TEZĂ DE DOCTORAT

Abstract

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Augmented Reality Applications for the Design and Manufacture of Products

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The subject of this PhD thesis has the purpose to evaluate the implications of Augmented Reality in product development. The thesis is structured in six research stages containing eight chapters, the present introduction chapter and other seven detailing the research.

In the introduction, an overview on Augmented Reality is presented. Starting from the definition of AR, a brief history of its evolution is recounted, starting from 1901 to the current date. A yearly analysis on the evolution of the number, type and domain of published scientific papers on AR from Thompson Reuters Web of science, SCOPUS and ANELIS databases is presented in this chapter. Also a popularity evolution for AR is conducted in this chapter using Google trends and Gartner's Hype Cycle on emerging technologies.

The second chapter of the thesis, makes a number of research contributions of the current state of the art in Augmented Reality application areas by examining the latest scientific papers and commercial applications. The researched AR application domains are: archeology, architecture, arts, commerce, constructions, education, everyday use, gaming, industry, medicine, military, office, sports and tourism.

In the third chapter an evaluation of the latest technologies available that are required to implement AR is presented. Starting with the AR display equipments, these are analyzed by their position related to the human body (head worn, hand held, spatially positioned) and by the display technology used (rendered over a live feed video, transparent optical technologies, projection technologies). Here, the latest products on the market are characterized. The next AR enabling technology analyzed in this chapter is used to track the real environment and the user's movements. Another technology required for AR implementation analyzed in this chapter provides the user interface and interaction method. Several solutions are evaluated including: 3D indicators and tangible user interfaces, haptic devices, gesture recognition, sight tracking, voice recognition and biometric devices. AR Software solutions without which AR cannot be applied are evaluated in this chapter. Being one of the most important AR enabling technologies almost all the solutions available on the market are evaluated and where possible tested. 13 software products are deeply analyzed and for 28 other a comparison table is created summarizing the main features. Additional AR requirements are analyzed such as networks, databases and intellectual content generation (3D models). After this evaluation the conclusions are stated emphasizing AR limitations in mobility, outdoor use, tracking/ tracing auto calibration, depth perception, user overload and overdependence and social acceptance.

The fourth chapter of the thesis, entitled "Augmented Reality Enabling Software and Hardware Test" is dedicated for software and hardware testing in order to be able to research

the implications of using Augmented Reality and which is the most intuitive way to interact with it. Different hardware and software equipments are tested. The first equipments tested are video capture devices. Five video capture equipment are tested and calibrated in order to obtain undistorted images for the AR implementation. The next technology tested is used for tracking the environment and the user's position in relation to the superimposed digital content. Four methods were tested in the laboratory: marker tracking, natural feature tracking, 3D feature tracking (markerless) and user movement tracking. The last method involved the use and programming of a Microsoft Kinect sensor. AR enabling software are the next technologies tested. Another key requirement for AR implementation, the content generation and synchronization software is tested. Here, three AR software are used to create AR applications depending of the complexity that is required. The last technology tested in this chapter, is used to visualize the AR content. For this, four equipments are used starting from a classic LCD monitor to Smart Glasses.

The fifth chapter of the thesis, entitled "Experimental Augmented Reality Applications Developed" presents the experimental AR applications developed. In this chapter ten AR applications, from which seven were also published in scientific papers are presented. All these applications are created to aid the product development process in various phases, from AR training applications (CAD, CAM, CNC training applications) to applications that can improve different industrial processes such as: AR implementation on a FESTO flexible manufacturing line, AR for cutting tools management, AR used for quality assurance, AR used to aid industrial robots programing, AR used for assembly operations, AR used to represent FEM and AR used for marketing. Each application created for this phase of the PhD thesis is based on the technologies tested in the previous chapter and analyzed in the third chapter.

The sixth chapter of the thesis, entitled "Augmented Reality" Collaborative Platform starts with an analysis on geographically dispersed teams and collaborative working environments presenting their advantages and disadvantages. Based on this analysis, an online collaborative platform for product development is created. This platform is composed from 12 steps designed to guide its users through all phases of a product's lifecycle, from analyzing the market's needs to recycle and improvement. Augmented Reality is applied in almost all the steps of the collaborative platform to improve the product development process.

The seventh chapter is dedicated to evaluate the experimental results of the AR applications by applying an online survey on the users which tested them. Also, inside this

chapter the collaborative platform's functionality is tested with a case study involving the development of a new gripper for an industrial robotic arm.

The last chapter of the thesis, presents the conclusions resulted from the personal contributions and future research directions.

Computer-aided technologies play a decisive role in shaping the environment in which we live and work. Because of this, new solutions must be found between human and machine interaction. A very important role in this context is augmented reality.

This thesis has investigated the application of Augmented Reality to improve the performance of the members from a product design team, in a geographically dispersed collaborative working environment.

In order to complete this research, an evaluation on all the AR required equipments available on the market have been conducted, from which the most suitable were further tested in practical experiments. The results of these experiments further determined the optimum parameters of these equipments to be used for AR implementation purposes. Also, these tests showed which are the most suitable technologies to be used for certain AR applications.

Using the tested and calibrated equipments, 10 AR applications were developed. These applications are designed to aid the product development process in different phases. The applications were tested by 76 users which provided feedback for further benchmarking. Among the results from the tested AR applications the most significant showed that, by using AR, the user's spatial vision is partially improved, making it possible to visualize a 3D model from reading a 2D technical drawing. It can be confirmed that this technology facilitates the 3D modelling techniques at an entry level stage. Also, it has been determined that augmented reality can be used to facilitate the CNC machining process, providing the instructions for choosing the right order for the machining operations.

The conclusion that can be drawn from these benchmark tests is that AR has the potential to replace current training tools such as printed instructions and with minimum modifications, these applications can and will be used to provide training services in other fields than CAD/CAM. These applications can easily provide maintenance, assembly instructions or machining instructions in an industrial environment. From the AR applications it has been determined that augmented reality can be implemented in both QA and QC activities providing great benefits and lower costs in any scenario where the process offers distinctive recognizable landmarks.

In order to test the AR implications on a collaborative environment a collaborative platform for product development was created. AR was applied on most of the stages from a product's lifecycle to aid the product's development process. This platform was tested using a case study involving the development of a new gripper for an industrial robotic arm.

AR can have vast industrial applications and based on the experience that have been gained, when applying AR, it can be confirmed that this technology facilitates product development, even though it is still in a conceptual stage. Using AR, production times and costs can be lowered and at the same time with an improved quality.

What follows is a list of the contributions made in this thesis:

Theoretical contributions:

- A state of the art on AR's chronological evolution since 1957 to the present date. This state of the art also involves an analysis on the evolution of the number, type and domain of published scientific papers on AR from scientific databases from 1991 to the present date.
- An analysis on the evolution of AR's popularity using Google Trends and Gartner's Hype Cycle for Emerging Technologies
- A study on existing AR applications in different domains:
    - A study on AR applied in archeology
    - A study on AR applied in architecture
    - A study on AR applied for arts
    - A study on AR applied for commerce and marketing
    - A study on AR applied in constructions
    - A study on AR used in education
    - A study on everyday AR use
    - A study on AR used in gaming industry
    - A study on AR used for industrial purposes
    - A study on AR used for medical purposes
    - A study on AR military applications
    - A study on AR used in sports and entertainment
    - A study on AR used for tourism
- An evaluation on the technologies, available on the market, which are required to implement AR:

    - Display equipment
    - Environment tracing and tracking sensors
    - User interface and interaction
    - AR Software
- A study on present AR limitations

Practical contributions

- AR equipment requirements tests
    - Video capture equipment tests and calibration
    - Tracking, detection and interaction equipment tests
    - AR software tests
    - Display equipment tests
- Created AR applications to aid the product's development
    - AR CAD training application
    - AR CAM training application
    - AR aided CNC training application
    - AR applied on a FESTO flexible manufacturing line
    - AR trailer assembly application
    - AR used for quality assurance
    - AR used for industrial robots programing
    - AR used for finite element analysis
    - AR used for marketing
- Evaluated the AR applications by surveying 76 users
- Realized an AR aided product development collaborative platform
- Evaluated the collaborative platform with a case study