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SMART VIRTUAL PRODUCT DESIGN TO BOOST CONSUMER PRODUCT INDUSTRY 4.0

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ABSTRACT

This paper describes a method capable of improving the cycle of product production for manufactured industrial goods. The system is known as Smart Virtual Product Development (SVPD), and by using explicit knowledge of formal decision events, it helps in the decision making. It stores and reuses past decisive events or set of experiences related to various activities involved in the process of industrial product development, i.e. product design, manufacturing, and inspection. This system can potentially be used by large companies producing a range of similar products in mass production, or by a group of small and medium-sized enterprises (SMEs). This research explains how to enhance product manufacturing through the use of SVPD in Industry 4.0, where cyber-physical systems have to play the key role. Analysis of basic concepts and method of implementation shows that this is an expert system which facilitates the manufacture of products that can play a vital role towards Industry 4.0.

1. Introduction

Industry 4.0 is also called Industry 4.0, which implies the initial introduction of the Fourth Industrial Revolution in Germany in 2011. The first three technological revolutions have taken about two centuries, and they are the result, firstly, of the introduction of water and steam-powered mechanical manufacturing facilities; secondly, of the application by division of labor of electrically powered mass production technologies; and thirdly, of the use of electrically powered mass production technologies.

Electronics and IT help to further manufacturing automation. The definition of the new technological revolution, centered on principles and innovations that include the Internet of Things (IoT), the Internet of Services (IoS) and cyber-physical systems (CPS) [4], focused on Internet connectivity that allows for constant contact and knowledge sharing not only between humans (C2C) and humans and machines (C2 M) but also between machines. In addition, the Industry 4.0 concept allows for product customization at lower cost, better quality and faster processing. It is a vision in which intelligent products, intelligent equipment and resources interact autonomously for dynamic optimization.

However, the methodology for adapting and implementing Industry 4.0 isn't transparent for most businesses. In this article a generic framework for Industry 4.0 is explained to test new technologies and create a new approach to them manufacture. The structure of this paper is outlined in section 2, as identified in the literature, as critical components of Industry 4.0, and their significance and challenges to implementation. Section 3 sets out a framework for Industry 4.0 implementation. A case study is presented in section 4 which monitors and analyzes whole body vibrations (WBV) and hand arm vibration (HAV) coming from a machine in real time.

Manufacturing companies that manufacture similar goods face shear competition because of: constant shifts in the industry, the need for short product lifecycles and the fulfillment of consumer demands to deliver better products at a lower cost. That forces them to routinely and systematically implement new product development strategies [1], [2]. Product design and manufacturing are important steps involved in the process of product creation, as they include detailed information and knowledge about consumer demands. Successful product development organizations acquire at least two types of design knowledge; first, with regard to the product itself, and second, with regard to its manufacturing in an efficient manner to meet costs, quality, and short development time. Manufacturing knowledge is an expression with enormous meanings, it can include: knowledge of the effect of material properties in decision making, selections of machines and processes, and understanding the unintended consequences of design decisions on manufacturing. To evaluate manufacturability in terms of criteria and metrics, such as cost and time, designers have to do manufacturing planning. Therefore, the use of incorrect information about manufacturing can lead to errors during product production and can damage the environment. Such errors are likely to be caused by designers depending on poor or insufficient information about manufacturing during the process of product design.

Through rising manufacturing automation, electronics and IT played a key role in the 3rd industrial revolution. Now the global manufacturing industry is moving in the direction of Industry 4.0, the fourth industrial revolution. Conventional production processes will be replaced by smart production which consists of new concepts, i.e. Internet of Things (IoT), Internet of Services (IoS), and Cyber-Physical Systems (CPS), Mass Communication, High Speed internet and accessible 3-D printing. The Fourth Industrial Revolution has addressed several changes in conventional production systems, leading to the development of more complex and smarter products with new capabilities [3]–[5]. It therefore affects the entire product lifecycle and causes the emergence of advanced digital tools for product development and prototyping, consisting of advanced computer platforms. Production of these smart products requires fundamental changes in the processes of classical product growth, which have undergone many advances in theory, techniques, and approaches in the last few decades. Therefore, the relationship between the product production cycle and the fourth industrial revolution is not discussed, but it is interesting because of the huge amount of data obtained from smart manufacturing. Different types of questions arise in terms of the product development process, such as: how can it help meet the requirements of customers, minimize the development cycle time and control the cost of product development. This all provided tremendous potential for the creation of new smart knowledge-based product development systems for smart product design and development.

The idea of smart manufacturing is also closely linked to knowledge-driven decision-making to fulfill the demands of consumers on new goods. It is very important to have complete knowledge of each manufacturing process and its possible outcomes in order to take decisions at different stages of product development. In addition, engineering expertise is incorporated in the product lifecycle in various stages in the form of rules, logical expressions, ontologies, predictive models, statistics, and information derived from previous experiences and sensors in real-world situations such as manufacturing, testing, product use, supply networks, and maintenance. Information is currently not completely documented and processed in a digital form across all phases of the product life cycle [6]. Organizations therefore aim at streamlining the capture and creation of knowledge through knowledge management.

2. Discussion

1. Product Development:

Product creation is a set of interconnected processes and sub-processes that include product design, manufacturing design, and product launch process and production start-up. The key goal of the product development process is to combine engineering and industrial design specifications into a systemic process that allows the achievement of lower production costs, better quality, and shorter development times with faster market access, so that it can contribute to the satisfaction of consumers and the financial benefits of companies. In the past, various classical approaches such as Stage-Gate modeling process, Ulrich and Eppinger product development process, Production funnel product modeling process, Simultaneous Engineering (SE), Concurrent Engineering (CE), Integrated Product Development (IPD), and Lean Product and Process Creation (LPPD) played key roles in product development processes.

The advent of the fourth industrial revolution, which involves a series of developments in both goods and manufacturing processes, was stated earlier. Therefore, adapting this new industrial pattern and producing smart and connected goods means extreme changes in the entire value chain of the organizations, particularly in the process of product growth. Organizations which produce smart products now need to follow the most effective approaches to product growth. Resource optimization and waste disposal are one of the important factors to consider when developing the smart products to increase the competitiveness of the company. This can be achieved through the introduction and development of new technological tools that can eliminate errors in early stages of product development. In recent past, Lean product and process development has achieved great success by integrating engineering knowledge into the process of product development. Few of the main lean enablers for product creation are: knowledge-based engineering, error proofing (Poka-Yoke), and Continuous culture of progress (Kaizen). This work also uses a smart knowledge management technique called Collection of Experience Information Structure (SOEKS) and Decisional DNA (DDNA) to enhance the production process of the product, which is one of the important steps in the growth of industrial product.

2. Set of Experience Knowledge Structure (SOEKS) and Decisional DNA (DDNA):

Set of knowledge structure on experience (SOEKS) has the ability to explicitly store and share the formal decision events. It is basically a smart decision support tool based on knowledge that stores and maintains the experiential knowledge [7]–[9]. Such experiential knowledge is used for future enhancement of decision taking if a new question is produced or presented. There are four basic components of an experience set (SOE, a shortened form of SOEKS): variables (V), functions (F), constraints (C), and rules (R).

Variables define the functions of the SOE, while functions create relationships among variables and are used to develop multi-objective objectives. Constraints are special functions implemented by SOE in order to achieve feasible solutions and monitor the efficiency of the system in relation to specified objectives and limitations. Laws, on the other hand, are the conditional relationships between the variables, which are described in the logical statements of IF-THEN-ELSE. Therefore, a formal decision occurrence within the SOE is defined by a specific set of variables, functions, constraints, and laws. Groups of SOEs create chromosomes representing the particular area / domain within the given area of decision-making, and store decisive strategies for a given domain. Accurately, it is commonly known as its DDNA the ordered and grouped sets of decisional chromosomes.

Knowledge set and DDNA have been successfully implemented in various fields such as industrial maintenance, semantic enhancement of virtual engineering applications, state-of-the-art digital control of geothermal and renewable energy, knowledge storage and periodic decision taking in banking and supervision activities, e-decision society, virtual organization, interactive TV.

3. Smart Manufacturing and Cyber-Physical Systems:

Smart manufacturing refers to the integration of modern manufacturing technology and emerging technologies to boost the manufacturing processes' efficiency, agility and sustainability. It uses the Cyber-physical system concept to control various physical entities in the manufacturing environment through the collaboration of computational elements. It is an evolving development process that combines today and tomorrow's manufacturing assets with sensors, computing systems, communication technology, control, simulation, data-intensive modeling and predictive engineering. Cyber-physical systems (CPSs) along with the internet of things, cloud computing, artificial intelligence and data science are core components of smart manufacturing [10], [11]. They can be described as the transformative technologies for managing interconnected systems with the possibility of human machine interaction between their physical assets and computational capabilities18. Owing to industry digitization powered by advancements in technology and communication, CPSs are becoming increasingly relevant in manufacturing. They have advanced machines and sensors which can produce large amounts of data. Using these computers, data analysis software can therefore be used to build intelligent, autonomous, and robust systems. CPS can be further developed in modern manufacturing organizations, especially high-tech industries, to handle information and experience in the form of big data and to exploit the interconnectivity of machines to achieve the target of smart factories.

4. Smart virtual product development system (SVPD):

Smart Virtual Product Development (SVPD) is a product development decision support platform that stores, uses and shares the experiential experience of previous decisional events in the form of SOEs. It is developed to overcome the need to capture knowledge in digital form in smart manufacturing in product design, production planning and inspection planning. This will help to increase product quality and time for development as required by the concepts of Industry 4.0.

4.1. Architecture of Smart Virtual Product Development:

Proposed Smart Virtual Product Production (SVPD) program consists of three main modules, namely design knowledge management (DKM), manufacturing capacity analysis and process planning (MCAPP), and product inspection planning (PIP). Such modules communicate with the system's decisional DNA that contains all of the related information of similar products. An archive of information is packed with past structured decisional activities involved in the manufacturing of these identical items in existing facilities. The proposed system will store crucial knowledge of DNA in the form of SOEs. The SVPD system architecture is shown at Figure 1.

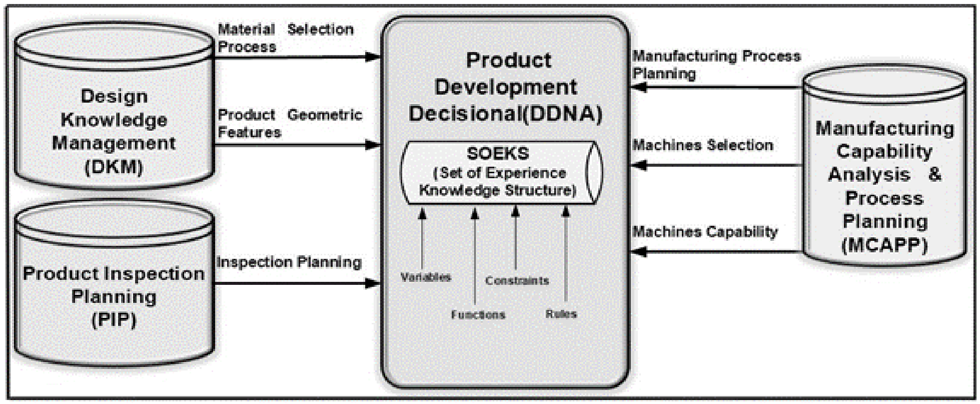

Figure 1. Architecture of Smart Virtual Product Development (SVPD).

These modules also have different steps to accomplish particular decisional activity. Design information management deals with the selection of materials and the creation of architectural features of products; manufacturing capability analysis and process planning offers solutions regarding the preparation of manufacturing processes, the selection of machines and the ability of machines to conduct different manufacturing operations; and inspection preparation includes the selection of various measuring equipment.

5. Design of a test case study for the MCAPP-module:

The design and development of a threading tap (a device that is called threading to build screw threads) is case study, as it was also used in previous work for the DKM module. Research consider a threading tap for machine use, as shown in Figure 2 with few significant dimensions. As mentioned above, this research addresses important variables in the MCAPP module, so research will explain how manufacturing process planning works, which is one of the key steps in this module.

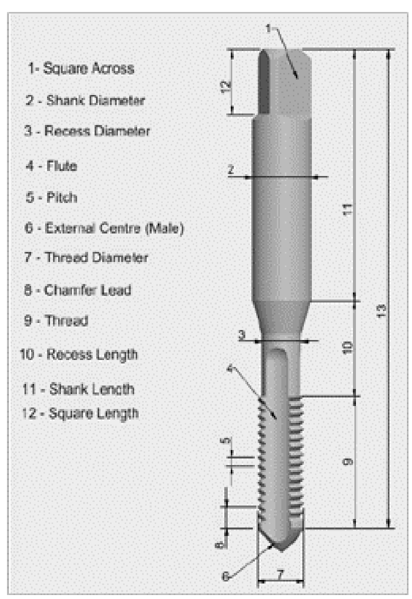

Figure 2. Important Dimensions in Threading Tap.

6. Working Algorithm of Manufacturing Process Planning:

Process planning for manufacturing is part of SVPD's production capacity analysis and process planning module. It addresses the processes needed in the current facility to produce the product. The current case study facility (Threading Tap) is a small tool factory that consists of a design office, a well-equipped machine shop (including traditional and non-conventional machines), metrology (inspection unit), and heat treatment area. In this stage, research need to determine which machining operations is required to produce the product under consideration. Each process will begin by inputting the question into the system's decisional DNA based on initial goals. For the present threading tap case study, let us consider that the selected material is high speed steel and the initial goal is to define manufacturing processes for that product. Such manufacturing processes may easily be retrieved from an existing Virtual Engineering (VEP) process of a specific product category. In comparison, a VEP is an information representation of manufacturing process planning involving the operations required, their series, and resources. The parser for manufacturing process planning is also written in Java code using the Windows 10 operating system as the DDNA is built in Java. The CSV file for manufacturing process preparation pseudo code for parser reading is shown below:

• Read variables, functions, constraints and laws.
• Develops set of variables, function set, set of restrictions and set of rules.
• Generates a Set of Interactions (SOE) = Variables set + Functions set + Rules set.
• Shape a fabrication process planning chromosome by collecting SOEs of the same type.
• List the Top 5 options suggested.
• The User selects the final solution and stores it for future reference as SOE in SVPD DDNA.

Likewise, the data for the selection process of the machines is stored in a CSV file in the form of a VEP, and is retrieved by a query request. The computer functionality data, however, is stored in a CSV file in the form of a virtual engineering object (VEO), and is retrieved by placing an input query. Whereas a VEO is the reflection of the knowledge of an engineering entity embodying its related information and experience. CPS specializes in its extension into knowledge gathering and reuse23.Working mechanism for all steps / sub-modules of MCAPP modules is shown in Figure 3.

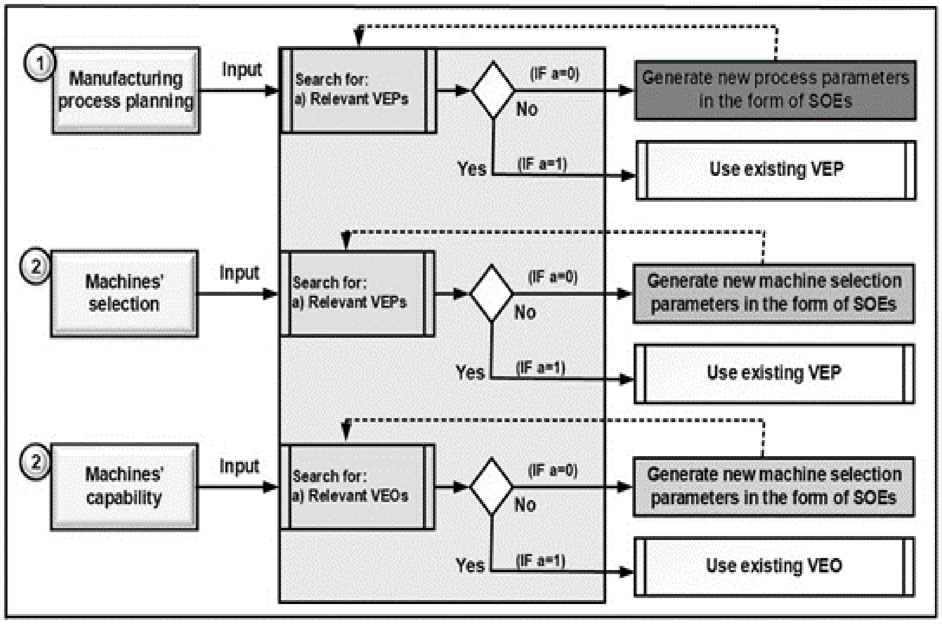

Figure 3. Working Of MCAPP Module.

3. Results and discussion

On a Dell laptop with windows 10 Enterprise 64-bit operating system with Intel ® Core TM I5-7300u CPU @ 2.60 and 8 GB of RAM, case study for manufacturing process planning was conducted. Parser for the preparation of the manufacturing process reads the data from a CSV file with information about 10 different types of threading forms according to the classification of material and the method of use. This CSV file stores production processes in the form of 22 variables, two functions, and three constraints. The parsing process for the planning of the manufacturing process was carried out, producing an average parsing time of 0.098 seconds as shown in Figure 4. It is considered a rather good time, given that due to the large number of variables, functions and constraints, certain SOEs are very complex. Parsing time for different SOE elements was similar; time to read variables 0.035 seconds, time to read the functions 0.046 seconds, and 0.012 seconds to read constraints.

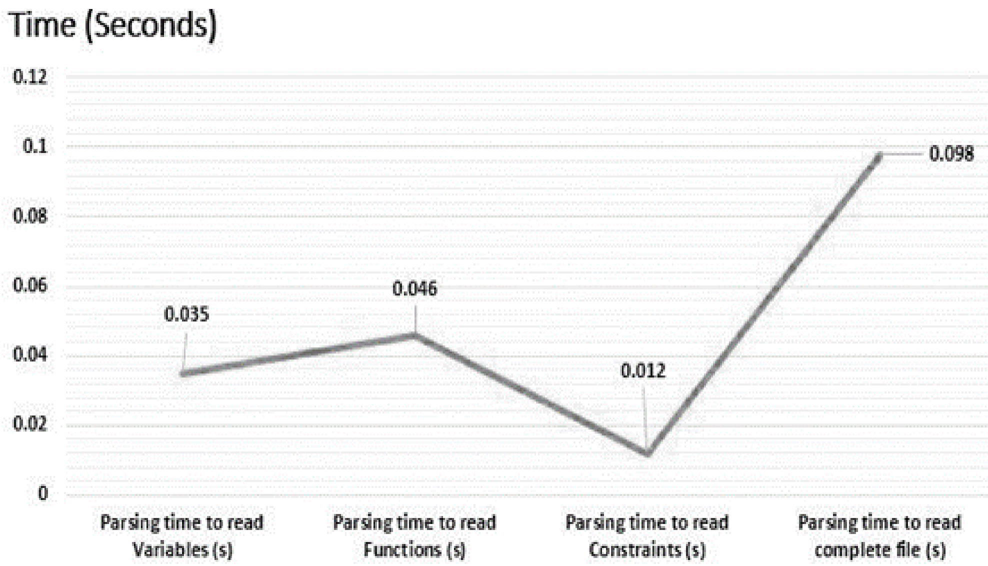

Figure 4. Parsing Time vs. SOE Elements for Manufacturing Process Planning.

4. Conclusion

This research revealed a system which uses experiential knowledge to support the process of product development. The program consists of three modules, namely design knowledge management module (DKM), manufacturing capacity analysis and process planning (MCAPP), and product inspection planning (PIP). Working on the MCAPP module was clarified by the creation of one of its sub-modules, i.e. process planning in JAVA manufacturing. From the results of the case study it is clear that this method is capable of improving the technique of manufacturing process planning by using the experiential experience of the specific products relevant to manufacturing.

The entire system's Decisional DNA is capable of seeking the correct solution for the question according to the defined priorities and constraints. The customer then chooses the final solution, and this process is stored as experiential information in the Decisional DNA of the product development system which can be used to solve a similar problem in the future. The SVPD System acts as an expert group as it captures, stores, maintains and reuses the experiential knowledge of all like products. Future research involves expanding the SVPD framework to clarify the essential variables involved in the functioning of the module for Product Inspection Planning (PIP).

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