A NOVEL HYBRID 2D AND 3D AUGMENTED REALITY BASED METHOD FOR GEOMETRIC PRODUCT DEVELOPMENT

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ABSTRACT

A method that uses the interaction of two and three dimensional environments to carry out the geometric modeling and refinement steps of the product development process is presented. The 2D environment is an interactive computer screen, where the initial sketching of the product takes place. This environment provides a direct one-to-one interaction and the feeling of using traditional pen and paper. Next, a characteristic feature of the 2D sketch is selected to be exported to a 3D environment, where 3D vision and manual interaction over an immersive augmented reality environment is provided to carry out the refinement steps. The 3D environment provides fully 3D visual feedback and geometry manipulation interaction. In this way, the advantages of 2D and 3D environments are used for a smooth transition between the sketching and the modeling tasks at the early stages of the design process.

The goal of this ongoing work is solving some limitations of the 2D nature of sketching, the speed constrains imposed by the transition between a 2D sketch and its digital 3D model representation and the limitations of current CAD systems to easily modify freeform surfaces under form development.

Keywords: Geometric modelling, Augmented reality, 3D vision.

1 INTRODUCTION

Given the key role that digital systems have in modern manufacturing processes nowadays, the creative part of the design process usually goes through the following stages: Sketching > 3D Digital modelling > Aesthetic analysis >Engineering simulation > Manufacturing simulation, as shown in Figure 1. Traditionally, sketches made by pen and paper are the most used tool to start developing and then communicating new design ideas. But then, because modern manufacturing processes needs accurate digital data of the final geometry, at some point sketches must be transferred into fully 3d geometric data. In this way, sketches and direct 3d modelling are the most used techniques for designers and engineers to represent the initial design ideas.

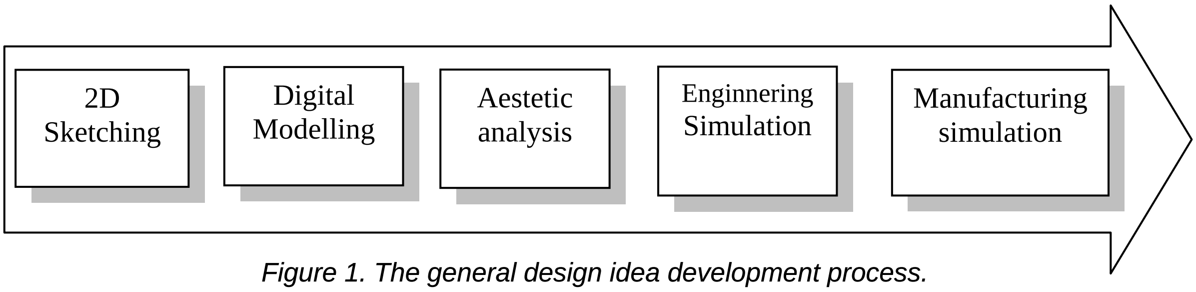

Figure 1. The general design idea development process.

Sketches are usually lines representing shapes (figure 2A), surfaces (figure 2B) or solid geometries (figure 2C) of undeveloped ideas of new products.

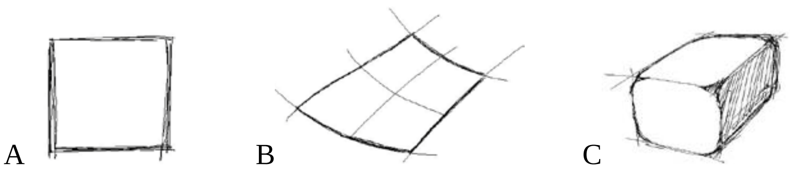

Figure 2. A Shape representation. B Surface representation. C Solid representation.

3D digital models are usually 3D surfaces (figure 3A) and digital 3D solid models (figure 3B). They are built at this early stage of the design process to start with a model that will become the input to modern manufacturing systems (whose first step is the Manufacturing Simulation, shown in Figure 1).

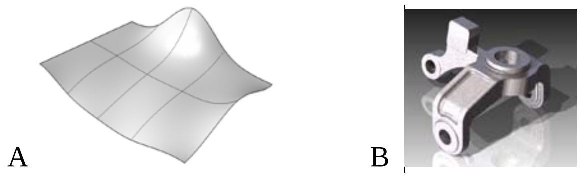

Figure 3. A digital 3D surface representation. B. A digital 3D solid model representation.

When moving from 2D sketching to 3D digital modelling two fundamental requirements should be met, namely: the transference of new ideas from the designer mind to the digital representation of them should be smooth and the data accuracy while moving through the different stages should be ensured, especially when transiting from 2D sketches to fully 3D digital modelling.

Meeting such requirements is still a challenge, mainly of interface nature. On one hand, current available tools to represent 3D objects rather hamper the smoothness of the product concept development: quick hand sketching is limited by its 2D nature, which has infinite 3D interpretations; 3D digital modelling is not only constrained by its updating speed (from sketches) but also by the functionalities of the software tools available, normally unable of accurately refine three dimensional free-form surfaces projected on a 2D screen. On the other hand, the transfer of the model data from one stage to another still lacks accuracy: in spite of many efforts in developing software tools for 3D interpretation of sketches [1], the transfer from 2D to 3D data still misses or misinterpret many features of the original design intent, whilst the transfer of free-form surfaces from sketches to the 3D digital representation is still a time consuming task that is mostly done by hand.

The main goal of this ongoing work is solving the above mentioned problems, namely: the multiple 3D interpretations of a 2D sketch, the speed constrains imposed by the transition between the 2D sketches and the three dimensional digital model representation and the limitations of current CAD systems to accurately refine three dimensional freeform surfaces projected on a two dimensional screen.

To date, the 3 difficulties just mentioned have been addressed by using immersive 3D sketching [2], 3D sketch interpretation and immersive 3D modelling [refs], respectively. 3D immersive sketching is a technique that allows sketching directly in a 3D space, by coordinating the 3D input and the user viewing. 3D sketch interpretation is the 3D geometrical and topological interpretation made from a two dimensional drawing [3], generally by applying 3D transformation concepts and machine learning techniques. Finally, immersive 3D modelling is a technique that allows drawing surfaces to build models directly in a 3D space.

To support immersive 3D sketching and modelling, Virtual Reality (VR) and Augmented Reality (AR) are, currently, the standard used technologies. According to the definition in [4], “VR is a computer-generated simulation of a three-dimensional environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors”. AR is the meeting point between the virtual and real world. To do so, 3D virtual objects are integrated into a 3D real environment –perceived by the user through 3D visualization technology like shutting glasses- in real time [5]. While in an immersive VR environment the user cannot see the real world around. In AR reality environments instead, the user can see the real and virtual world mixed together. AR has been used in applications in several fields like surgery [6], manufacturing simulation [7] and Education [8].

Currently, immersive 3D sketching has overcome the problem of synchronisation between the digital space, the real space and the user viewing. Thus, by using last-generation computers, it is possible to mix the real and virtual world smoothly and obtain an intuitive and direct 3D edition of virtual wire models by using 3D stereo viewing technology and fully 3D inputs [9]. Whilst in 2D digital sketching the input is commonly generated by using digital tablets, in immersive 3D sketching attempts a six-freedom-degree input is becoming a standard. However, because in 3D sketching the user has to deal with many parameters (depth, match of lines, etc) as well with ergonomic issues in the use of the 3D sketching device [ref], the time needed to build the 3D sketch is much longer than that required by 2D sketching. Additionally, no clear evidence of the benefit of 3D sketching in terms of creativity, aesthetics o overall quality compared with 2D sketches has been found [2]. It is worth mentioning that, in spite of these drawbacks, users recognise that both 2D and 3D sketching are relevant for early conceptual design and that 3D sketching improves the recognition of spatiality and spatial thinking [2]. Thus, further advances in 3D sketching could make this technology a promising alternative in the future.

Given the drawbacks of 3D sketching, traditional 2D sketching is still a widely spread activity for new product ideas development. Thus, efficient methods for correct interpretation of 2D sketches into 3D models are very much needed. 3D sketching interpretation is a very active area of research where the ultimate goal is automatic and correct transferring of 2D sketches to 3D models. However, despite many efforts in this direction, current techniques still have to overcome some key problems coming from the inherent ambiguity of handmade sketches [10, 11]: a single 2D projection, as a sketch, can be the result of many different 3D geometries, the hidden part of the sketch that only the human behind the pen has in mind can have different interpretations and even the designer sketching style can lead to different 3D models. The complexity of this problem has been addressed mainly by using machine learning techniques, like neural networks [1]. However, much research is still needed for a effective 3D sketching interpretation technique.

Immersive 3D modelling is defined as carrying out the modelling process directly in a real space supported by VR or AR technology [12], which provides a more natural and intuitive interaction between the designer and the modelling activity [13]. In this way, instead of creating 3D "lines" which define a wire 3D model, a surface or solid model parameters like curves for lofting or path direction are defined interactively by using 3D input devices.

Currently, applying the AR technology to CAD can be done by using Leonar3do, an AR kit that allows fully 3D interaction. Leonar3do uses a specially designed fully 3D airborne device called "bird" and stereo viewing (by using shutter glasses) to develop free-form 3D models. In order to have a better synchronization between the "bird" and the designer viewing, the system tracks the glasses position as well. Immersive 3D modelling is then performed by starting with a standard predefined geometry, like a cylinder or sphere, with a polygonal mesh representation. Successive refinements to the original 3D polygonal mesh are done by "touching" the 3D object with the airborne device. Although this technique allows easy 3D free-form refinement, building a 3D model from scratch is a real challenge mainly because of the high number of interactions required to get an approximate shape fitting the idea in mind (something more easily done by using a sketch as a starting point).

2 THE NEW APROACH

The method proposed in this work is a hybrid technique that combines the advantages of digital 2D sketching and immersive 3D modelling based on AR. The digital 2D sketching provides a quick and simple way of express the design idea, direct one to one interaction, and the traditional feeling of using pen and paper. Immersive augmented reality technology provides the fully 3D visual feedback and geometry manipulation interaction to carry out 3D refinements, in a real 3D space.

The method is performed in 5 steps, as shown in Figure 4. First, a 2D sketch made on an interactive computer screen is used as a starting point (Step 1). Second, by using the 2D sketch as a reference, an approximate 3D solid model is built (Step 2). Next, the 3D model is transferred into an immersive 3D AR environment for interactive 3D refinements (Step 3) and visual evaluation (Step 4). Finally, the model is transferred back into the 2D interactive environment (any standard CAD package) for further development (Step 5). This last step is required because the precision achieved with the airborne device is not as good as that obtained with the pen in digital tablets, which can be fed with precise numerical data. As 3D technology improves, the last step could be eliminated.

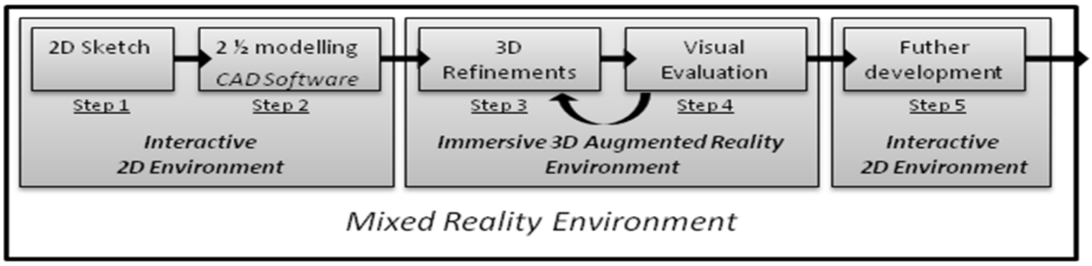

Figure 4. The proposed method.

3 THE FIRST IMPLEMENTATION

In order to test the proposed method the following standard equipment had been used:

Hardware	Software
- Desktop personal computer - Cintiq 21XU interactive computer screen (2D sketching) - Leonar3Do Virtual Reality Kit (3D interaction) - 120 Hz computer screen (3D viewing, included in Leonar3Do Kit)	- Rhinoceros 4.0 (2D interface) - LeoWorld 1.0 (3D interface)

The interactive screen was placed horizontally and the 3D screen vertically, as shown in figure 5A. The first sketch is carried out on the interactive screen (Figure 5B) and then placed as background in the perspective view of Rhinoceros 4.0 CAD package (figure 5C). This is the implementation of Step 1 of the method proposed in this work. The background figure is used as a guide to sketch a planar curve (figure 5D) that is then used as the starting point of the 3D model (figure 5E). This is the implementation of the second step of the method. Next, this first 3D model is transferred into Leonar3Do kit for surface refinements and visual evaluation, which are the third and fourth steps of the method (Figure 5F).

For this first implementation, the polygonal mesh is refined by using the standards tools available in LeoWorld like “smooth” which redefine the polygonal mesh to be smoother and a sculpting tool which pushes the polygonal mesh adding mode features.

Figure 6 shows the modelling process of a 3D free-form using the method proposed in this paper. The first input (figure 6A) is a sketch made directly on an interactive screen, by using a digital pen. Because the sketch has not yet been defined precisely, contain ambiguous information [L10] only well interpreted by the user. Next, by using the isometric view of commercial CAD software, like Rhinoceros, the sketch is placed on the background (figure 6B). In order to start modelling, using the sketch as image reference, the view is set to fit the sketch point of view. Later, using the sketch as reference, a NURBS curve is drawn directly on the interactive screen, using the sketch as reference (figure 6C). The closed curve is then used to model a base planar surface (figure 6D) and extruded to model the first solid representation (figure 6E). An approximate fillet is then made for 3D shape approximation (figure 6F). The resulting model is converted into a polygonal mesh (figure 6G) and transferred into the Leonar3Do system (figure 6H) , where the 3D free form refinements are carried out in order to get a shape closer to the design idea (figure 6I). The resulting model is then transferred back into Rhinoceros (figure 6J) to reconstruct the surface by using cross sections (figure 6K and 6L). The last step, at this stage, is necessary to keep the surface continuity.

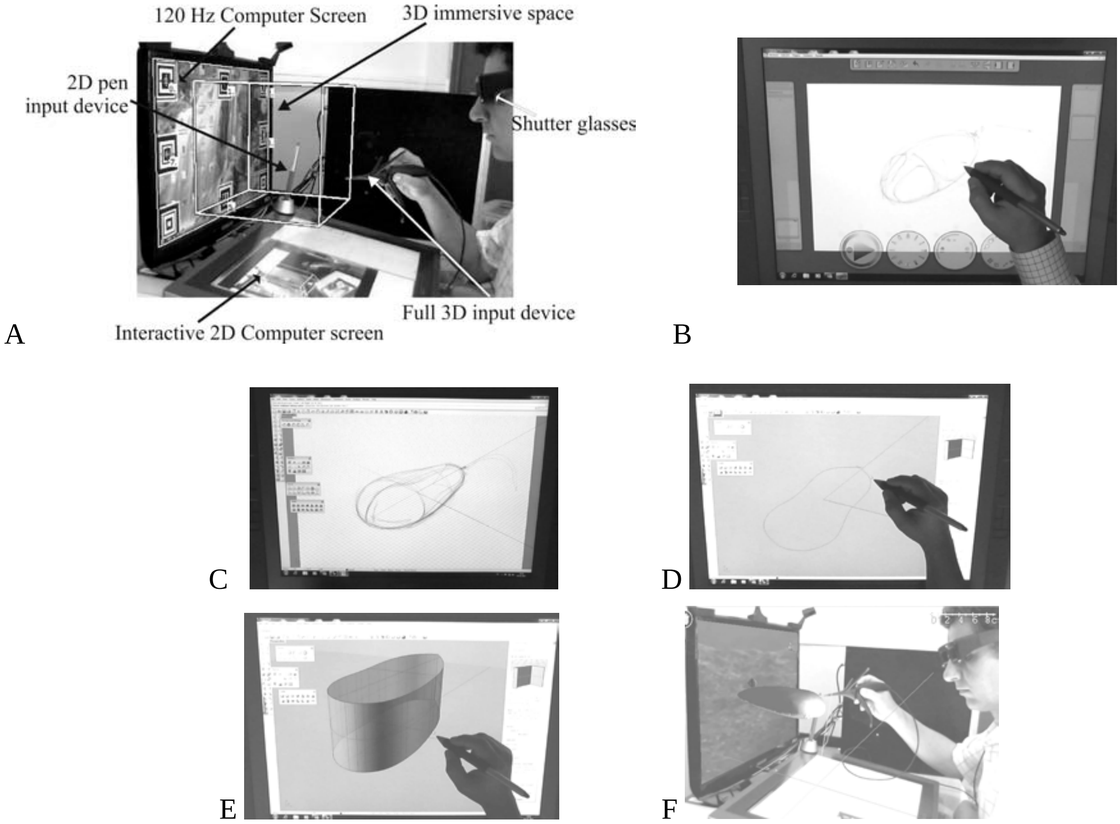

Figure 5.The first method implementation.

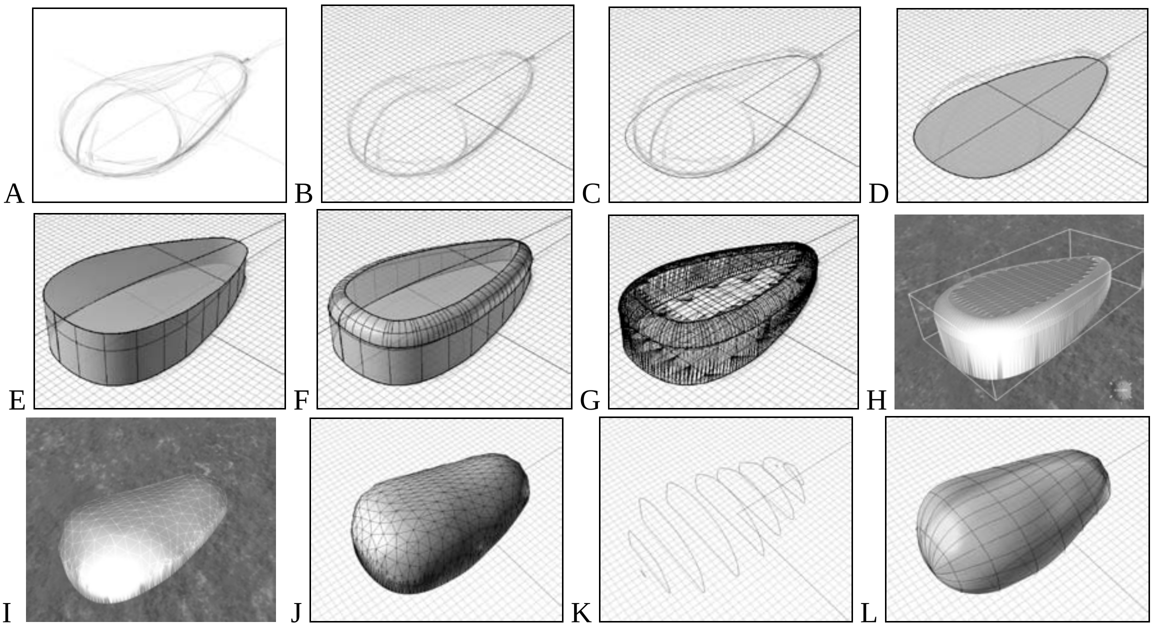

Figure 6. The modelling process of a 3D free-form model by using the proposed method.

4 SUMMARY AND CONCLUSIONS

In this paper a novel hybrid method that combines 2D and 3D technologies to perform 3D free-form modelling starting from a 2D sketch is proposed.

Because of the natural and intuitive interfaces used - interactive screen for 2D sketching and fully 3D immersive AR environment for 3D refinements- the method has been shown to be an appropriate tool to assist in the creative stages of the design process, allowing a smooth transition between the sketching and modelling tasks. The interactive screen has proven to be a very much suitable device to support the sketching activity, because of the direct one-to-one interaction and the feeling of using traditional pen and paper. The use of Leonar3Do VR kit has provided a very natural tool for free 3D manipulation. Actually, the ability of picking and moving geometries, with totally 3D freedom, gives the user the feeling of manipulating a real object.

At this first implementation stage, standard tools from LeoWorld software have been used, which is designed for working with polygonal meshes. However, a surface manipulation based on NURBS should give de method a more precise control over the surfaces under development.

The method is expected to be suitable for more advanced design stages like engineering design and analysis simulation as well, which is part of further research. Because of the 3D online viewing and manipulation tools, the user should be able to visually detect possible design weakness, carry out specific simulations and eventually correct the original design.

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REFERENCES

[1] Usman K. and Abdelaziz T. Freeform surface inference from sketches via neural networks, *Neurocomputing*, 71, 2008, pp. 3282-3294.

[2] Israel J.H., Wiese E., Mateescu M., Zöllner C. and Stark R. Investigating three-dimensional sketching for early conceptual design—Results from expert discussions and user studies. *Computers & Graphic*, 33, 2009, pp.462-473.

[3] Company P., Contero M., Varley P., Aleixos N. and Naya F. Computer-aided sketching as a tool to promote innovation in the new product development process. *Computers in Industry*, 60, 2009, pp.592-603.

[4] Oxford dictionary, www.oxforddictionaries.com.

[5] Azuma R.T. A Survey of Augmented Reality. *Teleoperators and Virtual Environments*, *6*(4), 1997, pp. 355-385.

[6] Fischer J., Eichler M., Bartz D. and StraXer W. A hybrid tracking method for surgical augmented reality. *Computers & Graphics*, 31, 2007, pp. 39-52.

[7] Dangelmaier W., Fischer M., Gausemeier J., Grafe M., Matysczok C. and Mueck B. Virtual and augmented reality support for discrete manufacturing system simulation. *Computers in Industry*, 56, 2005, pp. 371-383.

[8] Kaufmann H. and Schmalstieg D., Mathematics and geometry education with collaborative augmented reality, *Computers & Graphics*, 27, 2003, pp. 339.345.

[9] Bourdot P., Convard T., Picon F., Ammi M., Touraine D. and Vézien J. M. VR-CAD integration : Multimodal immersive interation and advanced haptic paradigms for implicit edition of CAD models. *Computer-Aided Design*, 42, 2010, pp. 445-465.

[10] Lim S. W. , Lee B. S., Duffy A. H. B., Incremental modelling of ambiguous geometric ideas (I-MAGI): representation and maintenance of vague geometry, *Artificial Intelligence in Engineering*, 15(2), 2001, pp. 93-108

[11] Olsen L., Samavati F. F. Sousa M. and Jorge J., Sketch-based modeling: A survey. *Computer & Graphics*, 33, 2009, pp. 85-103.

[12] Stark R., Israel J.H. and Wöhler T. Towards hybrid modelling environments-Merging desktop-CAD and virtual reality-technologies. *CIRP Annals – Manufacturing Technology*, 59, 2010, pp.179-182

[13] Ye J., Campbell R. I., Page T. and Badni K. S. An investigation into the implementation of virtual reality technologies in support of conceptual design. *Design Studies*, 27, 2006, pp.77-97.

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