Structure of Multifunctional Cooperative Robotics System based on the Ontological Approach

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Abstract. The conducted analysis of the known methods and decisions in the field of cooperative robotics shows that with a considerable number of effective decisions in the industry there are still a number of unresolved issues that are difficult to formalize and require the use of artificial intelligence components to solve them, among which the most important are the need for the representation of joint production environment, and the need to ensure that the relevant knowledge and information is clear for the Cobot(s). In this paper, the structure of the multifunctional cooperative robotics system based on the ontological approach is proposed. This system is based on ontology-based intelligent agents (OBIAs), all joint knowledge of the system is represented as ontologies. The developed structure of the multifunctional cooperative robotics system based on the ontological approach considers both cobots and humans as actants of the cooperative joint production environment, whereby they have access to all the tasks, messages, and joint knowledge of the multifunctional cooperative robotics system. The use of ontologies provides the following advantages for the developed system: processing of complex tasks and "understanding" of natural-language tasks and messages; planning and analysis of the information by each agent and the cobot; increasing the effectiveness of agents' and cobots' decisions; formalization of the "common sense" semantics; accelerating and improving the quality of processing natural-language information.

Keywords: Multifunctional Cooperative Robotics System, Cooperative Robotics Industry, Cooperative Joint Production Environment, Joint Knowledge, Ontology-Based Intelligent Agents (OBIAs).

1 Introduction

The use of autonomous industrial robots is now a key issue for Industry 4.0 [1]. Cooperative robotics is a new branch of industrial robotics that enables joint production. Cooperative production is largely dependent on the presence of a cooperative (collective, collaborative) robot (cobot). Cobot is a variant of an industrial robot equipped with a system of sensors and computer vision, which allows with a high probability of preventing a cobot from colliding with a person and obstacles. Such robots are intended for use in close collaboration with persons and next to people. The cooperative robot must have the following features: no need in integration (the whole system must be workable immediately); no need for programming or training (the robot must be ready to work in minutes); wide functionality; advanced logic for work considering the environment, including automatic disaster recovery; ensuring operational safety (even in a collision at full speed) [2]. The primary task of the cobot is to help solve complex non-automated tasks. Cobots change the concept of automation from fully-automated operations to semi-autonomous operations, where the employee's decisions will influence the actions of the cobot and vice versa [3].

To date, cobots have already been used successfully in the food industry (for example, the Mjolkursamsalan Ayureyri dairy plant (Iceland)), in electronics manufacturing (for example, at Paradigm Electronics (Canada)), in the automotive industry (for example, in cars assembly at SEW-Eurodrive in Baden-Württemberg (Germany), in the sewing industry for automated sewing (startup Sewbo), in the machine-building, in the metalworking industry, for packaging and palletizing, loading and moving, for product quality checks, in connection and telecommunication (startup Creating Revolutions), even for robotic massage [4]. The promising startups in which the robotic arm have a related role (robot-barista, etc.) are also popular. However, the potential field of their application is much wider – all types of production (including light and food industry), office work, social sphere [5].

Creating cooperative robots that work in close contact with humans is a rapidly evolving trend. The actuality of the development of such robots is due to the need to assist people in performing heavy work in industrial enterprises and daily chores in-home, care for the elderly and disabled persons, medical care in hospitals and post-operative rehabilitation, providing leisure and training. Cooperative application, which is natural for such tasks, implies absolute safety, high functional flexibility and autonomy of the used robots. Such cooperative application requires the development of new technologies in the field of management, the creation of new design solutions, the development of algorithms for planning and execution of movements that ensure the safety of physical interaction between people and cobots [6].

Considering that the cobot market will predictably reach $ 12303 million to 2025 from $ 710 million in 2018, i.e. it will increase by 50.31% during 2018-2025 [5], the actual task now is rational planning and improving the quality of analysis of the information, which humans and cobots exchange in the joint environment, as well as improving the effectiveness of the decisions of persons and cobots. The solve of this task can be accomplished by developing the multifunctional cooperative robotics system or technology based on the ontological approach, which is *the purpose of this research*.

2 Literature Review

The cooperative robot shall meet the requirements of International Standards, the main one being ISO/TS 15066:2016 [7], which is, in fact, a technical specification, in particular, of the safety requirements for the cobots, for the interoperability of industrial robotic systems and the work environment. This standard is a guide to assessing the risks involved in working together with humans and cobots. According to [7], there are 4 forms of joint work (teamwork): Safety-rated monitored stop – it's used when the robot operates largely independently, but sometimes a person can enter in robot's workspace; Hand guiding – it's used for precise operations with heavy objects; Speed and separation monitoring – it's used for simultaneous human and robot operation; Power and force limiting – it's also used for simultaneous human and robot operation, with the force and power of the robot being controlled so that accidental contact between the robot and the operator will not cause harm.

In cooperative robotics, both humans and robots perform tasks on the same product in a joint workspace, but not simultaneously. A cooperative joint production workspace (environment) is an environment where a robot and a person can perform tasks simultaneously while working automatically [8, 9]. The most important challenges of the cooperative environment are summarized in Figure 1 [9].

Let's analyze the literature to find known methods and solutions for the field of cooperative robotics – Figure 2.

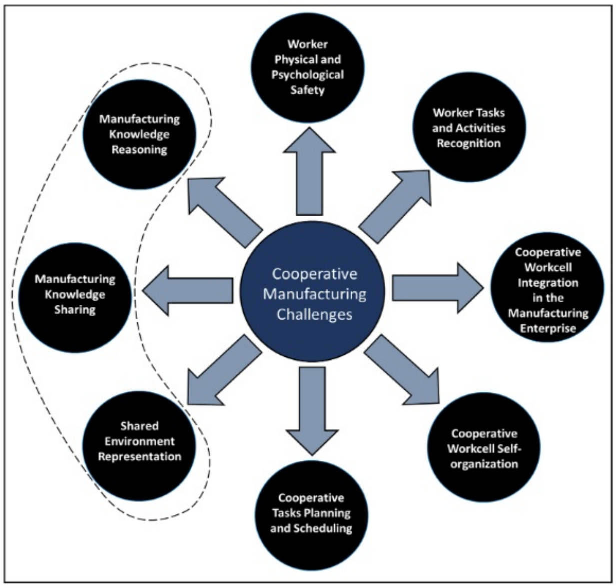

Fig. 1. The most important challenges of the cooperative environment [9]

Fig. 2. The known methods and solutions for the field of cooperative robotics

All components of the cooperative system communicate and exchange their knowledge, process general information. This knowledge and information are usually provided in a natural language that should be understood by the cobot. Using ontologies provides comprehensibility of such knowledge and information to the cobots.

Ontology is a collection of concepts which able to model terms of vocabulary into domain knowledge. Ontology provides a better understanding of contextual knowledge. From the perspective of computational science, ontology is defined as a concept to model the system structure. For example, the relevant entities and relationships that exist from observations are useful for specific purposes. Ontology associated with discovering and modelling reality under particular perspectives. It focused on the structure and nature of an object. Ontology also referred to a representational knowledge. Ontologies can describe abstract things (work processes, knowledge or tasks) as well as real things (devices) [21-23].

Let's analyze the known ontological models for the field of cooperative robotics. Thus, [9] presents a multi-agent system based on ontologies for a cooperative environment. In [3], an ontology-based architecture is proposed as a solution for sharing and transferring the knowledge, which are necessary to achieve complex scenarios of employee-cobot interaction. The authors [24], using ontological engineering, cloud library and semantic technologies, have developed a robotized ontology-based surgical care system. The semantic analysis technology Compreno, introduced by ABBYY in April 2014, which is based on ontologies, that formalize the description of the entire set of terms and relationships between them, enables cobot to understand natural language in a cooperative joint production environment [25].

The conducted analysis of known methods and decisions in the field of cooperative robotics indicates that nowadays there are still a number of *unresolved issues*:

- how can the cooperative robotics system handle more complex tasks that can be solved by only humans?;
- how to ensure the reliability of the physical cooperative robotics system in the real world?;
- how to more rational plan and analyze the information, which is received by each individual robot (and then are made their decisions more efficient)?;
- how to organize easy human intervention in the cooperative robotics system according to needs?;
- how to formalize the "common sense" semantics?;
- what form should be used to represent the cooperative joint production environment and components?;
- how to speed up and improve the quality of natural-language information processing?

All of these unresolved issues are difficult to formalize and require the use of artificial intelligence components to solve them. Currently, there are a number of solutions in which artificial intelligence components are effectively used in the cooperative robotics industry, but one of the reasons for a large number of unresolved issues in the industry (in particular, the problem of analyzing information in a cooperative joint production environment) is the disparity of existing solutions. There are currently a number of effective solutions with using the ontology in cooperative robotics as a basis of the multifunctional cooperative robotics system, but they all belong to different methodological approaches and are not integrated with each other, that is, there is currently no multifunctional cooperative robotics system or technology based on the ontological approach.

3 Structure of Multifunctional Cooperative Robotics System based on the Ontological Approach

Cooperative using implies absolute safety, high functional flexibility and autonomy of the used cobots. For this, the development of new systems and technologies in the field of management, the creation of new solutions, the development of algorithms for planning and execution of movements is necessary, that ensure the safety of physical interaction between people and cobots.

Given that a simple scheme of two-tier tasks scheduling is not suitable for a cooperative joint production environment, then the multilayered scheme of a multifunctional cooperative robotics system is important, which includes the tasks analysis, tasks coordination, tasks performance, and task supervision. The requirement of exchange of information is also important since the robot in the team can only perceive local information. Many tasks are currently too complex for robots and cobots, therefore coordination between people and robots must be ensured.

The cooperative joint production environment includes cobot(s), persons (collaborators) and other components of production (including product). All components of the cooperative joint production environment should communicate and share their knowledge, and should process general information.

The multifunctional cooperative robotics system is a distributed intelligent system in which the joint knowledge is used, the possibility of re-use of knowledge is realized. The system consists of many rather independent modules (agents) that work within this system and exchange knowledge with its other modules via messages. In this system, cobots and persons work as a team in the cooperative joint production environment. Each has its own tasks and responsibilities that require mutual coordination and communication.

The knowledge and information, which are exchanged by all components of the cooperative robotics system, are provided in a natural language that must be understood by both the cobots and the agents. Use of ontologies provides such an understanding of natural-language knowledge and information. Ontologies are the most used structure for modelling the subject domains, for which cobots are used.

Structure of multifunctional cooperative robotics system based on ontological approach is represented on Figure 3.

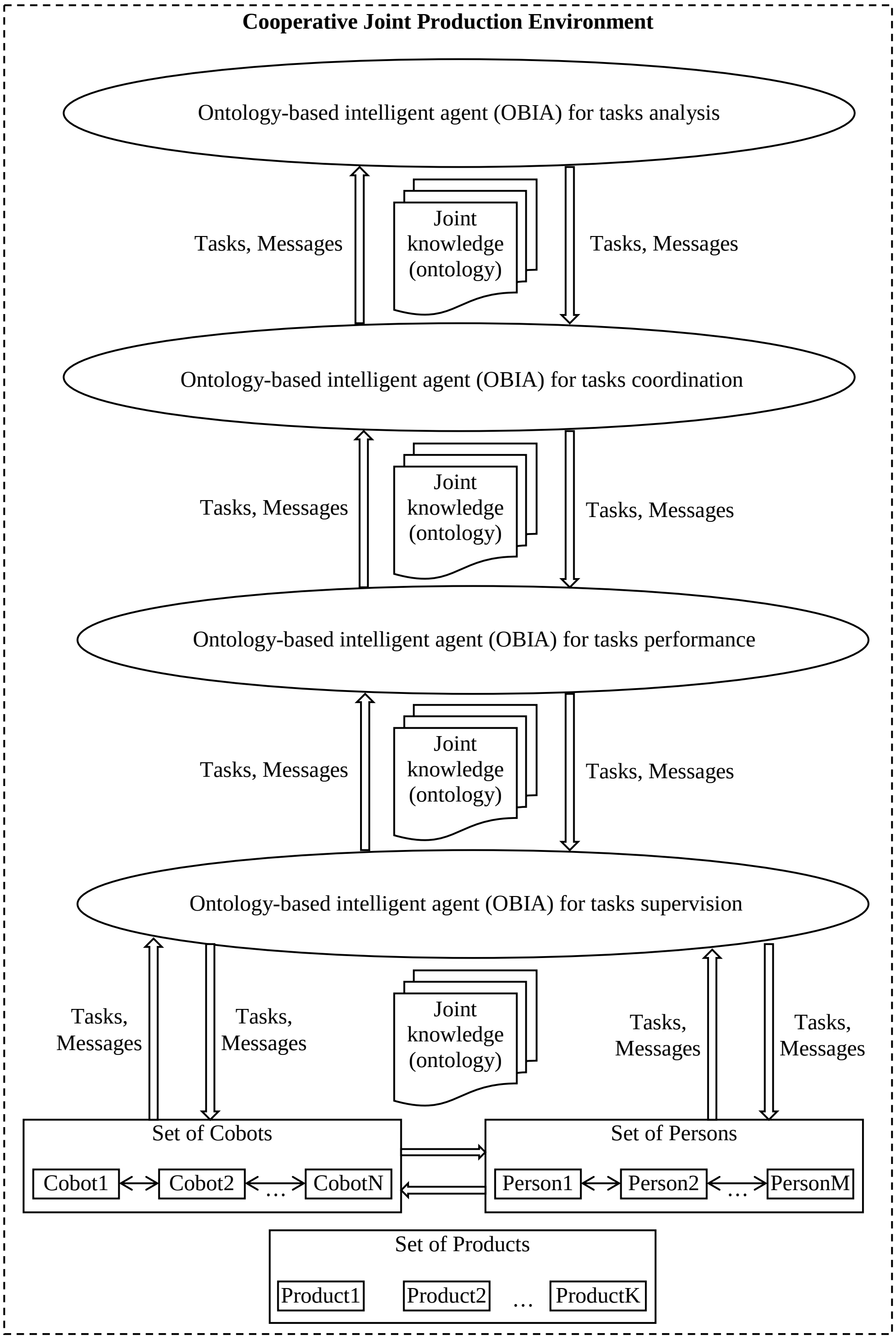

Fig. 3. Structure of multifunctional cooperative robotics system based on ontological approach

The basis of the developed multifunctional cooperative robotics system based on ontological approach is the ontology-based intelligent agents (OBIAs) for tasks analysis, tasks coordination, tasks performance and tasks supervision. OBIAs are the systems situated within and are the parts of a cooperative joint environment that sense that environment and act on it, over time, in pursuit of their own agenda and so as to effect what it senses in the future. These OBIAs act, directing its activity towards achieving goals, upon an environment using observation. OBIAs also learn and use joint knowledge to achieve their goals. OBIAs accommodate new problem-solving rules incrementally, adapt in real-time, learn and improve through interaction with the environment (with the joint knowledge), analyze themselves in terms of behaviour, error and success. OBIAs are used to autonomously gather information on a regular, programmed schedule or when prompted by the user (cobot or person) in real-time. OBIAs are free to choose between different actions. These agents seize the initiative to seek the best plan of action to accomplish their assigned goals in light of the current situation and past experience and then act on the cooperative joint production environment. The proposed OBIAs are described by their environment (dynamic description), actions (change in the environment brought about by the agent), desires (overall policies or goals of the agent), action selection architecture (the agent decides what to due next by consulting both its internal state, the state of the world, and its current goal).

4 Results and Discussion

Let's consider the benefits of the developed multifunctional cooperative robotics system based on the ontological approach. The developed system and the ontology-based intelligent agents (OBIAs), that compose it, can handle complex tasks and "understand" natural-language tasks and messages through the use of ontologies. Using ontologies for the representation of the joint knowledge helps more rationally to plan and analyze the information, which is received by each individual agent and cobot, and to make the agents' and cobots' decisions more effective. The presented structure of the multifunctional cooperative robotics system based on the ontological approach organizes easy human intervention into the system because the persons enter to the proposed cooperative joint production environment and have access to all the tasks, messages and common knowledge of the multifunctional cooperative robotics system. The use of ontologies in the structure of the developed multifunctional cooperative robotics system provides the formalization of "common sense" semantics, as well as speeding up and improving the quality of processing the natural-language information.

Thus, the developed structure of the multifunctional cooperative robotics system based on the ontological approach solves a number of now unresolved problems in the field of cooperative robotics through the use of artificial intelligence components (in particular, ontologies, which are currently the most effective structures for working with natural-language texts and for formalizing the subject domains). So, the proposed multifunctional cooperative robotics system is effective for the cooperative robotics industry as it solves a number of difficult formalized tasks.

There is a huge amount of data coming daily to cobot through the production environment. The problem is providing the safety and security of cobot and all the data in a cooperation joint production environment in which people, cobots and computer devices communicate and interact with one another.

5 Conclusions

In this paper, the structure of the multifunctional cooperative robotics system based on the ontological approach is proposed. This system is based on ontology-based intelligent agents (OBIAs), all joint knowledge of the system is represented as ontologies. The use of ontologies provides the following advantages for the developed system: processing of complex tasks and "understanding" of natural-language tasks and messages; planning and analysis of the information by each agent and the cobot; increasing the effectiveness of agents' and cobots' decisions; formalization of the "common sense" semantics; accelerating and improving the quality of processing natural-language information. The developed structure of the multifunctional cooperative robotics system based on the ontological approach considers both cobots and humans as actants of the cooperative joint production environment, whereby they have access to all the tasks, messages, and joint knowledge of the multifunctional cooperative robotics system.

The future research of authors will devoted to: 1) developing the theoretical basis for a smart production environment to ensure the safety and security of the cobot and all data in a cooperative joint environment; 2) realization of the proposed multifunctional cooperative robotics system based on ontological approach. Further work of the authors will be aimed at solving these tasks.

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