Augmented Reality integration in Product Development

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1 Introduction

To maintain a competitive edge in global market, manufacturing enterprises must leverage their digital information assets, which include a tremendous amount of engineering data: CAD models, FEM analysis, tolerances, annotations, etc. An emerging technology called Digital Master embeds all the engineering knowledge about a product into its CAD model. Tools and process to efficiently manage, distribute, and modify this information are essential. The digital master, which virtually eliminates the stacks of technical drawings, is not yet completely adopted in industrial practice, mainly because engineering software does not support at best all phases of the virtual product development process. At present time, PLM, PDM and EDM tools use standard desktop-based Graphical User Interfaces (GUI), which demonstrated the following limits: scarce usability for not CAD professionals, low cooperation level, limited management for different expertises and low integration between real and virtual models.

As far as regards usability, current GUIs in PLM are mainly based on part features tree view and spreadsheets operations. These GUIs may not be user friendly to navigate and perceive complex CAD models or to be used in manufacturing environments. Moreover desktop GUI does not facilitate team working, because of the physical barrier of the computer screens (called "immediate individual environment"). Effective tools should provide a better digital cooperative workspace similar to a meeting table and should improve communication among experts in different fields.

An additional drawback of current PLM software is the lack of a unique workspace where virtual models, technical drawings and physical products can coexist for discussion. This scenario is common in industry because a virtual shape (i.e. CAD model) often needs to be compared with physical mock-ups.

According to the authors’ vision, user interaction in product development process could tremendously benefit from Augmented Reality (AR) technology (Fig. 1).

Born in military and aerospace applications to augment information-dense environments with digital data, AR can provide an ideal solution for Digital Master exploration. In fact, Dunston demonstrated with engineering user tests, that the perception of 3D design can be improved using AR [1].

Moreover AR system can provide different levels of model perception according to the type of display and the viewpoint control. Lee categorized them in three main configurations [2]. In mobile configurations the viewpoint is coincident to the user’s eyes. This can be achieved by see-through displays or by using projectors (spatial augmented reality). The users are free to change their viewpoint while the digital content is overlaid onto the real scene. In fixed configurations, the real scene is acquired by a fixed camera positioned accurately to cover the entire workspace. The augmented scene is visualized on a display, usually a large screen, decoupled from the real world. The user is not compelled to wear or hold any

Fig. 1. AR visualization of a 3D CAD model with technical annotations on a paper drawing

Abstract

CAD data has grown in complexity while computer assisted tools must be improved in the following aspects: usability for non CAD experts, cooperation support, understanding of 3D geometries and integration between real and virtual models.

We present a novel scenario for product development integration based on Augmented Reality. The main advantage of our approach is to add contextual information directly on the real industrial product or even on technical drawings. The users can interact with digital information through the physical environment for direct product digital data navigation and visualization.

We validate the AR integrability in the product development process presenting some practical applications in critical phases as: (i) PLM data access, (ii) FEM simulation and visualization, (iii) collaborative review for design alternatives, (iv) quality inspection of manufactured geometries. We experienced significant improvement in the product development speed, increase in the collaboration potential and reduction of paper sheets in the product environment.
Several different industrial showcases of AR are reported in the ARVIKA project (www.arvika.de). They demonstrated that one of the most important aspect of AR is the possibility to use tangible interfaces. A Tangible User Interface (TUI), is a user interface in which a person interacts with digital information through the physical environment. TUIs have emerged as an alternative paradigm to the more conventional GUIs letting users manipulate objects in virtual space using real, thus “tangible”, objects [3]. The early developments of TUIs date back to the early 1980s, when Frazer explored different approaches to parallel physical and digital interactions with his 3D data input devices [4].

The ARIEL system [5] was one of the first examples in literature of TUI applied to technical augmented reality environments. ARIEL is based on a graphics tablet for capturing user gestures and on a projector to overlay 2D multimedia annotations onto real technical drawings. Their experiments proved the benefits of a tangible medium (i.e. the paper drawings) when augmented with digital content.

Terry et al. presented JUMP, a tangible interface for augmented paper-based architectural documents [6]. They presented a novel set of tangible tools for the navigation and interaction using 2D augmented technical drawings. In JUMP, filter tokens can be placed on the paper to modify the visualization of electrical, mechanical, and structural information. They developed also a physical rectangular selection tool by framing a portion of the drawing with physical brackets.

Some researchers have proved by user tests that gesturing, navigation, annotation and viewing are the four primary interactions with design artefacts in technical meeting [7]. According to their studies, the form of the design information (2D vs. 3D, digital vs. physical) has minimal impact on gesture interactions, although navigation varies significantly with different representations. They spotted bottlenecks in the collaborative design process when meeting participants attempted to navigate digital information, interact with wall displays, and access information individually and as a group.

However, most researches in literature are proof-of-concept prototypes which hardly progress beyond the lab-phase. For this reason, the attention of commercial PLM software producers is more and more focused on user-friendly interfaces in order to deal with the growing database complexity. Dassault Systemes, for example, in its latest commercial products, lets users intuitively browse, zoom, select and inspect the product definition dynamically using virtual 3DLive turntables. 3DLive turntable is an innovative interface, specifically developed for 3D model understanding and tangible rotation using a touch-screen Tangible interfaces are a novel approach to access product contents efficiently and user friendly. In our idea, the user can introduce a tangible element with a unique visual ID in the workspace (office desk, meeting table, production workbench, etc.). This visual ID can be a binary coded image, the marker, working as spatial reference for the AR visualization overlay. These markers can be printed or attached as stickers on paper, i.e., technical drawings. We decided to use these tangible interfaces, for three main reasons: (i) because drawings are currently used in any product development stage, (ii) because technical users are used to handle, store and sort sheets of paper (iii) because of simplicity and the low costs of implementation. We implemented such interfaces in our AR engineering framework [8].

## 2 AR in Product Development phases

The objective of our work is to highlight a set of general scenarios and specific test applications, exploiting augmented reality interfaces, in the context of product development. In particular, we expect AR to play a significant role in specific phases of the product development chain, namely:

- Design (review, evaluation, alternatives, etc.)
- Analysys (FEM, simulations, etc.)
- Manufacturing, assembly and quality control
- Maintenance
- Marketing etc.

![Fig. 2. A non-exhaustive scheme of the AR supported phases in Product Development](image)

The scheme in Fig. 2 represents a schematization of the phases in product development which can benefit from AR technologies and some specific applications. In section 3 we present and compare the most effective general AR scenarios in product development. In section 4 we describe some specific applications that we implemented to prove the effectiveness of AR integration.


3 Product Development Scenarios

Product development brings together a large number of activities and a single workspace does not satisfy all the user requirements. In this section we present a non-exhaustive list of possible scenarios based on tangible interfaces. For each scenario we outline the following aspects: hardware configuration, viewpoint type, TUI/GUI interaction level, application field, physical collaboration support and remote co-working capabilities.

3.1 Augmented User

The user wears see-through AR glasses connected to a wearable PC. See-through displays allow the user to be aware of the real industrial environment. This configuration allows maximum mobility for the user letting him/her work in a large workspace with free hands. EDM database is accessed via wireless network. The interaction is achieved mostly by TUI with none or limited GUI. Suggested applications for this setup are: inspection, training, etc. Disadvantages may include the display resolution, the limited field of view and the optical tracking robustness in hostile manufacturing environments (e.g. dust, electrical noises, bad lighting, etc.).

In another setup the user holds a handheld (flashlight-like) camera and a wearable PC connected to the network. The user is free to move in the industrial environment and to teleconference with other users remotely logged. The difference compared to previous setup is the viewpoint mobility. The user can move the camera in the industrial environment, reaching potentially every location under wireless coverage. Local tracking is provided by markers (in future may be RFID active markers) and broadcasted to the system. This scenario is particularly important in maintenance, where remote experts can guide and assist the user. The user loads his/her customized visualization of the model and broadcasts it remotely. The main advantage of this configuration is the maximum mobility for point of view. This may also lead to an unsteady point of view due to the fact that the user must hold the camera. TUI and GUI interaction is also rather limited.

3.2 Mobile Window

The user holds a tablet PC with a camera on the back side (Fig. 3). Tablet displays allow the user to be fully aware of the real industrial environment. This configuration allows a good mobility for the user letting him/her work in a large workspace but it requires that at least one hand holds the tablet. EDM database is accessed via wireless network. The interaction is achieved mostly by GUI with the tablet pen. Suggested applications for this setup are: design review, inspection, etc. Disadvantages may include the weight of the tablet and the single-handed interaction limitation.

3.3 Augmented Desktop

The user works on a desktop workstation with a camera pointing on a free area on the desk which will be the augmented workspace (Fig. 4). The AR workspace is limited to the user’s desktop and the model interaction is achieved by moving the TUI (augmented technical drawings) and by the traditional desktop GUI with a mouse and a keyboard. In normal use, the TUI is just a support to the ordinary GUI. For this reason, this scenario is suggested for all EDM tasks which involve an heavy use of keyboard entry of numerical or text data: e.g. detailed design, engineering, numerical analysis, etc. The main advantage of this setup is the similarity with the traditional working environment, allowing an easy access even for a non technical user. Users, in fact, find much easier and intuitive the navigation of 3D models using a tangible metaphor. A limiting factor is that it must be implemented in an office-like environment.

3.4 Augmented Workshop

This scenario is similar to the augmented desktop as regards the hardware setup, but it is designed for a production stage environment (Fig. 5) instead of a clean office desk. The user is on a workbench on the production line where no keyboard or mouse is present. The user can interact by touch screen on industrial monitor and by tangible augmented drawings. An industrial buttonbox can also be used. The main advantages are: both hands free for the user, possibility to display high resolution rendering of the 3D model and EDM data, comfortable working environment, similar to a non augmented one. Ideal applications may be quality check or guided assembly.
3.5 Augmented Collaborative Table

This scenario supports collaborative workspace at best. It consists of a meeting table with the function of shared augmented area and of a large screen. The screen can be vertical or horizontal and eventually have stereographic or holographic display. The configuration is depicted in Fig. 6. All users can access to the augmented shared area with their tokens and they can annotate the model using their own PC laptop for precise GUI input. Remotely located users can join the group and participate with virtual meeting tools. The system will take care of the synchronization of the digital master data including annotations, chat and history. The main applications of this scenario are marketing and design review: the shared workspace can contain virtual CAD models, real pre-production mock ups, on-line technical content and simulation results for collaborative discussion. The main advantages of this scenario are the high collaboration support, the coexistence of real and virtual products and the social contact of real meetings.

3.6 Augmented Presentation

This scenario considers a speaker who wants to present a solution to a large audience. A large screen is the main visualization device. The data management is achieved mainly by TUI in form of digital drawing or mock-up placed on the speaker’s stand (Fig. 7). The audience can access to the same digital data with personal visualization devices and can add annotations which are updated in real time for all the members of the discussion.
access to multimedia content and web 2.0 technology, and custom/role oriented interface.

Collaboration can be fostered by sharing the digital workspace using personal ATD or by sharing a common ATD. In the first case all the users of the team are able to see and annotate the Digital Master with their data in their personal AR environments. In the second case, exchanging ideas in a common physical workspace is promoted using face to face dialogue and supported by augmented visualization and annotations. The only ATD interface may not support at best all product development activities. A flexible combination of GUI/TUI benefits from the advantages of each approach. The user may exploit TUI for intuitive model navigation and GUI for precise control (i.e. through touchscreen, digital pen, mouse, keyboard). ATD can be used effectively in any scenarios presented in the previous section.

4.2 Real time tangible engineering simulation

We implemented and evaluated the idea of a “touch and see” real time FEM analysis [10]. The main goal was to allow the user to modify the simulation parameters via a tangible interface and immediately visualize the results overlaid on the real object. Augmented reality visualization techniques display the results as a video overlay “attached” to the real model which can be handled naturally by the user to explore the data.

In our implementation a specific module extracts the data from an engineering simulation software (COMSOL Multiphysics) and uploads them to the visualization system. The user can modify the simulation parameters via a tangible interface and instantly visualize the results overlaid on the real object. Augmented reality visualization techniques display the results as a video overlay “attached” to the real model which can be handled naturally by the user to explore the data.

We used this system in two different approaches. In the first we used marker tracking to change the boundary conditions (i.e. loads/constraints) in the FEM simulation. Once the tracking system detects a change in the position or ID (mapped to discrete values) of the marker, it updates the simulation. When the results are available they are visualized in the AR environment (Fig. 9).

In the second approach we use the video tracking to measure displacements in a cantilever.

The system detects, in real time, position and orientation of the two cantilever extremities and it updates the boundary condition in the FEM simulation (Fig. 10). This approach is known as “displacement control” instead of the previous “load control”. First tests demonstrated that single marker setups do not allow for sufficient precision and stability. We tested different marker configurations by changing number, border width and size. The best results were obtained using multimarkers (a set of three markers of different size which work as a single more precise marker).

The benchmarks demonstrated that, with a few hundreds nodes model, the application is ‘real time’ (simulation refresh rate > 6Hz; visualization refresh rate > 30Hz) and the user is not aware of the simulation latency. Due to the required precision and calibration, the best scenarios for this application are Augmented Desktop and Augmented Workshop.

4.3 Design alternatives evaluation

We tested an innovative AR based approach to the design review of a sail skiff within a university project [11].

In the final stages of construction of the sailboat the students faced many design problems. In particular, the rigging of the deck is a complex problem because it requires the integration of different components in 3D space. Traditional CAD systems do not support well this design phase considering the multiple variables and alternatives to be evaluated in teamwork.

Collaboration is crucial because new components must be evaluated at same time by designers, manufacturer, users, etc. Test alternatives directly on the real prototype resulted in an increase in costs and time. On the other hand, the pure virtual prototyping on a CAD system may not be efficient, if we cannot model all the components in the scene or their movement trajectories and functionalities. Therefore AR technologies allowed to test new alternatives with quickly designed parts on the real prototype in a collaborative environment. This is the key to a faster designing process while significantly improving the overall results.
Students of the design team virtually tested (Fig. 11) several designs configurations of the aluminium wing tubes, changing geometry, dimensions and base points, before choosing the optimal design. Sport sailors simulated the real sailing conditions and checked for collisions among the rigging hardware.

In Fig. 12 we tested the functionality of a virtual spinnaker throat with the real spinnaker pole sliding in and out. Also in this case we changed several shapes before finding the correct one (Fig. 13). We ran this application with Augmented User and Mobile Window setup.

4.4 Quality inspection

The sailing team faced also the problem of verifying the final hull geometry produced from wood panels. The design of the hull resulted from a numeric fluid dynamic optimization process and resulted in a complex double curvature shape. Hull check phase was even more complicated due to the fact that manufacturing process was executed by inexperienced groups of students.

We decided to study quantitatively the discrepancies between our designed CAD model and the realized prototype, focusing particularly on the shape of the hull being it critical to performance in water. The hull, however, being freeform, is not easily measurable requiring a very large number of measurements and a robust reference system. We reverse engineered the hull (Fig. 14) with photogrammetric techniques and obtained a tessellated model.

We compared the result with the digital reference model using a commercial geometry inspection software (Geomagic Qualify).
We export the report (Fig. 15) as a 3D model and registered it on the real prototype inside our AR environment (Fig. 16). The AR visualization allowed a collaborative review among all the team members: boat designers, manufacturers and teacher supervisors. As matter of fact, the deviations from the designed CAD model have been explained (due to added reinforcement) and considered for a revisioned version of the design.

![Fig. 15. Geomagic Quality report](image)

![Fig. 16. Geometry inspection report overlaid on real prototype](image)

We validate this innovative workflow in quality inspection and demonstrate its potential in the particular case using the Mobile Window and Augmented Presentation setup.

## 5 Conclusion

We expect Augmented Reality to play an increasing role in specific phases of the product development. In this work we present some industrial scenarios that can be effective in a next future. The main advantage of the proposed approach is to add contextual information directly on the real industrial product or even on technical drawings. The users can interact with digital information through the physical environment via tangible interface for direct data navigation and visualization.

We validate the AR integration in the product development process presenting some practical applications in critical phases as: (i) PLM data access, (ii) FEM simulation and visualization, (iii) collaborative review for design alternatives, (iv) quality inspection of manufactured geometries. We experienced significant improvement in the product development speed, increase in the collaboration potential and reduction of paper sheets in the product environment. Of course a lot of work is still to be done in order to improve the hardware and software technology. Hardware needs better and cheaper visualization devices (headmounted display or tablet pc). From software point of view there is no a common platform (like windows or linux operating system) and plug and play approach. Developing AR application still requires programming skills very hard to achieve for engineers. This makes difficult the development of application in design and manufacturing. As future work we would like to further study and understand the optimal interfaces to be used in each phase of product development process.

## References


