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Thinking factory for the future: from PLM to augmented reality

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Abstract

Virtual engineering technologies become an emerging field in industry and research. Nowadays, industrials are using Virtual and Augmented Reality in different phases of their manufacturing process (advanced manufacturing process visualization, assembly tasks, training, etc.). The purpose of this paper is to introduce the advantage of linking augmented reality application, to help employees on their daily tasks. This involves the connections with the existing components of the information system in the factory, especially PLM system used to handle the CAD models. Some principles of solutions are proposed to show how the integrative frameworks can support the realization of manufacturing activities.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities D.2.12 [Software Engineering]: Interoperability—Data mapping

1. Introduction

Today, industry actors are making a significant effort to reduce their production costs and mainly the cost of non quality defined as the incurred costs due to the failure of achieving the minimum required product quality. The increasing of this cost is mainly due to three reasons: the lack of information, gaps in training and the unavailability of documentation in production lines. Otherwise, one of the main challenges in today production systems is to provide factory actors with robust tools helping them to perform, with more efficiency, their daily activities and to enhance their reactivity in different working situations.

These facts explain the necessity to use, in the factory, advanced digital tools based on Information and Communication Technologies (ICT). Indeed, industrial engineering experts highlight the key role of ICT for industry and affirm that a better integration of these tools may increase the firm profitability and leadership in competitive markets.

In this context, considering the PLM (Product Lifecycle Management) approaches characterized by its distributed and multi–IS (Information systems) connection properties, the basic idea of a "Digital Factory Assistant" concept is to extract the relevant knowledge and allowing each person being able to respond on any given situation, mainly thanks to knowledge extraction and high-speed simulation methods. By means of this assistant, the operator benefit from an omnipresent support along the manufacturing process.

For the same purpose, Virtual Reality (VR) and Augmented Reality (AR) based facilities connected to digital assistant should enhance the friendly exploitation of stored knowledge and information regarding the variety of actors profiles, their levels of expertise and the complexity of their tasks.

The literature survey pointed out that the use of VR and AR technologies can give more advantages for knowledge presentation and help user for the visualization and the interpretation of huge mass of information, if it is correctly structured.

To build knowledge based assistant combined with VR/AR facilities, it is required to define transformation mechanisms. These mechanisms aims to ensure the formatting of data files from their original format, as it is stored in the enterprise IT system, to specific format, making possible their exploitation by the VR/AR tools. Since such kind of as-

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sistant intend to return knowledge from distributed sources relying on different interactions with IT systems, the problem of interoperability should be addressed as a part of the technical solution for the implementation of "Digital Factory Assistant".

This paper presents a new vision about the role of ICT tools in the factory for the future according to the concept of "Digital Factory Assistant". It presents an integrated workflow that help connection between the PLM software used to manage CAD models in one side and the augmented reality projection system that support data presentation, in the other side. It describes also interoperability module that ensure data extraction from PLM server.

This paper proposes, throughout a concrete industrial case study, original principles of solution for the use of these technologies to enhance the efficiency of manufacturing activities in aeronautic domain. However, the scope is not to define a technical implementation of an AR/VR framework.

The next section presents a literature survey about the role of PLM and AR/VR technologies in the manufacturing field. The section 3 will introduce the research context of this work while the fourth describes the proposed workflow model and its main components. The fifth section is dedicated to the illustration of the proposed principles of solution in industrial case study. Then the last section presents the conclusion and discusses the future works for the implementation of the proposed solutions.

2. Literature Survey

In industry, PLM systems are used to manage the lifecycle of the product and all related data and information with aim of enhance the collaboration between different teams. According to [Sri11], "the scope and definition of PLM are expanding and maturing to meet the demands of an increasingly complex network of industrial partners spread globally and bound together by common business objectives." PLM is a collaborative backbone allowing people throughout extended enterprises to work together more efficiently [SI04].

Many applications of these systems has been developed and tested on real use cases with the aim of supporting a wide range of the manufacturing processes. New vision of the factory of the future shows that the integration of PLM system with RA/AR facilities can give lot of advantages for the improvement of job performances in the workshop [LBBC12].

Regarding AR and VR technologies, several frameworks are proposed in the literature for assembling task [BJT12], factory planning [PBDM07] and production tasks [?] [CM92]. A recent review of research and development of augmented reality (AR) applications in design and manufacturing is presented in [NOCM12]. The authors also discussed the recent hardware systems used in AR and a number of industrial applications.

Considering the large variety of potential applications in manufacturing, different AR technologies are proposed in the literature. For instance, Laser Projection Technology (fig.1-a) is proposed by [NMBT13] to assist conventional assembly methods and hard manufacturing templates in a wide variety of applications. Head mounted projector is another interesting AR technology for manufacturing applications. This technology is used in ARKIVA project as a solution to replace the conventional instruction manual and provide additional current process–related information for aircraft maintenance (fig. 1-b) [FJS02]. In the same category, the concept of UDset (fig 1-c) is used to project graphical templates for the location and orientation of composite cloth during the layup manufacturing process [CM92]. Spatial Augmented Reality (SAR) is another technology that employs data projectors to superimpose computer generated virtual objects directly onto physical objects surfaces. (fig 1-d) shows an application of such technology proposed by [ZLT*12] for spot welding inspection in automotive industry. The concept of projected SAR is exploited by [OGL08] to assist operator facing to industrial CNC machines (fig 1-e). By means of the ASTOR system, the operator views the machine operation through the holographic optical element, which is illuminated with stereoscopic images from the projectors driven by a PC. The setup allows 3D annotation to appear in the workspace, augmenting the operator view of the process with relevant information. Due to the advantages and maturity of projected AR solutions, a commercial tools is proposed by CentrelineDesign company [Cen14] to provide exact projections on aircraft parts of features, like welding lines or dots show the user the correct location on the object quickly and easily (fig. 1-f).

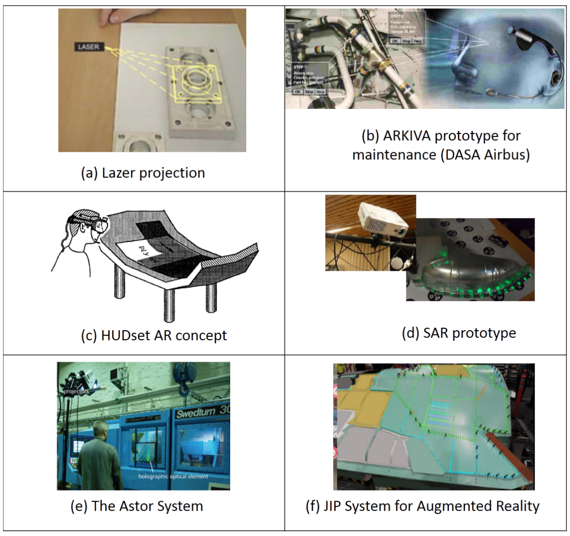

Figure 1: *Augmented Reality based systems in manufacturing domain*

The recent developments point out concrete advantages of new AR technologies to enhance operators activities in manufacturing field by providing him by relevant information with the good format. However, the solution implementation for each case study requires manual process for extracting and preparing data to be projected. The connection of such solutions with current information systems should enhance considerably the efficiency of manufacturing process by automating and accelerating data retrieval and extraction from data sources on one hand, and by supporting data format transformation, on the other hand.

Indeed, the aim of linking visualization tools with existing components of the factory information system (such as PLM) used to handle the CAD models are discussed in previous works. However, in most of augmented reality applications [PBDM07] [CM92] [KRC11], the transformation process from CAD models to AR models concerns a small number of modeled objects.

In specific applications of AR in the manufacturing field, the application of this technology requires the transformation of a large number of CAD models. Therefore, there is a need to automate the CAD-AR transformation taking in consideration the interoperability issue raised by data extraction from PLM.

3. Scientific research context

Different visions about the factory for the future have been developed in recent years. According to many authors, the factory of the future will be adaptive, intelligent and knowledge-based.

In this context, we aim to build the concept of "Digital Factory Assistant" (DFA). The DFA is a knowledge-based system dedicated to support factory actors on their daily tasks by providing them the needed information at the right time and in the right place according to the user working situation. The DFA is based on information and knowledge reuse, implementation of decision support capabilities, advanced numerical simulation of the manufacturing process and the application of virtual and/or augmented reality in order to guarantee a better restitution of the information. The assistant interact also with the existent enterprise information system by means of a generic framework allowing the access to CAX models (Computer Aided Design/Manufacturing), Product Lifecycle Management information (PLM), material flows, process chains, simulation data and Enterprise Resources Planning (ERP) systems [BMBBE13].

The generic architecture of the DFA is composed of four main layers:

- *Communication layer*: the communication layer deals with the human machine interactions and the information and knowledge representation issues. Augmented reality is used in this layer to propose better information representation. This layer implements also advanced simulation interfaces connected to the manufacturing process simulation module. The aim is to guarantee a better understanding and control of the process.
- *Context management layer*: This layer is related to the human-machine level, where contextual information related to user working situation can be acquired. The proposal of this assistant is based on context awareness issue [Sch13]. Context-aware systems have the particularity of anticipating the user needs in a particular situation and act proactively to provide appropriate assistance.
- *Knowledge management layer*: The role of this layer is to introduce a new way of definition, representation, and exploration of knowledge in the factory. The main idea is to provide workers by useful knowledge according to a multi–level structure where each level represents the completeness degree of knowledge [LBBC12]. In fact, the proposed decision support system is based on dynamic knowledge representation: in a process of decision-making, the actor combines different types of data and knowledge available in various forms.
- *Interoperability layer*: in addition, the function architecture is provided by a set of connectors aiming to support the communication between the DFA and different components of the enterprise information system. This layer is developed as a part of a global interoperability approach aiming to support the ability to exchange services and data between various systems.

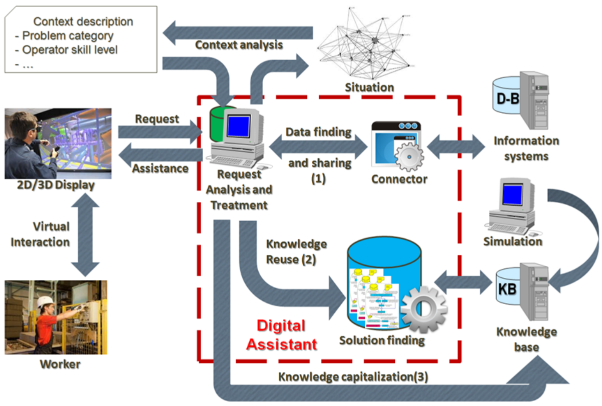

Figure 2: *Functional architecture of the "Digital Factory Assistant"*

This paper deals with two types of interactions with the DFA (Figure 2). The first category concerns the communication between the user and the knowledge module of the digital assistant throughout projected augmented reality. The second category of interaction concerns data exchange between the augmented reality projection system and other parts of the existing enterprise information system through specific connectors. The next section aims to describe the workflow allowing the data exchange between a part of the existing information system in the factory and the augmented reality projection system.

4. Workflow Descritpion: From CAD to AR

One of the biggest issues that an AR framework may encounter is its full independence from other IT systems. This issue can be raised when the use case being applied requires the transformation of a large number of CAD models. The manually preparation task in this case will be a tough task and require more time and money. To overcome this issue, we propose in this work to link the AR system with other kind of software widely used in industry, particularly PLM system.

The basic idea is to automatically extract the needed CAD model from a PLM system and transform it into a 3D model that can be supported by the AR system. The process of extracting and transforming the CAD model is explained in the figure 3.

As mentioned in the introduction, the projected augmented reality system may deal with different AR models that each one represents a CAD model of the product. When working in the shop floor, the worker input the reference of the product that he will work on it. The first step in the designed workflow is to check if the correspondent CAD model of the product is already transformed into an AR model or not. In the case where the CAD model has not been transformed yet, the CAD extraction and transformation process are executed and the AR model will be forwarded to the AR system. The transformation process consists of a specific script that transforms the CAD model to an AR model.

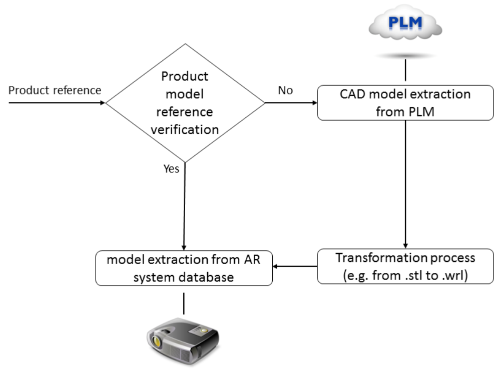

Figure 3: *Transformation from CAD model to AR system*

The CAD model extraction consists of the retrieval of the correspondent CAD model of the reference being entered. As mentioned above, the framework uses PLM system that manages the product data and particularly the CAD model. To extract the CAD model, it is needed to set up a connector that connects the AR system to the PLM system.

To be more specific, the PLM solution used in this work is called Windchill. Windchill, developed by PTC (Parametric Technology Corporation), is a PLM system offering to users a large variety of tools to support different aspects of their collaborative development projects and data and document management. Regarding the growing interest in interoperability, PTC has embraced Open Standards, such as Service Oriented Architecture (SOA), as its strategy for supporting integration between the PLM and other applications.

For this need, Windchill exposes functionality for integration purposes through a standards-compliant Web- Services framework populated with an extensive library of prebuilt services. Windchill integration with other enterprise applications requires the use of low–level APIs and complex application adapters. Supporting new integration scenarios is a labour intensive and requires strong development skills. For this need, Windchill Info*Engine server provides mechanisms for retrieving and manipulating the data that users or custom applications want to view or receive from the PLM Server. The proposed connector for the AR system is based on Info*Engine Java 2 Enterprise Edition (J2EE) integration engine. The Info*Engine J2EE connector uses SOAP protocol to allow communication between Info*Engine and other applications.

The implementation of the proposed solution is achieved by a set of interactions between the different components of Info*Engine framework and the interoperability client application. As it is shown in figure 4, the client application communicates directly with the Info*Engine SOAP servlet that catch and process SOAP requests and send the required information to the client application.

For this need, the SOAP servlet invokes tasks execution on the SAK (Service Access Kit), which is an API facilitating the development of Java applications, including JSP pages, using Info*Engine functions and features. During task execution, SAK interacts with the naming service in order to instantiate required services. With the naming service, SAK can identify all network addresses and configuration properties in the LDAP directory. In the meantime, the client application has a direct connection to the SAK and the naming services to extract the services parameters and code interpretation respectively, which are required for the definition of the Web- Service request.

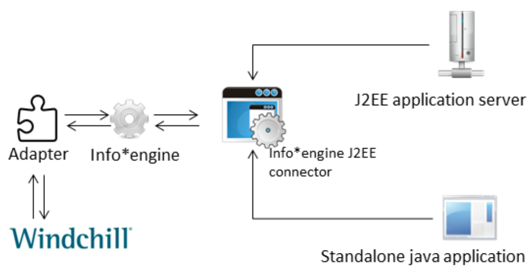

Figure 4: *Info*engine integration process*

5. Use Case Analysis

The role of equipment in a successful manufacturing process of the end product is very important. Obviously, it is more important when the OEM develops specific product or modifies existing models to satisfy a particular customer requirements. In this case, the manufacturing process may be customized for each particular product and the OEM production service has to order new specific fixture tool in order to support specific assembly operations.

Most of the end-product assembly operations require fixture tools for the parts handling. Figure 5 shows an example of fixture tool from the aeronautic domain. Such kind of tools is used as a template to set the position of the holes for the drilling and the riveting of the aircraft parts. The development and manufacturing processes of the fixture equipment are sequential ones as explained here. First, the design department delivers the engineering data (CAD or CAE files) of the considered product parts. The production engineering and management departments specify and plan the detailed assembly processes and required tools for achieving the assembly operations. Then, detailed functions and constraints of these tools are specified. The purchasing service negotiates and sends the order to suppliers. Several suppliers remotely located are asked to develop the detailed specifications of the tool and to manufacture various parts. Finally, the tool is sent to the OEM production workshop to be used.

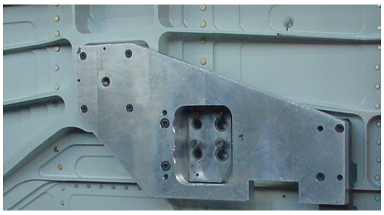

Figure 5: *Example of fixture tool*

However, due to the specificity of this kind of products (fixture tool), several challenges are to be resolved and innovative assistance functions should be developed to enhance the manufacturing process efficiency the fixture tool. For instance, the following challenges should be considered:

- During the manufacturing process of the fixture tool, some modifications may occur on some aircraft components. These modifications imply changes on the specification of fixture tool.
- Another critical issue concerns the maintenance and the reproduction of the fixture tool. In some cases, due to an intensive use of the tool, some holes will be damaged and it will be necessary to repair it or to reproduce an identical tool. It is the same need if the tool will be lost in the factory floor shop.
- During the lifecycle of the aircraft, some maintenance operations require to repair some parts at the local maintenance floor shop of the client, which it will be geographically distant from the manufacturer. In this case, identical fixture tool are to be created locally.

For all these cases, suppliers have to be very reactive to cope with time of delivery constraint and to guarantee the quality and the precision of the fixture tools. It has to manage a huge mass of data and documents that is not very easier, especially for Small and Medium Enterprises (SMEs). The combination of the facilities given by actual PLM systems and new development of Augmented Reality and Virtual Reality can give several advantages to help supplying workers to perform rapidly their activities to reduce the time of delivery of the fixture tool.

6. Implementation Perspective

To implement innovative solutions, augmented reality combine a set of specific devices such as camera, video projector, trackers, etc. with a high computation capacities. Figure 6 presents an augmented reality solution connected to the Digital Factory Assistant to assist suppliers and production department to rapidly produce fixture tools. Regarding different challenges identified in the use case, different augmented reality solution are proposed:

First, by means of an augmented reality projector, the AR system projects, on the metal sheet (that is the raw material to be manufactured), the CAD part of the fixture tool, extracted from the PLM to help worker to identify immediately the global geometry and the position of the different holes. The worker can then directly fulfill cutting and drilling activities on the metal sheet to obtain the final fixture tool. Within this technique, the AR can also project a set of fixture tools on the same plate in order to assist worker to optimize the material and time of work by producing a variety of tools at the same time and from the metal sheet.

Second, to assist the modification of existing fixture tool, the AR system extracts from the PLM the new CAD file of the modified end product and projects it on the real fixture tool. The worker can easily add new holes in the tool without any additional design effort from the production department.

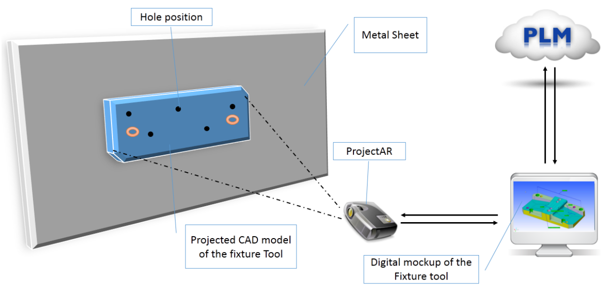

Figure 6: *Principle of AR solution 1*

For the third case, the association of an additional AR camera to the previous technique should give more advantages to obtain a reversed copy of the fixture tools from a real end product parts. This will be particularly useful to give assistance to the maintenance worker, in the case when he does not have the original CAD file of the fixture tool.

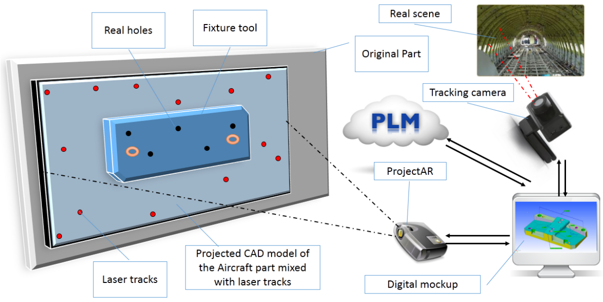

Figure 7: *Principle of AR solution 2*

In this case, the worker uses specific laser pointer to track the original position of the rivets (Figure 7). The AR system can reproduce the different position on the CAD file of the aircraft part, extracted from PLM and then presented it to the worker by means of the AR projector to make a hard copy of the fixture tool.

7. Conclusion

In this paper, a new hybrid framework combining PLM workflow and augmented reality technologies is presented with the aim to propose assistance to the manufacturing workers in their daily activities.

An interaction workflow is proposed in the framework with the aim to simplify CAD-AR transformation by allowing the extraction of the CAD model from PLM system to the augmented reality system. Interoperability mechanism is also developed to support the communication between PLM and Augmented Reality system.

The analysis of a real manufacturing case study from aeronautic domain pointed out several challenges that the proposed framework can give valuable contribution. Three principle of solution are proposed as a proof of concept for the Digital Factory Assistant.

After validating the advantages of the proposed functional architecture, future works will focus on the development of the different components and the implementation of the solution in real industrial case.

8. Acknowledgment

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