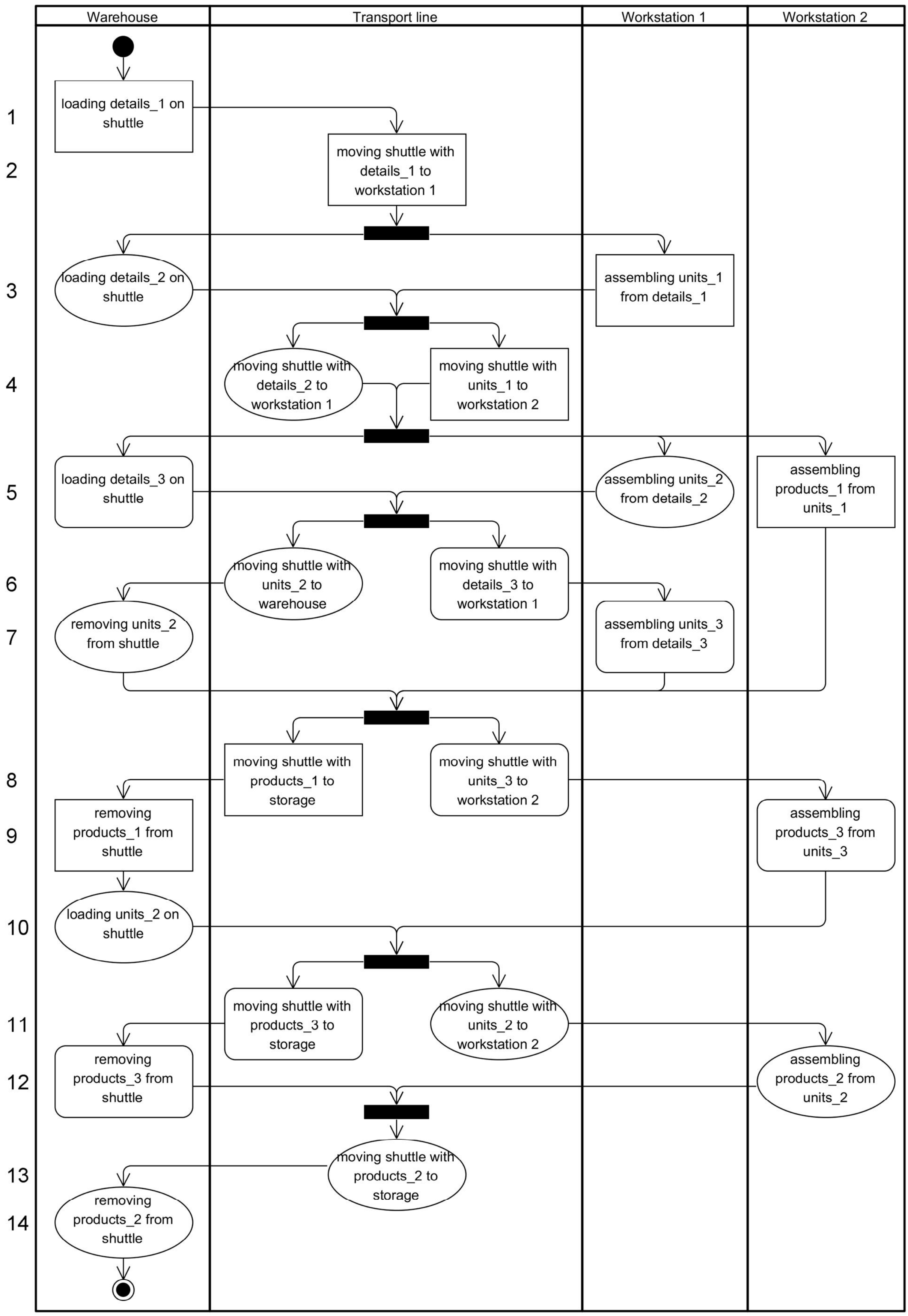

Fig. 5. Workstations interaction scenario

based on ontology-based publish / subscribe mechanism (see Fig. 6) that provides interoperability support between two workstation and provides them possibility for self-organization. Each workstation can publish information in smart space, which it would like to share with other smart space resources. If a workstation is waiting for needed information, it has possibility to make subscribe transaction for this information. Information is published using the ontology that conforms to the rules of the Resource Description Framework (RDF) [10]. In accordance with these rules all information is described by triples "Subject - Predicate - Object".

Abstract context is an ontology-based model integrating information and knowledge relevant to the problem. Operational context is an instantiation of the abstract context with data provided by information sources [11]. Service *i* influence to the environment (action *1*). It make correspondent changes to the operation context. Operational context of service *i* is matched with operational context of service *j* that is changed too in according with changes for operational context of service *i*. Changing of the service *j* operational context of causes the changing of it behavior and abstract context structure.

Abstract context is described by an ontology that has been created based on the micro lens assembly process description, presented before. The ontology is presented in

Fig. 7 and reflects main concepts of the modelled process. It includes classes for technological objects: “Warehouse” – to describe current state and parts stored in warehouse; “Transport Line” – to describe position of shuttles and details loaded in them;

“Case Assembly Workstation”, and “Final Assembly Workstation” to describe the assembly process on each workstation. Ontology also includes classes for details, units and products, that describe their main characteristics.

Information for the operational context is provided by services that are developed for each technological object, presented in the ontology. Services are also developed to control modelling process through the COM object provided by DELMIA. Knowledge processors are interoperating through the smart space by changing operational context according to the results of executed activity in the model. Interoperation process and knowledge processors are described below.

B. Warehouse service implementation

The warehouse service controls functions of storing details, unis and products. They can be loaded to or unloaded from shuttle at the transportation line. The type of required component is read from the ontology.

Service is subscribed to the event of shuttle arrival to the warehouse station on transport line. It is according to the following triple pattern has appeared in the smart space:

(<>, <#current_station>, <Warehouse>),*
where <*> is a shuttle ID. After the appropriate triple has been published in the smart space, the service updates his status to the “Busy” and checks content of the cargo at the shuttle. In the case of empty cargo, the warehouse service queries from the smart space a kind of component that should be loaded to the cargo. If this component could be found in the warehouse, the service loads it to the cargo on the shuttle; otherwise, the shuttle stays empty. Information about loaded component is publishing to the smart space:

(shuttle_id, <#hold>, components_set_id).

In case of any components already placed in the cargo, the warehouse service unloads it to the store. At the end of the operation, the warehouse service updates own status in the smart space to “Ready”.

C. Transportation Line service implementation

The transportation line service controls moving of components between the stations and warehouse. It contains map that provide routes between stations and warehouse to each component set. Shuttle is moved only in case of current and next workstations have statuses “Ready”. For this purpose, the transportation line service subscribes to the following pattern in the smart space:

(<>, <#status>, “Ready”)*

When shuttle’s origin and destination stations report “Ready” status, the transportation line service executes function of shuttle moving. After the shuttle reaches destination, the transportation line service updates shuttle’s current position in the smart space to the destination station.

D. Case assembly workstation service implementation

The case assembly workstation service controls the case assembling process. It requires details from the warehouse to build units. This service is subscribed to the event of shuttle arrival to the workstation’s station on the transportation line that is according to the following triple is published in the smart space:

(<>,<#current_station>, <Case_assembly workstation>)*

The case assembly workstation service changes status to “Busy” and starts assembly process described earlier in section 2. At the end of the process, assembled unit is loaded to the shuttle and station status is changed to the “Ready”. The transportation line service get this status by subscription and send the shuttle to the final assembly station if it has status “Ready” to start assembling of product, or to the warehouse otherwise.

E. Final assembly workstation service implementation

The final assembly workstation service is organized in similar way with the case assembly workstation service. It requires units to build final product. This service is also subscribed to the shuttle arrival event:

(<>, <#current_station>, <Final_assembly workstation>)*

After the assembling process is finished, the product is loading to the shuttle and sending to the warehouse. The warehouse service checks the shuttle and unloads the product to the storage.

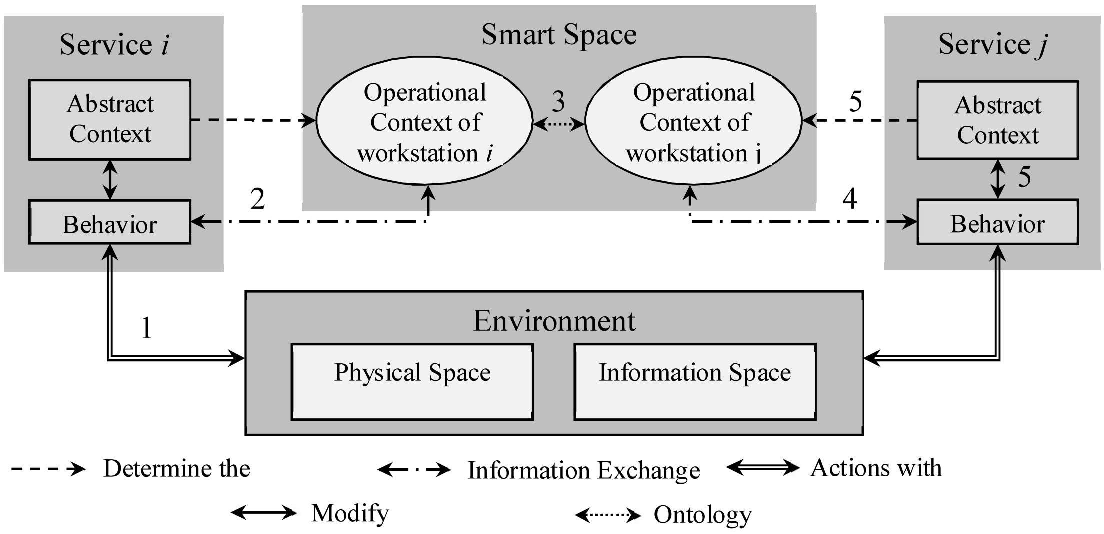

Fig. 6. Workstations interaction in smart space based on ontology-driven publish / subscribe mechanism

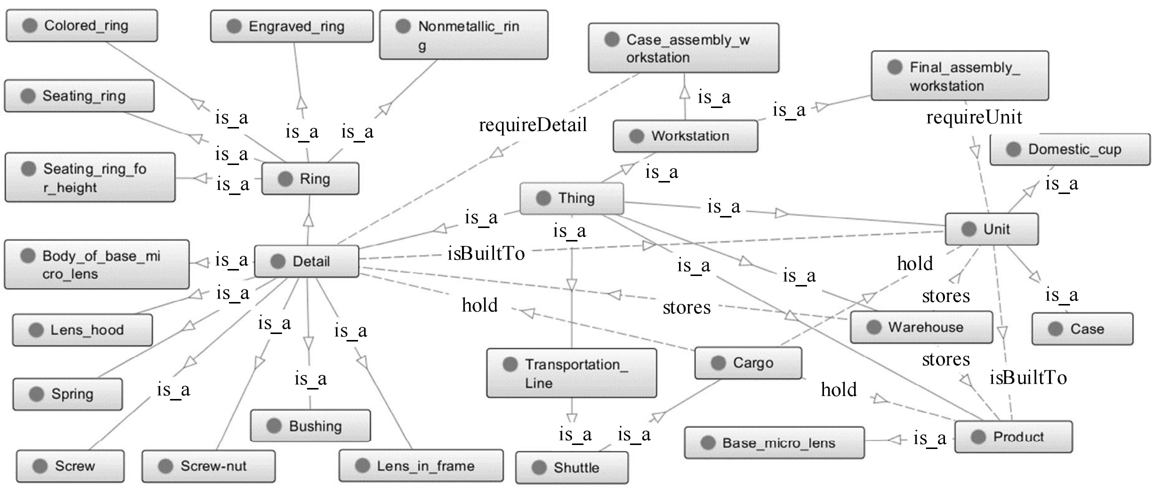

Fig. 7. Assembly line ontology

I. Conclusion

The paper presents a 3D model and implementation of smart space services for base micro lens assembly line control. Modelling has been implemented using DELMIA modelling system. For testing the base micro lens assembly process the services for assembly line control have been developed. These services share their information in smart space (interact with each other) and control workstations of 3D model. Modelling shows that presented workstations interaction approach is applicable for the hybrid automated line device assemble. Using the ontology-based publish / subscribe mechanism for the workstation interactions takes more time in compare than direct communication but significantly increase flexibility of such system (e.g., workstation can be changed by another one and scenario will continue in case of appropriate ontology model appearing of this workstation in smart space).

For the future work, authors are planning to implement the considered scenario flexible automated assembly line accessible in ITMO University.

Acknowledgment

The presented results are part of the research carried out within the project funded by grants # 16-07-00462 and 16-29-04349 of the Russian Foundation for Basic Research, programs # I.5, III.3, and # I.31 of the Russian Academy of Sciences. The work has been partially financially supported by Government of Russian Federation, Grant 074-U01.

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