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Using Augmented Reality and Computer-Generated Three-Dimensional Models to Improve Training and Technical Tasks in Aviation

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USING AUGMENTED REALITY AND COMPUTER-GENERATED THREE-DIMENSIONAL MODELS TO IMPROVE TRAINING AND TECHNICAL TASKS IN AVIATION

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Augmented Reality (AR) technology has considerably improved since its inception, and especially over the last few years, to the point of becoming a relatively reliable and potentially cost-effective tool in many fields. Significant advances have been made by software developers to improve the quality of AR tools and the hardware necessary to access these tools has become common. However, AR is mostly unknown or underused in the aviation industry, either in education and training or in professional environments. This paper aims to demonstrate the potential of AR for training and professional technical applications in aviation, especially when combined with 3D model visualization tools. The current state of AR is discussed, and a technical project showcasing AR is used as a demonstration.

Augmented Reality (AR) is defined as the technology that overlays computer-generated data on top of a real image or view through a digital piece of hardware (MacMillan Dictionary). The type of data displayed can vary from simple text lines to videos and even interactive 3D models. In order to access and visualize the AR content, the hardware required consists of a camera, a display and a data processing unit equipped with the proper software to achieve the task [5]. This equipment is currently integrated – albeit at different quality and performance levels – in personal computers, cell phones, tablets and certain head-mounted devices (HMD) among others. Augmented reality has been used – or at least experimented with – in many domains, such as marketing, entertainment, as well as in medical and technical fields (Hincapie, 2011).

Currently in the aviation industry, data related to performing training or field technical operations is delivered primarily in one of two ways: through paper-based instructions and manuals or in digital format. The digital data is either similar in content and format to the paper-based instructions or may contain enhanced visuals and some level of interactivity. Each of these methods of data delivery has advantages, but also severe drawbacks, which lead to technical documentation being considered the primary human factors challenge in aviation maintenance (FAA, 2012). In fact, 45 to 60% of safety incidents were procedure related or involved technical documentation. Thus, there is a clear need for the implementation of new ways to deliver information to technicians for training and in the field that will facilitate retention of knowledge and execution of the tasks while decreasing errors and thereby diminishing safety hazards for the worker and ultimately the users of the aircrafts.

This paper will demonstrate that applying augmented reality to the delivery of technical information can procure benefits unattainable with classic methods, while solving many of the issues associated with the latter.

The paper is organized as follows. An overview of the current data delivery methods is given, as well as a presentation of the current state of augmented reality technology. Section 4 details the developmental steps for AR-enhanced data delivery and demonstrates the potential use of augmented reality in aviation. The subsequent sections of the paper analyze the benefits and drawbacks of augmented reality as applied to technical tasks in aviation.

Background

Current Education, Manufacturing and Maintenance in Aviation

Over the past few decades, the volume of air travel has considerably increased and aircrafts have become increasingly modern, complex and inclusive of numerous and diverse auxiliary systems. Thus, the concepts and processes associated with manufacturing, maintenance and training – of aviation professionals – have also significantly increased in breadth and complexity. In turn, this has led to a large volume of reference material being necessary to perform tasks in the aforementioned fields. As highlighted in previous publications (Nee, 2012), manufacturing for instance has become much more complex and demanding and in virtually all cases requires exchange of information in real time between different units of production.

Traditional methods of information delivery and exchange – specifically standard printed or digital texts and manuals – are still very widely used in industry, and although they are cost-effective and well implanted throughout the industry, they have several disadvantages when considered in the modern aviation world. Indeed, if one considers the recurring need to update information (through Advisory Circulars, Airworthiness Directives or manufacturer publications), it is clear that traditional methods -consisting of end-user additions to publications for instance – incur undeniable inefficiencies and thus potential safety risks.

Also, workers in the field that use traditional methods of information delivery typically experience many issues when performing given tasks. Indeed, instructions are usually detached from the equipment that the technicians are performing work upon, which leads to the need to constantly switch focus between their instructions and work platform (Ong, 2008). This causes a – sometimes high – loss of time and productivity, as well as a higher potential for errors and injuries or damage.

In addition, as the authors describe in *An Introduction to Augmented Reality with Applications in Aeronautical Maintenance* (Hincapie, 2011), the information in traditional methods can be challenging to locate and extract. Indeed, workers and students – especially if inexperienced - can be led to frustration, poor performance and potentially costly mistakes when trying to find information in traditional texts and manuals.

The issues outlined here are even more critical when paired with the high volume of work and time pressure that the aviation industry imposes on its workers. Thus, with the advent of modern technologies, it is imperative to search for new methods that would solve some or all of these concerns and concurrently have relatively low costs of implementation (economic, human and technological). In this paper, augmented reality is evaluated as a potential new method of information delivery that could supplement the current infrastructure while solving the problems discussed above.

Augmented Reality

Definition. Augmented Reality (AR) consists of the display of information (text, images, videos, interactive content) that augments a scene that is actively captured by a camera (De Crescenzio, 2011). Thus, the three basic components needed to display AR content are a camera, a memory/processing unit and a display surface. Nowadays, these are found in a plethora of portable devices (smartphones, tablets, etc.) and even on wearable technology (glasses, head mounted displays -HMDs). However, it is important to note that the quality and quantity of the data overlaid is very dependent on that of the hardware and software contained in the unit used to display.

Technological Advance. Augmented Reality has been the subject of much research and development over the past decade. This has led to the technology being tested and used in many sectors. As Ong and Nee illustrate (Nee, 2012 & Ong, 2008), AR is being widely used in marketing and advertisement, and has been successfully demonstrated and used in medical, military, entertainment, maintenance and manufacturing fields.

In addition, hardware and software tools that can display AR content continuously gain in computing power and camera and display quality while maintaining or even reducing their size. Indeed, Hincapie and his co-authors observe that modern smartphones for instance boast state of the art sensors (compass, gyroscopes, GPS sensors) which could easily be used to provide higher quality AR content (Hincapie, 2011).

Issues with Augmented Reality. Traditionally, one of the biggest issues with Augmented Reality has been the size and weight of the hardware needed (Hincapie, 2011). Indeed, head-mounted displays for instance can be relatively uncomfortable to wear, especially for extended time periods. They typically lead to fatigue and limited range of movement, which in turn can cause errors and safety issues. However, there are multiple options to compute and display AR content, and considering technological advances, it is possible to find or design ideal platforms for the aviation industry.

Another concern related to AR is that computing power is still limited (especially for the display of complex 3D models) (Hincapie, 2011). Along the same line, considering that the AR data is usually stored on servers and accessed (usually wirelessly) through networks by the end-users, there is the issue that real-time data access, tracking and computation for correct display can be hampered by slow or faulty connections. These are valid concerns, which need to be considered and addressed by implementing the proper network infrastructure and choosing the adequate hardware for any given application.

Potential of Augmented Reality in Aviation Manufacturing, Maintenance and Education

Research, Experiments and Trials. There have been many research projects involving AR in manufacturing, maintenance and education. Many of these have focused on comparing augmented-reality methods of information delivery to currently common ones such as text, images and video.

Regarding educational applications, one such project conducted by Ong, Yuan and Nee, has demonstrated that AR is more effective than other forms of instructions, as it reduces errors and makes tasks easier (Ong, 2008). Another study by Macchiarella and Vicenzi (Macchiarella, 2004), which was designed to compare AR to video and text-based learning methods, compared short-term and long-term recollection of a topic in an aviation setting. The results obtained showed that AR produced significantly better long-term retention of information and thus was a better learning platform.

Industry applications for AR have also been tested by researchers. In *Augmented Reality for Aircraft Maintenance Training and Operations Support* for instance, the development process for an AR project is highlighted as well as the need to analyze the risks associated with each technical step in order to mitigate them using augmented reality. A case study by the authors validated this with subjects that properly followed the given procedures (in this case for an oil check) and did not commit errors or perform unneeded operations. Another experiment also tested the application of AR to industry practices, but focused on inspection procedures (Chung, 1999). Groups of participants measured the thickness of a part using either manual, computer or AR-aided methods. These two types of tasks (procedural and inspections) are the most common in the aviation industry, and therefore AR would be advantageous if it were integrated into professional task and information delivery.

Advantages of Augmented Reality. Beyond some of the efficiency and safety improvements discussed above, AR can provide multiple new ways to enhance information delivery in aviation. In fact, as Kesim and Ozarslan note, it allows for much better visualization and manipulation of objects and figures displayed on-screen (Kesim, 2012). In addition, information is displayed in the user's field of view, which gives them the ability to assimilate it better and concentrate more on the tasks to perform (Ong, 2008). The flexibility of AR also makes it applicable to several different types of processes (Hincapie, 2011), and AR-enhanced information is virtually always physically smaller (in weight and volume) than comparable information in print or other computer-based formats (Ong, 2008). This translates into more mobility, but also less time wasted accessing and retrieving information since the right information can be shown when and where it is needed (Ong, 2008). In practical tasks then, AR provides the benefits of added efficiency, safety and reduced waste of resources.

In training and education, augmented reality has been proven as a more effective learning tool than text or video-based methods (Macchiarella, 2004), and could for instance help reduce training time and costs in maintenance, which typically amount to about 2000 hours (Hincapie, 2011).

In design and manufacturing, AR could be used to simulate and improve products and processes before or during their implementation, and thus ensure their proper execution with minimal to no repetition or rework (Ong, 2008). In all of the previously mentioned domains, another proven advantage to AR is its collaborative potential: with the modern network technologies, design, approval, manufacturing and maintenance information and procedures can be shared and visualized by multiple entities in real-time in order to enhance information transfer (Kesim, 2004). One example would be the remote diagnosis of an aircraft system by experts who later guide a less-experienced maintenance worker through a complex repair that the latter would otherwise not be able to complete (Gautier, 2007). In this case, the aircraft could be dispatched again much faster than would have otherwise been possible through phone and text communication. In addition, there would be cost-saving implications since the experts would not have to travel to the aircraft's location to perform the required maintenance.

How Augmented Reality and 3D can be used in training and tech task delivery in aviation

Methodology for Development of AR Tasks

Creating Augmented Reality scenes for use in educational or professional environments is typically a four-step process:

- Planning of the AR scene
- Preparation of object or environment to be augmented
- Addition of content to be overlaid
- Save or upload of the created AR scene.

Planning of an Augmented Reality scene. As mentioned previously, there are many software, hardware and content options available to produce and access augmented reality content. Choosing the right combination of these elements is essential for the successful deployment of the scene. Many variables dictate this choice, among which:

- The profile of the user: when developing an AR scene, it is important to keep in mind the intended user's level of knowledge on the topic, familiarity with the technology, and even physical limitations among other attributes. For instance, an AR scene that is intended to present an overview of a turbine engine's main sections may be produced in different ways depending on its audience. If it were to be used by students who are familiar with AR technology and the basics of powerplant theory, the interface would be more detailed and content-rich than if it were destined to the general public, in which case there would be less technical content and more on-screen guidance on the use of the technology.
- The user's environment: this is a critical factor for the successful deployment of an AR scene because the user must be able to access and use the AR content with maximal ease and comfort, and minimal potential damage to the equipment or their environment. Some factors to consider are lighting conditions, distance from a network access point if applicable, amount of physical space around the user and noise concerns.
- The user's task or objective: it is important to visualize the user and their intended use for the technology. For instance, an AR project intended to provide instructions for a complex part removal may require the use of AR glasses and on-demand instructions in order to allow for full mobility of the user.
- There are many other factors to consider related to the development of Augmented Reality content, such as available hardware, network access or lack thereof and software limitations.

Preparation of Object or Environment. After planning the AR scene, the next step in the development of an AR project is to prepare the object or environment that will be augmented. The basis to achieve this is to recreate a model of the object or environment that the computing platform can recognize and visually augment. This can be done in different ways depending on the software/hardware platforms being used, but as Nee explains, it is more common to use software-based scanning and tracking methods (Nee, 2012). Below are the main methods used to save objects and environments for augmentation, as outlined by Nee (Nee, 2012):

- Marker-based technologies: using this technique, the software platform transforms certain features of the objects or environments into fixed reference points for augmentation. These features can be two-dimensional (QR codes for instance) or three-dimensional points (Metaio, n.d.).
- CAD model: it is also possible to use computer-generated three-dimensional models to activate augmented reality content. Indeed, this method is similar to using markers, except in the sense that the reference points are generated by the digital objects.
- Location-based technologies: This method involves using the location of the user to trigger augmented reality content.

Addition of content. After the object or environment has been prepared, the AR scene developer can add content that will be overlaid on the user's interface. This is typically done using a dedicated software platform which is compatible with that of the user.

There is a multitude of content types that can be overlaid using augmented reality. Some of the most useful in an aviation context are:

- Text
- Images
- Videos
- 3D models
- Links

In many of the software platforms currently in use, it is also possible to animate the overlaid content or allow the user to interact with it in order to enhance the usability and efficiency of the scene.

Save or upload of the scene. Once the AR scene is ready for deployment to the user, the last step is to save or upload it, depending on the retrieval method of the user. In fact, AR projects can be transferred to the user's platform either directly (with physical device connections or through a network), or through a third-party service (augmented reality application for instance).

Demonstration of an AR application in aviation training and task instruction delivery

The Hangar of the Future Research Laboratory in the Aviation Technology department at Purdue University has been conducting research on using Augmented Reality applications to enhance training and work instructions for a few years (Hangar of the future). Researchers in this laboratory have developed dozens of AR-enhanced projects and demonstrations that are applicable to training and industry tasks. One of these, which uses a Pratt & Whitney 4000-series turbine engine as a platform will be detailed below.

The purpose of this AR project was to demonstrate the capabilities and versatility of the technology in an education environment, but also in a professional manufacturing or maintenance setting. Thus, the user interface was designed to include informational content about the systems, as well as step-by-step instructions to perform certain tasks. This project was created using the Metaio suite of AR software. This includes the scanning application *Toolbox*, the AR content creation platform *Metaio Creator* and *Junaio*, an application which allows the users to access the created content (Metaio). This Hangar of the Future project was primarily intended to be accessed on tablets and smartphones. Those devices were chosen because of their relatively low cost, high computing power, portability and popularity.

The project essentially consists of two parts: one that can be used for familiarization with turbine engine components and functioning, and a second that provides step-by-step instructions to perform certain hands-on laboratory projects. In both of these sections, several different data formats were used to convey information clearly and efficiently. Text boxes and images were displayed for descriptions and illustrations, as well as for users to select in order to navigate to displays that contain additional information. For instance, text and images were used to describe the different sections of the turbine engine and illustrate the air flow through them. In addition, videos were used in multiple cases to provide supplemental audio-visual information. This was the case to demonstrate proper cable routing and attachment for example. Finally, computer-generated three-dimensional models (3D) were used to enhance the visualization of certain parts, as they provided the possibility for the users to manipulate the object on-screen. This capability was used to provide visual details of the full authority digital engine control (FADEC) unit of the engine.

This augmented reality project constitutes phase I of this research, and has demonstrated the feasibility and applicability of augmented reality as a tool for education and delivery of task instructions in an aviation setting. The next stage will be to design and execute an experiment that will test and measure students' perception of this technology.

Conclusion

This research paper has shown that augmented reality has the potential to positively impact information delivery in aviation in many ways, both for training and professional purposes. However, developing successful augmented reality project requires a careful and methodical approach, which was followed by this research team and the Hangar of the Future laboratory at Purdue University to create an application for students in the Aviation Technology department. This project demonstrates that incorporating augmented reality in educational and professional fields is a realistic and feasible possibility, and its impact – as well as the students' perception – will be evaluated in the second phase of this research.

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