Universitatea *Transilvania* din Braşov

HABILITATION THESIS
SUMMARY

Applicability of Digitalization in Systems Engineering

Domain: Systems Engineering

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Digitalization is the use of ***digital technologies*** to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a ***digital business***. **Digital business** is the creation of new business designs by blurring the digital and physical worlds. In the same time, the goal of using digital technologies is to increase the efficiency of already running processes.

The studies regarding the degree of digitalization penetration in various domains of activities show currently a stronger impact on end-user consumer related domains like media and trade where, thanks to fast evolution of mobile devices(e.g. smart-phones, tablets etc.) and/or thanks to high processing computing(e.g. multi- and many-core based systems), new approaches were enabled in retail business or stock markets. The strong regulated or sensitive domains(e.g. utilities, healthcare) are at the start or on the bring to take off of the process that poses besides a challenge a good opportunity regarding innovative approaches due to the natural effects/goals of digitalization: increase of the production efficiency. This can be achieved by considering the following levels of development:

a. Generation of models that represent the process/system as close to reality as possible;

b. Acquisition of data from the process/system regardless where are located the sensor/acquisition devices as a result of fast evolution of communication technologies; storage and handling of paramount volume of data in short time intervals;

c. Speed up the simulation of the customized models based on points a and b as well as analysing the collected data; detection of behavioral patterns in real time;

d. Dynamically generate/manage commands for improving the supervised process/ business (e.g. energy optimisation in a plant, predictive or prescriptive maintenance, etc.); use the customised models to simulate the effect of the commands on the process before applying- digital twin approach.

The work presented herein has been focused mainly on the levels a&c, touching also elements of the levels b&d.

A methodology to model the induction motor with variable impedance has been developed for evaluating the performance when a variable capacitor is inserted in the rotor circuit. This algorithm helps in evaluation of required capacitor values for achieving the desired performance. Theoretical approach shows the possibility to improve power factor, efficiency and the torque-speed diagram based on the derived set of equations. The practical solution proposed to emulate dynamic controlled high value capacitors was based on a previously developed concept and consists of an ac capacitor placed in the middle of an H bridge with bi-directional switches. The use of this mechanism avoids the insertion of supplementary resistive and reactive elements in the rotor circuit. The experimental results obtained for a small induction motor correspond to those predicted on simulations. The power factor and efficiency are improved at any given load. The speed-torque characteristic is improved by an increased peak torque. Optimum performance at each load condition can only be achieved by dynamic variation of the emulated capacitor value. Equivalent analysis has been performed for single phase induction machines.

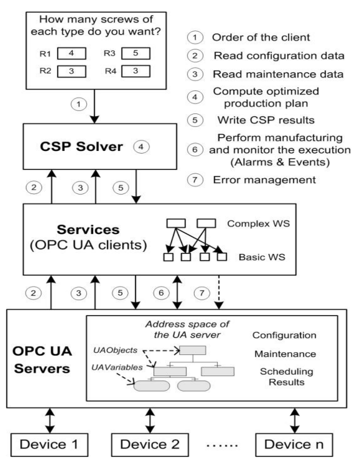
People with cardiovascular disease or who are at high cardiovascular risk (due to the presence of one or more risk factors such as hypertension, diabetes or already established disease) need early detection and management using counseling and medicines, as appropriate. Development of personalized cardio-vascular models has a significant contribution in this endeavour. The complexity of the models-if all aspects are considered –physiological, electric, mechanic, fluid dynamics etc.- impose for practical aspects to consider for certain of its components to be dealt in a simplified manner. The challenge of precise modeling of the human cardio-vascular system is derived from the fact that it represents a closed circuit with a high degree of interdependence between the individual compartments. Studying the local blood flow is very important, since certain pathologies, like the local thickening of the blood vessel or the formation of a stenosis, are strongly influenced by the local hemodynamics. On the other side certain local changes, like the modification of the vascular lumen, may lead to a global redistribution of blood flow, triggering some compensatory mechanism which assures a high enough flow rate in the distal part of the affected vessel. 3D or full-scale blood flow simulations are computationally very expensive and can only be performed for a reduced number of vessels. Both the reciprocal influence between the systemic or global hemodynamics and the local one, and the high computational requirements of 3D simulations, have led to the concept of geometrical multi-scale modeling of blood flow, which has been applied in author's activity in order to analyze the coronary circulation. Thus, only the local regions of interest inside the coronary arterial tree, e.g. the segments which contain a narrowing and plaque deposits, are simulated using full 3D models, while the rest of the circulation is represented through reduced-order models (1D models for the large arteries and lumped models for the small arteries and microvasculature). Reduced-order models produce reliable results in terms of pressure and flow rate waveforms (1D models), they correctly take into account the effect of the distal vessels and of the microvasculature (lumped models) and lead to execution times which are more than two orders of magnitude smaller than the corresponding 3D simulations. One dimensional blood flow models have been investigated based on Navier-Stokes equations considering the viscoelasticity of the walls, relevant aspects being boundary conditions based on methods such as explicit/implicit Lax-Wendroff. The goal of achieving patient personalized models has required to be able to estimate these conditions at rest and hyperemia states. These aspects have been explored along with stenosis models for evaluating Fractional Flow Reserve factor that allows a non-invasive evaluation of the degree of stenosis.

There has been significant interest in exploring high performance computing techniques for speeding up the algorithms in medical domain, e.g, of three-dimensional blood flow models due to the extremely high computational requirements. Although one-dimensional blood flow models are generally at least two orders of magnitude faster, the requirement of short execution times is still valid. Thus, when blood flow is modeled in patient-specific geometries in a clinical setting, results are required in a timely manner not only to potentially treat the patient faster, but also to perform computations for more patients in a certain amount of time. It is crucial to match the patient-specific state in a hemodynamic computation. The tuning procedure requires repetitive runs on the same geometry, with different parameter values (e.g. for inlet, outlet or wall boundary conditions (BC)), until the computed and the measured quantities match. This increases the total execution time for a single patient-specific geometry. Therefore, investigation activities have been performed taking advantage of high performance computing platforms such as GPUs for optimizing the processing time of various sets of differential equations as basis for more advanced models. Next phase has been to focus on the GPU based acceleration of the one-dimensional blood flow model, especially using two algorithms: a novel Parallel Hybrid CPU-GPU algorithm with Compact Copy operations (PHCGCC) and a Parallel GPU Only (PGO) algorithm. These have been applied on a full body arterial model composed of 51 arteries and the speed-up of the two approaches is evaluated compared to both single-threaded and multi-threaded CPU implementations. The computations have been performed using two different second order numerical schemes, with an elastic or visco-elastic wall model, and Windkessel or structured tree boundary conditions as representative examples of physiological non-periodic and respectively periodic outlet boundary conditions. The simulations showed speeds-up of several order in magnitude compared to sequential implementations.

The costs for setting up production activities and installations are approximately one third from total manufacturing expenses. The dynamic of the customer markets, globalization, the need to correlate with raw materials fluctuating prices as well as availability pressure the manufacturing companies to remodel its strategies based on innovation in such a way to find new approaches to configure distribution systems to deliver the desired customer service at the specified due date and at the lowest possible cost while maximizing the enterprise profit. Therefore, an investigation direction has been to optimize production schedules by automatically using the results of these plans and schedules for the manufacturing of the parts, thus, to produce in a minimum time the required products. This optimization shall be achieved based on a general architecture that can be used, practically, in almost any factory, therefore, to provide as main characteristics: reusability, flexibility and adaptability, fulfilling the following criterions from functional point of view:

- optimization of manufacturing processes through the computation of optimal production plans;
- automated usage of the optimal production plans (without the intervention of a human operator);
- development of a flexible and reusable architecture, which shortens the maintenance, installation and setup times and consequently improves the ability to react to changes in the market demand;
- seamless transition from current practice to the novel approach that is presented in the following paragraphs.

There has been developed a conceptual design of an architecture that satisfies the above requirements -as depicted in the picture below- having the following characteristics:



- The OPC UA(**O**LE-Object Linking and Embedding- for **P**rocess **C**ontrol **U**nified **A**rchitecture) servers collect data from all devices, sensors and actuators, model them in a standardized and unified way and assure real-time communication with the devices.
- The second component is represented by several service layers, which, as backbone of the architecture, guarantee its flexibility and adaptability; Software Services has represented an important concept in the implementation of this layer;
- The third component of the architecture (Constraint Satisfaction Problem- CSP solver) addresses its main goal, namely the optimization of production plans and schedules.

The service-oriented architecture has been successfully implemented and validated on laboratory flexible manufacturing lane.

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