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Modelling a multidisciplinary interface for mechatronic system design

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ABSTRACT
The foundation of mechatronic system design is the integration of multiple fields, including software, electrical, and mechanical engineering. Both academics and industry have expressed interest in how to construct mechatronic systems with an integrated multidisciplinary design. However, yet, no remedies have been put out that can completely resolve this issue. The logical or physical link connecting the mechatronic system's components or the component with their surroundings is represented by the idea of a multidisciplinary interface. The multidisciplinary interface model is one of the best tools for helping designers achieve integrated multidisciplinary design throughout the development process since designing mechatronic systems is a multidisciplinary task. To facilitate the multidisciplinary integration of design team members from various disciplines, the study introduces a multidisciplinary interface model for mechatronic system design. On the one hand, the suggested approach guarantees that the designers' interface will be consistent. Conversely, it assists the designers in ensuring that the various elements work together properly. Three principles are included in the interface model: compatibility rules, data model, and classification. A case study based on a 3D measurement system implements the interdisciplinary interface paradigm [3].

Keywords: *Mechatronics Design, Production Model, Multidisciplinary Integration, Interface, System Engineering*

I. INTRODUCTION

At the Yaskawa Corporation, the words mechanics and electronics were combined to create the phrase "mechatronics." As technology has advanced, the term "mechatronic" has expanded to encompass computation and software [1]. These days, mechatronic systems are thought of as the consequence of combining information processing, mechanical components, and electrical/electronic systems. Since designing mechatronic systems involves many different disciplines, multidisciplinary integration has been suggested and is becoming increasingly important for mechatronic systems [2,3]. "Design data-related problems" are one type of issue that needs to be resolved to produce an integrated interdisciplinary design [4]. These "design data-related problems" pertain to the management and editing of the variety of product data from many fields. But neither industry nor academia have offered a workable approach that can completely address the issues with mechatronic system design [5].

To help designers overcome issues connected to design data and accomplish integrated multidisciplinary design of mechatronic systems, the study introduces a novel multidisciplinary interface model. In the context under consideration, the term "interface" refers to the physical or conceptual connection that unifies the parts of a single mechatronic system or the parts with their surroundings [6]. In addition to providing high-level direction for the organization and administration of the development process, these interdisciplinary interfaces can be used to show the collaboration of various design teams. Three concepts are included in the paper's suggested multidisciplinary interface model: interface compatibility rules, interface model, and interface classification. First and foremost, the classification of interfaces is regarded as the cornerstone of the multidisciplinary interface model since it not only provides a great deal more information about an interface but also aids designers in preventing confusion caused by improper use of interfaces during the early stages of mechatronic system design [7]. Second, because it incorporates all the data that stakeholders can access, store, service, and reuse, the product model can be a useful and efficient tool for supporting the design of mechatronic systems [8]. A specific product model for mechatronic systems will include the interface model. It reflects the relationship between the interface and other product model components in addition to considering the information of the proposed interface categorization. Finally, the interface compatibility criteria are crucial for ensuring that the various parts of a mechatronic system are integrated correctly and for demonstrating interdisciplinary cooperation with the aid of interface models.

In summary, the multidisciplinary interface model offers a shared representation for interfaces created by members of the design team with varying specialities and disciplines. Therefore, on the one hand, the suggested approach guarantees interface consistency, which can be specified by various designers. Conversely, it assists designers in ensuring that various components are integrated correctly, and from a second angle, it might guarantee multidisciplinary integration and collaboration among design teams.

II. RELATED WORK

Software engineering has made extensive use of interfaces between systems or subsystems since the mid-1980s [9, 10]. A distinct module of a program performs one of the desired functionalities during the software development process. Interfaces are used by these modules to communicate with one another. A complicated system is further subdivided into smaller systems as it grows more sophisticated. At the core of Systems Engineering's multidisciplinary character is the interface definition [11]. One of the most effective systems management tools is interface management [12]. The interactions of subsystems created by many disciplines can be described by the interface in mechatronic systems, which refers to the logical or physical relationship integrating the elements of one mechatronic system or the elements with their surroundings [6]. Therefore, it is important to provide a correct taxonomy for interfaces to represent more facts about an interface and assist designers in preventing misunderstanding caused by improper use of interfaces.

Steward [13] refers to sub-system interactions as "information flows" to address cooperation issues during the design phase of mechatronic systems; however, these information flows are not thoroughly explained. The relationships between various components are described by Counsell et al. [14] as material, information, and power. According to Sellgren [15], interfaces can be divided into three categories: touch, attachment, and constraint. The physical interface is the primary emphasis of his proposal. The definition of a physical interface is also outlined in the international standard ISO/IEC 81346 [16]. Nevertheless, the relationship between modelling and controlling for the standardized interface specification has not yet been fully realized [17]. The interconnections between mechanical and electrical/electronic disciplines are categorized by Chen et al. [18] as "constraints." However, little mention has been made of the interactions between the fields of software and mechanical, electrical, or electronic disciplines. For complicated systems, Pahl et al. [19] offer a technique called Modular Product Development (MPD). The product is first divided into modules using this approach. This approach mentions the energy, material, and signal exchanges between the modules.

By further classifying energy as electrical, mechanical, hydraulic, etc., Liang and Paredis [6] create a more thorough classification based on the idea of Pahl et al. Nevertheless, the relationship between software and other disciplines is not considered by these two approaches. According to Komoto and Tomiyama [20], certain physical implementations—such as a function that fixes the connection between two mechanical components or a function that maintains a position—have nothing to do with the transformation of energy, material, and signal. However, two components can be connected as interfaces using their physical implementations. As a result, geometric elements are essential to the design process. The authors emphasize that such geometric information should also be taken into consideration. The interfaces are distinguished by Sosa et al. [1] based on information dependency, material dependency, energy dependency, structural dependency, and geographical dependency. Such a categorization approach could result in overlapping interfaces being misused. For example, "a requirement related to transferring airflow, oil, fuel, or water" is how the material dependency is defined. Nonetheless, this type of material transfer frequently involves energy transmission, which was dubbed "energy dependency." The interface representation issue is highlighted by Betting and Gershenson [7], who also attempt to find a general representational schema. The initial proposal proposes seven sorts of interfaces: spatial, field, attachment, control and communication, power (electrical), transfer, and environmental. Following that, the seven interface classes are distilled into four main interface classes: field interfaces, control and power interfaces, attachment interfaces, and transfer interfaces. The field interface is described as "an interface that transmits energy, material, or signal as an unintended side-effect of the intended function of a module" in the simplified classification. This classification starts to take interfaces' detrimental impacts into account. The field interface, however, needs to be explicit because it is so broad.

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III. INTERFACE CLASSIFICATION FOR DESIGN OF MECHATRONIC SYSTEMS

The existing interface classifications exhibit several shortcomings, as was covered in the previous section. Furthermore, the present categories have not disclosed certain interface aspects. Based on a literature analysis, the paper proposes a new classification system for interfaces based on three attributes: Type, Configuration, and Desired/Undesired. The specifics will be provided later. The first characteristic focusses on the kinds of transfers that take place via a single interface. The following four broad categories of interfaces will be proposed:

- Geometric interface indicates how one element is physically connected to another, which is mainly related to mechanical geometry of interface defined in the feature-based product model for Computer-Aided Design.
- Energy interface indicates how energy (electrical energy, mechanical energy. . .) is transferred between elements.
- Control interface indicates how one element will be controlled by others, which is mainly related to the electronic discipline of mechatronic systems.
- Data interface indicates how communication information is transferred between components, which is mainly related to the software discipline of mechatronic systems.

These days, the tendency of processing several flow and data transfer types through a single interface is demonstrated by the growing integration of mechatronic systems. In general, there are two types of interfaces. In the first instance, the interface is used to perform primary transfers, while other types are handled as subsidiary transfers. An example of this would be the interface between two electrical components, which is thought to be the main means of transferring electrical energy (voltage). In the meantime, the two components have a stronger physical integration thanks to the geometric connections (pin numbers) that are thought of as this interface's subsidiary forms of transfers.

The second instance relates to an interface that processes multiple transfer types concurrently and makes it difficult to determine which transfers are prioritized. For example, data is sent between conductors that are being utilized concurrently for the transmission or distribution of AC electric power using power-line communication technology [41]. In other words, one interface can transfer both power and data at the same time, and both are equally important to this interface. It is necessary to further deconstruct and refine the interfaces mentioned in the two scenarios into sub-interfaces based on the many transfers that occur via them. Interface configuration is the second feature that was overlooked in earlier studies. The component, environment, and interface are the three key components of mechatronic systems. Therefore, in addition to (1) the interface between components (C_I_C), the interface between a component and the environment (C_I_E), the interface between a component and an interface (C_I_I), the interface between two interfaces (I_I_I), and the interface between an interface and the environment (I_I_E) should all be considered in interfaces related to the design of mechatronic systems.

- Interface between two components (C_I_C) indicates how one component connects, interacts and collaborates with another.
- Interface between component and environment (C_I_E) indicates how the component operates and functions in certain environment.
- Interface between component and interface (C_I_I) indicates that one interface must be accommodated by the effects generated by other components, such as heat, magnetic fields, vibration and other effects, or one component must be accommodated by the effects generated by an interface.
- Interface between two interfaces (I_I_I) indicates that two interfaces are affected and interacted by each other.

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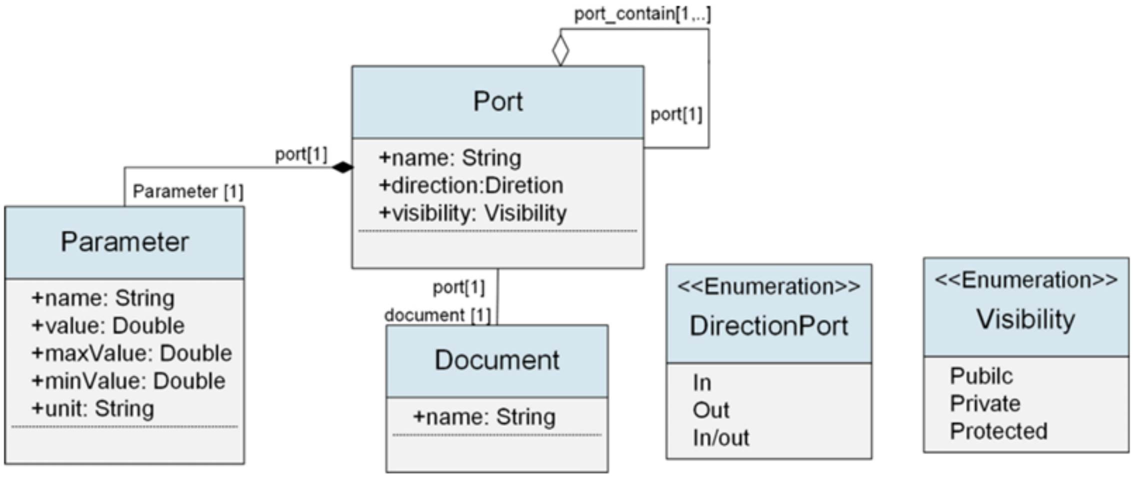

Figure No. 1 – UML Diagram for Port

The section presents the interface model. On the one hand, the Interface and the Port class represent the interface categorization and the port along with its associated attributes. Conversely, it illustrates how the interface and other entities are related. The suggested interface model contains the main components of the current product models, allowing for the construction of a mapping between the interface model and the current product models. The key components of the suggested interdisciplinary interface model are displayed in Table 3, along with their counterparts in various product models. As a result, existing product models can be extended using the interface model.

IV. THRE DIEMENSION MEASUREMENT SYSTEM

A three-dimensional (3D) measuring system was used as the case study to illustrate the multidisciplinary interface model in this section. This measurement system is designed for shape and reconstruction of the measured object's surface based on optical measurement. The design of the system necessitates multidisciplinary integration because this 3D measuring system is regarded as a mechatronic system that integrates mechanical components, information processing, optical technology, and electrical/electronic systems in a synergistic manner. The structure of this 3D measurement system will be shown in the upcoming subsections.

There are two modes of operation for the 3D measurement system: Active mode 1 and Active mode 2. Fig. 6a illustrates the measurement system's operation on Active Mode 1. On the surface of the measured object, a fringe pattern is created and projected. After then, the distorted image that the object's surface reflects is recorded and examined. The depth information of the measured surface can be obtained by comparing the original fringe patterns with the distorted image. Altering the light's path can change the measuring mode (Fig. 6b) [6]. The design approach of this 3D measuring system, which was implemented using Dassault Systems' 3DEXPERIENCE platform1, will be presented in the parts that follow. It is based on the multidisciplinary interface concept.

By examining the fundamentals of the 3D measuring system, the functional model can be identified. An architectural model can then be built in accordance with the functional model. The 3DEXPERIENCE platform's implementation of the RFLP technique (Requirements–Functional–Logical–Physical) may be used to generate both the functional and architectural models [47]. To guarantee consistency throughout the design process, a mapping between the functional and architectural models can be constructed prior to the detailed design phase. The functional and architectural models are created in the 3DEXPERIENCE platform using the VPM Functional Logical Editor workbench. The primary and supporting functions provide a fundamental framework for the designers to build a functional model at the functional design stage. The system and its subsystems can be developed in accordance with the main function and subfunctions during the logical design stage. Six subsystems can be used to broadly break down the 3D measurement system. The fringe patterns are projected onto the measured object by the pattern projection sub-system (C1.1), and the deformed image receiving sub-system (C1.2) receives the distorted image that the measured item reflects. The 3D image reconstruction sub-system will compare and assess the original fringe patterns and the distorted image (C1.3). The mode switch sub-system (C1.4) can switch between the measurement modes. The mechanical support sub-system provides support for the entire system (C1.5).

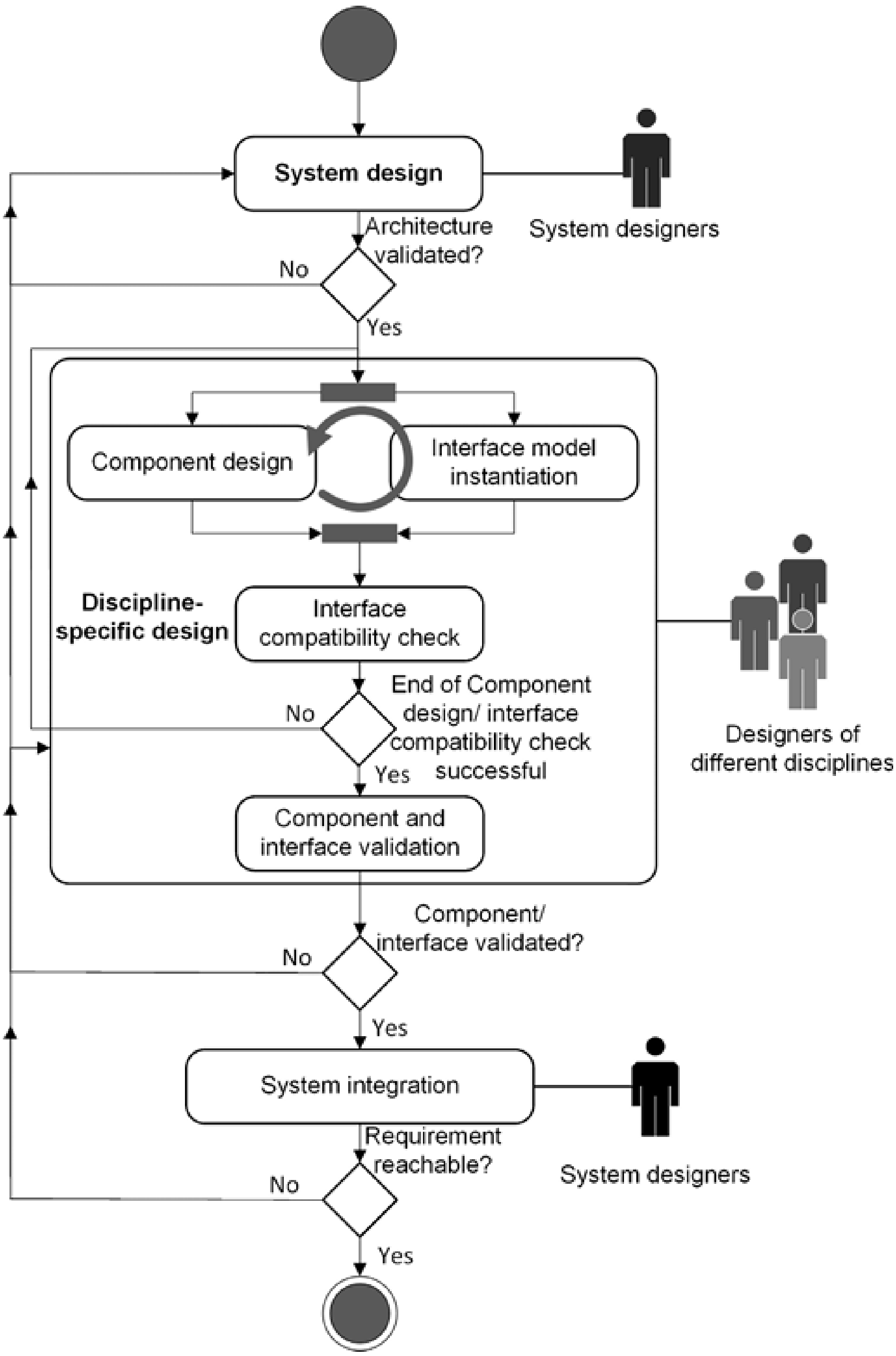

Figure No. 2 - UML activity diagram for the process based on multidisciplinary interface model.

One of the most crucial components of the 3D measurement system is the pattern projection subsystem. The sub-system and its constituent parts are depicted in Fig. 7 during the 3DEXPERIENCE platform's logical design phase. The power supply sub-system provides power to the DMD (C1.12), which is illuminated by a white light source (C1.11). The DMD creates fringe patterns, which are then injected into the image guide (C1.13). A fiber bundle made up of optical fibers makes up the image guide. It is attached to the compact probe (C1.14), which is made up of objective lenses and a diaphragm. The compact probe's pattern is projected onto the object's surface. An image guide ensures that light is transmitted between the tiny probe and the DMD. Careful consideration must be given to this image guidance. On the one hand, a high-resolution image guide is required to fulfil the industrial equipment inspection requirement. Alternatively, the visual guide must be adaptable enough to the industrial setting (E1). Consequently, it is possible to create an interface (I1.1) between the image guide (C1.13) and the industrial environment (E1). The optical team's designers selected the image guide with the highest resolution (FIGH-100-1500N), which has a minimum bending radius of 200 mm, to get a better reconstruction outcome.

V. CONCLUSION

To help designers better integrate interdisciplinary skills, the study has proposed a new multidisciplinary interface model that can be used during the collaborative design of mechatronic systems. The interface compatibility rules, interface classification, and interface model form the foundation of the modelling approach. The interface classification helps designers avoid confusion caused by improper use of interfaces and gives them access to a lot more information about an interface. The interface model will be developed as a component of the mechatronic systems product model. It considers more than just the data that the interface classification suggests. However, it also illustrates how the interface and other product model elements relate to one another. A common representation of the interfaces created by design teams from various disciplines can be given to the designers by the suggested interface model. With the aid of an interface model, interface compatibility should be verified to ensure that the various components interact properly and, ultimately, to minimize needless iterations in later design stages. To show how the multidisciplinary interface model can effectively support the design of a mechatronic system by utilizing the 3DEXPERIENCE platform, a case study—3D measurement system—has been conducted.

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