TOWARDS AN INTEGRATED APPROACH OF PRODUCTION SYSTEMS

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Summary The core of this research is to build new and executable strategies for embedding both current and new simulation capabilities into factory material processing and product evaluation; thereby creating a human friendly "robotic" factory environment where online simulation can be used to control both process and product performance in real-time.

INTRODUCTION

Traditional factories can be pictured as black boxes operating on materials (inputs) to produce parts (outputs); the black box consisting mainly of manufacturing processes. However, many processing constraints have to be taken into account in order to fulfill the important requirements of manufactured parts. Thus, one needs to give careful thought to the materials and the process. This is the manner by which natural feedback acting on materials and processes was introduced to manufacturing activities many years ago. **However, the traditional approach seems to be too limited for several reasons:**

The subtle coupling between materials, processes and products. The behavior of materials is strongly dependent on the forming process itself and consequently on the properties of manufactured parts. If this assertion applies for any kind of material, it is especially restrictive in the case of composite materials that do not exist "a priori", because it is precisely the forming processes that create them. Thus, nowadays, materials, processes and manufactured products can no longer be considered separately, their interdependency is incredibly strong.

When classical process control becomes insufficient. Online material and process control and optimization are carried out by considering different approaches. The most common approach consists, as described above, in considering the manufacturing process as a black box whose behavior is modeled by a transfer function relating certain inputs (concerning the material and process) to certain outputs (generally related to the quality of manufactured parts or productivity). This modeling may seem poor. The advantage is that it can be performed rapidly due to its simplicity. This compromise between accuracy and rapidity was often used in the past and this pragmatic approach has allowed us to control processes and to optimize them, once the transfer function modeling the system is established. The establishment of such goal oriented transfer function is the trickiest point. For this purpose, it is possible to proceed from a sometimes overly simplified physical model or directly from experiments (allowing us to extract a phenomenological goal oriented transfer function) or from a well-balanced mixture of both approaches. In all cases, the resulting modeling can only be applied within the framework that served to derive it. The multi-scale description of materials, processes and structures and their couplings usually requires a sufficiently detailed description of them and, in that case, traditional goal oriented simplified modeling becomes inapplicable and manufacturing processes are confronted by their limits.

When numerical simulation becomes too expensive. When considering the physical modeling of materials, processes and structures, all of them result in complex mathematical objects, non-linear and strongly coupled partial differential equations. Such mathematical objects are supposed to represent physical reality up to a certain degree of accuracy. However, the numerical tools capable of solving these complex models require the use of powerful computers that can require hours, days and weeks to solve them. Known as numerical simulation, its output solution is very rich but it seems inapplicable for control purposes that require fast responses, often in real-time. Until now, numerical simulation has been used offline but in some cases it allows us to define simplified models (with their inherent limitations and drawbacks) running in real-time that could be used online but such simplified modeling has the previously quoted drawbacks.

Issues of optimization and inverse methods. Optimization and inverse methods require the solution of many problems, each one related to the selection of trial design parameters. These parameters concern the three main ingredients of manufacturing systems: materials, processes and parts. The first ingredient is addressed in the framework of computational materials whereas the last one constitutes structural mechanics (including damage and failure analysis). Both of them are affected by the current limitations of numerical modeling and mainly by the computing time needed for performing standard optimization procedures.

The colonization of robots. Robots colonized factories many years ago but they suffer from two main limitations. Their control is carried out from material and structural models that are simple and process models that imply an excessively low degree of freedom and their architecture does not allow for new challenges, such as producing very large structures. They don't seem to be well adapted to next generation factories. Bio-inspired robots could open numerous avenues but their introduction to production systems requires further development in many related fields. For example, autonomous operation requires efficient advanced control strategies, some of them based on finely detailed

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data simulation coming from haptic devices, images and sound. This simulation must be accurate enough and run in real-time.

The inevitable uncertainty. In production systems, in its widest sense, it now seems obvious that there are many causes of variability for materials, processes and structures. The introduction of such variability, randomness and uncertainty in the whole production chain is a priority for the next decade. Although it was a priority in the preceding decade, the practical progress attained seems fairly weak.

Distancing R&D. R&D is too far from production activity, the machines and the employees that supervise the conformity of its function. In some malfunctioning scenarios, the employer needs to make quick decisions (without requiring the intervention of the R&D department) despite being a non-specialist.

The recurring dream of producing quickly and cheaply. The factory, like every component of our society, is faced with a new and very rigid constraint: producing quickly and cheaply. In the context of production systems, one needs to treat reality (not an overly simplified vision of it) considered globally (the whole system with all its couplings and interconnections), as fast as possible (real-time is compulsory in some applications) and by using, if possible, devices that are as light as possible, facilitating their use by non-specialists and their introduction into embedded platforms making use of the most recent breakthroughs such as augmented reality on handheld devices. Obviously these possibilities and facilities do not exclude traditional aspects that cannot be circumvented in certain applications, in particular, in complex structural analysis, when the models to be used sometimes remain under construction.

Research should overcome the main drawbacks of modern factories, allowing the achievement of the following **objectives**: (i) taking the subtle coupling between materials, processes and products in their use environments into account; (ii) defining advanced simulation-based control strategies instead of current control procedures based on transfer functions that are phenomenological or too simplistic; (iii) solving a sufficiently general parametric model once and offline in order to compute the numerous problems involved with optimization or inverse procedures online at a sufficient speed; (iv) the introduction of a new generation of robots and bio-inspired robots whose autonomous operation requires efficient advanced control strategies, some of which are based on fine sufficiently fast and accurate simulation of data coming from haptic devices, images and sound; (v) the consideration of uncertainty quantification on the material, processes and products level; (vi) the relocation of R&D activities to production systems, in such a way that employers can supervise processes, making fast decisions in malfunctioning scenarios by making use of embedded systems that are simple enough to be used by non-specialists; and (vii) address production systems with all their complexity, as fast and cheaply as possible.

ADVANCED REAL TIME SIMULATION OF PROCESSES

The main objective of the present research is to address the simulation of "real" models encountered in material forming processes with all their complexity from the geometrical and constitutive points of view, some of them never until now solved because of their computational complexity. These models should be solved very fast, in some cases in real time, by using light computing platforms [1]. Classic simulation techniques fail to fulfill the above requirements. An appealing alternative consists in considering offline solutions of parametric models, in which all the sources of variability – loads, boundary conditions, material parameters, geometrical parameters, etc. - will be considered as extra-coordinates [2-5]. Thus, by solving the resulting multidimensional model only once, we have access to the solution of the model for any value of the parameters considered as extra-coordinates. Now, from this general solution computed only once and off-line we could perform on-line real time post-processing, optimization, inverse analysis, analysis of sensibilities, stochastic analysis … by using very light computing platforms like Smartphone. We could also adapt the model on-line while its simulation is running within the framework of dynamic data-driven application systems – DDDAS. The price to be paid is the solution of parametric models defined in high dimensional spaces but the use of the Proper Generalized Decomposition allows such solutions. However, some models involve an infinite number of parameters, as the ones involving trajectories that should be optimized. In that case only coarse parametric off-line solution can be computed, but they could be coupled with advanced real time systems. However, many challenging issues arise, as the ones related to mutli-scale synchronizations leading to dedicated real time scheduling and architecture, and the dynamic adaptation of the real time software requiring formal designs. The coupling between approaches, real time controllers and fine simulation-based control strategies has never been tested and without any doubt it could constitute a change of paradigm in the real time control of systems.

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