




Research Article

CAX Integration and Its Design Application Based on Feature Extension of Sensor Components

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In order to improve the information and product originality level of intelligent manufacturing industry based on sensor technology, this paper summarizes the current situation of CAX integration based on sensor technology and its design application and analyzes the shortcomings of existing CAX integration, aiming at accurate, complete, timely, and barrier-free transfer of sensor product data and information between CAX system and MRPII/ERP management information system. The concept and information model of feature extension of sensor components oriented to the whole process of sensor intelligent manufacturing is presented. Taking feature extension of sensor components as the integration link, CAX integration framework structure and its design application mode based on feature extension are established, while key technologies and implementation ideas to realize the integration and the design application are put forward, which provides an effective path to realize the sensor integration of CAX and management information systems such as MRPII/ERP.

1. Introduction

Sensor technology is one of the rapidly developing high and new technologies in today's world. It is also an important symbol of the development of contemporary science. Together with communication technology and computer technology, sensor technology forms the three pillars of information industry in the 21st century. If a computer is an extension of the human brain, then sensors are an extension of the human features. Therefore, each developed country regards sensor technology as the key technology of this century to try to develop. The application of sensors is also more and more extensive and has penetrated into various professional fields. However, the innovation of sensor technology and the ability of new product development are lagging behind the advanced level at home and abroad, which restricts the development of industrial automation and information technology.

The computer integrated manufacturing system (CIMS) based on sensor technology is a crucial technology for the informatization of manufacturing industry. CIMS requires fast, lossless, and distortionless communication of product information between computer aided X (CAX) systems and management systems such as manufacturing resource planning (MRPII) and enterprise resource planning (ERP). CAX integration technologies have been studied by researchers for decades, and commercial softwares such as Solidworks and Pro-E, which are typical computer aided design or computer aided manufacturing (CAD/CAM) integration, have been widely used in several industries. Fruitful research results oriented towards enterprises APPs have been achieved in unified platform integration technology for multisystem and cross-system. However, limitations still exist in these technologies, and integration requirements cannot be fully fulfilled.

The most concerning issue for the application of CAX system integration based on sensor technology is the

unblocked connection between CAD and other CAX systems [1–3]. Researchers have been made great effort on dealing with this issue, and several integration framework models have been proposed in different cases. CAD system and PDM system integration mode are studied [4]. 3D CAD software SolidWorks 2010 and the small PDM system are designed. CAD, CAPP, and CAM integrated system framework based on PDM is proposed, and the customization content and implementation technology involved in the implementation of the framework are researched in depth [5]. CAX systems are integrated with PDM system by adopting message-driven Hub Spoke integrated mode [6]. A new framework for the design of a CAX information management and integrated system (CAX-IMIS) based on product data management (PDM) techniques and STEP integration technologies is proposed [7]. Seamless integration of CAD/CAE was achieved, and the quality and efficiency of the shell nosing design were improved [8]. A knowledge-based integration system framework for mechanical product development is obtained [9]. The workflow of virtual modeling and simulation of CAX system is presented, and the design of new bicycle plastic bottle is introduced [10]. The future development and concept for CAX system structure affecting the auto companies and their suppliers are presented [11]. Researchers combined CAD, CAM, and computer-aided process planning (CAPP) with computer software on the product data management (PDM) platform, using the unified control program to realize the extraction, exchange, sharing, and manipulation of the information. This can guarantee not only unblocked information flow within the systems but also effective operation of the systems, thus, realizing the CAX integration goal [12]. Klocke et al. [13] proposed a method of extended function blocks to reduce data loss within adaptive process chains by introducing data port list, which realized the integration of CAX systems. Li et al. [14] presented a digital collaborative design model and investigated product design process integration technology based on Webservice. A new concept of closed-loop manufacturing process from numerical control machine to CAD/CAM systems based on STEP-NC was put forward [15].

To realize information integration in CAD/CAM, they introduced feature recognition technology in CAM programming and established the interaction of data management, manufacturing process management, and enterprise resource planning. Moreover, Ni et al. [16] proposed a heterogeneous system integration framework oriented to enterprise business cooperation and analyzed the key technologies related to the framework, such as ontology modeling, ontology mapping, and semantic interoperability mechanism, which provides a new architecture and method for business cooperation based heterogeneous system integration. A feature technology-based CAX integration system was presented [17–19]. The system realized the integration of subsystems CAD, CAM, and CAPP through the STEP interface and is adapted to product design and process planning of CAD system with different formats. Some researchers also studied ERP/CAX integration based on CORBA, COM/COM+, and JavaRMI component technology and PDM/CAX integration based on ontology/PLM, aiming to realize the connection between CAX and

enterprise resource management systems, and support cooperative design.

Since the end of 1990s, the application of CAX integration has been focusing on enterprise APPs and enterprise knowledge. As a result, the integration application of CAX has gradually developed from the separate application of each unit technology system to the local connection of multiple CAX systems and finally to realize the overall integration [20–22]. In addition, deep learning platforms [23], dynamic system [24, 25], and fault diagnosis field [26] may be utilized for the design analysis of sensor parts and integration in engineering. From the previous work, it can be concluded that the existing CAX integration technologies mainly focus on STEP-based, PDM-based, and feature-based integration.

Nevertheless, there are still a lot of challenges in establishing the enterprise manufacturing integration system based on CAD/CAM/CAPP to meet the requirements of industrial informalization. First, STEP-based integration pattern use the neutral file to provide CAX systems with a “intermediate transformation” or “intermediate interface,” which results in the loss of CAD design intention and cannot fully satisfy the integration requirements. Second, PDM-based integration technology only provides a platform for centralized management of product data. When data and information are transmitted between CAX systems through PDM platform, the intrinsic properties of the CAX single system expression will be lost and the integration requirement cannot be fully satisfied. Furthermore, even though the feature-based integration technology can solve the problem of the information exchange and sharing between CAX systems, this is confined within the CAX. Information exchange among subsystems as CAD, CAM, CAPP, and CAFD have to be supported by feature recognition and feature mapping technology. Therefore, the seamless integration of CAX system and management information systems such as CAQ and MRPII/ERP cannot be achieved. Meanwhile, the existing features are intrinsically CAD-based 3D geometries which do not contain the information including manufacturing features, fixture features, quality features, and resource features, thus, limiting the practical application of integration systems.

Focusing on the above limitations, this paper has investigated a feature extension technology and its information model thoroughly. Besides, a CAX integration framework based on information extension is established, and key technologies to achieve seamless integration are studied. This work can promote the development of CAX system towards the direction of high integration, networking, virtualization, and intelligence.

2. Principle of Feature Extension of Sensor Components and Its Information Modeling

General speaking, a feature should be with the multidomain property which includes the design, manufacture, quality, and the resource domain. This property makes the feature a complete knowledge for engineering applications, independent from a specific engineering system. The main idea

of the proposed feature extension is to construct a novel type of feature which has merits of independence, completeness, reusability, and revisability. Such type of feature can guarantee the integration of CAx and meet the requirement of feature's property mentioned above.

In the next pages of this section, the principles and the information modeling of the proposed feature extension method will be introduced in detail.

2.1. Definition and Expression of the Feature Extension of Sensor Components. The feature extension is a geometrical unit which is adaptive to products'/components' lifetime and includes the complete information of products or components. The complete information (of design, manufacturing, clamping, quality, resource, and management) and its corresponding features are packaged in the feature extension. This property makes the proposed feature extension accessible for different application systems to obtain desired information.

According to the basic concept illustrated above, the feature extension can be expressed as a set of a series of features:

$$F = \{F_D, F_M, F_F, F_Q, F_E\}, \quad (1)$$

where F is the feature extension (i.e., the unit geometrical entity); F_D is the design features set in which all design information of F is packaged, including feature ID, feature name, materials and thermal processing information, technical requirement, and geometrical topology; F_M is the manufacturing feature of F , which is packaged with information concerning manufacturing details, such as manufacturing technologies, tools information, and manufacturing equipment; F_F is the fixture features package of F , where assembling information including orientation, clamping, and guiding; F_Q is packaged with the quality features of F , which is consisted of detection planning, detection standard, and detection method, etc.; F_E is the resource and management feature set where the resource and management information (resource planning, logistics, delivery schedule, etc.) of F is packaged.

The next, construction of the five features sets will be illustrated in detail.

2.1.1. Expression of F_D : A Matrix. The proposed feature extension requires the feasibility of interior features' labeling and matching. To meet such requirement and to make the expression more reasonable for the design features, the design features set F_D can be designed as follows:

$$F_D = [\mathbf{f}_{ID}, \mathbf{f}_{NM}, \mathbf{f}_{GM}, \mathbf{f}_{SZ}, \mathbf{f}_{DV}, \mathbf{f}_{MR}, \mathbf{f}_{THM}]^T, \quad (2)$$

where each f_x in F_D is a column vector with N elements, corresponding to N samples of the feature extension. Among those, f_{ID} is the label vector indicating the unique identification of the N samples; f_{NM} is the name vector storing the names of the N samples; f_{GM} is the geometrical vector, presenting the geometry entity of the N samples; f_{SZ} stores the geometrical size and tolerance of the feature exten-

sion; f_{MR} and f_{THM} are used to store the materials and thermal processing methods, respectively, of the N samples.

It can be concluded from the above statement that the design feature F_D has a form of matrix; each column of F_D indicates the design feature of a certain feature extension.

2.1.2. Construction of F_M : Tree-Structured Data. The manufacturing feature F_M is supposed to be extracted from design feature F_D , which acts as supplement (technical details) of relevant features packaged in F_D . Considering the constitution of manufacturing knowledge, the F_M can be designed as tree-structured data, functioning as the core structure and information.

Based on the above analysis, the F_M is designed as is shown in Figure 1.

2.1.3. Expression of F_F : A Logical Rule Based on Relevance. To comprehensively describe the fixture feature, F_F is much easier than other features set since the F_F can be treated as inheritance from F_M . Therefore, the F_F packaged in a feature extension can be designed as a logical variable that indicates whether the feature extension is an F_F or not, expressed as:

$$F_F = [0, 1]. \quad (3)$$

2.1.4. Structure Design of F_Q . The quality features set F_Q includes the products' or the components' quality planning, quality strategy, detecting method, and detecting planning, etc. Those are tightly related to the F_D and F_M . All necessary information must be included in the F_Q so that the CAQ can access required message. Thus, the F_Q can be structured into the one presented in Figure 2.

2.1.5. Packaging of Resource and Management Feature Structure Design of F_E . The resource and management features that set F_E are usually determined by F_D and F_M which are tightly relevant to enterprises' management strategies. Therefore, a certain requirement (of a company) for resource management should be packaged in the feature extension. Following this concept, the packaging of the resource and management features can be designed including not only manufacturing but also management details, as is shown in Figure 3.

2.2. The Information Model of the Feature Extension of Sensor Components. The feature extension proposed as (1) is to improve the design quality in manufacturing and to optimize the management operation of companies. More specifically, a feature extension is an improved type of feature set inherited from its original features. A feature extension extends the concept of "feature" by adding new properties (e.g., quality, fixture, and resource) into traditional features set. That means the core of a feature extension is a geometry entity in which all properties required by CAx and MRPII/ERP systems are packaged.

Following the discussion above, the information model of the proposed feature extension can be presented as Figures 4 and 5.

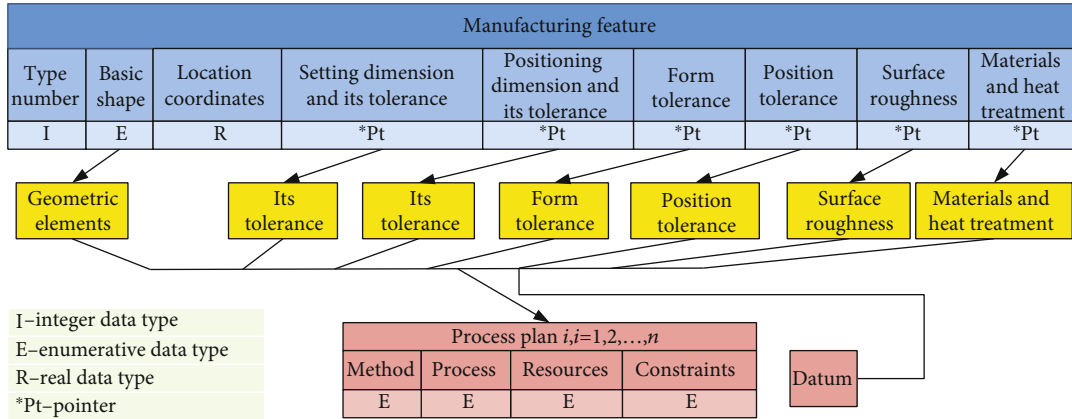
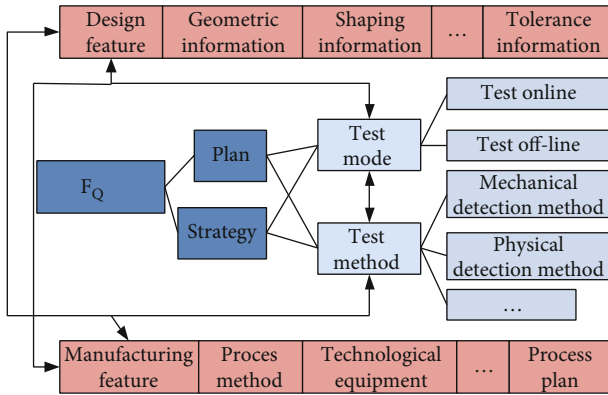
FIGURE 1: Tree structure of the manufacturing feature (F_M).

FIGURE 2: Structure of the quality feature.

As is shown in Figure 4, the proposed feature extension is designed to be a 3-layer structure, including support layer, property layer, and expression layer. The support layer is a set of feature mapping, feature knowledge, and feature rule, controlling the self-organization of the information included in it. As a result, the support layer finally map the design feature F_D into manufacturing, fixture, quality, and resource & management feature, i.e., the F_M , F_F , F_Q , and F_E ; the mapping constitutes the property layer.

Finally, after the mapping processing of the support layer, the expression layer which is presented as a geometry entity, by which the feature extension displays and expresses, is packaged with all properties provided by the property layer, serving the integrated systems with their required information.

We can conclude from the above illustration that the feature extension expresses explicitly as a special type of geometry entity which can be treated as an informational entity, serving as a bridge between CAx and other management applications. Figure 5 describes the packaged content and the informational structure of a feature extension. Obviously, a feature extension contains the whole features information of products or components indexed.

3. Structure Design of the Integrated CAx System Based on the Feature Extension of Sensor Components

The main purpose to the proposed feature extension method is to accordingly establish an integrated platform face to enterprises which combines all the CAx systems, enterprise information management systems, and the work flows of those, together. This platform functions as an information hub system for all specific applications which is with properties of unified portal, feature-leading, and collaborative operation, whose core is the proposed feature extension.

The next, we shall illustrate the structure design of the integrated CAx system which is based on the proposed feature extension technology.

3.1. Architecture Design of the Application Level for the Integrated System Using Sensor Technology. The layers design of the application level of the integrated system is presented in Figure 6, which is consisted of four layers: the user interface (UI) layer, the controlling layer, the application integration layer, and the data support layer.

In the following content, the definition of the four layers will be introduced.

3.1.1. The UI Layer. This layer is designed to provide the users with a unified portal which permits users to operate and invoke the integrated CAx system.

3.1.2. The Controlling Layer. The main task of this layer is to control the information acquisition from the feature extension of every CAx or MPRII/ERP system in the integrated system. Meanwhile, the controlling layer grants each application authorities of accessing and obtaining the database, according to the logic of operation flow.

The controlling layer guarantees the cooperation (between the applications embedded in the integrated system, in the collaborative design stage) of processes, knowledge, and multidisciplinary optimization.

3.1.3. The Application Integration Layer. The application integration layer is embedded with CAx systems and other

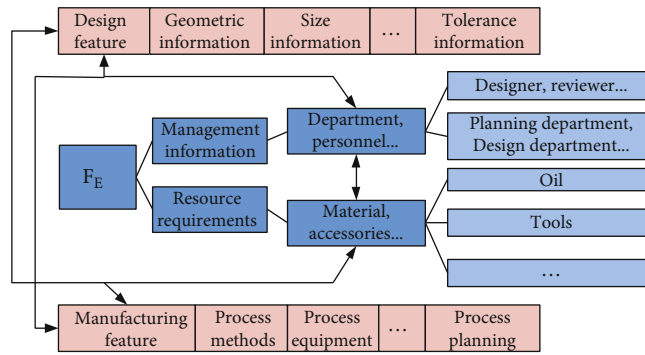


FIGURE 3: Structure of the resource and management feature.

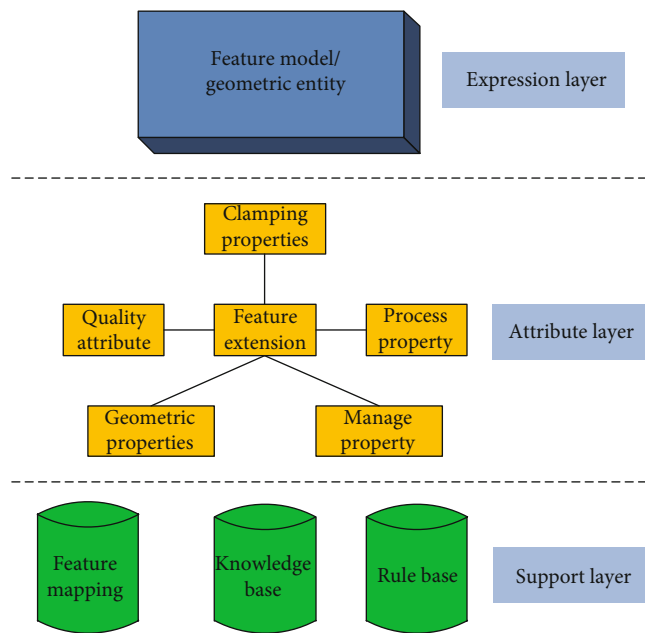


FIGURE 4: The layer structure of the feature extension.

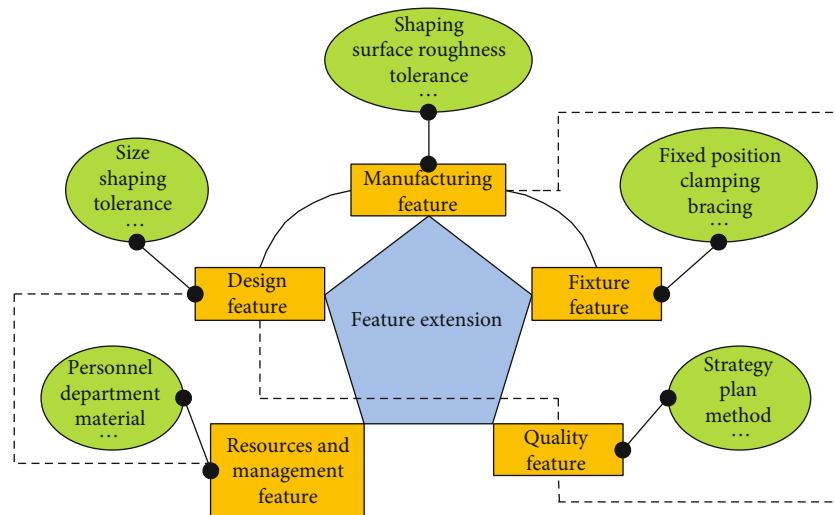


FIGURE 5: The information model of the feature extension.

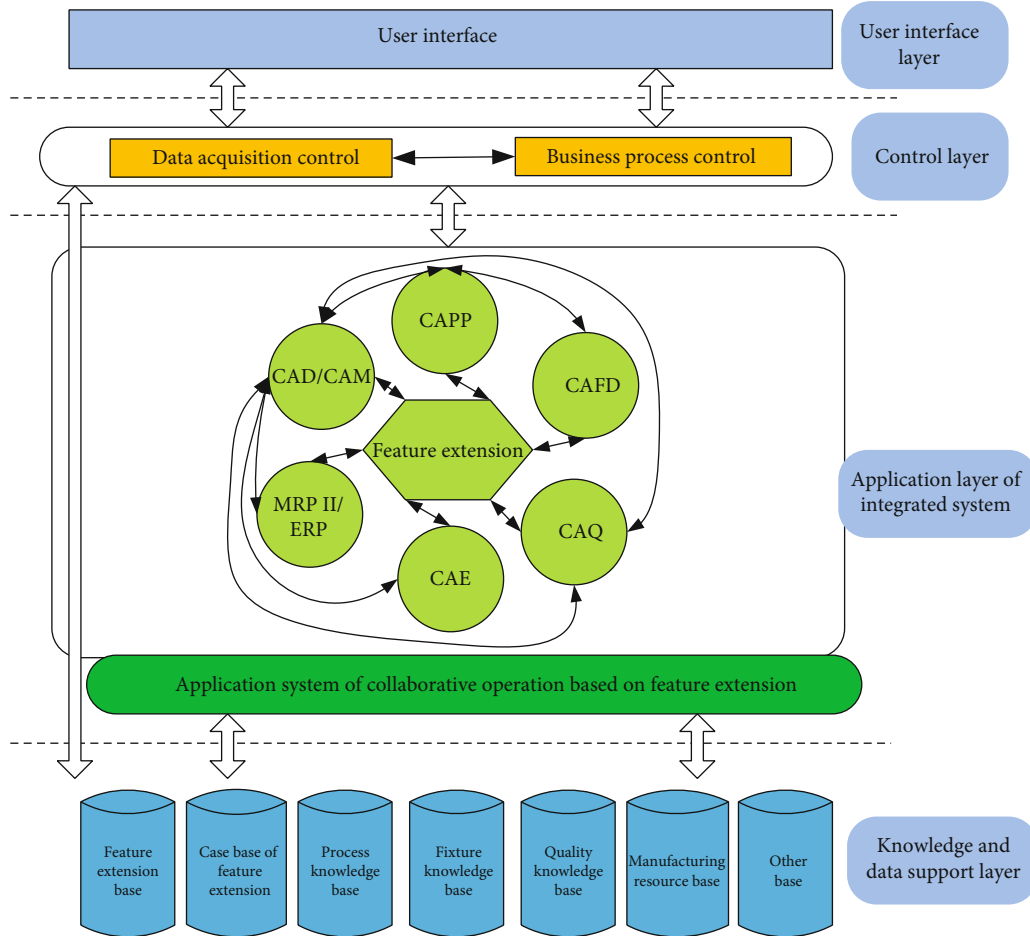


FIGURE 6: Structure of the integrated CAX system based on the feature extension.

management systems such as MRPII/ERP. In another words, the application integration layer is an integration of applications of CAD modeling, CAPP technology planning, CAFD fixture design, CAQ quality detection and controlling, CAE engineering analysis, and MRPII/ERP enterprise resource management, etc.

Among the integrated application described above, the CAD/CAM is in the key technology of the integration design. And the feature extension is the central component of this layer since the applications can be embedded in this layer by the different types of information packaged in the feature extension.

3.1.4. The Data Support Layer. The data support layer comprehensively manages different types of database (i.e., the extended features database, the feature extension samples database, and the technical knowledge database), so that the data presentation and the upper-layer operation of the feature extension can be supported.

3.2. Key Issues in Feature Extension's Realization and Solutions Based on Sensor Components. The previous section has introduced the 4-layer structure of the integrated CAX system proposed in this research. In this section, based on the definition of the feature extension and the structure

property of the 4-layer integration, we shall discuss the technical details on how a feature extension matches its corresponding CAD entity and how a combination of feature extensions forms a feature extension sample.

3.2.1. The Realization of Feature Extension Based on API. A numbers of commercial CAD softwares, such as Solidworks and Pro-E, provide users with an amount of APIs for secondary developing. Since, users can expediently define different feature extension via the APIs during geometry modeling.

More specifically, the APIs can be used to package a variety of information (including the design, manufacturing, fixture, quality, and resource and management information) in geometry entity when geometry modeling is carried out. Then, the integrated information and the geometry entity are bundled to be the unified feature extension.

The realization of feature extension using APIs demonstrated above has a remarkable merit that users are able to modify the properties packaged in a feature extension according to certain engineering requirements.

3.2.2. The Matching between the Feature Extension and the CAD Entity. Here, we shall introduce procedure that how to establish the matching between feature extension and CAD entities. The procedure has four steps:

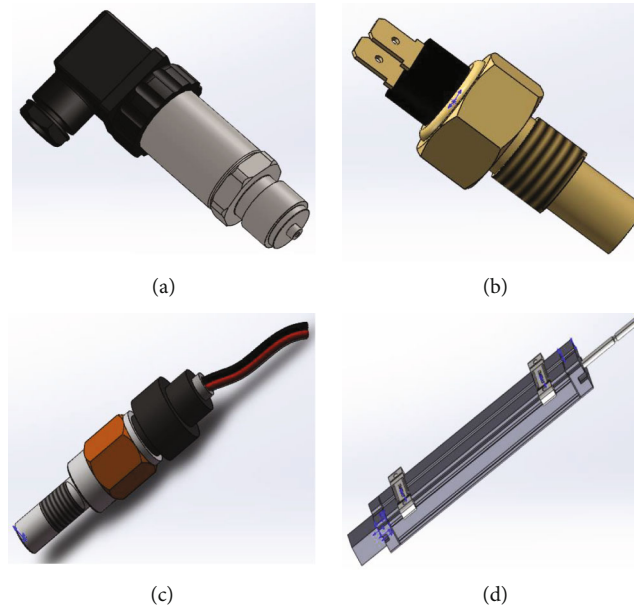


FIGURE 7: An example of feature extension based on (a) pressure sensor, (b) water temperature sensor, (c) speed sensor, and (d) GEFRAN displacement sensor.

Step 1. Obtain features constituting the feature extension from a CAD entity, using feature recognition technology.

Step 2. Compare the recognized features in Step 1 with the default members stored in the feature extension database and calculated the similarities. The member with the largest similarity becomes a candidate solution of the desired feature extension corresponding to the CAD entity.

Step 3. Modify the candidate solution obtained in Step 2 to make it the solution for the matching.

Step 4. Store the solution of Step 3 into the feature extension database, so that the database can include more matching examples with the matching procedure kept carrying out.

3.2.3. The Assembling of the Feature Extension. As is demonstrated before, the feature extension is in fact an extended features set. The feature extension is bundled with a corresponding geometry entity. Thus, the feature extension is expressed as a special geometry entity with other nonconventional features, i.e., a geometry entity with engineering semantics.

Different from simply bundling the features, the feature extension is determined by the features matching (as is illustrated in 2); the feature extension replaces the original features of its corresponding CAD model. Then, a novel type of entity model (of component) which is completely consisted with the feature extension solutions is obtained; such entity is embedded with all properties of the component's feature extension, realizing the advantages of CAx-independence and available to the proposed integrated CAx system.

Often, a component usually consisted of several structures. Obviously, according to the analysis above, the

matching solution of each structure (of the component) needs to be assembled to be a feature extension entity.

Generally speaking, the relation between the solutions of a component can be determined by the original CAD model's topology and attachment details of structures. Assume that the component consisted of n geometrical features and A denotes the feature relation matrix of the component's CAD model, and the matrix A can be expressed as

$$\mathbf{A} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}, \quad (4)$$

where a_{ij} is the relation between the n geometrical features (such as the location and attachment relations). The elements where $a_{ij} \neq 0$ indicate that features a_i and a_j have certain relations, e.g., geometrical adjacency and form and location tolerance baseline. Whereas the elements where $a_{ij} = 0$ indicate features a_i and a_j are irrelevant.

Accordingly, the component expressed by the solutions of feature extension consisted of n feature extension solutions. Now, assume B is the relation matrix of the feature-extension-solution-expressed component, and the relation of A and B can be expressed as

$$\mathbf{B} = \mathbf{f}(\mathbf{A}), \quad (5)$$

where f is a general matrix function. Equation (5) indicates B is automatically generated by A , and the elements of B are the replacement of A .

```

Private sub Cmdqueding_Click()
Dim part as object
Dim boolstatus as Boolean
Dim longstatus as long
Dim sql as string
Dim length as long
Dim filename as string
Dim rs as NewADODBRecordset
Dim cn as NewADOBCConnection
If cn.State<>adStateCclosedThen cn.Close
Cn.Open "provider = SQLOLEDB; persist security info = false; user ID = sa; Initial_Catalog = machine; data source = FORD4"
If rs.Status<>adStateClosedThen rs.Close
Rs.CursorLocation = adUseServer
...
End sub

```

ALGORITHM 1: A program fragment of developing A sensor feature extension.

```

...
Set swap = CreateObject("sldworks.Application")
Set part = swap.ActiveDoc
Set filename = PartGetTitle
Swap.LoadFile2 app.Path+"\\" + "filename.Sldpart", ""
...
Part.SelectByID"01D1@MaxC@filenameSLDPRT", "DIMENSION", 0.08775564, -0.00467529, 0.017438243
Part.Parameter("@MaxC").SystemValue = 01D1
Part.ClearSelection
...
End sub

```

ALGORITHM 2: A program fragment of modifying the feature extension attribute with user defined function fldtofile.

4. Design Application Strategy of the Applied Feature Extension

The definition and the development designs of the extended feature are two key issues for the integrated CAx system based on feature extension. One practical solution for the key issues mentioned above is to carry out a secondary development on widely-used commercial CAD softwares. This measure can sufficiently make use of the mainstream softwares' advantage and simplify the programming procedure. To solve the secondary development, this research offers an idea, as is concluded as the following four stages.

4.1. Define Feature Extension and Establish Extended Feature Library. The main task of this stage is classifying and coding the extended feature. Therefore, we can establish the information model for every type of extended feature and further develop a feature extension sample in a commercial CAD system. After that, the extended feature library and the feature extension sample library can be constructed accordingly.

4.2. Properties Packaging for the Extended Features. Noticing that the commercial CAD software offer abundant geometry

modeling methods, other features, such as manufacturing, clamping, quality, and resource information, can be packaged with products' geometry feature. The benefit is that once done, the complete information of products during their lifetime can be generated in the geometry modeling stage.

4.3. Transformation from Products' Geometry Model to Feature Extension Entity. The main task of this stage is to construct a matching algorithm that relate the geometry and feature extension entities. This operation guarantees the visible models of products are not only geometry entities but also accessible general information entities for CAx and MRPII/ERP enterprise resource management systems.

4.4. Automatic Acquisition of Products' Information. It is necessary to provide the follow-up procedure with original information of products or components. For example, once the manufacturing information is obtained by the CAPP system, the technology planning can be generated automatically. Therefore, the CAx systems must be able to acquire the information of products or components automatically. One possible solution is to control the work flow and authority of each system.

5. An Example of Feature Extension of Sensor Components

In this paper, SolidWorks can be used as the development platform, visual basic, and SQL server are used as development tools, and SolidWorks API and user-defined functions are called to develop features extension and modify their properties. The following is a program fragment to develop a sensor feature extension (as shown in Figure 7) and modify its attributes.

6. Conclusions

To improve the design quality and product originality in manufacturing and to optimize the management operation of companies, this research develops a feature extension method that integrates CAx applications and MRPII/ERP together, so that the manufacturing and the management domains can be combined tightly. First, feature extension of sensor components is defined and extended feature library of sensor components is established. Classifying and coding are the main procedure. Second, feature extension properties of sensor components are packaging. Due to abundant geometry modeling methods by offering commercial software, manufacturing, clamping, quality, and resource information can be packaged. Then, the products' geometry model is transformed to feature extension entity based on sensor technology. Finally, sensor products' information is automatic acquisition.

The information model and the design application strategy have been studied in detail in this paper, which are constructive to researchers and engineers engaged in advanced manufacturing especially in sensor development. In the next step, we plan to apply the technology proposed in this research to a small-scale enterprise (a university company) to evaluate the performance and to further improve sensor research.

Data Availability

These sensor model data in this paper comes from the secondary development of Solidworks API software.

Conflicts of Interest

The authors declare no conflict of interest in this paper.

Authors' Contributions

Yaohong Tang and Mengmeng Song contributed equally to this work and should be considered co-first authors.

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