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Research on the Collaborative Product Design Platform Based on the Internet of Things

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Abstract

To improve the response to customers' demand and the efficiency & quality of product design in the networked collaborated environment, a new modeling framework of the product design platform based on the Internet of Things (IoT) is put forward. In accordance with the requirements of collaborative product design among the supply chain partners, the design platform established on the IoT is given to optimize and carry out the design process through the network. The fundamental structure, feasibilities, functions and key technologies of this platform are described in detail. Further more, a set of key issues are raised in this architecture, and the techniques employed in the solution are presented. All of these researches would provide significant practical references for enterprises to build the related product design platform.

Keywords: *Collaborative Product Design Platform, Internet of Things, Modeling Framework, Supply Chain Solutions*

1. Introduction

Product design involves the application of professional knowledge in a structured way to satisfy customers' specified demands. The customers' demands change continually and modern designers are subject to these pressures such as rapidly changing technologies, increasingly complex technical systems, and working in large, multidisciplinary teams. Recently, Collaborative Product Development (CPD) is widely researched to help designers to improve the decision-making in the process of product design. Particularly, a distributed CPD system, which is being done more often by geographically and temporally distributed designers, is paid more attention [1]. A number of issues have been taken into account in the CPD systems, *e.g.*, information system architecture, communication tools, engineering applications, product geometric representation, and etc.. Existent CPD systems mainly focus on supporting such activities as common access of data and collaborative visualization and design of components and assemblies [2]. By applying CPD in the design process, many issues can also be considered in an early design stage such as manufacture ability, the components belonging to other teams, etc..

The development of information and network technologies has greatly promoted the networked collaborative product design, which makes designers from various sites to cooperate with each other via the networks so as to contribute their skills & knowledge conveniently and realize off-site design. For instance, some CAD tools have been developed to support distributed collaborative design over the Internet. In fact, Web-based and agent-based collaborative systems have been the main two categories of collaborative CAD systems that have been reported to support geographically distributed users in the collaborative design tasks [3-5]. However, these systems are mainly computer-centric systems where the users are desk-bound, and the spatial relationships can be unclear. In addition, the prevailing researches pay much attention on the basis of Computer Supported Cooperate Work (CSCW) [6]. Generally, CSCW can integrate various resources of different designers and enterprises so that they can share data quickly and improve the designing

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efficiency. Some symbolic researches in this field are: Arguing that any changes in shape can be described by the related change of model parameter, the literature [7] suggests designers parameterizing the visual characters and sharing three-dimension model by using CSCW to realize cooperative design. The literature [8] emphasizes the role of product database to support the large amount of information in networked cooperative design, and it also studies how to manage database to keep the consistency and concurrency of the product model. The literature [9-11] describes the construction of cooperative design platform, introducing the function of each part and the necessary technologies to achieve the goal. The literatures [12-13] advance a cooperative design platform mainly based on grids, solving the problem of different data co-existence by using grids.

These achievements have built a solid foundation for the further research. However, there are still some limitations. For example, some literatures focus on the way to unify the product's draft format; some discuss the management and classification of database, while some tend to apply the existing technologies. But none of these gives enough attention to get information before the design, nor discusses on the supervising and controlling of the design process. Most importantly, there is no expectation for probable questions-solving during the whole product lifecycle process from the view of upstream & downstream of the product. Therefore, the questions raised in this paper are: what kind of concept model is particular suitable for product design; what system architecture of a Collaborative Product Development platform in a distributed environment should have; what technologies should be used to support system integration and group collaboration; how design engineers and domain experts can cooperate on solving a problem, improving the effectiveness, efficiency, and accuracy of product design. The developments in related domains can offer some help. First, commercial Computer-Aided Engineering (CAE) tools have been widely applied in industry and computer programs for specific analysis tasks have also been developed. Secondly, with the rapid advancement of information and communication technologies, systems integration and collaboration technologies have been developed and deployed in different engineering application domains. These put two further questions forward: how to support the integration of technologies and how to make full use of the design models created in different stages, sites or designers.

The Internet of Things (IoT), the basic concept of which is that the emerging connected fabric of applications, devices and endpoints (such as Radio-Frequency Identification (RFID) tags, sensors, actuators, mobile phones, etc.) are able to interact and cooperate with each other through unique addressing schemes, is rapidly gaining ground in the modern wireless telecommunications environment. From the perspective of business users, the most obvious effects of the IoT will be equally visible in fields such as automation and industrial manufacturing, logistics, business & process management, intelligent transportation, and so on.

With the gradual applications of the IoT, the collaborative product design is now introducing new elements to provide purified, real time, total information for the product. Here, the elements are the relative entities such as: the things mentioned above, humans, design processes, the physical environment, and so on. Therefore, under the environment of the IoT, the design process allows monitoring new parameters of the product and its environment along its whole lifecycle. Obviously, this is a new paradigm for a product design and plays a great role in managing the design process, supervising and guiding designers' behaviors. Through the process of monitoring and authentication, the gathered information can be analyzed and transformed to knowledge which can then be used to optimize the whole product lifecycle. This is allowed by the track and trace capabilities of the RFID technologies and the condition monitoring capabilities provided by the sensor systems. Accordingly, new business opportunities and new technological challenges have been created by this new paradigm of product design.

Hoping to make some contributions to the research field of product design in the context of the IOT, this paper tries to (1) devote to the new concept of product design from the supply chain view, (2) analyze the role of the IoT to support product design, (3) provide a modeling framework for the collaborative product design platform based on the IOT, and (4) discuss the fundamental structure, main functions and key technologies needed.

2. Product Design on Supply Chain Solutions

With the intensive global industrial competition and the rapid changes of consumers' needs, enterprises are increasingly relying on collaborative product solutions to support the design process. The solutions mainly include the establishment of dynamic alliances of the supply chain, management of design tasks, supervision of design process, management of relationships among the supply chain parterres, and so on.

Product design is an intelligent activity, which begins from the analysis of customers' demand, going through concept design, structure design, detailed design and ending up with product descriptions in the form of documents. Changes in competition make enterprises to be aware of the importance of building strategic partnerships. Under the mode of Extended-Enterprise cooperation (see Figure 1), during the process of design, designers should establish a mode based on the supply chain that consists of suppliers, manufacturers, retailers and final customers.

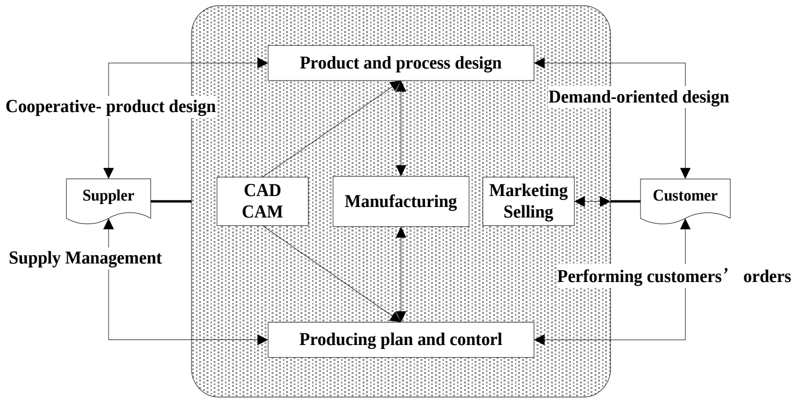

Figure 1. The Mode of Extended-Enterprise Cooperation

The goal of the concept design is to get the basic scheme of the product, including functions design, layout design and preliminary structure design. Simply speaking, this phase begins with the market analysis, and designers should analyze data from the view of customers to determine the original design proposal--it is called demand-oriented design. Then, with the help of internal and external experts, the designer can subdivide and specify the abstract design (so-called cooperative-product design). For instance, to reflect customers' demand more accurately, the designer should get some valuable information as customers' impression & preferences on the product from the channel dealers (such as distributors and retailers) through the market & selling research. Then the designer can forecast and decide the core questions combining with the data. In the process of product development, the designer may invite experts from such institutions to give some advice for the product's configuration, layout and structure, etc.. At the same time, the designer may also need advice from suppliers for the parts choosing, materials attributives, etc.. All these have great influence on the form of final product.

The detailed design is to determine all the concrete parameters for each component and part. Using engineering drawing or 3D geometric model, the designer can determine the shape, size, tolerances and other parameters. Taking into account the importance of designing flow from the view of supply chain, the designer should also invite outside experts again to participate in order that the designer can gain more practical suggestions.

Based on the descriptions above, we can get the design flow chart as Figure 2.

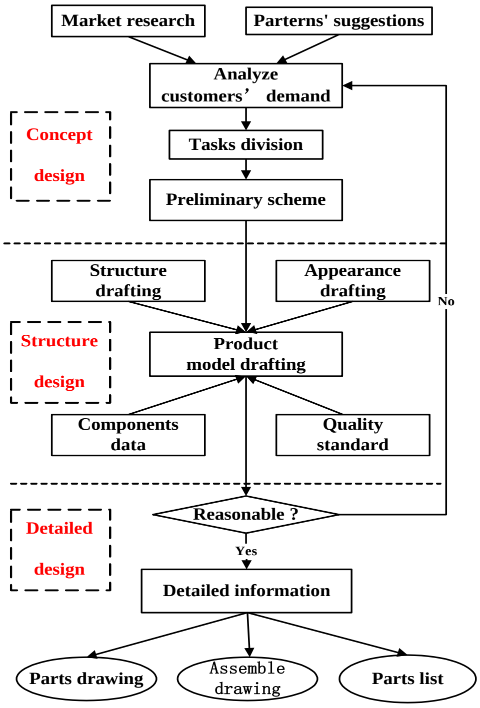

Figure 2. Product Design on Supply Chain View

3. Product Design based on the Context of the IoT

3.1. A Brief Overview of the IoT

The definition of the IoT is still fuzzy [14], but all the people who share such a vision believe that it is possible to create a world-wide network of interconnected things, which will probably be readable, recognizable, locatable, addressable, and controllable via the Internet [15]. Actually, these things, which belong to the physical world, will make use of different technologies (*e.g.* embedded systems) to create a digital or virtual space, where they will interact with each other and other entities (*e.g.* software processes, human beings) through well-defined interfaces. As a consequence, things are expected to become active participants in business, information and social processes. Observe that this digital space will be tightly related to the real world, namely, the things will not only be able to maintain their real identity in the virtual world, but also to access information from the real world (*e.g.* their physical location, the state of their environment) and interact with real-world entities.

The improvements that the IoT can bring to a product designer are mainly in creating new supports in some application aspects. For example, designers' working environment can be effectively protected and monitored, and new services can be created to foster the development and inclusion of products and people. Other particular examples of specific services are the designer activity monitoring (*e.g.* designers' healthcare and working situation), infrastructure integrity management (*e.g.* critical infrastructure supervision), and so on.

3.2. Product Information Model in the IoT

The idea of a Product Information Model (PIM) is based on the concept that the status and performance of each part, component and the designer--should be continuously monitored by the product management platform and made available to third parties via a series of APIs (Application Programming Interfaces), even though some information is confidential.

Accordingly, nothing can be built legally unless it is compatible with the production information model. For instance, the facilities management services communicate with each other and the PIM, sharing the data in the most cost-effective and resource-efficient way. Besides, the data can automatically transmitted with each other and the costs of materials, parts, components are calculated to match supply and demand. In this sense, planning and design is an ongoing organizational process, in which the performance of each item is being reported in real-time and compared with others. Moreover, designers' changes can be inferred, as can the design process, environmental performance, as well as the overall efficiency of the product.

3.3. Securities of Product Design in the IoT

The IoT is extremely vulnerable to attacks for several reasons. First, its components often spend most of the time unattended--and thus, it is easy to physically attack them. Second, most of the communications are wireless, which makes eavesdropping extremely simple. Finally, most of the IoT components are characterized by low capabilities in terms of both energy and computing resources (this is especially the case for passive components) and thus, they cannot implement complex schemes supporting security during the process of product design. More specifically, the major problems related to securities concern authentication and data integrity.

3.3.1. Authentication: Authentication is difficult because it usually requires appropriate authentication infrastructures and servers that achieve their goal through the exchange of appropriate information with other nodes. In the IoT such approaches are not feasible given that passive RFID tags cannot exchange too many data with the authentication servers. The same reasoning applies (in a less restrictive way) to the sensor nodes as well. In this environment, several solutions have been proposed for sensor networks in the recent researches [16]. However, existing solutions can be applied when sensor nodes are considered as part of a sensor network connected to the rest of the Internet via some nodes playing the roles of gateways. In the IoT context, sensor nodes must be seen as nodes of the Internet, so that it becomes necessary to authenticate them even from nodes not belonging to the same sensor network. In the last few years, some solutions have been proposed for RFID systems; however, they still have some serious problems [17]. Finally, none of the existing solutions can help in solving the proxy attack problem, also known as the man-in-the-middle attack. Consider the case in which a node is utilized to identify something or someone and, accordingly, provides access to a certain service or a certain area (consider an electronic passport for example, or some keys based on RFID).

3.3.2. Data Integrity: Data integrity solutions should guarantee that an adversary cannot modify data in the product design process without the system detecting the change. The problem of data integrity has been extensively studied in all traditional computing and communication systems and some preliminary results exist for sensor networks [18]. However, new problems arise when RFID systems are integrated in the Internet as they spend most of the time unattended. Data can be modified by adversaries while it is stored in the node or when it traverses the network. To protect data against the first type of attack, the memory is protected in most tag technologies and solutions have been proposed for wireless sensor networks as well. This is based on a common secret key shared between the tag and the destination of the message, which is used in combination with a hash function to provide authentication. The above solutions proposed to support data integrity have serious problems when RFID systems are considered. Actually, the password length supported by most tag technologies is too short to provide strong levels of protections. Moreover, even if longer passwords are supported, their management still remains a challenging task, especially when the entities are involved belonging to different organizations. In fact, these conditions are very common in the case of the IoT. Finally, all the solutions proposed to support security use some cryptographic methodologies. Typical cryptographic algorithms spend large amount of resources in terms of energy and bandwidth both at the source and the destination. Such solutions cannot be applied to the IoT, given that they will include elements (like RFID tags and sensor nodes) that are seriously constrained in terms of energy, communications, and computation capabilities. It follows that new solutions are required able to provide a satisfactory level of security regardless of the scarcity of resources. In this context, a few solutions have been proposed for light symmetric key cryptographic schemes and for sensor network scenarios). However, as we already said, key management schemes are still at an early stage (especially in the case of RFID) and require large research efforts

4. Product Design with the Supports of the IoT

In the context of the IoT, product design could mainly be supported in the aspects as follows.

4.1. Providing Overall Information about the Product

By means of tracking the product and analyzing the sale data, the designer could get detailed information from the customers about the advantages and disadvantages of the product so as to improve the concept design. Besides, the application of the IoT fulfills Customer's Relationships Management (CRM) more conveniently and efficiently, and the system on this foundation makes information-gathering, customer-accessing and after-sell-survey much easier.

In the phase of structure design, by collaborating with suppliers through IOT, the designer can get the environment and product data directly. Then, the designer can refer to suppliers to reducing defectiveness and costs.

In the phase of detailed design, by using Electronic Product Code (EPC) to get the specific information of size, other important parameters, etc., the designer can provide updated data of the product for the transition of the designing drawing into the instructive process flow chart.

As there are multiple local copies of an object or a part located in the local databases of the designers, when changes are made to a displayed scene of one designer (such as changing the dimension of one feature on a part), these changes must be propagated to copies located in the local databases of the other designers. It is important to synchronize these changes and avoid confusion in the modification of the part.

4.2. Controlling Design Process

By setting a deadline for the whole task and dividing it into several subtasks according to the Work Breakdown Structure (WBS), the design tasks can be assigned to the designers. At the same time, the manager can accelerate the subtasks according to the standard to control the design progress. To guarantee the tasks to be carried out on time, the manager can give clear instructions to designers at the right time. Typically, a practical control of the editing right for the product design may be as follow.

At any time, only the designer with the authority of editing can edit the product model and information. Other designers can only receive the updated information and provide their feedbacks to the modifications. If some designers disagree with the modifications made by one designer, such modifications can not be allowed, and a virtual panel with the names & feedbacks of the dissenters will be displayed to inform all the designers. A discussion will be initiated among the designers to reach an agreement on the design modifications. After a designer has obtained approval from all the other designers, the server will invoke the modeling module to update the solid model and product design information according to the parameter package. The designers have the options of setting their preference on the feedbacks through their interfaces, e.g., the designers can set their preference as 'agree to all modifications' or 'provide feedbacks on modifications.

After the modeling process has been invoked, the ‘editing right’ is held by the server to prevent any designers from initiating another round of modifications until the current modeling process and information extraction process have been completed..

4.3. Managing Designers

During the whole process, the relationships between designers are collaborative and designers can communicate with each other anytime via the IoT which is of powerful communicating abilities. A designer working under the IoT will be no longer in the fixed working timetable, because the designer can arrange his own time reasonably and the only thing he (or she) has to do is submitting the drafting on time. Besides, designers can ask for coordination meetings via the IoT to make necessary modifications according to the practical environment only if the applicants are more than a certain number.

4.4. Arranging Logistics for the Supply Chain

Real-time information processing technologies based on RFID and NFC (Near Field Communication) can realize real-time monitoring of almost every link of the supply chain, ranging from product design, raw material purchasing, production, transportation, storage, distribution, return processing and after-sales services. It is also possible to obtain products related information promptly, timely, and accurately so that enterprises or even the whole supply chain can respond to intricate and dynamic markets in the shortest time. A typical example of the application result is: the reaction time of traditional enterprises is more than 100 days from requirements of customers to the supply of commodity, while advanced companies that make full use of these technologies (such as Wal-mart and Metro) only needs few days and can basically work with zero safety stock. Additionally, real-time access to the ERP program helps the shop assistants to better inform customers about availability of products and give them more product information in general.

A classical example is perishable goods such as fruits, fresh-cut products, meat, and dairy products are vital parts of our nutrition. From the production to the consumption sites thousands of kilometers or even more are covered and during the transportation the conservation status (temperature, humidity, shock) need to be monitored to avoid uncertainty in quality levels for distribution decisions. Pervasive computing and sensor technologies offer great potential for improving the efficiency of the food supply chain.

5. A Modeling Framework for the Collaborative Platform based on the IoT

In this paper, a Collaborative Product Design Platform (CPDP) based on the IoT is defined as: A platform through which the designers located in different places communicate and cooperate for the same tasks by means of the IoT. What makes it outstanding is that the applications of the IOT, which can help people to manage and supervise the product, the designers and even the whole process. This platform can also provide all the information and parameters anytime from anyplace, including the first-hand data about the environment. All these are beneficial to designing products more efficiently and successfully.

This paper puts forward a modeling framework for CPDP based on the circumstances of the IOT, through which companies and designers from different places could cooperate with each other and they are managed and coordinated in real-time. Therefore, this platform is designed according to the functions and supports that the IOT could provide.

5.1. Basic Modeling Structure for the Platform

The basic modeling structure of the Collaborative Product Design Platform is as figure 3. This structure contains four levels. The top level, which is called applications interface, is to help designers’ work based on internet & computers, and designers in different areas have access to the interface. The designers can also browse different kinds of information about the product through the interface and design the part that belongs to them and send the results to the second level (Cloud Platform), where the results will be dealt and saved. The designing documents from the designers contain two kinds of style: 2-D drafting and 3-D drafting. Designers can lessen the complexity by using 2-D design in early stage. In the final stage, designers have to finish 3-D design and work out the final results. Make some micro modulate on its size and shape through using design data offered by the cloud platform, and finally designers can submit the product. Therefore, cloud computing platform mainly provides powerful calculations to accumulate, choose, process the gathered information, form constrain formulation and solve them, and then save the final data to the databases.

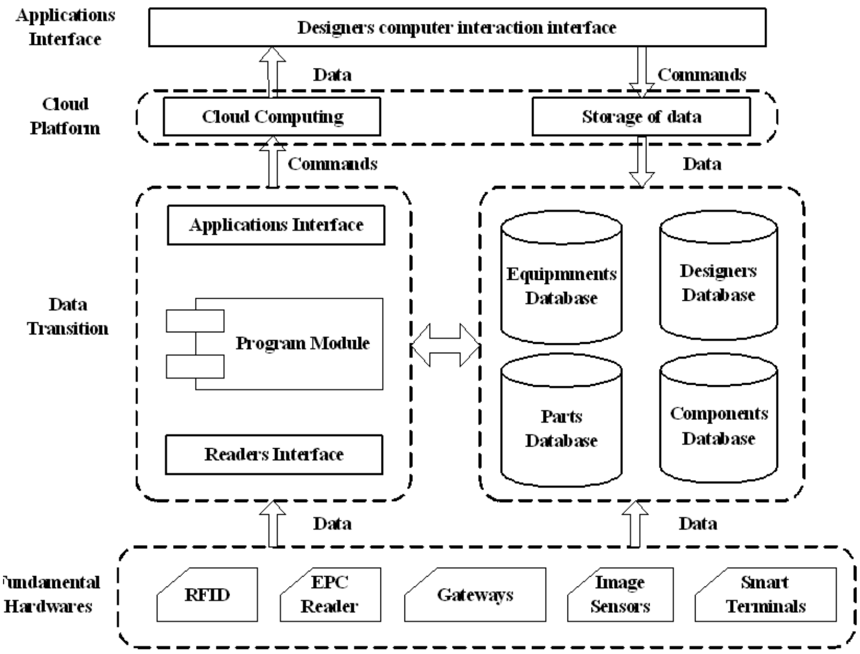

Figure 1. Basic Modeling Structure for CPDP

To synchronize the product models in different designers, a propagation mechanism in the third level is implemented to efficiently transmit the relevant data via the network. In this mechanism, the features that have been modified are differentiated on the server side and synchronized with the unchanged features on the designer side. The features that have been modified can be classified as either an added feature, deleted feature, edited feature or an updated feature. Based on the parent-child relationships of the features deposited in the database on the server side, the differentiation processes are as follows:

1) When a feature is classified as an added feature, the features on which it nests will be updated and the updated information will be transmitted to the designers to update the virtual models.

2) When a feature is classified as a deleted feature, this feature and its sub-features are deleted and the features on which this feature nests are updated. Accordingly, the information of the deleted feature will be transmitted to the designers to update the virtual models.

3) When a feature is classified as an edited feature, i.e., the parameters of this feature have been modified, this feature is updated. According to the types of feature modifications, the affected features are processed according to the relative rule

4) The unique feature name assigned by the software (Solid Works) is used to distinguish the features so as to avoid the naming consistency problems.

5.2. Main Functions of the CPDP

EPC (Electronic Product Code) and RFID can help designers to get data of the parts under any circumstances. In the process of design, designers can browse these data at any time they want, and they can foresee the possible risks and problems in a more convenient way. Therefore, they can improve the design quality and reduce the failure rate.

Based on storing data collaboratively, cloud computing can process these data rapidly so that design results can be received, processed and classified timely. It doesn't only reduce the design complexity, but also guarantee the design quality.

The technologies of video, audio and electronic conference make designers communicate with each other freely and monitor others' progress at any time. With appropriate process-controlling methods, designers can reduce the conflicts. Besides, this platform has the common functions as data and users management. The main functions of this Collaborative Product Design Platform are: Users management, Projects management, Tasks management, Designers management, Equipments management and Data management.

6. Key Technologies for the Platform

6.1. Gathering the Information

The data about the product and the environment in each design phase from which computers gather the information via IOT are in form of codes, which needs to be decoded into languages by the middleware to be understood by the designers. Middleware refers a series of programming module that has certain characters, which is located between operating system software and utility software, and mainly providing developing circumstance for upper level. It can process all the information and event flow, also has the function of filtering, grouping and counting. So designers can reduce the data that are sent to information system and prevent information from being read incorrectly. The working principle is as Figure 4.

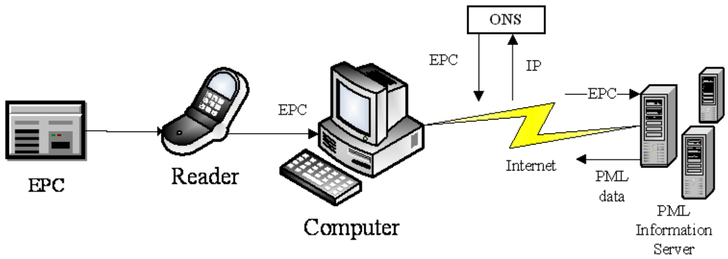

Figure 4. The Working Principle of Information-gathering

When RFID readers identify the EPC, the information stored in it will be sent to the middleware. Then, the middleware system will find the location where information are stored by ONS (Object Name Service) on the internet or intranet and then indicate the server which has these data including PML (Physical Markup Language) to analyze and send information to cloud platform to be stored. PML, which is simple and universal and is applied to control physical things and environment far away, is a new kind of computer language. All the documents are stored in the specific server to provide documents for other computers. PML server will be maintained by manufacturer, and it also stores the other products' information.

6.2. Processing the Information

The development of the IoT has built up a substantial foundation for the collaborative product design, and the overall information it collects will provide great supports for designers to fulfill the design comprehensively and efficiently. However, how to analyze and apply the relative technologies timely, effectively and correctively is another key problem.

By dividing the whole task into small ones by computer process programs, the cloud computing platform can process millions of dada within a second. Virtual technologies change physical resources into virtual ones that have the same functions and connections. This can reduce the complexity and provide a logical condition for designers. Besides, it also makes a sole server support many virtual machines' works. Collaboratively storing data, this pattern can express data abstractly in computer languages so that designers can manage the unified data and guarantee the safety and reliability.

Further more, there are a wide range of technologies that will be involved in building the IoT. The enhancement of the communication networks infrastructure (e.g. through ultra-wideband networks, 3G and 4G networks) will be essential, as well as the adoption of IPv6 in order to provide a unique IP address to each thing involved in the network. The technologies that allow the location and identification of physical objects (e.g. RFID) will also be fundamental in this context. There are also other technologies that will influence on the successful development of IoT applications, such as computer vision, biometric systems, robotics, and others. One of these technologies, wireless sensor networks, is able to provide an autonomous and intelligent link between the virtual world and the physical world, and in fact it has been thoroughly studied.

7. Conclusions

The design of modern products requires a more advanced integrated and collaborative approach. It is already a trend to employ the IoT technologies on which the design and other processes are seamlessly integrated from the supply chain view. In this context, it is necessary to study an integrated design platform system for collaborative product design. Such a platform will allow designers and engineers geographically distributed to collaborate in a virtual environment. All of these studies in this paper could provide practical references for enterprises to build collaborative product design platform based on the IoT.

The major contributions of this paper can be summarized as follows: 1. A new perspective for product design is based on the whole lifecycle development and supply chain management. 2. From this viewpoint, this paper presents a modeling framework of product design platform supporting collaborative design in the context of the IoT. 3. The fundamental structure of the platform is proposed and the main functions and key technologies are discussed in detail. 4. Such an IoT-based platform could be as the prototype implementation solution for the collaborative product design.

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