Virtual and Mixed Reality Interfaces for e-Training: Examples of Applications in Light Aircraft Maintenance

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Abstract. There is evidence that recent developments in Augmented Reality (AR) technology has the potential to be applied as pervasive media on multiple devices in different ways and contexts, especially with low-cost devices including Mobile Augmented Reality (MAR) applications on smart phones or Pocket-PCs. In this paper we present a framework in order to combine the pervasive e-education concept with augmented reality content for e-training. We analyze current research, discuss some examples from ultralight / light sport aircraft maintenance and show how to apply this framework generically. We present a learning engine to deliver this special type of content and provide a further outlook of future research. A user-centered approach must ensure that the developments can stimulate motivation and enhance performance of the end users in different training sessions. The main benefit is, that the end users are enabled to better perceive complex, technical facts, systems and components.

Keywords: e-training, augmented reality, pervasive e-education, performance support, human computer interaction, usability engineering

1 Introduction and Motivation

Recent developments [1-7] have shown that Augmented Reality (AR) technology has the potential to be applied as a pervasive medium on a variety of platforms in different ways, ranging from Head Mounted Displays (HMDs) to hand-held Mobile Augmented Reality (MAR) applications on smart phones or Pocket-PCs [2],[3],[4], [5],[7]. AR, which links real and virtual worlds, opens new paradigms for interacting with computers and enables new ways of experiencing learning [1],[6] These new paradigms emerged – on the one hand – from the need of modern businesses for implementing a process of continuous innovation, permanent construction of knowledge and transfer of knowledge to their workers [8]. On the other hand, companies are more and more forced to offer context-based, time-of-need-based learning and performance support tools to support their workers and customers in fulfilling their job duties [9].

In the specific context of an aviation application scenario, it is interesting to note that not only pilots but also aviation maintenance personnel is a highly mobile international end-user group. While performing operational and maintenance tasks on the flight line or at different maintenance facilities, directly on the airplane or in the workshop, these people need the possibility to work independent of location, while still following the rigid instructions for continuing airworthiness.

This paper explores educational uses of Virtual Reality (VR) and AR technology especially for application workflows in training and maintenance of ultralight / light sport aviation. It describes the status of an ongoing project, highlighting the initial studies and the proposed outline of the system to be developed. State-of-the-art research was analyzed, with focus on the technical challenges, recent developments, new interaction and interface opportunities and a description of possibilities to provide virtual multimedia content for learning with electronic means for aircraft maintenance.

Given the necessary technology, psychological research becomes both possible and essential in order to provide a user-centered development and to ensure the best possible assistance for the end-users. Results must always be incorporated at systemic level, which in this context includes – for example – the consideration that the proper combination of learning content and learning context is of critical importance. Learning content must be developed in such a manner that meaningful and sustainable learning effects with the learners can be created [10]. At this point, it should be noted that there are also research results indicating that there is no influence of media on learning results [11]. However, Driscoll and Carliner [12] argue that well designed learning content can engage learners by making them active participants in real-world problem-solving, thus creating meaningful and sustainable learning experiences. We suppose that this is especially true for VR and AR applications, because of their use of immediate interactive engagement.

Practical examples will demonstrate the learning benefit in aircraft operation, maintenance and installation. Visualization, animation and simulation content applied in VR and AR open a wide range of possible application scenarios and can change static content into dynamic virtual multimedia content [13]. These are composed of 3D objects, images, illustrations, text, sound, 3D avatars and videos.

1.1 The Specific Case of Aircraft Maintenance

Several research studies in this field fail to combine knowledge from x-learning [5] with AR/VR technologies and their effect on how these can improve the way we interact with learning material. We strive for overcoming this deficiency. For example, in combining the Magic Book concept [6] and the magnifying glass approach [16], we demonstrate within a prototype scenario the way in which our perception of and interaction with content in standard training literature could alter so as to create meaningful and sustainable learning experiences and job aids supporting pilots, maintenance technician and employees' tasks.

Sometimes small problems occur during the maintenance process, which the maintenance technician would be able to solve with the relevant on the job support having access to Learning on Demand (LoD) instructions and to trouble shooting or diagnosis references on his current available device (just-in-time learning). In such performance support cases, we need to consider models that detail the person / time / place / context / device / medium in the relevant setting [19] and thereby provide a form of quasi-intelligent assistance. This concept is based on the assumption that jobs are conglomerates of little tasks [20] with each task being now supported by a job aid in the form of a LoD sequence.

Furthermore, it is also of importance for aviation maintenance engineers to participate in continuous training and mandatory recurrent training sessions. Consequently, this research will also provide examples of important learning support to supplement traditional face-to-face (F2F) and hands-on/on the job training such as carrying your virtual instruction with you on your laptop/smartphone and showing the procedures to be performed in a multimedia augmented environment.

2 Background and Related Work

Our work on AR/VR based e-training in aviation is built on related work in (handheld) AR/VR, pervasive e-education and the combination of both. In this section we briefly review and highlight past work in these areas.

There are already applications of AR for training and education in mathematical content [21], biology, mechatronics, engineering education [20] and aeronautical engineering [3]. Further on some examples show the application of Mixed Reality (MR) for museums [23], [1], [24] and military use [25]. Another growing field of applications can be found in edutainment [26] and gaming [27].

In the past years, a trend has been observed, bringing AR into mass market using handheld devices (mobile phones) [7] and more integrated head-worn displays (HMDs) [28]. Authoring toolkits for AR-applications have matured in their usability and are close to become easier in handling of their User Interface (UI) e.g. similar to the authoring of text or illustration in technical communication. In our experiments and research, we currently use the AMIRE toolkit [29] to perform the various test settings on a laptop. AMIRE already was tested successful in an industrial scenario in an oil refinery [30]. The extension has been developed AMIRE-ES [2] for use with mobile devices. A similar AR programming and authoring platform is "Studierstube" [31]. It presents a framework for the development of mobile, collaborative and ubiquitous AR applications. Another practicable solution for AR on low-end handheld devices in a markerless environment is presented and a topic for research within the ULTRA-Project [32].

Adobe Acrobat 3D provides the possibility to create PDF-documents with embedded 3D models and animations. With the freely available current version of Adobe Reader even quite complex 3D models can be viewed and manipulated on a standard PC.
Pervasive E-Education [14],[15],[16] has potential to be applied for Technical Training in corporate environments in different business domains when presented as a concept to assist teaching and learning for Life Long Learning (LLL) and Continuing Engineering Education (CEE). However, so far nobody explored to combine the concept of pervasive e-education and the integration of AR and 3D learning content in different settings. Our work addresses this gap.

3 Issues in Ultralight/Light Sport Aviation Training

Based on the above framework, our goal is to set up training scenarios for an international target group in ultralight / light sport aviation (LSA), which ranges from an aircraft operator (pilot) to the aircraft maintenance technician, who performs maintenance direct on the airplane or repair in his workshop. According to their specific requirements they have different tasks, technical documentation and instructions for continued airworthiness they need to be trained on. An aircraft operator (pilot) needs to be trained on how an aircraft is operated correctly, e.g. how to start the engine and which limits not to exceed. The aircraft maintenance technician (AMT, A&P) needs more to know when, where and how to perform maintenance checks, e.g. to inspect the spark plug condition and gap on a piston aircraft engine. An AMT in the workshop has to have specific training on e.g. how to repair a component like a gearbox. Also in case of problems the aircraft operator (pilot) and/or the AMT also may need to get support to perform troubleshooting, e.g. where to start with search for cause of failures.
Currently all this training is mainly done in a traditional classroom setting for getting the theoretical background. The practical training part is mainly performed as a hands-on training in the workshop direct on the aircraft or aircraft engine. During this time, the highly qualified person is away from the workplace or has to travel to a certain place in the world to get this specialised training. Therefore, it is obvious that training can benefit from AR/VR based e-training in various ways as the pilot or technician can access training resources via the world-wide-web from everywhere. For the practical training aircraft parts and aircraft systems can already be viewed in advance in a virtual world on the workplace or supporting information can be given by AR technology in standard training material/ technical documentation or direct on the real (training) object in a concurrent way. But in order to gain a wide accepted basis for such a framework social, technological as well as psychological aspects have to be considered and the stakeholder requirements need to be carefully analysed.

4 System Architecture and Implementation

In this section we describe the components of our system, which is under way. Most of the components are in the process of implementation.

4.1 The Learning Engine

Learning Management Systems (LMS) or course / content management systems (CMS) are quite common in e-learning environments providing content. For a virtual training centre an LMS can integrate administrative, curricular, communicative and social infrastructure. This central platform can provide various kinds of content ranging from text-based up to high-tech interactive, multimedia and 3D. As a structured repository the system provides capacity to administrate AR content for download to the different end-devices. The Open Source CMS "Moodle" [33] is very popular and used over a wide range. It offers a variety of UI languages for an international community of training participants. We have chosen Moodle as our prototype-platform because it shows to be quite flexible and a good choice for a first research prototype of learning engine. The central learning engine will administrate, store and provide the relevant training content available as text, multimedia, 3D or AR presentation. The user can access the virtual training center (learning engine) from different end-devices like laptop, MDA by being connected via LAN, WLAN, 3G/UMTS or HSDPA to the internet and access if authorized the different learning and performance support material right at the time when needed. The overall architecture can be seen in figure 1.

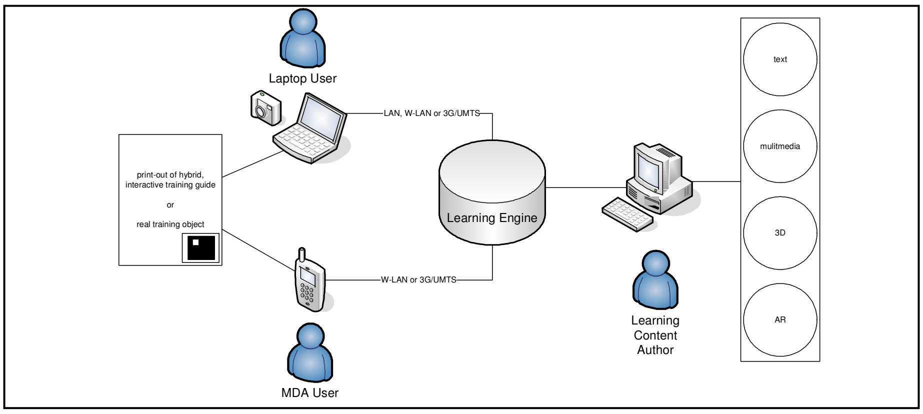

Fig. 1. The architecture of our learning environment

4.2 Content Typology

In the content authoring process content can be added for each type of training along the Reality-Virtuality Training Continuum [34] (figure 2) based on the original mixed reality continuum [35]. Thus, we can establish what we call a content typology. In figure 2 we show that starting from the left in reality in the classroom the technician gets normally theoretical instructions and training directly on the object like in our example on the aircraft engine. This process is assisted by training aids like cut-away parts, single parts or by training manuals showing technical drawings and illustrations. Further from the left to the right the augmentation increases until a user gets a virtual aircraft engine designed in 3D by CAD specialists presented. Between these 2 worlds, different levels and kinds of augmentation by e.g. video, text, 3D objects, sound can assist the AR user.

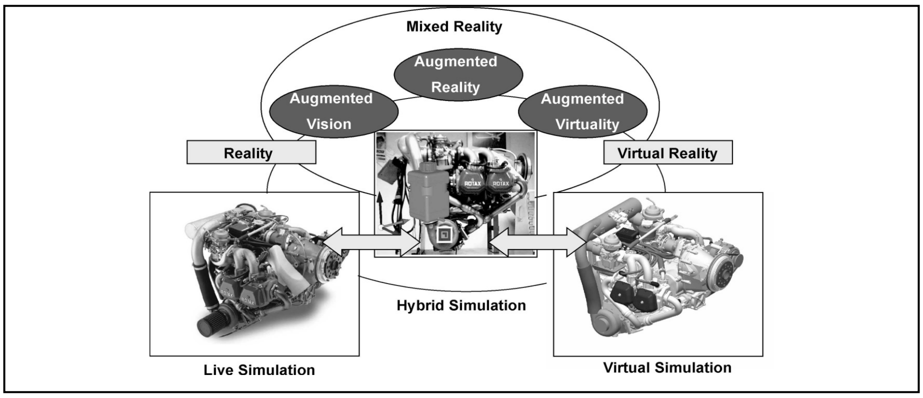

Fig. 2. Reality-Virtuality Training Continuum demonstrated in our specific application on an aircraft engine. Left: real aircraft engine. Middle: real aircraft engine blended with a virtual element of an overflow bottle (cooling system). Right: virtual engine as designed in 3D.

4.2.1 Standard Training Manuals

These training manuals are edited in a standard desktop publishing process together with Subject Matter Experts (SMEs) or as an extract from the technical documentation. These are provided in hardcopy or distributed electronically in a PDF.

4.2.2 3D Knowledge Objects (3KO)

As per definition of NGRAIN Corporation [34] Knowledge Objects and 3D Knowledge Objects (3KO) are defined as self-contained, reusable chunks of data. The extension to 3D Knowledge Objects (3KO) means that they contain a 3D simulation of a piece of equipment. The concept of 3KOs combined with recently available Acrobat 3D forms a quite immersive and interactive way to reuse for e-training 3D data of the Digital Product (e.g. modelled and available form Pro Engineer (Pro/E)) created in the Digital Engineering Process. A 3D enriched PDF file allows to interact with the 3D models with a standard mouse and offers different functionalities like rotate, pan, zoom, spin, set different lighting, play animation and much more.

4.2.3 Augmented Reality Knowledge Objects (ARKO)

Extending the definition of Knowledge Objects for Augmented Reality (ARKO) means, that they include the methods for use in an AR environment. Digital Parts (imported e.g. from Pro/E into blender for conversion or animation and then authored in AMIRE) are reused, but this time blending virtuality and the real world. The user can interact with the virtual object e.g. using a web-camera or MDA (figure 4) as a tangible interface. In moving the interface or the print-out of the hybrid, interactive training guide or the physical training object (in our case tracked by a marker card) a new way of learning is possible. Depending on the choice of user and the availability of the different media and tools learning in different ways is possible (figure 3).

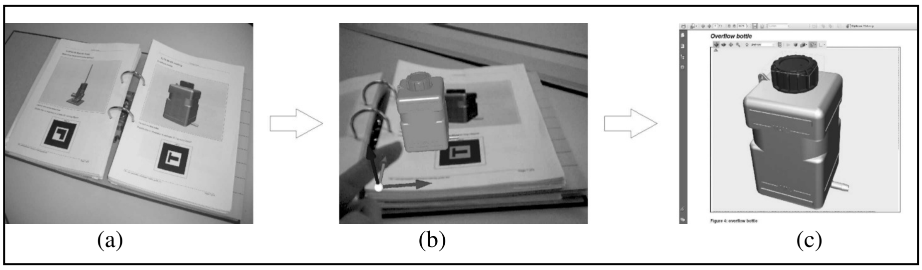

Fig. 3. Reality-Virtuality Continuum for a hybrid, interactive training guide: (a) the traditional paper-based material; (b) AR view into the training guide; (c) interact with 3D training content.

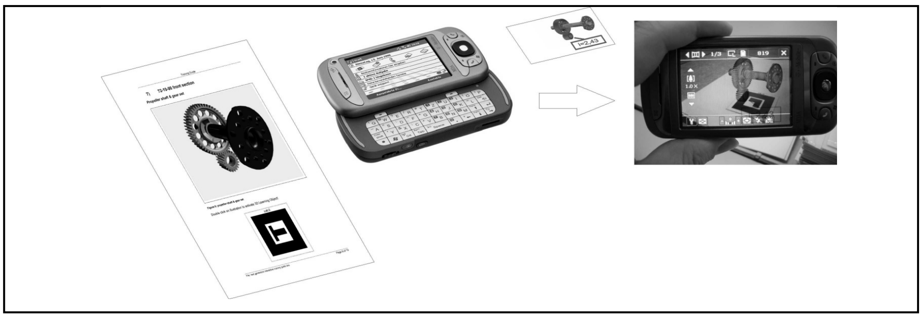

Fig. 4. Augmented Reality view on a MDA prototyped by through a Hybrid Mock-up (real MDA with transparent slide (paper) mock-up of 3D model)

4.3 Hardware/Software

For the technological experiments following hardware and software was chosen and showed to be technically sufficient:
a) Hardware:

A standard laptop (with internet access) resolution ranging from 800 x 600 px to 2048 x 1536 px with external 1.3 Megapixel Web Camera and a MDA Vario II with Windows Mobile 5, Quadband, HSDPA, WLAN and USB, TFT screen with a resolution of 240 x 320 px, internal 2 Megapixel digital camera.
b) Software:
We selected the following Open Source software packages: Moodle Server (CMS), MySQL (database), PHP (scripting language), PYHTON (dynamic object-oriented programming language), Blender (software for 3D modeling, animation, rendering etc.), Blender Pocket (port of Blender for Pocket PC), AMIRE (framework for Authoring MR under LGPL), Open Office (multiplatform and multilingual office suite), Mozilla Firefox (web-browser). Additionally, the following commercial software was used: ProEngineer (parametric feature-based 3D Solid modelling CAD software), Adobe Acrobat 3D (assembling 3D training guide PDF and convert PRO/E files), Acrobat Reader 8.0 (PDF reader), ClearVue PDF (mobile PDF reader), Remote Display Control (in order to access the MDA), Microsoft Active Sync (in order to synchronize PDA with PC), Microsoft Internet Explorer Mobile.

4.4 User Interaction Combining Learning Engine with Learning Content

The user accesses the portal by opening a web browser and typing the URL of the virtual training centre. Depending on his access rights the focus either stays in the public area or enters the secured training area. On the platform there is a possibility to choose between the different content e.g. opening the PDF file on the screen or printing it. Using the PDF file allows to open the 3D data of a digital product/part. For use on a PDA, this data must be split into an adopted PDF content and into a separate 3D content, as PDF viewer on Windows Mobile does not offer yet 3D viewing capability. In the current implementation, the AR content must be downloaded locally to the laptop or the MDA and be opened there with an appropriate AR viewer. As easy authoring/prototyping for handheld AR content we have set up a rapid prototyping method to be able to get a look and feel for handheld AR in using transparent slide mock-ups.

5 Conclusion and Future Work

In this paper, we showed that combining the x-learning concept with AR and VR has potential for future pervasive e-training in aircraft operation and maintenance as compared to the traditional mainly paper-based F2F-training methods. Research allows us to presume that this approach is the first example of this concept and technology with the target audience in aviation. The respective target groups are provided with different types of information access and content and may choose between various types of content representation. While reading PDF files or print-out material, our mobile approach enriches the traditional way of training through the embedded VR content, which allows information to be viewed in 3D. AR allows the 3D training material to be examined at the workplace; a workbench in the workshop or the use of a training device in a real environment subject to the weather. However, much further research is necessary in order to bridge the gap between the potential benefits of these new technologies and the usability of these systems. We will concentrate on developing interfaces based on user centered design principles, particularly in the area of authoring tools.
Further experiments will be based on our first findings and will encompass different AR devices including lightweight HMDs and Ultra-Mobile-PCs (UMPCs). Augmented Reality 2.0 aims at enabling people to work together in order to create and share AR content online and distribute it for AR applications. Another possibility is the collaboration with AR avatar on the chair next to them in order to improve their learning performance. For this purpose the AR based learning paradigm must be evaluated against learning from print based material and classic desktop VR based content.

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