Modelling of cooperating robotized systems with the use of object-based approach

K Foit\textsuperscript{1}, A Gwiazda\textsuperscript{1}, W Banas\textsuperscript{1}, A Sekala\textsuperscript{1} and P Hryniewicz\textsuperscript{1}

\textsuperscript{1}\textit{Silesian University of Technology, The Faculty Of Mechanical Engineering, Institute Of Engineering Processes Automation And Integrated Manufacturing Systems, ul. Konarskiego 18a 44-100 Gliwice, Poland}

E-mail: krzysztof.foit@polsl.pl

Abstract. Today’s robotized manufacturing systems are characterized by high efficiency. The emphasis is placed mainly on the simultaneous work of machines. It could manifest in many ways, where the most spectacular one is the cooperation of several robots, during work on the same detail. What’s more, recently a dual-arm robots are used that could mimic the manipulative skills of human hands. As a result, it is often hard to deal with the situation, when it is necessary not only to maintain sufficient precision, but also the coordination and proper sequence of movements of individual robots’ arms. The successful completion of this task depends on the individual robot control systems and their respective programmed, but also on the well-functioning communication between robot controllers. A major problem in case of cooperating robots is the possibility of collision between particular links of robots’ kinematic chains. This is not a simple case, because the manufacturers of robotic systems do not disclose the details of the control algorithms, then it is hard to determine such situation. Another problem with cooperation of robots is how to inform the other units about start or completion of part of the task, so that other robots can take further actions. This paper focuses on communication between cooperating robotic units, assuming that every robot is represented by object-based model. This problem requires developing a form of communication protocol that the objects can use for collecting the information about its environment. The approach presented in the paper is not limited to the robots and could be used in a wider range, for example during modelling of the complete workcell or production line.

1. Introduction
Robots used in the production process getting better in implementing the activities carried out by worker. Newly designed manipulators are equipped with the pair of arms and be able to perform better in activities where the worker must use both hands. Some production lines are also equipped with multi-manipulator cells, which can perform the tasks that are beyond the capabilities of individual robot. Such cell realizes the task in a manner similar to the group of workers, so the robots should act in the way that ensures the correct accomplishment of work. The cooperation of manipulators may have a different character, but the most specific one is the collective manipulation with the same object [1-3] – the manipulators form a closed kinematic chain, analysis of which is more complicated. There are also other problems like load balancing between arms, force and position control etc. In some cases the kinematic chain may be closed for a while, but the manipulated object is motionless. It occurs when the one robot holds the object, while the other acts on it with some type of tools.
Regardless of the case, the cooperation between robots requires the cooperation between its control systems. The paper will discuss some issues connected with communication between the cooperating robots. In addition to the hardware solution, which means the use of appropriate connections (network) and communication protocols, it is also necessary to provide the right solutions at the level of program development. It is essential that there should exist some forms of messages that will be interpreted in the right way by all involved systems.

2. The Current State of Knowledge

2.1. Industrial and computer networks, topology of networks, hardware.

The one of the fast growing areas of industrial automation is the application of the computer networks. There exist many different solutions developed by many different manufacturers. Some of the network systems are specialized in a particular field, such as networks dedicated to the transmission of signals from the sensors, intended for control the drives or communication between robotic systems. Regardless of the application and manufacturer, network systems use of certain standards. The most important of these standards is the layered OSI model (ISO/IEC 7498-1), which structure is shown in figure 1. The networks are also characterized by topology, what is – in short – the organization of network nodes. The commonly used topologies are shown in figure 2.
Every protocol or standard is created in a way that respects the OSI model. It is important to take into consideration the fact that not every layer of OSI must be implemented.

In the case of industrial computer networks, the commonly used transmission medium is a copper wire or fiber optic. The wireless connections – although used – are not intended to connect network nodes of strategic importance, because this type of transmission is very susceptible to interferences. Wireless transmission of data is suited for less error-prone systems, like MES (Manufacturing Execution Systems) modules that collect the information about production process the PLC and save the data to the central database.

In the industrial network, a wide range of protocols are used, beginning from the simplest RS-232 protocol, through RS-485, Profibus, Ethernet, CAN etc. The type of used protocol is determined by communication requirements between network nodes (e.g. The AS-i protocol is best suited for sensors network, while the Ethernet is better for overall data communication). In the most of cases, the three basic structures can be distinguished: Master-slave, Multimaster and Ad-hoc.

The Master-slave structure is fairly widespread. It often uses the advanced properties of the PLC controllers for supervising and coordinating all the remained network devices. In the multimaster systems, every device has the same rights (for example in Ethernet or Profibus DP networks), while the ad-hoc networks are used for connecting two devices, like e.g. computer and robot controller. In such cases, the RS-232 or RS-485 standards are sufficient for this type of tasks.

The principles discussed above also apply to the networks where some of nodes are the controllers of robots. From the point of view of used physical links and protocols, the communication between the robots will occur in the same way as in the case of other automation devices.

2.2. Cooperating Robots: Communication and Programming Issues

Problems of cooperation between several robots are often referred to the mobile robotics [4, 5, 6]. Many authors use agent-based approach in order to take advantage of methods based on behavior of a community of living organisms. Jung and Zelinsky point out that “Cooperation and communication are closely tied. [...] If we are to implement a concrete cooperative task that requires symbolic level communication, we must first identify the relationship between communication and cooperative behavior” [5]. They use three levels of representation: iconic, indexical and symbolic to build the system of communication between two cooperating mobile robots that is based on living organisms communication abilities. As a starting point they use the results of researches on communication strategy in human society and animals’ world. A slightly different approach is presented by Yan et al. [6] that advises to be careful when considering the Multi-Robot Systems (MRS) and Multi-Agent Systems (MAS). They refers to the model of Multi-Agent System as “[...] traditional distributed computer system in which individual nodes are stationary”, while the Multi-Robot System “[...] involves mobile robots that can move in the physical world and must interact with each other physically”. The authors also point out that there exist two types of strategies: cooperative or competitive. They emphasize the role of communication during realization of the cooperative strategy because of possible resource conflicts like sharing the communication medium, manipulate of the same object or sharing the same workspace.

The problems connected with communication medium sharing are discussed among others by Ye et al. [7] and Rybski et al. [8]. The first team examined the optimal use of communication bandwidth, while the other proposed the method of communication, developed for low-bandwidth networks. The mentioned method uses the scheduling that dynamically assigns the available resources to the robots in order to maximize the efficiency of data stream. The others publications that deals with the same problem are [9,10].

In the case of manipulation of the same object by more than one robot, the researchers concentrate mainly on the issues connected with kinematic chain [1-3]. The interesting discussion about self-organized group of robots is presented in [11], where robots mimic the behavior of the swarm of ants. In turn, Miyata et al. [12] proposed the system based on central motion and task planning, in order to
achieve optimal effectiveness of the swarm of robots. The robots are divided into small teams that are delegated to the specific tasks.

Most of the issues concerning the cooperation between the robots are discussed in relation to mobile robots. The collaboration of typical, arm-equipped industrial robots is described in [13]. The method presented by Braun et al. refers to the group of robots that forms a workcell. The robots manipulate the same object at the time and the movement is supervised by common controller. This can provide the higher level of functionality, where all the robots, that form the workcell, could be treated as the single, “virtual” robot with several arms. In the other paper, Norman et al. [14] draw attention to an important aspect of manipulators’ cooperation, which is the accuracy of movement. They proposed the so-called Indoor GPS system to control the position of each robot’s arm.

As it could be seen, there is no standard approach to the problem of control of the robots that form a group and providing communication between them. At the highest level of generality it does not matter if we consider mobile robots or stationary ones, the used methods will be more or less the same, starting with the physical medium of transmission and eventually using the control algorithms for the specified group of the robots.

3. The Communication Between Object-Base Models of The Robots

The object-based model of the robot is the form that is not identified with particular type of a robot. It is possible to mention the brand and type in the object structure, but it is not necessary. In other words, the object-based model of robot could represent different brands and types of real robots that have similar properties (technical data, capabilities) and kinematic structure. In general, we could define the object as a set of features $F$ (equation (1)):

$$O = \{F\} \iff F = \{R, A\}$$

where $R$ is the set of routines (procedures, functions) and $A$ the set of attributes. Objects will communicate with each other using the attributes and routines in order to set the appropriate attribute. In that manner we have three major ways of implementing the communication. The first one (figure 3a) is to use the blackboard or “scratchpad”, where each object can write and read data. The blackboard is represented by the memory block, which is organized in a way that is recognized by all objects (robots). For example the blackboard could store the orientation of the subject of manipulation, coordinates of robots’ effectors, tools’ statuses etc. This is the implementation of public data structure that is the simplest method of storing the data, however very dangerous – in the case of writing improper data into the structure, entire system could be damaged. Therefore a slightly different solution should be used (figure 3b), wherein the table is a private property of one of the objects. This object supervises the correctness of the data written into the memory, by providing the read and write routines, that are available to the other objects. These routines could be either public or inherited, depending on the structure of objects. The third possibility bases on assumption that there is no public data structure available, but every object keeps the private copy of the data and shares it with the others (figure 3c). The communication model is therefore changed, because every object updates their own data table that then could have the read-only status for others. This solution is closer to the pattern of communication between agents in agent-based model [15], where the flow of information is regulated by sending requests to the other agents and receiving answers from them.
Conclusions
The communication between objects in robotized systems is a complex problem. The main issue is the choice of appropriate hardware and communication protocols. The next step is to take into account the specific nature of the considered problem. Most of the research works describe the cases connected with mobile robotics and uses the agent-based description of the model. However, many of conclusions could be also used in stationary robotics – like sharing of the communication medium, simultaneous manipulating of the same subject or planning the collision-free paths. Especially valuable is the idea of considering the management of multiple robots that form the workcell as the control of virtual, multi-arm robot.

The model of the robot in the form of the software object is most commonly used in all kinds of simulation programs. During performing the simulation in programs that allow advanced mathematical modeling (for example, Matlab, LabView, etc.), sometimes there is the need to deal with the representation of the object-based model in the form of source code. The methods of communication between objects that was described in this paper are only the basic solutions – they are the most universal, but not the most effective ones. On the other hand, they could be implemented and elaborated in many programming environments that support procedural or object-oriented programming.

Acknowledgements
The work is realized within the project titled: “Modular automated production stand with instrumentation for non-invasive confirmation of product quality” funded by The National Centre for Research and Development, agreement No UOD-DEM-1-495/001.
References

[1] Hayati S 1986 Hybrid position/force control of multi-arm cooperating robots, Robotics and Automation Proceedings of IEEE International Conference 3

[2] Al-Yahmadi A S, Abdo J and Hsia T C 2007 Modeling and control of two manipulators handling a flexible object Journal of the Franklin Institute 344.5 pp 349-361

[3] Bicchi A and Prattichizzo D 2000 Manipulability of cooperating robots with unactuated joints and closed-chain mechanisms Robotics and Automation, IEEE Transactions 16.4 pp 336-345

[4] Di Marco M, Garulli A, Giannitrapani A and Vicino A 2003 Simultaneous localization and map building for a team of cooperating robots: a set membership approach Robotics and Automation, IEEE Transactions 19(2) pp 238-249

[5] Jung D and Zelinsky A 2000 Grounded symbolic communication between heterogeneous cooperating robots Autonomous Robots 8.3 pp 269-292

[6] Yan Z, Jouandeau N and Cherif A A 2013 A survey and analysis of multi-robot coordination International Journal of Advanced Robotic Systems 10

[7] Ye W, Vaughan R T, Sukhatme G, Heidemann J, Estrin D and Mataric M J 2001 Evaluating control strategies for wireless-networked robots using an integrated robot and network simulation Robotics and Automation, Proceedings ICRA. IEEE International Conference 3 pp 2941-2947

[8] Rybski P E, Stoeter S A, Gini M, Hougen D F and Papanikolopoulos N P 2002 Performance of a distributed robotic system using shared communications channels IEEE Transactions on Robotics and Automation 18(5) pp 713-727

[9] Nerurkar E D, Zhou K X and Roumeliotis S I 2011 A hybrid estimation framework for cooperative localization under communication constraints Proceedings of IROS’11 pp 502-509

[10] Krontiris A and Bekris K E 2011 Using minimal communication to improve decentralized conflict resolution for non-holonomic vehicles Proceedings of IROS’11 pp 3235-3240

[11] Kube C R and Bonabeau E 2000 Cooperative transport by ants and robot Robotics and autonomous systems 30.1 pp 85-101

[12] Miyata N, Ota J, Arai T and Asama H 2002 Cooperative transport by multiple mobile robots in unknown static environments associated with real-time task assignment IEEE Transactions on Robotics and Automation 18(5) pp 769-780

[13] Braun B M, Starr G, Wood J E and Lumia R 2004 A framework for implementing cooperative motion on industrial controllers. Robotics and Automation IEEE Transactions 20(3) pp 583-589

[14] Norman A R, Schönberg A, Gorlach I A and Schmitt R 2010 Cooperation of industrial robots with indoor-GPS Proceedings of the international conference on competitive manufacturing–COMA 10 pp 215-224

[15] Finin T, Fritzson R, McKay D and McEntire R 1994 KQML as an agent communication language Proceedings of the third international conference on Information and knowledge management, ACM pp 456-463

[16] Alves J Blackboard https://openclipart.org/detail/49363/Blackboard, Accessed: 28.02.2015

[17] Agone, Notes, CC Zero License, https://openclipart.org/detail/22037/Notes, Accessed: 28.02.2015