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Decisional DNA, Set of Experience Knowledge Structure, Virtual Engineering Objects

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VIRTUAL ENGINEERING OBJECTS (VEO): DESIGNING, DEVELOPING AND TESTING MODELS.

In this article, the development and implementation of the concept of Virtual Engineering Object (VEO) is described. A VEO is a computerized real world representation of an engineering object. VEO will act as a living representation of the object capable of adding, storing, improving and sharing knowledge through experience, in a way similar to an expert of that object. In this paper, it is shown through test models how the concept of VEO can be implemented with the Set of Experience Knowledge Structure (SOEKS) and Decisional DNA. The SOEKS/DDNA is a flexible and standard knowledge representation structure to acquire and store experiential knowledge. A test case study for three different drilling machines, drilling tools and the working holding devices is developed to test and demonstrate the implementation of VEO. The test model confirmed that the concept of VEO is able to capture and reuse the experience of the engineering artifacts, which can be beneficial for efficient decision making in industrial design and manufacturing.

1. BACKGROUND

A large percentage of the product's life cycle time is spent on routine tasks; it takes up-to 80% of the design time. It is noted that around 20% of the designer's time is spent in searching for and absorbing information, and 40% of all design information requirements are currently met by designer's personal records/stores, even though more suitable information may be available from other sources. This implies that design information and knowledge is not represented in a shared and easily accessible knowledge base [1].

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Wang et al. [2] provided a good example of a new car being designed where 40–50% of its parts are entirely the same as existing ones, 30–40% require slight modification of existing ones and only 10–20% of the components are entirely new. Evoking a previously solved case to solve a new one is the basis of the design reuse theory; thus, past experience can play a vital role.

It is evident that manufacturing planning at the conceptual or early design stage is the key for designers to evaluate manufacturability in terms of criteria and metrics such as costs and time. However, there are not many techniques and software tools for conceptual manufacturing planning.

Cyber Physical System (CPS) is emerging as a must have technology needed by industry [3, 4]. CPS are integrations of computation with physical processes [4, 5]. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa. In the physical world, the passage of time is inexorable and concurrency is intrinsic. Neither of these properties is present in today's computing and networking abstractions [4]. CPS aims to integrate knowledge and engineering principles across the computational and engineering disciplines (networking, control, software, human interaction, learning theory, as well as electrical, mechanical, chemical, biomedical, material science, and other engineering disciplines) to develop new CPS science and supporting technology. Scalable CPS architectures for adaptive and smart manufacturing systems which dynamically enable the continuous design, configuration, monitoring and maintenance of operational capability, quality, and efficiency are, in fact, a requirement for the industry [6] . According to the European commission under the Horizons 2020 programme, the self-learning closing feedback loop between production and design should be included in future factories for optimizing energy expenditure and minimizing waste as a direct relation to the enhancement in control and immediate information processing that a CPS will provide.

Many knowledge-based techniques have been used in past that aim to organize past, present, and future information. Some of the important objectives of these techniques are sharing the information, forecasting, and generating new knowledge. Knowledge-based techniques used in the past had limited success as they were having some shortcomings like they were time consuming, not very intelligent, etc. Moreover, most of these knowledge systems are designed for a specific domain. The applicability of these systems significantly decreases in any other area. This makes them less flexible and less versatile. They do not have any standard knowledge representation. Most systems lack the capability for information sharing and exchange [7-9]. Another important limitation of current knowledge-based techniques is that they do not take into consideration formal experience. However, in recent times, SOEKS and DDNA, a smart knowledge representation technique, have emerged as strong general purpose solutions to the above-mentioned shortcomings that other knowledge based systems are facing. They are a combination of organized information obtained from formal decision events and has been successfully implemented in a variety of domains [10].

2. INTRODUCTION TO SOEKS AND DECISIONAL DNA

Sanin and Szczerbicki [11-16] introduced for the first time the Set of experience knowledge structure (SOEKS) and Decisional DNA (DDNA). SOEKS is a new, multi-domain knowledge representation technique, not only capable of gathering experience and formal decisions but also a tool for decision making process. Unlike other knowledge based systems, DDNA is more focused on extracting and evolving knowledge through experience, and reusing this knowledge to support decision-making.

2.1. SET OF EXPERIENCE KNOWLEDGE STRUCTURE (SOEKS)

The SOEKS is a dynamic structure, which feeds on the formal decision events and uses them for the representation of the experiential knowledge. A formal decision is defined as "a choice [decision] made or a commitment to act that was the result [consequence] of a series of repeatable actions performed in a structured manner" [17]. A SOE (short form of SOEKS) has four components; variables (V), Functions (F), Constraints (c) and Rules (R) as shown in Fig. 1. Each formal decision is represented and stored in a unique way based on these four components.

The variables are the source of the other components of SOEKS and are the centre root or the starting point of the structure. The functions are based upon the relationships and associations among the variables. They create links between dependent and non-dependent variables constructing multi-objective goals. The third components of SOE are constraints, like functions and are connected to variables. They specify limits and boundaries and provide feasible solutions. Rules, the fourth component of SOEKS, are conditional relationships that operate on variables. Rules are relationships between a condition and a consequence connected by the statements 'IF-THEN-ELSE'.

2.2. DECISIONAL DNA (DDNA)

The concept of DDNA is the metaphor of human DNA. A group of SOE of the same category comprises of a kind of chromosome, as DNA does with genes. These chromosomes or groups of SOE make a category, and they are bases for making decisions. Each module of chromosomes forms an entire inference tool, and creates a Decisional DNA as shown in Fig. 1.

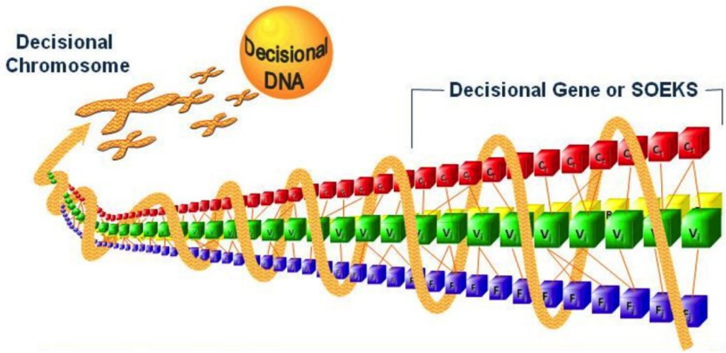

Fig.1. Decisional DNA [18]

3. VIRTUAL ENGINEERING OBJECT (VEO)

VEO development together with Decisional DNA aim at enhancing industrial design and manufacturing. The need to carry out this development and rationale to adopt SOEKS is already discussed in the previous sections. In order to improve industrial design and manufacturing, we aim to capture the experience and knowledge of engineering artefacts, than re-use this knowledge for better decision making. To achieve this goal we conceived Virtual Engineering Objects (VEO).

A VEO is a representation of an artefact which can behave like an expert of that artefact and can help the practitioners in effective decision making based on the past experience. The concept of Virtual Engineering Object (VEO) is powered by SOEKS and DDNA; it is designed to have all the knowledge of the engineering artefact along with the associated experience embedded in it.

VEO provides a standard knowledge representation format and eventually forms various networks of VEOs based on their past manufacturing experience. These networks of VEOs form a part of a bigger Cyber Physical Systems (CPS) umbrella.

3.1. FORMULATION AND ARCHITECTURE OF VEO

A VEO can encapsulate knowledge and experience of every important feature related with an engineering object. This can be achieved by gathering information from six different aspects of an object viz. Characteristics, Functionality, Requirements, Connections, Present State and Experience as illustrated in Fig. 2.

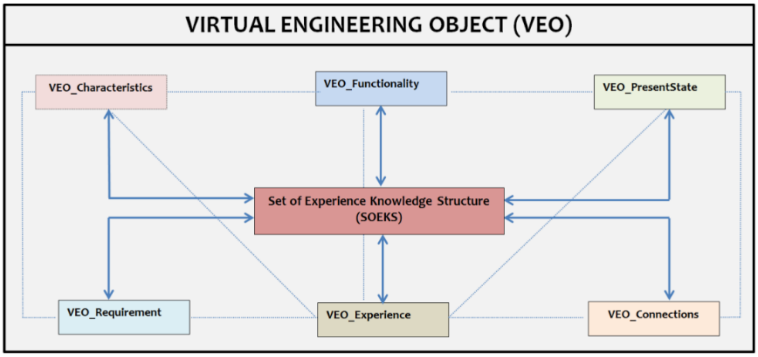

Fig. 2. Proposed VEO Structure [19]

The main features of a VEO (shown in Fig. 2) are as follows:

Characteristics describe the set of physical features and expected benefits offered by the artefact represented by the VEO. Not only the information like its geometry dimensions, appearance, weight etc. are captured in this module but also the possible advantages like 'versatility' and the 'ease of operation' can also be achieved from this. Knowledge stored in Characteristics assists in better decision making like which VEO is best suited for a given physical condition and also when more than one VEO of a similar kind are available it helps to decide which is the best in the given situation.

Functionality describes the basic working of the VEO and principle on which it accomplishes its operation. Knowledge related with the functioning and operation of an object like the time consumed, its working boundary limits and the outcome of the process that is performed are stored in Functionality. This module of the VEO assists in storing, selecting and reusing the functional/operational details of the object.

Requirements describe the set of necessities of the VEO for its precise working. Information like type and range of the power source, the space required and the extent of user expertise necessary for operating a VEO can be stored.

Connections describe how the VEO is related with other VEOs. Many engineering objects work in conjunction with other objects. These connecting VEOs may be a "part" or may be a "need" of each other. This module of VEO structure is essential for the scaling up and establishing the interconnections of VEOs in manufacturing scenario.

The ***Present State*** of the VEO highlights parameters of the VEO at the current moment. It is like taking a picture and storing information of that particular moment. It also gives an idea about the background of the VEO like its 'reliability' and 'precision' up till now.

The ***Experience*** of the VEO deals with the knowledge and information which is dynamic in nature, which keeps on changing with each new decision, operation or event. In other words every formal decision related to the VEO is stored in the Experience. This element of the VEO keeps on updating with every activity that is done on the VEO.

3.2. IMPLEMENTATION OF A VEO

For the purpose of implementation of VEO, we integrated it with the Decisional DNA. As discussed in section 2.1, SOEKS consists of Variables, Functions, Constraints and Rules. Moreover in section 3.1, we also discussed that a VEO structure include elements like Characteristics, Functionality, Requirements, Connections, Present State and Experience. SOEKS for each element of the VEO in the system are created individually. The goal behind this was to provide a more scalable setting, similar to the one that would be found in describing a diverse range of engineering objects. Weights are assigned to the attributes of the variables of an artefact, and then the six sets of SOEKS are generated. These individual SOEKS are combined under an umbrella (VEO), representing experience and knowledge.

3.3. DESIGN OF TEST CASE STUDY

As a case study, we considered a manufacturing set up having three different drilling machines, three drilling tools and three work holding devices. Fig. 3 shows the framework for the case study, information and specifications about these above mentioned engineering objects were gathered from standard sources and data is stored according to the SOEKS format. Moreover, every formal decision taken is also stored as a SOE, which leads to the formation of interconnected VEO's.

The objective of this study is not only to develop VEO's for engineering artefacts but also demonstrate that different VEO's connect and forms a network. Furthermore to prove that the experience captured from this VEO network can be reused for better future decision making and efficient utilization of resources.

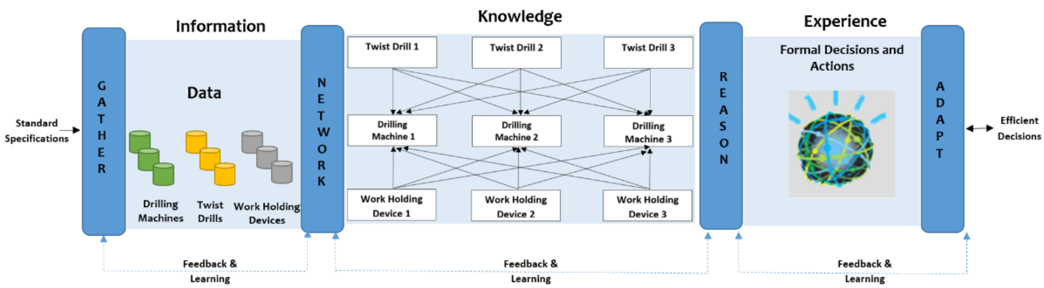

Fig. 3. Framework for the case study

A detailed VEO structure for a drilling machine used in the test case study is discussed and shown in Fig. 4. Effort is made to capture and store all the relevant information of the VEO adhering to the format of the SOEKS.

In the ***Characteristics*** section of drilling machine, VEO physical parameters like area, volume, maximum capacity, manufacturer details, service details are stored. Furthermore rules are laid to extract knowledge about the VEO like 'ease of operation' and 'adaptability'. In ***Functionality***, variables related with the functioning of a drilling machine like cutting speed, feed, depth of cut, drilling diameter, drilling depth etc. are defined along with their operational limits. In addition to this knowledge, the outcome of drilling operation like quality of surface finish and machining precision can also be represented in the form of rules. How much Space is required? What and how much power source is required? What kind of expertise of the operator is necessary? All these information for each and every operation can be stored in the ***Requirements*** section of the VEO.

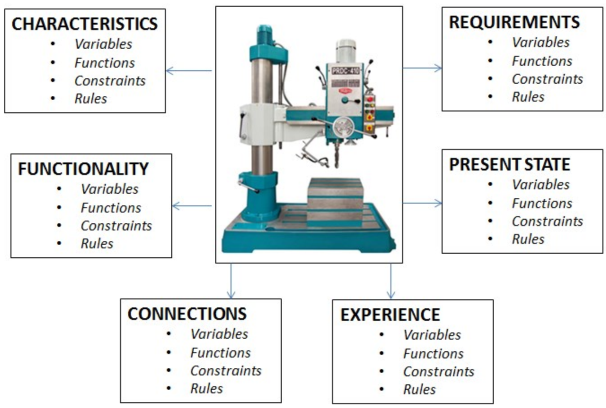

Fig. 4. Test Case VEO Architecture for Drilling Machine

We considered drilling machine, the machining tool e.g. Twist Drill and the work holding device e.g. vice, as separate artefacts/VEOs. And Information of these and their relation with main drilling machine VEO are stored in the ***Connections***. In the ***Present State*** not only whether the VEO is free or idle is determined but also knowledge about VEO like its overall reliability and machining precision can be extracted. And, lastly, in the ***Experience*** all the dynamic information related to each operation performed and the formal decisions taken on the drilling machine are stored.

This VEO structure is implemented using JAVA programing language, the reason being, Decisional DNA developed in JAVA has been successfully applied in various other domains. Every Variable [20] is stored as a SOEKS variable. An illustration of a variable (*VEO Name*) stored as a SOEKS variable is as follows:

```
<variable>
<var_name>VEO_Name</var_name>
<var_type>CATEGORICAL</var_type>
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<var_cvalue>DM1 </var_cvalue>
<var_evalue>DM1 </var_evalue>
<unit></unit>
<internal>false</internal>
<weight>0.0</weight>
<l_range >0.0</l_range>
<u_range >0.0</u_range>
<categories>
<category></category>
</categories>
<priority>0.0</priority>
</variable>

Six JAVA classes (Characteristics, Functionality, Requirements, Present State, Connections and Experience) for a VEO each having SOEKS Variables, SOEKS Functions, SOEKS Constraints and SOEKS Rules are developed [20]. SOE for each class are stored individually. In a separate class these SOEs are combined to form knowledge and experience repository of an entire VEO. From this knowledge base, manufacturing information related with the VEO can be extracted for future decision making.

Similar to above discussed VEO format of drilling machine, similar structure for twist drills and work holding devices are also developed.

The formal decisions that are taken with regard to the engineering objects are stored adhering to the structure of SOEKS and VEO. Thus, we are able to capture and store information of every operation that is performed and then update the knowledge base of the VEO. The gathered information is effectively and efficiently converted into Decisional DNA structure. The next step is to be able to query the VEO and based on the experience it can predict and suggest options available according to our need.

CONCLUSION

In this test case study, we presented an approach to represent engineering artefacts based on knowledge and experience. We described the architecture of our approach and implementation that uses SOEKS/DDNA to represent VEO. We demonstrated this approach through some initial tests. As the illustrative result shows, we can model and represent engineering artefact virtually.

We are able to capture and store information of every operation that is performed on the VEO and then update the knowledge base of the VEO. We developed an approach that allows a VEO to capture and reuse its own experiences. The SOEKS and DDNA based VEO proved to be a suitable and comprehensive tool for knowledge discovery. We designed the architecture of our approach and implemented and tested our concepts in the form of a case study. The next step in this research is to apply the DDNA to the gathered experience of VEO which can be used as an effective prediction tool and can improve manufacturing decision making. Finally, a VEO can be seen as a specialized form of CPS that enables users to make their knowledge shareable, transportable, and easily understandable.

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