Chapter 22
Ontology-Based Modelling of State Machines for Production Robots in Smart Manufacturing Systems

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ABSTRACT

The integration of modern IT technologies in production equipment does not only enable them to acquire information from different sources and provide it to others but also to make decisions depending on the situation. Due to the limited processing power of such equipment, usage of state machine to describe and program it is considered a promising direction. However, the necessity of intensive interaction of the equipment units causes problems related to interoperability, which are usually solved with the usage of ontologies. The objective of the presented research is to model state machines of production robots via ontologies. The results are demonstrated on the example of a fragment of an automated production line.

INTRODUCTION

Today, when the Internet of things becomes widespread, the number of devices enabled with functionality that allows them to access the Internet is growing. This functionality was originally oriented to information search and retrieval; however, the development of information and communication technologies causes the appearance of both new opportunities and requirements: many modern devices are aimed to

DOI: 10.4018/978-1-6684-3694-3.ch022

assist people in various human activities not only acquiring information, but also analyzing it and making decisions depending on the current situation (Knight, Xiang, & Sullivan, 2016; Lee, Bagheri, & Kao, 2015). These capabilities have become one of the driving forces of the development of cyber-physical systems (CPS) (Gubbi, Buyya, Marusic, & Palaniswami, 2013; Wortmann & Flüchter, 2015) comprised of a set of interacting resources in the information space and devices in the physical space in real time.

CPS are based on infrastructures providing for communication, computing, and control, and integrate sensors, computing devices, services and communications. Physical devices that are part of CPS often have limited computing power, which significantly decreases their programming possibilities. In this regard, the finite-state machine is one of the widely used approaches to solve this problem.

The automata theory has appeared within the framework of the control systems theory (theoretical cybernetics) due to the intensive development of the computer technologies and related fields of mathematical knowledge, primarily for modeling abstract digital systems (abstract computers or abstract machines). The further development of the information technology has led to the automata theory application far beyond the modeling of digital hardware, extending it to the foundations of the modern theoretical informatics. Abstractions and models developed within the automata theory are used in such disciplines as the formal grammar theory, mathematical linguistics, logical models, mathematical logic and formal axiomatic systems, coding theory, computational complexity theory, and other (Anderson, 2006).

The automata theory is widely applied in different areas, e.g. (Johansson et al., 2014):

- Design of logic control systems;
- Text processing and compiler building;
- Specification and verification of interacting processes systems;
- Languages for describing documents and object-oriented programs;
- Optimization of logic programs, etc.

One of the popular directions in this area is automata-based programming, i.e. the approach to the design software systems with complex behavior, on the basis of the model of an automated control object (extension of a finite-state machine) (Kiljander et al., 2014). Programming of equipment by means of automata-based programming has been discussed many times (e.g. (Dolog, 2004; Naumov & Shalyto, 2003)). It has certain advantages and disadvantages and there is no ultimate answer if it is always better or not, however in a number of situations (including some CPS cases) it is reasonable to use, e.g., (Zheng, Wang, Chen, Liu, & Shen, 2018; Zieliński, Figat, & Hexel, 2019).

The necessity of close interaction between CPS devices imposes additional requirements related to interoperability between them. The research question considered in the paper is if it is reasonable to describe CPS finite-state machines by means of ontological modelling to facilitate the interoperability support in CPS, would such an implementation provide for any improvement in terms of programming and interoperability, and to what would be an efficient way of such description. In order to design the service finite-state machines and their ontological descriptions the RMM (Relationship Management Methodology) methodology that provides for means of structured application design and simplifies further adaptation and maintenance (Isakowitz, Stohr, & Balasubramanian, 1995) has been used.

The reminder of the paper is structured as follows. The next section presents the state of the art overview. It is followed by introduction of the notion of the finite-state machine and description of the application of finite-state machines to CPS services behavior description. Then, a proof-of-the-concept is done through applying the developed ontology-based approach to description of finite-state machines