The Perspective Flexible Manufacturing System for a Newly Forming Robotic Enterprises: Approach to Organization Subsystem Formation

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***Abstract*—This paper discusses the question of organization subsystem deployment as a part of The Perspective Flexible Manufacturing System for a Newly Forming Robotic Enterprises The general concept of the system is presented, the place of organizational subsystem in its structure is established. The representation of the organization subsystem for the specific technical case – robotic collaborative cell - is formed. The critical unit responsible for formation and control of simultaneous work of a human and a collaborative robot is developed. The process model and its detailed structure are developed, mathematical representation of the game-based model, image processing and matrix game submodels are formed. Initial modeling of image processing and matrix game submodels and the total game-based model were developed. Conclusions about the human and collaborative robot effective interaction are made, directions of further researches are defined.**

***Index Terms*—manufacturing system, multiagent system, organizarion subsystem, game-based model, robotic manufacturing, robotic enterprise**

I. Introduction

Within the framework of research and development of Perspective Flexible Manufacturing System (PFMS) for a Newly Forming Robotic Enterprises, mentioned in the work [1], as a science-driven product for a specific task, the authors put forward a hypothesis that it is critical to create a module for simultaneous work of a human and a collaborative robot (cobot) for organization subsystem. For this purpose, it is necessary not only to observe primary safety standarts requirements [2], but also to take a look on system representation of all organization subsystem elements. The purpose of this article is to test the hypothesis about formation and control of effective cooperation between a human and a cobot. To achieve this goal, the following tasks need to be solved:

-- to consider the system as a whole to determine the problem;

-- to develop an approach for the system research and development that would be appropriate and relevant at all stages of the system's life cycle;

-- to apply the obtained approach to solution for collaborative robotic cell for drilling and riveting of the aircraft panelling;

-- to analyse the results and define directions of further researches.

Manuscript received April 17, 2019; revised April 19, 2019.

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II. Concept

The PFMS under development is based on dynamic organization and observation subsystems [1]. Subsystems implementation and their mechanisms are shown on fig. 2. This effect is achieved due to the implementation features of the organization and observation subsystems. Organiziation subsystem is based on the multiagent system with dynamic mechanism of coalition formation [3-6], observation subsystem – end-to-end structural and parametric wavelet identification tool [7, 8].

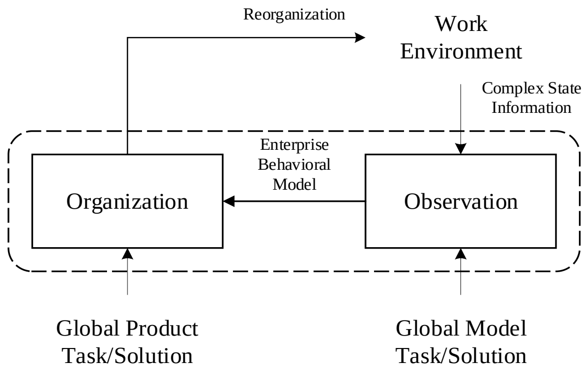

Fig. 1. Subsystems implementation and their interaction mechanisms

Consider the details of the organization's subsystem and its functions.

A. Organization level

The system used to organize manufacturing tools is a multi-agent group control system, that use a dynamic mechanism of homogeneous and/or heterogeneous coalitions formation [9, 10]. The implementation of such a mechanism brings the system closer to the hybrid control architecture. However, system formation rules are associated with the identification results in interpretation in real-time. The analysis of the modern multiagent architectures showed, that of greatest interest is the coalition model of the system, the essence of which lies in the formation of subgroups of agents. Each group may be

ISBN: 978-988-14048-7-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

considered as a separate self-sufficient system, and as part of the global system. For example, homogenous coalitions are good in a quick readjusting of the production line, heterogeneous - with the selected manufacturing process formation (fig. 2).

The following mechanisms of coalitions are considered:

-- homogeneous - localization of agents by type - “robot”, “equipment”, “human”;

-- heterogeneous - localization of agents according to their functional characteristics - the execution by agents of a single production operation.

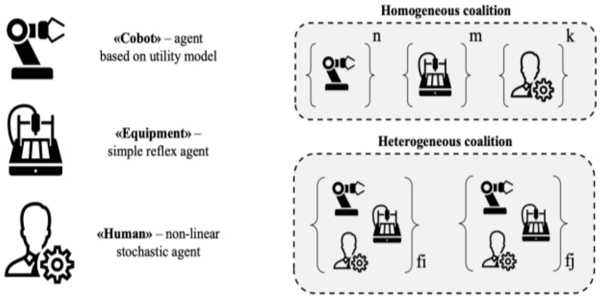

Fig. 2. Mechanisms of coalition formation

This approach will form the production line model in the most perspective way due to the similarity with the real workflow at the designated manufacturing divisions [11-13]. The mechanisms of coalitions formation can be considered as a one of the instruments of a flexible manufacturing systems, which allows to rapidly form groups for newly implemented manufacturing processes [14].

In this case, the module of formation and control of simultaneous work of the human and the cobot is reduced to the lower level of the cell within a heterogeneous coalition. This imposes a number of constraints, as there is an active intersection of the subsystem abstract representation with the work of real physical objects.

B. Organization subsystem detalization

The platform for the PFMS primary application is a collaborative robotic cell for drilling and riveting work on the aircraft panelling.

The functionality of the drilling and riveting works can be considered from the human and robot points of view. For the entity “Human” – *H* the monotony, in other words, the quantity of operations *q*, is the main factor of difficulty *Diff*. However, *H* has a high mobility level, that makes the contribution of reachability *d* to *Diff* relatively small and constant. For “Cobot” – *K* there is an opposite situation due to the constrained working area, while the monotony of the work does not affect its performance.

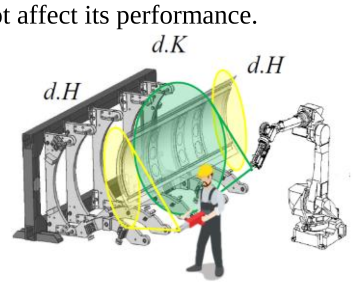

Fig. 3. Example of Human and Cobot working together: d.H - Human workspace, d.K - Cobot workspace

These dependencies allow concluding about the possibility of the highly efficient combination of simultaneous human and robot performance. The collaborative robot performs the most of monotonous operations, the worker is involved when performing operations in a work area inaccessible to the robot. Such a combination makes it possible to reduce the total operational time and overall labor intensity with minimal interference with the existing process.

Consider systematically the form and control task of the human and cobot simultaneous work against the background of the whole PFMS description.

III. Form and Control Task of the Human and Cobot Simultaneous Work

As an example the concept of manufacturing robotization is considered in the framework of the aircraft fuselage assembly. The essence of this solution is the simultaneous work of a human and a cobot within one technological process - drilling and riveting works.

The time spent on assembly operations is about 50-75% of the aircraft manufacturing cycle, and their labor input is 30-40% of the aircraft manufacturing labor input [15]. The main method of connecting the power units of the glider structure (spars, nerves and bends) is riveting. The drilling and riveting operations take about 30-45% of the labor intensity of assembly works. Drilling time is 30%, countersinking is 13%, rivet insertion is 4%, rivet riveting is 53%. Specifics of production, complexity of aircraft construction, variety of conditions of approach to the riveting zone determine the use of hand drills and riveting hammers, the use of which does not allow to achieve high productivity, does not guarantee the stability of the quality of connections and adversely affects the human body, causing such professional diseases as vibrational disease and professional hearing loss.

A. Requirements analysis

Based on the case, that abstract representation work of real physical objects have active intersection when developing the organization subsystem the following requirements to the representation of the module as a link were formed:

-- clarity - modeling of the unit at all stages of the life cycle should be close to the concept of a “white box”;

-- systematic - integrity on and below levels with other models;

-- ability to be scaled and detailed - sufficient flexibility of the mathematical apparatus;

-- appropriate - the adequacy of the display of real physical systems;

-- imitation - similarity in structure to real physical processes.

The sum of these requirements allows to form a single consistent methodology of unit modeling at the initial stage.

B. Methods and methodology

Proceeding from the formed requirements, the following method of model-oriented design with operation research [16, 18-19] the scheme of support models is proposed in fig.4.

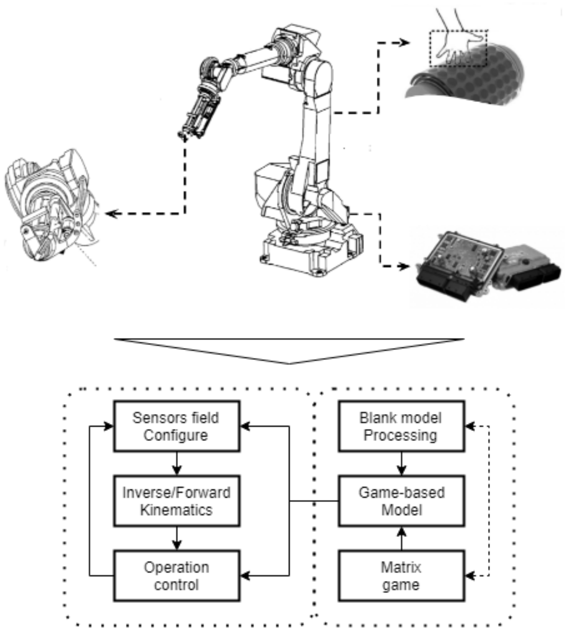

Fig. 4. Transfer to model-oriented representation

According to the figure, the following reference models are highlighted:

-- sensor field model - the task of configuration from the theory of operations;

-- inverse and forward kinematics - the task of quaternion algebra to obtain data on the current and possible positioning of the manipulator;

-- operational control - the task of point generation using the game model - step-by-step matrix machine.

Consider in more details the game-based model as a key point on the way to transparency and adequacy of further research. It is based on two submodels: the model of workpiece marking with the use of image processing and matrix game.

This matrix game is classified as [16, 20-21]:

-- discrete – with a finite number of players, steps, events, outcomes;

-- perfect information – all players know the steps previously made by all other players;

-- sequential dynamic – later player have some knowledge about earlier actions;

IV. Result

The total game-based model is described as the following method, that is used to compare the time spent in different human-cobot interaction mode. Fig.5 illustrates the matrix representation of the piece of aircraft skin panelling. Elements of the matrix characterize values of riveting complexity function Diff, that depends from distance of the skin hole to a panel edge and distance between skin holes. This information could be collected based on image or 3D-model of the panel.

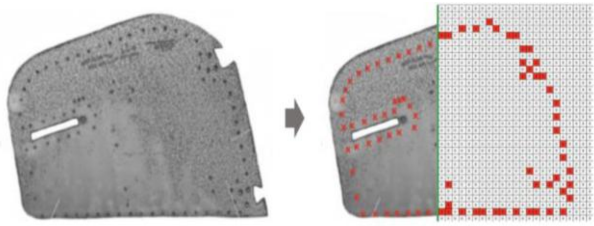

Fig. 5. Getting a matrix panel model

Further, in the cycle the vector-functions of mutual influencing entities "Human" - H and "Cobot" – K are implemented. They are characterized by a unique set of parameters, such as the working area, mobility, stock of rivets, fatigue, etc. The vector-functions sequentially change the values of matrix elements; when all matrix elements are zeroed, the cycle is interrupted. The following scenarios were considered: only the robot; only the human; the robot and the human in different operational proportions. The number of cycles directly reflects the relative contribution of vector-functions to the matrix zeroing.

V. Discussion

The first results of the modeling showed that the number of cycles for riveting joints when choosing the optimal ratio of vector-functions contribution is reduced by at least 1.5 times when using the simultaneous work of a human and cobot.

VI. Conclusion

The concept of robotic assembly of aircraft hull structures was proposed. A simulation methodology was developed to assess the productivity of cobot and human collaboration. It is confirmed that the combination of a cobot and a human allows reducing the total operational time to perform drilling and riveting works. Further, it is planned to implement the game-based model as cellular automatic machines and to generate rules of dynamic sharing of united for human and cobot workspace.

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ISBN: 978-988-14048-7-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

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ISBN: 978-988-14048-7-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)