Robotics and Computer-Integrated Manufacturing 37 (2016) 79–89

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim

A context-aware approach in realization of socially intelligent industrial robots

Tomislav Stipancic*, Bojan Jerbic, Petar Curkovic

Department of Robotics and Production System Automation, Faculty of Mechanical Engineering and Naval Architecture, Ivana Lucica 5, 10000 Zagreb, Croatia

ARTICLE INFO

Article history:
Received 27 August 2014
Received in revised form
8 July 2015
Accepted 23 July 2015
Available online 3 August 2015

Keywords:
Cognitive robotics
Context-awareness
Probabilistic graphical models
Ontology
Ubiquitous computing

ABSTRACT

Contemporary industrial environments are usually constrained or limited in order to fit a fast, cheap and non-error prone production. Human-like system capabilities are not generally desirable there. But, recent trends in industrial robotics demand robust, flexible and efficient robots with a certain level of autonomy. Therefore, new and different approaches and perspectives in designing of industrial facilities are required.

This paper reveals how a context-based reasoning can be used to achieve an intelligent robot group behavior. In order to achieve adaptivity, self-recovery or scalability of the system, a COgnitive MOdel for the Robot group control (COMOR) is developed. COMOR can be understood as an interpreter used to transform high-level context to low-level data, allowing machines to make context-based decisions.

COMOR has three main parts and relies on a simulated Social Capital phenomenon as a feature of people. The first part is used to collect significant information from the environment. The second part is used to provide a set of possible solutions respecting the semantic domain description. The last part of COMOR is used to provide a behavioral component ensuring an optimal solution to given environmental conditions.

1. Introduction

In most cases, contemporary machines are using explicit knowledge. On the other hand, a contextual perception presumes much more implicit understanding. A research of new methodologies and paradigms is therefore directed toward the development of adaptive, anthropmatic and cognitive agent capabilities [1]. To achieve this kind of technology in industrial environments it is good to bear in mind a couple of things. It is not possible to predict all occurrences or changes that an environment could derive. Deterministic chaos that surrounds us inevitably obstructs absolute expectations always producing slightly changed situations [2]. Chaos is present in both, temporal and space continuum, resulting with inconsistencies and uncertainties in all dimensions. Every environment is naturally unstructured, which can be revealed if observed by using an appropriate scale. In other words, if we neglect a sub-molecular level, it is not possible to completely determine any environment, no matter how tight the applied tolerance ranges may be. This is connected with issues of sensitivity and instability and may result in malfunctioning, even if small environmental changes occur. Each object, process or condition is also unique by its very nature. How to deal with such challenges? One way is to accept deterministic chaos as a natural phenomenon just like it is accepted by nature.

Contemporary systems are usually programmed for a limited range of activities foreseen in advance by a system developer. Such systems by default cannot act in any unpredicted situation. This kind of systems can be called reactive because they react only based on expected environmental stimulus. The reactive system can be very fragile if something unexpected occurs and usually does not have any self-recovery capabilities to prevent or to correct errors aroused from unexpected situations. On the contrary, the system that is able to partially realize context can potentially do both: it can act reactively and it can comprehend the present and predict future results or actions [3]. It seems that human beings and animals are adapting to their environment in a similar way. A development philosophy therefore should move toward the development of intelligent machines capable of adapting to their environment where nothing is ideal or accurate.

A contextual perception implies understanding of a problem domain much broader than a single agent could comprehend. It can be carried out through interaction between the agent and its environment. A context-based dynamic information control needs less predetermined operational and structural knowledge. Therefore, context of space and time becomes an important subject in a development of intelligent systems [1].

* Corresponding author.
E-mail address: tomislav.stipancic@fsb.hr (T. Stipancic).

http://dx.doi.org/10.1016/j.rcim.2015.07.002
0736-5845/

A COgnitive MOdel for the Robot group Control (COMOR) is a reasoning mechanism developed to transform context to data, a form that is much more suitable to be used by robots. By using COMOR, a robot within the group combines information from the environment along with its prior knowledge about the domain of interest and believes of a human expert(s) while making unambiguous decisions. By using this approach the robot placed in physical environment achieves the ability to partly comprehend context and make context-based decisions.

2. Theoretical background

To mathematically describe COMOR, a multi-agent approach is used. In this approach, agents belonging to the same group are able to communicate mutually as a part of the same environment. In the model of interaction (Fig. 1), all agents are able to share information within the same time domain. These agents are not able to perceive their environment only, but to make actions similarly as robots in the physical world.

Respecting COMOR, agent-to-agent and agent-to-environment interaction can be both mathematically described as

$$\exists\, G\left(\vec{E}_{A1}, \ldots, \vec{E}_{An}\right) \forall\, t_i \to G_{opt}\Big|\vec{F}, \tag{1}$$

where the information collected by sensors and COMOR are mathematically defined as vectors, respectively:

$$\vec{E}_A = \left[\vec{E}_{A1}, \ldots, \vec{E}_{An}\right] = \left[f_{A1}(S_{11}, \ldots S_{1m}), \ldots, f_{An}(S_{n1}, \ldots S_{nm})\right], \tag{2}$$

$$\vec{F} = (CO, BN). \tag{3}$$

In Eq. (2), vectors $\left[\vec{E}_{A1}, \ldots, \vec{E}_{An}\right]$ detect a targeted phenomenon by providing explicit information, collected by sensors S. This is the first step in contextual perception of the environment. Therefore, it can be said that these vectors contain information acquired by sensors that are placed ubiquitously into the environment in a meaningful way Eq. (4).

$$\vec{E}_A = f(S) \tag{4}$$

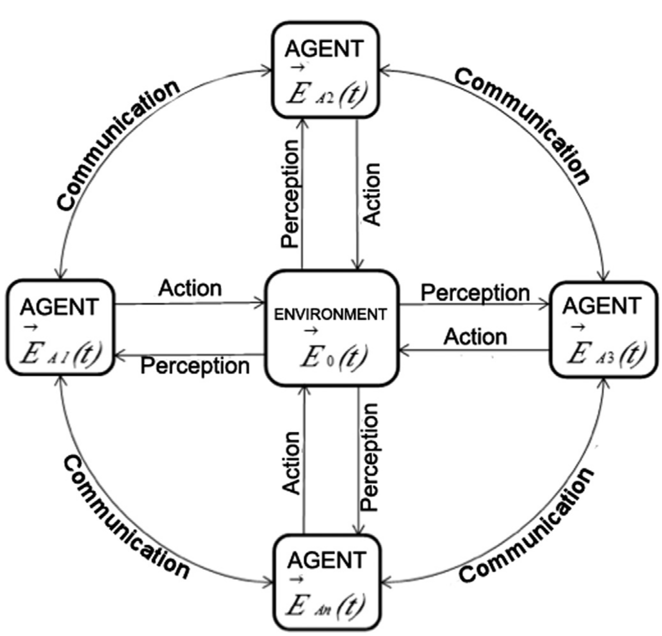

Fig. 1. Multi-agent system: the model of interaction.

Based on Eq. (1), it can be concluded that there is at least one function G to describe context of an environment at a given moment t_i, by using information from Eq. (2) altogether with a set of criteria defined in Eq. (3) that generates a desired (optimal) robot group behavior G_{opt}. As a part of the vector $\vec{F}$, the marks CO and BN defined in Eq. (3) are abbreviations for Core Ontology and Bayesian Network, respectively.

By following the presented mathematical formulation, a hypothesis of this paper is:

By finding the function G_{opt} defined in Eq. (1) and respecting the information stored in Eq. (3) along with other information collected by sensors Eq. (2), it is possible to alter a behavior of an agent within the group.

3. The model

COMOR is aimed to use in industrial like environments for robot assembly operations. The Model's main components are shown at (Fig. 2) and includes the following: (1) information gathering by means of ubiquitous sensors based on principles of Ubiquitous Computing [4], (2) semantic representation of a domain and (3) probabilistic reasoning inspired by the Social Capital phenomenon used to provide a single solution for a given industrial tasks.

A synergy of all Model components ensures a flexible robot behavior respecting both, current environmental conditions and predefined knowledge about a particular domain of interest. By using this knowledge and estimates, COMOR can generate a collaborative robot group work applied in real-life scenarios. A single robot is thus able to behave in more human-like fashion and seemingly non-predictable scenarios.

3.1. Environment

Due to the requirements like high-degree of automation and large series of products, contemporary robotic assembly systems cannot afford mistakes aroused from the non-deterministic nature of an environment. Therefore, classical industrial environments are usually determined in advance as much as possible.

The environment shown at (Fig. 3) is used for COMOR development and testing. This assembly system is a part of the Laboratory for assembly system planning at the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia.

Along with all accompanied system components, this environment contains a certain number of sensors placed seamlessly to ensure ubiquitousness. Within the Core Ontology, which is the second part of COMOR, the knowledge about the domain is stored in taxonomy and generated by means of Descriptive Logic. This way, the knowledge becomes sharable and reusable.

Within a semantic description, the working environment is

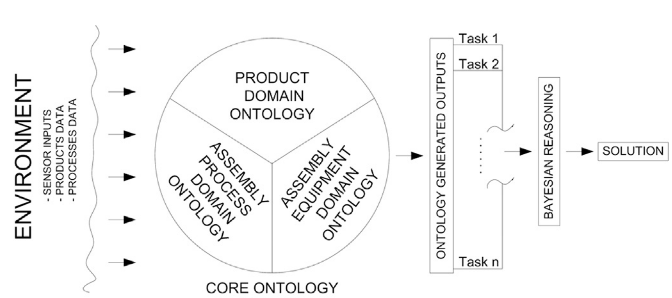

Fig. 2. COgnitive MOdel for the Robot group control (COMOR).