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Review Article

Towards a Unified Representation for Human-Robot Control Architectures

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ABSTRACT

Purpose: The actual and futurist development of different kind of intelligent robots and their various possible interactions with humans are pressing towards a homogeneous representation of Human-Robot control architectures. This paper intends to contribute to an outline towards the development of a unified control architecture for Human-Robot Interaction Systems (HRIS) that eliminates the distinction between humans and artificial intelligent systems when working together as team members.

Methods: This unification should be based on formal analogies that categorise the functions and competencies of both human operators and intelligent artificial systems as well. According to a review of some models developed for robot control architectures and for human operator performances; one can found formal analogies that can be amenable to a common control architectural representation.

Results: In this context, two models are particularly remarkable: the hybrid multi-layer control architecture for representing artificial intelligent systems in the one hand; and Rasmussen's human performance model in the other hand.

Conclusion: These two models can be initiated a basis for establishing a unified representation for the control architecture of HRIS involving human and robots as team members to carrying out tasks and missions in a collaborative way.

Keywords: Human-robot control architecture; Human-robot interaction; Intelligent robots; Robotics; Artificial systems

INTRODUCTION

Since about these last two decades, a development of systems involving humans and various forms of robots is widely expanding. Most of these systems are dedicated to locally and/or remotely achieve complex tasks and missions in a cooperative way by teams composed of humans and competent robots. Examples of such Human-Robot Interaction Systems (HRIS) are space exploratory systems, humanoid robots evolving in various environments, military systems for future wars, robot-assisted surgery, exoskeletal systems for handicapped people, and assistive robots for disabled people, etc [1-5].

The analysis of some modern HRIS has revealed the emergence of some new amazing issues. For instance; under certain circumstances and conditions; there are functions and tasks which were usually considered as highly cognitive and exclusive of the domain of human beings; that can be actually carried out by some artificial intelligent systems. They can be carried out with comparable or even better performances than by human beings. In addition, modern intelligent robots can be trained, can learn behaviors from humans or other artificial systems and even can use self-learning techniques to enrich their competencies and improve their performances [1-3,6]. Moreover, analysis of critical situations related principally to safety purposes in some HMIS has shown that human beings, contrarily to a general belief, are not always more reliable than some dedicated modern artificial intelligent systems [1, 6-9].

According to these considerations where some intelligent systems can compete with humans, one may expect a possible interpenetration and a confusion of roles between humans and robots working as teams in HRIS. It arises therefore new

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problems of task allocation, coordination, and management of conflicts. As a consequence, there is a need to develop HRI models which can represent both entities: Humans and Robots without functional discrimination. In short, the idea consists of generalizing the notion of human-human teams to hybrid human-robot teams. Such a fully satisfying unified model does not exist yet but is particularly required for analysis, design and control architecture of futurist HRIS.

MODELLING ROBOTS, HUMANS AND HRIS

Many approaches and models have been proposed to address this challenge. Among the proposed approaches, we can distinguish two opposite trends. The first one attempts to model artificial intelligent systems as living beings. The second one attempts to model the living beings within the technological framework of automation. Correspondingly, for some behaviours, there are models that approximate to some extend intelligent robots as human beings. Inversely, for some behaviours, there are also models that approximate to some extend human beings as intelligent systems.

Historically, HMIS began during the Second World War when robots were used to tele-manipulate nuclear materials. At the beginning, during the tele-manipulation stage, modeling human performance started by attempting to apply automation techniques and theory of systems to model human operators. The human, included in a closed loop, was first modeled from the control system theory as a compensatory system. Other models stemming from the information-processing theory have also attempted to model the cognitive aspects of human beings as a processor. In this direction, many efforts have attempted to establish theories of Intelligence in order to understand human mind functioning and to design artificial intelligent systems. Of course, many of these approaches were inspired from living systems with the human brain as an ultimate intelligent one. One remarkable control architecture stemming from cognitive architecture design is known as SOAR (State, Operator and Result). This architecture is considered as a unifying approach of the theory of intelligence and that is to be capable of general intelligence. SOAR attempts to reproduce all the cognitive aspects of the brain functions and human behaviours including memory, problem solving, learning, etc. [10-14]. The best illustrative example of these efforts is actually the humanoid robot which is designed to emulate human beings competences and social behaviour [15-18].

In fact, in the context of HRIS, most carried out studies and projects have been mainly devoted to human-robot interactions in the sense that they were oriented to study interfacing techniques to enable easy communication, interaction and reciprocal "understanding" between humans and robots [1,3,16-18]. And there have been little works devoted to modeling human-robot teams in a common representation useful in particular for control architectures [5,19-23]. The best proposed models remain system and context dependent and the development of such a unifying model seems to be still a far reaching goal [5,17,23-25].

Nevertheless, by analyzing some intelligent robot models, some human performance models, and some HMI models; one can distinguish very few models which can be amenable at least formally to a common hybrid representation for control architectures. The convergence seems to be met with the following models each coming from one opposite direction. The first one is the control architecture based on multi-layer representation which is designed for intelligent artificial systems such as robots [26-28]. The second one comes from the modelling of a human operator interacting with automation that is Rasmussen's human performance model [29-32].

CONTROL ARCHITECTURES FOR INTELLIGENT SYSTEMS

Actually, there are also two main approaches in control architectures for intelligent systems particularly those acting dynamically in real world environments: the deliberative-based and the behaviour-based architectures. Deliberative-based control architecture is a classical one and requires sequentially the processes of sensing, modelling, decision-making, and then acting. Intelligence here is assumed to be a very complex process. This approach presents many drawbacks when applied to systems evolving dynamically in real complex world environments. It requires the modelling of environments which is not always available and even lacks accuracy. It can also be very much time consuming which affects the adaptive capability of dynamical systems.

By contrast, in behaviour-based architectures, the artificial system should just have a collection of simple behavioral schemes which react to changes in the environment, in a stimulus-response fashion [26]. And, intelligence here is considered just as a result of direct interaction of the artificial system with the environment by means of sensors. Soon, this type of approach became the new fashion for control architecture design of autonomous robots. Nevertheless, most behaviour-based applications have mainly focused on navigation issues of mobile robots and particularly upon the obstacle avoidance problem [27]. Of course, some architecture have attempted to expand this approach to including manipulation and assembly tasks but it reveals to be not an easily adaptable solution for many type of these tasks [33,34].

As a compromise between these two opposite control architectures, they instead have been combined for complementing each other. As a result, complex artificial intelligent systems should have both reactive capability to respond to immediate new situations as well as deliberative capability for model-based reasoning. For that purpose, most recent control architectures are generally designed in an hybrid layered fashion which combines at a low level the behaviour-based control and at a higher level the deliberative control [22,25]. Many hybrid architectures have been already designed and implemented in various ways, but principally, as a uniform layer, a bi-layered and three-layered architectures. The last architecture tends to become the most popular one for complex and distributed robotics systems (Figure 1), with multi-layer architectures, the robot functions are organized according to the degree of abstraction of the system response. They are classified as: reflexive, reactive, deliberative.

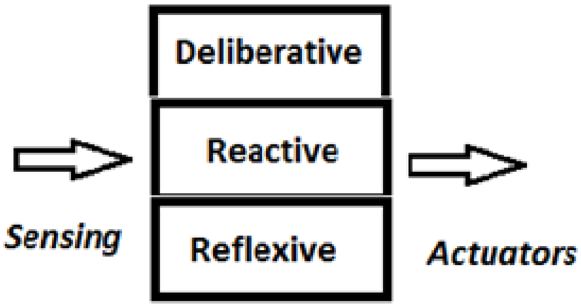

Figure 1: Three-layer robot control architecture.

Other control architectures developed in the context of the cognitive approach tend also to have a layered structure [12,13,15].

HUMAN MODELLING AND RASMUSSEN'S MODEL

It is obvious that human beings are very complex systems which are not so easy to model as robots. Human beings manifest many different aspects which are not yet fully understood. Some aspects are sometimes beyond the question of computation and processing capabilities such as conscience, emotions, benefit of being genetically pre-programmed. They present high sophisticated cognitive capabilities for learning, self-learning, analyzing and synthesizing information and knowledge, problem solving, planning, decision-making, interactive social living, adaptability, etc. They have also many aspects which are dependent and varies from one person to another such as the psychological specificities and personal capabilities.

As a human being is a very versatile system, therefore, it is impossible to capture all its aspects into a single model that will become useless because of its extreme complexity. So there have been many proposed models dedicated to only capturing some particular aspects of his/her behaviours. Developing techniques and models to understand how the mind works is the purpose of cognitive sciences. Since the apparition of computers, an interesting active field of research has emerged named computational cognition. It gathers techniques and models that attempt to understand human cognition through simulating some aspects of human behaviours and mind activities. Illustrative examples of computational cognition are the artificial neural networks that simulate the neural activity of the brain.

However, as we are particularly concerned with the specific domain of human interaction with automation, so our precific subject of interest is known as human performance modelling. Human performance modelling serves for analysing, human behaviour *via* analytical or computational means. It is a tool for understanding, analysing, predicting the human operator interaction with automation. It serves also to optimizing the performance of the overall HMIS.

There are many models of human performance but Rasmussen's model seems to be the more convenient for our purpose [30,31]. It has some features and resemblances that fit well with control architecture of autonomous systems and intelligent robots. Briefly, Rasmussen's model has been developed for supervisory control. It helps to analyse the operator performance when he/she interacts with an automated system when carrying out given tasks. [29,35,36]. It is a cognitive model. According to Rasmussen, "we distinguishes three categories of human behaviour according to basically different ways of representing the constraints in the behaviour of a deterministic environment or system; three typical levels of performance emerge according to the degree of abstraction involved: skill-based, rule-based, and knowledge-based performance" [29]. From the information point of view, sills, rules and knowledge are respectively linked to signals, signs and symbols (Figure 2).

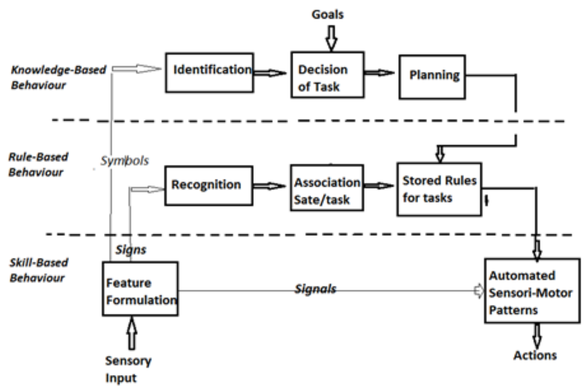

Figure 2: Rasmussen's model.

OUTLINE OF A UNIFIED HMIS ARCHITECTURE

The hybrid multilayer behaviour-based control architecture intends to model the activity of intelligent artificial systems. Inversely, the Rasmussen's model intents to model the performance of a human operator considered as a cognitive agent when interacting with automation.

The formal comparison of the multi-layer control architecture to Rasmussen's model shows some similarities on their structures, organizations and purposes. These two models meet each other because they attempt to describe the same object: a complex intelligent system that is constrained to behave dynamically in real world environments. Both architectures are multi-layered. In both of them, the functional decomposition is related to the degree of abstraction. In both of them, the functional organization is such that the degree of abstraction increases with the level of layers. Skill-based performance can be associated with reflexive functions (first layer). Rule-based performance can be associated with more relatively elaborated functions such as reactive functions (second layer). Knowledge-based performance can be associated with deliberative functions (third layer).

Based on these remarks and as already tried by few studies and projects [17,22,28,36,37], one can infer that a same hybrid three-layered control architecture can be used at least formally to represent human operators as well as intelligent artificial systems as team members without functional discrimination. This representation can be used and considered as unified model for HRIS from the control architecture perspective (Figure 3).

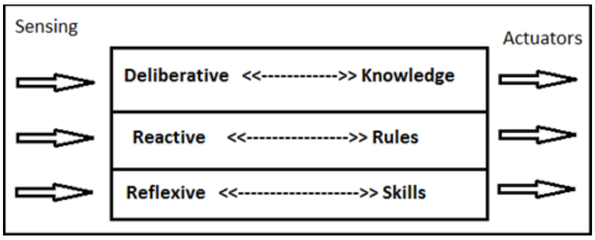

Figure 3: Unified HMS model.

Practically, to implement this control architecture, the same methodology adopted for intelligent systems can be used to model human operator performance. Basically, a collection of human behaviours that may serve the mission or the task have to be identified. Then, they have to be analyzed and categorized into the appropriate corresponding three levels of abstraction according to their complexity. Finally, all behaviours and competencies of human operators and intelligent systems have to be inserted together into their corresponding levels regardless of their membership nature.

As this unified multi-layer control architecture should support cooperation and collaboration between team members, therefore many issues and challenges have to be tackled. For instance, in case of competitive situations, the highest layer of the architecture should support and manage schemes for task allocation based on optimization of performance of the overall system. The architecture should manage conflicts and critical situations as it should also support delegation of authority. As intelligence is fundamentally constituted of dynamic and adaptive processes, this architecture should enable a dynamical management and update of the content of layers with new learned behaviours and new acquired knowledge. In fact, this is a large open field for new research topics to be investigated.

This view is also fostered by the venue of futurist humanoid robots that may physically resemble to human beings with certainly some more oriented specificities and competences. They may be physically stronger and capable of supporting harder conditions where human beings cannot survive in. They may not be affected by psychological effects such as stress and emotions. If one considers the fast technological development, one may expect that they will sense better their environment and will perform many functions better than human beings. All this means that analysis and design of HMIS composed of teams formed by human beings and humanoid robots require unified control architecture.

CONCLUSION

This paper intends to contribute to the development of a unified representation for control architectures of HRIS composed of hybrid teams constituted of human operators and robots involved in collaborative tasks.

The review of literature enables to distinguish some formal similarities between two relevant models. The first one is the hybrid multi-layer control architecture dedicated for designing intelligent and autonomous systems. The second is Rasmussen's operator model dedicated to model the human operator performance as an intelligent system. Considering the formal similarities between these two models, single unified multi-layer control architecture can be suggested for control architecture for HRIS constituted of teams composed of both human beings and competent robots without functional discrimination.

The unified architecture should also necessarily enable a dynamic self-management of new learned behaviours and new acquired knowledge between its layers. The design of this unified architecture opens a large field of research in order to solve new issues and challenges such as cooperation, competition, management of conflicts, and delegation of authority among team members.

CONFLICT OF INTEREST

The author declares that they have no conflict of interest.

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