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Cloud-based Control of Thermal Based Manufacturing Processes

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Abstract

With non-conventional manufacturing processes, being increasingly integrated into manufacturing process chains, controllers and control strategies, remote nowadays, have to take into account a plethora of phenomena and criteria. The current study addresses the challenges, associated with the framework of the thermal oriented processes, having holistic (digital) modelling as a main objective. Herein two different case studies are performed; numerical examples regarding big data impact on manufacturing and simulation-based paradigms of control design taking into account communications. Implementation of the aforementioned takes into account the controller's complexity.

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1. Introduction

With the automatic process control, dealing with the monitoring process behavior and the adjusting parameters [1], the signals become more and more vital, with the data communication requiring more resources [2]. The Cloud based Cyber Physical Systems [3] and Big Data [4] have therefore become a necessity.

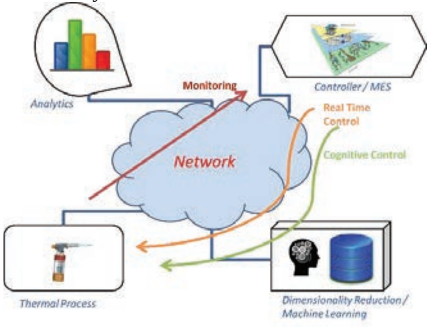

Fig. 1. Generic Schematic of Cloud Control

In addition, as Industry 4.0 [5] is increasingly come across in literature, Big Data in Process Control and Shop-floor Level in general, are expected to occur in the near future; this depends on five major factors: Regarding the Data size, the aggregation in remote control and Manufacturing Execution Systems [6] are already of a high level. Moreover, the Data related Velocity is affected by a sampling rate, which can be quite high, especially due to sensors, such as those of acoustic emission [7]. Regarding Data Variety, there is a plethora and diversity of reporters (machine tools, AGV's, robots [8], workers) and Key Performance Indicators [9]. Furthermore, the Veracity of Data is of high importance, since security [3], integrity, time-stamping and accuracy, due to control precision, all add up to this. Finally, there is the Value of the Data: Laser Welding Quality Assessment, on its own, involves a lot of data the usefulness of which is disputable.

On the other hand, the effect of communications on control is quite known [2]. As previously stated, the introduction to manufacturing and to processes control, is relatively new. However, there are older studies that imply such effects [10,11].

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As such, there exist two major issues that can be addressed under this prism. The first one – under numerical case study, in Section 3, is the effect of control on data communications. As it is often addressed in literature [4], there are five factors (the “five V’s” as stated above) that add up to the complexity of data acquisition, storage and processing / analytics [12-14]. Given the fact that cloud-based control (Fig. 1) is to be achieved, the effect of control through communications [2],[15-17], the effect of control signals is clear on Volume, Velocity, Variety, Veracity and Value.

The other issue that is studied (Section 4), is the exact opposite; as depicted in Figure 1, Cloud control forces the control signal to be transmitted through dedicated networks or even the internet. Various kinds of delays [2] are present thus, making the study on the effect of data communications in control systems, a necessary aspect for investigation.

2. Approach

Regarding the first case study (Section 3), a numerical example is given utilizing available data on cognitive control of Laser Welding in Automotive, to assess the probability of coming up with Big Data in Manufacturing (in process level).

Moreover, when approaching the control design (case study 2 / Section 4), as the communicational issues have to be taken into account, a thermal process is modeled as a system, described by an equation of differences. The process related metrics are selected and the effect of the communication delays on them is examined. In this regard, the paper is structured in the following sections, describing the approach followed for the design and evaluation of a static controller, towards the creation of a networked control strategy.

i. Effect on performance, related to quality [18]: It regards the system’s efficiency in tracking a temperature profile as input.

ii. Effect on stability: Dealing with the capability of the system’s output (temperature) practically, not to be exceeding high values

iii. Design and evaluation of a static robust controller.

iv. Effect on energy efficiency [19] is then investigated. This Key Performance Indicator (KPI) is relatively new in manufacturing and has been driven by societal needs. It reassures that the desired behavior is achieved by minimizing the resources (Energy Consumption in this case).

3. Case Study I: Effect of control signals on data communications

3.1. Description

Among the rest dominant monitoring technologies (vision & thermal cameras, optical sensors) implemented into thermal processing, acoustic emission sensing has been also investigated in literature and was put into practice in several cases [20,21]. The particular technique constitutes a very good paradigm of control, pushing manufacturing towards IoT and big data.

To begin with, acoustic emissions can be detected by a corresponding sensor in frequencies up to *1 MHz* [22] (corresponds to data velocity). For the conduction of a conservative calculation, a sampling frequency of *1.5 MHz* will be used. For the reassurance of the data veracity, a bit depth of *32 bits/sample* is considered. Then, for reasons of value reassurance, 3 sensors per machine tools are regarded. To demonstrate a quite range of data volume, 3 machine tools per shopfloor have been considered and two shopfloors in general. Consequently, a total bandwidth of *864 Mbps* for pure information is required. Judging by the capacity of the media [23,24], an optical network has to be used

3.2. Results

In the same context, using a thermal camera [25], the bandwidth required is:

$$bW = 80 \times 80\, pixels \times 10 bits / pixel \times 10 kHz \quad (1)$$
$$bW = 64 kbps$$

If one increases the number of sensors to achieve a multi-spectral image processing, the bandwidth will be equal to:

$$bW_N = 64N\ kbps \quad (2)$$

with *N* being the number of spectral channels.

Using as an example the welding of an automotive door, with *112* stitches [35] of *0,22 sec* [35,27] the storage capacity required is approximately equal to *1.8N MB*. Finally, an estimation of the data effect on the processing method is given. Since a matrix inversion is always relevant to these cases (i.e. PCA method [28]), the following diagram gives the inversion time through the Matlab’s “inv” command [29]. A random matrix of dimensions $n^2 \times n^2$, with n being the pixels per direction, is considered and inverted. The inversion time is given in seconds. In Figure 2, the results are shown for this case. Moreover, in order for this subject to be addressed, the same results are shown, provided that a degree of parallelization is achieved by utilizing Schur’s complement for matrix sizes over $16^2 \times 16^2$.

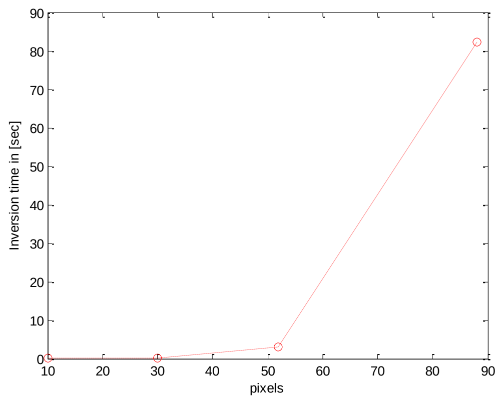

Fig. 2. Matrix Inversion Time as a function of Matrix size.