Future Generation Computer Systems 28 (2012) 605–617

Contents lists available at SciVerse ScienceDirect

Future Generation Computer Systems

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

Visual understanding industrial workflows under uncertainty on distributed service oriented architectures

Anastasios Doulamis *, Nikolaos Matsatsinis

Decision Support Systems Laboratory, Technical University of Crete, Kounoupidiana, Chania, 73100 Crete, Greece

ARTICLE INFO

Article history:
Received 15 May 2010
Received in revised form
2 January 2011
Accepted 11 February 2011
Available online 27 February 2011

Keywords:
Service oriented architecture
Computer vision
Industrial scheduling
Distributed cameras

ABSTRACT

Service Oriented Architecture (SOA) is an evolution of distributed computing based on the request/reply design paradigm for synchronous and asynchronous applications. In such architectures, application developers or system integrators can build scenarios by composing one or more services without knowing the services' underlying implementations. In this paper, we adopt a SOA framework for on-line scheduling complex industrial workflows. The proposed SOA consists of three main layers; the input layer, the benchmarking layer, the prediction layer and the scheduler. The main innovation of our SOA architecture is the prediction layer that supports computer vision tools able to visually observe how an industrial workflow is actually executed. This way, we can automatically estimate the actual execution time for a process. In particular a new self-initialized visual tracker algorithm is proposed in this paper to robustly trace workers' trajectory in a plant via visual observations. Then, part-to-whole curve matching is presented so as to find correspondences among the traced curve and the ideal one and thus improving scheduler efficiency. The input layer interoperably describes industrial operations using the XPDL (an XML-based) format. The benchmarker evaluates much faster than real-time and in an off-line mode how long it takes for an industrial workflow to be executed on a given resource guaranteeing an almost real-time implementation of the video processing algorithms on the plant. The last component of the proposed SOA is the scheduler with the goal to assign the workflows to the available resources. In this paper, a Maximum Benefit First (MBF) scheduler is presented which maximizes the total gain received by the industry when completing execution of all the beneficial operations with minimum violations of their delivery deadlines (that is with the minimum compensations). Experiments have been conducted on a real-world industrial plant of Nissan Iberica automobile construction indicating the efficiency of the proposed system.

1. Introduction

Probably one of the most crucial managerial tasks within a large scale industry is *production-schedule (planning)*, that is allocation of a number of available industrial operations (workflows) to available production resources (raw materials, equipment, utilities, manpower) over a scheduling time horizon [1–4]. Industrial planning can guarantee the sufficient execution of predefined operations (products' construction/high quality assembly), satisfy predefined operations' deadlines (production consistency/time precision in products' delivery) and thus improving the economic growth of the industry. Planning involves organization of a set of activities, of greater or lesser complexity, in an attempt to ensure the maximum possible operational availability for the industrial resources, to better exploit the existent human power potential, to abate unforeseen faults and/or to make any unavoidable stoppage for servicing or repair as short as possible (thus imposing minimal impact on the final production) [1,3]. It is also crucial for safety reasons in order to avoid unpredictable accidents that would be disastrous both for humans and/or for expensive machines.

The contemporary way for industrial planning is through written orders that the manager or senior engineer gives to the employees (workers) per regular time intervals [5,6]. The workers should precisely follow these orders to produce manufactured goods of high quality and safely execute the industrial operations. This yields a *static planning* which does not take into account the dynamic nature for a job execution. It is clear that there is distant between the scheduled completion time of a task and the actual one since unforeseen obstacles are involved in the process to delay or even fasten the task's execution. This is even more crucial if one considers dependencies among the executed industrial operations. It is probable, for instance, to have to complete a task before commencing another one. This means that a task delay may cause corresponding delays in executing other tasks probably resulting in a large portion of unexploited production resources.

The most crucial information needed for a dynamic (on-line) production scheduling is to record (capture) the current on-going

* Corresponding author. Tel.: +30 28210 37430; fax: +30 28210 37348.
E-mail addresses: adoulam@ergasya.tuc.gr, adoulam@telecom.ntua.gr (A. Doulamis), nikos@ergasya.tuc.gr (N. Matsatsinis).

0167-739X/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.future.2011.02.008

operations taking place in the plant. This way, we can estimate tasks' progresses (expectations of the actual tasks' completion times) so as to re-schedule them and re-plan the industrial workflows to better exploit the available production resources increasing industry's productivity. To record, however, the current progress for the industrial operations, we need to use either (i) foremen (manual recording), (ii) Radio Frequency (RF) sensors (automatic recording), (iii) intelligent agents, (iv) neural networks, (v) fuzzy analysis and (vi) graph partitioning theory. In the first case, the economical benefits gained by the adequate scheduling are actually crossed out by the additional manual cost and the exploitation of more human resources. In the second case, the use of RF sensors restricts the independent acting (working) of the industrial personnel (workers). In addition RF's are only suitable for constrained industrial environments [7–13]. On the other hand, agents have been also applied to schedule industrial production as reported in [14,15]. Furthermore, the neural network analysis, the fuzzy description of the scheduler and the graph partitioning techniques are intelligent tools which are applied on sensorial data to get efficient scheduling schemes [16–18].

The recent advances in computer vision [19,20] and machine learning society [21,22] have endowed the cameras with smart capabilities in terms of detecting static (non-moving) objects, tracking moving entities, or even understanding/interpreting events, actions and/or behaviors which occur in a working place. The goal of these activities is to transform industries into "smart factories" in which one can on-line plan the production resources, draw conclusions about salient events or even avoid hazardous situations (accidents) that may compromise workers' safety [15]. Smart video surveillance systems, properly modified to satisfy the industrial requirements and robust enough to work in harsh industrial environments, can enrich modern factories with automatic decision making tools and intelligent/smart capabilities increasing, in the sequel, their productivity and competitiveness.

The main difficulty for an on-line scheduling of the visually observed industrial workflows arises from the distributed and heterogeneous nature of the visual sensors. Cameras are actually placed at different locations within an industry. On the other hand, the type, format and properties both of the sensors and of the captured content highly vary inflating heterogeneity issues. Service Oriented Architectures (SOAs) define standard interfaces and protocols that allow developers to encapsulate information tools as services that clients can access without knowledge of, or control over, their internal workings. Thus, tools formerly accessible only to specialists can be made available now for all [23]. In SOA, data and functionality are decoupled yielding to minimal dependencies among the service requesters and providers [24]. The service oriented approach suits well the industrial operational environment as well as with service maintenance. Services that do not themselves hold any significant amounts of data, but transform it, can be implemented by the external service providers [25].

1.1. Related works

On-line scheduling visually observed industrial workflows is a research topic which has not been exhaustively surveyed in the literature. This is due to the fact that recognition of events, actions and workflows in a complex industrial environment is generally a very arduous task while the inclusion of on-line scheduling algorithms that will exploit the performance of the computer vision tools makes the problem even more challenging. The adoption of a new Service Oriented Architecture (SOA) able to handle the distributed nature in executing the industrial operations and the heterogeneity and diverseness of the data constitutes another innovation of this paper. We describe the main original issues of this paper in Section 1.2.

Several works have been presented in the literature for scheduling industrial processes, most of them exploit concepts coming from scheduling operational tasks in computational processors [26–28]. However, the incorporation of computer vision tools able to understand the actual (real-time) execution of industrial processes is rather limited. In [29] a survey of industrial vision systems for recognizing and identifying manufactory operations is presented, while in [30] salient features are extracted able to identify industrial tasks. Recently, works that exploit distributed information from multiple cameras that synthesize a network of sensors have been presented. More specifically, in [31] tracking of salient industrial objects is implemented using a visual sensor network, while in [32] video adaptation techniques are supported implemented again across a network of cameras. Tracking of visual objects before detection is proposed in [33], while compelling intelligent agents are used in [34] to track the visual objects. Finally, the work of [35] detects salient events by incorporating multiple wireless cameras that communicate with each other.

All the aforementioned approaches exploit computer vision tools to understand the current on-going operations in an industry. However, in real-life cases, many distributed and heterogeneous sensors' cameras are required to describe the current conditions since industries are often large-scale terrains. Service-Oriented Architectures can help towards this direction since they provide a transparent decoupling framework through which services provision tools and requesters can be operated independently one from the other significantly improving the reliability and interoperability of the on-line production scheduler schema.

The [36] proposes a SOA able to support industrial information systems. In particular, [36] presents an architecture which can couple both management and production processes under a common service oriented approach so that different levels of interoperability will be supported. A SOA framework that supports the optimization for the execution of services' workflows is presented in [37]. In this work, the authors develop a new services' wrapper that enables dynamic service grouping for optimizing the execution time. The efficiency of the architecture was tested on a real-life medical imaging application. A semantic SOA has been developed in [38] to create a unified framework through which different industrial operations can be integrated. The approach exploits intelligent agents that are properly tailored with the semantically-described SOA. In the same framework, [39] proposes a real-time SOA for automating the industrial processes.

Surveying industrial tasks and workflows using web services has been presented in [40]. Generally, industrial workflows can be classified into the following categories; single and static, multiple, concurrent and static, single and dynamic and multiple, concurrent and dynamic. The first adverb refers whether more than one workflow is simultaneously executed within an industrial environment. The second adverb refers to the nature of the executed workflow, in terms of changing the way of conducting a service upon environmental conditions and/or customers' requirements. In this paper, we deal with static but concurrently executed industrial workflows, since in the examined automobile construction environment, only well-defined activities can be conducted. Another way of classification is the type of venue on which a workflow is executed. Our case deals with industrial workflows. On the other hand, other systems deal with other types of workflows, such as office automation systems, robotics, etc. The adoption of a SOA architecture and the use of web services enables a flexible and transparent interaction between the field devices and human operators. Dynamic scheduling and routing of single industrial services is presented in [41] since changes in equipment and production demand cannot be predicted at the design stage. Therefore, decision taking mechanisms must rely on real