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H^2CM: A holonic architecture for flexible hybrid control systems

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ABSTRACT

Several studies typically arise from the interaction of discrete planning algorithms or control and continuous processes, normally called hybrid control systems. It consists in three distinct levels, the controller, the plant and the interface. Hybrid control systems are conventionally modeled by switching patterns using the whole system instead of atomic resource. Therefore, the reconfiguration process is complex because it must take into account the system as a whole, making the hybrid control systems inflexible and more susceptible to uncertainties. The need for flexibility thus leads several teams to investigate the application of holonic paradigm to hybrid control systems. The objective of this paper is to demonstrate the possibility to apply almost directly a holonic discrete-event based reference architecture to hybrid control systems. A case study of industrial electricity generation process was taken, specifically a combined cycle plant (CCP) for verifying the proper operation of the proposed architecture.

1. Introduction

Manufacturing systems are traditionally divided into three main classes, namely discrete-event, continuous and semi-continuous processes [1]. Discrete processes class deals with systems where the individual parts are produced using various discrete loosely coupled operations (such as machining, drilling or grinding), then pieced together in an assembly line to create the main end-product. The control of these kinds of systems is classically optimized via scheduling techniques, able to determine the best order of parts to manufacture in order to maximize a given criteria, such as makespan or mean tardiness. However, this fully predictive approach is progressively replaced by predictive–reactive approaches, able to react to disturbances appearing when applying the schedule on the shop floor [2]. Mehta and Uzsoy [3] classified these approaches into four main categories: completely reactive approaches, predictive reactive approaches, robust scheduling and knowledge-based scheduling. Another explored way is to redefine the control architecture in order to give autonomy of action and decision to specific entities. This concept is usually denoted as holonic paradigm, creating holonic manufacturing systems (HMS) [4]. Holonic control architectures are flexible architectures which allow online reconfiguration of processes. A holonic manufacturing architecture shall enable easy (self-)configuration, easy extension and modification of the system, and allow more flexibility and a larger decision space for higher control levels [5].

The second class deals with continuous processes. It involves continuous flow of materials such as water or bulk chemical for example and utilities through process units interconnected via piping streams. Their behavior is usually described as a system of differential equations, describing the outputs of the system considering the inputs and the values of the parameters that can be addressed. The optimal control of the system generally consists in inversing the system, i.e. determining the best set of parameters in order to obtain the desired outputs considering the inputs.

Semi-continuous processes, belonging to third class, also involve continuous flow of materials and utilities, similarly to continuous processes, but are not operated with a purely steady-state mode. Several studies typically arise from the interaction of discrete planning algorithms and continuous processes, called hybrid control systems (HCS) [6].

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The hybrid approach used in this paper is a HCS, which has a continuous-time linear time-invariant plant described by linear differential equations, which involve continuous valued variables that depend on continuous time. It is controlled by a discrete-time linear time-invariant plant described by linear differential equations, which involve continuous-valued variables that depend on discrete time [6]. According to [7], HCS consists in three distinct levels (Fig. 1). The controller is a discrete-state system, a sequential machine, seen as a discrete event system (DES). The controller receives, manipulates and outputs events represented by symbols. The plant is a continuous-state system typically modeled by differential equations and is the system to be controlled by the discrete-state controller. The plant receives, manipulates and outputs signals represented by real variables that are typically (piecewise) continuous. The controller and the plant communicate via the interface that translates plant outputs into symbols for the controller to use, and controller output symbols into command signals for the plant input. The interface can be seen as consisting of two subsystems: the generator that senses the plant outputs and generates symbols representing plant events, and the actuator that translates the controller symbolic commands into piecewise constant plant input signals.

The need for flexibility thus lead several teams to investigate the application of holonic paradigm to HCS [8–10]. The objective of these works is to develop a control architecture that would fit the specificity of hybrid systems. Therefore, they all focus on creating holons based on the classical functions to be executed on this kind of systems. Although efficient, these approaches lack of generality and disconnect the results from the set of results already available from the numerous studies in the field of discrete-event systems. The objective of this paper is to demonstrate the possibility to apply almost directly a holonic discrete-event based reference architecture to HCS.

In Section 2, a state of the art of holonic modeling in hybrid systems is provided. Then, a proposal of holonic modeling in HCS is detailed in Section 3. A study case is presented in Section 4, followed by the implementation of holonic paradigm before the conclusion and perspectives.

2. State of the art

2.1. Product resource order staff approach (PROSA)

PROSA is one of the most referenced holonic architectures. Unlike other reference architectures such as ADACOR [11], HCBA [12], ADACOR[2] [13] or ORCA-FMS [14], the holons defined in the architecture are relatively generic and disconnected from the sole application to discrete manufacturing environments. This feature makes it a very good candidate for being the basis of an extension of the paradigm to a different class of systems. This is the main reason why this paper relies on PROSA only to illustrate the proposed concepts.

PROSA name derives from an acronym Product Resource Staff Order Approach [15]. The architecture consists of 4 basic holons that are the product holon, the order holon, resource holon and staff holon, see Fig. 2. The product holons (PH) deal with all the data related to the references produced in the HMS. They roughly act like a database for all the other holons of the system to enable them to access all the data (routings, bills of materials, etc.) needed to be able to produce the right products with a sufficient quality. The resource holons (RH) corresponds to physical entities able to act on products (such as factories, machines or tools) and contain all the data and knowledge to be able to control and organize these entities. The order holons (OH) handle the product during its manufacturing, deal with the logistics needed in the routing of the product. These holons interact with each other to achieve better production, thus a system of holons that can co-operate to achieve a goal or objective is calling holarchy. Finally is the staff holon, its function is to help basic holons to find a solution to difficult decisions, it plays the role of an external expert to basic holons. Therefore, the staff holon is meant to be part of complex decision making mechanisms. The aim of this article is to define the general framework in which those mechanisms would be implemented, but not to define the best ones in a specific case. Thus, the staff holon is not used in this paper.

2.2. Holonic approaches of hybrid systems control

The application of holonic systems on continuous systems has been studied by several authors. An implementation of holonic production system on a continuous system is for example proposed by [9]. In this work is showed from Table 1 that control problems of both a static and dynamic nature occur at every level of the manufacturing problem.

Although the algorithms and problem domain are obviously different, in each case there is a clear problem of regulating a control variable via feedback in order to align an output variable with a desired setting. Within a holonic context, the key unifying requirement in all of these different static and dynamic control algorithms is that they be goal seeking. That is, the control algorithm should be provided with a set of requirements and must first convert these requirements into a solvable problem before solving the problem. The goal seeking system depicted as in Fig. 3

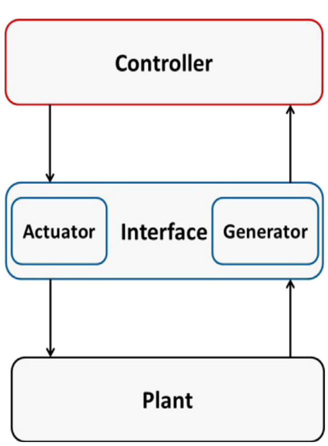

Fig. 1. Hybrid control system.

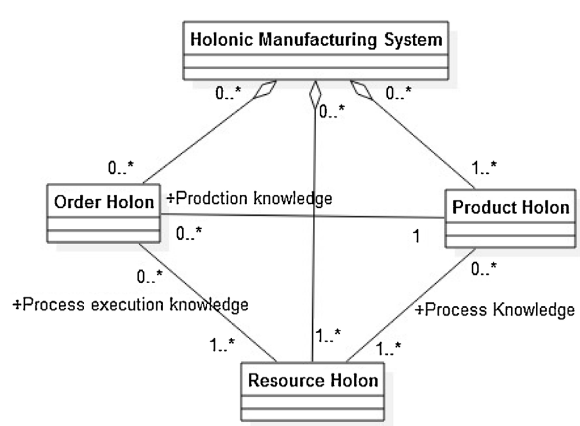

Fig. 2. Basic building blocks of a HMS and their relations, based on [16].