Augmented Reality in Engineering Education: Current Status and Future Opportunities

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CONTEXT

Augmented Reality (AR) uses digital information to enhance a user's real environment, most commonly visually, without replacing their real environment. With the ubiquity of mobile devices in the classroom AR is a more accessible teaching tool than ever before. This paper reviews recent literature to discover the current teaching applications of Augmented Reality relevant to an engineering higher education setting as the basis for highlighting near future opportunities for research and implementation.

PURPOSE

This review will assist engineering educators in understanding the potential applications of AR for teaching future engineers and will provide a context for designing AR solutions and content.

APPROACH

24 peer reviewed articles published since 2012 were reviewed. The papers were selected on the basis that they were relevant to a higher education setting and implemented an AR solution for teaching an engineering topic or skill. This review identifies common themes in current research in order to make suggestions for future implementations and research directions.

RESULTS

There are many teaching applications of AR in an engineering education setting. AR can be an accessible way to teach topics in a safe environment that ordinarily would involve a high level of risk or cost. It is effective for spatial training, especially for isometric and orthographic drawing practice. Additionally, time and space constraints of lab based teaching may be reduced by using AR in a pre-lab classroom environment or for online and distance education.

CONCLUSIONS

AR enhanced learning is generally well accepted by students. If the usability of the solution is high, students tend to achieve better outcomes using AR skills based training compared to paper based methods of instruction. This is often attributed to the novelty of the solution, which is overall reported to increase student motivation and engagement with learning.

KEYWORDS

Augmented Reality, Higher Education, Engineering Education.

Introduction

What is Augmented Reality?

Augmented Reality (AR) is not a new technology. It has been described in research literature for more than twenty years, classified on a continuum from real environment to virtual environment (Milgram, Takemura, Utsumi, & Kishino, 1995). Although the exact definition of AR has evolved with the technology over time, it is generally accepted that AR is different to Virtual Reality, which replaces the user's real environment with a virtual one. AR exists concurrently with Mixed Reality, incorporating aspects of mixed digital and real environments. In simplest terms, AR uses digital information to enhance a user's real environment, currently most often visually, without replacing that real environment.

Figure 1: Milgram's Reality-Virtuality Continuum

An example of AR in industry is the DAQRI Smart Helmet (DAQRI, 2016), a ruggedized Head Mounted Display (HMD) for work environments. An HMD is a type of visually transparent wearable display designed to provide a user with additional contextualised digital information, usually visual, while leaving their hands free for other tasks.

In 2016, AR has achieved mainstream consumer status through the release of the Pokemon Go mobile Augmented Reality game (NianticLabs, 2016). In the game players hunt for virtual creatures (Pokemon) in their physical environment using an iOS or Android mobile device and attempt to catch them for their collection or to battle other players. The AR elements of the game include the ability to view Pokemon on a mobile screen as if they were really situated in the player's environment, and the location based gameplay interactions of encountering a Pokemon and battling other players at a Gym. With more than 100,000,000 installs on the Android platform alone (GooglePlay, 2016), it is conceivable to say that many current and future university students in Australia have now experienced AR first hand. This author has also witnessed several university academic staff playing Pokemon Go!

How can AR be used effectively in education?

Although AR is not a new technology, the lack of commercially available or affordable hardware coupled with the programming skills required for development of systems and content previously made AR out of reach for most non-specialist users. Two main innovations have recently made AR more accessible for classroom use: The ubiquitous nature of smartphones and tablets in the classroom, and the availability of more open and easy to use software solutions for AR development.

It is generally accepted that AR is an effective teaching tool for spatial training, visualising abstract concepts and collaborative learning, as well as increasing student engagement and improving motivation (Wu, Lee, Chang, & Liang, 2013). Located learning is a distinct advantage of teaching with AR, as is the relatively low barrier to entry considering the decreasing cost of the technology.

These benefits are only realised, however, if the usability of the AR solution is high, the cognitive load due to multitasking is low and the learning content is relevant to students (Wu et al., 2013). This review will assist engineering educators in understanding the current applications of AR for teaching future engineers, and provide a context for designing future AR solutions and content.

Methodology

For this review, 24 relevant peer reviewed papers were selected from engineering research databases on the criteria that they were:

- Recent (Published from 2012 onwards)
- Implementing an AR solution for teaching an engineering topic or skill
- Relevant to a higher education setting

The purpose of this review is to show the current applications of AR in an engineering education setting, identifying common themes in current research in order to make suggestions for future implementations and research directions.

Review of AR Teaching Applications

Visualisation

Collaborative visualisation

The use of AR for collaborative visualisation in the classroom gives learners the opportunity to manipulate and discuss the same learning object in situ, in real time. Suyang, Behzadan, Feng, and Kamat (2013) implemented a tabletop AR display integrating a temporal aspect in the visualisation of engineering processes, addressing the problem that “2D or 3D models do not reflect temporal progress, while scheduling bar charts do not demonstrate the corresponding spatial layout.”

In an earlier work, Shirazi and Behzadan (2013) developed an AR enhanced textbook with context-aware simulated animations for civil and construction engineering, reporting a "majority of students rated the mobile AR tool as an effective educational platform and suggested that it should be as well used in other courses. In general, it was found that AR visual simulation coupled with collaboration and interaction can provide multiple affordances in support of technology-based and situated learning". Building on this work, Shirazi and Behzadan (2015) later found that providing learners with an AR textbook encouraged collaboration and discussion in class, and students reported high levels of satisfaction with this learning method.

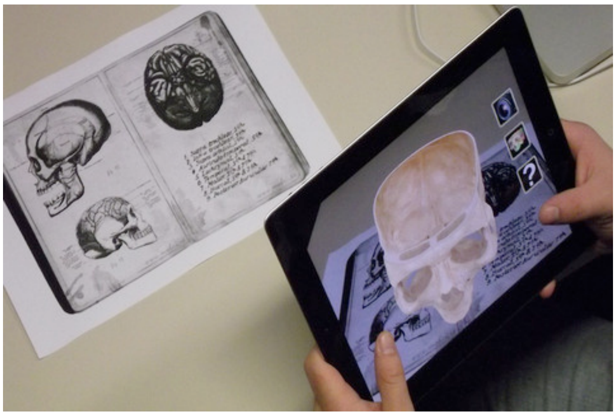

Figure 2: Augmented textbook example (MaheiEngineering, 2016)

Rendering the invisible, visible

Matsutomo, Miyauchi, Noguchi, and Yamashita (2012) developed a visual AR tool to teach students about magnetic fields and interference, which is not ordinarily visible to learners in their daily lives. "In this system, the user can freely and independently change the position of magnets and currents. The user can, in real-time, observe and understand the magnetic field which is caused by the interference." (Matsutomo et al., 2012)

Teng and Chen (2012) provided students with a real time AR 3D visualisation of OpenGL operations. They assisted learners to "visualize the intermediate results of applying different operations to the 3D objects so as to help users to understand the underlying mechanism of OpenGL"(Teng & Chen, 2012). Learners better understood the "relationship between program codes, rendered OpenGL image, and the configuration of virtual camera and objects in 3D space" (Teng & Chen, 2012).

Spatial training

Several of the reviewed publications implemented AR as a spatial training tool as an aid for orthographic and isometric drawing. Other spatial training applications included virtual object manipulation (usually through the use of an AR textbook), teaching remote control skills or for simulating spatial aspects of real construction environments.

Drawing

Three papers discussed the implementation of mechanical engineering visualisations for the purpose of improving isometric and orthographic drawing skills. Generally, AR is used to allow students to manipulate 3D objects in order to understand and draw different views of the objects more effectively than 2D representations. Camba, Contero, and Salvador-Herranz (2014) reported that while student reviews were mixed for their implemented technology, satisfaction with the learning experience was high. Figueiredo, Cardoso, C. D. F. Goncalves, and Rodrigues (2014) discovered that applications for tablet based visualisations were readily available on the market and relatively easy to implement. Gonzalez, Dominguez, Martin-Gutierrez, Contero, and Alcaniz (2012) found that students improved their spatial ability compared to traditional methods “giving new life to classical paper and pencil exercises”.

Virtual object manipulation

Similar to the above applications for drawing, AR can be used for teaching engineering design graphics skills to mechanical engineering students through virtual object manipulation, as a pre-drawing activity or to complement other 3D spatial training curriculum. After implementing AR textbook materials, Gutierrez and Fernandez (2014) measured improved academic performance and higher student motivation. Dorribo-Camba and Contero (2013) reported that learners understood their first implemented AR interface quite easily, and that many students “agreed or strongly agreed with the statements that AR provides a significant advantage over traditional printed resources and that AR could also be beneficial in other engineering courses, which indicate a high level of acceptance, motivation and interest in the technology.” However, Dorribo-Camba and Contero (2013) also found that students viewed AR as supporting traditional methods of instruction, rather than replacing them.

Robotic and digital control

AR can be used to train control skills. Frank and Kapila (2016) implemented an AR Graphical User Interface (GUI) to control a robot. “The goal is to reinforce ideas regarding spatial relationships associated with moving coordinate systems and conceptual understanding of forward and inverse kinematics" (Frank & Kapila, 2016). Frank, Brill, and Kapila (2016) also used AR to allow students to control a motor test bed to “reinforce connections and gain insights regarding the effect of the discrete-time pole locations.” Borrero and Marquez (2013) tasked students with using an AR control system to interact with a real robot in a remote lab, finding a high level of general acceptance with students reporting that they think AR helps them learn.

Spatial simulation (construction)

By augmenting a real wall as a simulated construction environment using a smartphone and AR object markers, A. Sanchez, Redondo, Fonseca, and Navarro (2014) taught the steps in the process of opening a void in a load bearing wall. Students using the AR system achieved better academic performance over the control group, attributed to increased motivation.

In general, the results of using AR for spatial training were superior to traditional paper based tools on most measures. However, as Alvarez et al. (2014) reported from their civil engineering 3D terrain representation prototype findings, AR scored slightly lower than 3D PDF in terms of student satisfaction due to minor technical issues with their AR implementation. This again shows the importance of usability in the design and implementation of any AR application for teaching, although both the 3D PDF and AR outperformed traditional 2D methods of instruction. If the technology is implemented well, the learning experience and outcomes are positive.

Safety

Operating high risk equipment

As students learn the fundamentals of using high risk equipment, they must transfer their theoretical knowledge of occupational health and safety to operating equipment safely. AR welding provides an intermediate step, allowing students to practice working in a live welding environment without safety risks. Okimoto, Okimoto, and Goldbach (2015) used an AR welding helmet to simulate a work-like environment, finding "students were initially very motivated to do the training, especially for the high degree of novelty” and that “the simulated process provides students with greater security in the initial phase of training”, citing the fumes and high temperature as potential risk factors for inexperienced students.

Lab and on-site safety awareness

Safety, particularly risk prevention, is well suited to AR instruction as it allows students to experience elements of potentially dangerous situations without risk. One example is lab safety (Mayo, Quintana, & Rogado, 2015). Another is for training students in safe work practices on construction sites. AR discovery based learning using live video from construction sites was trialled as a safer and more accessible way than site visits to give students practical experience "given the high demand for skilled workforce in the construction industry, the high level of risk associated with equipment operations on site, and the fact that appropriate operational and safety skills take long time to accumulate” (Behzadan & Kamat, 2013).

Online and distance education

Remote labs

Remote labs for electronics, computer systems and robotics can be enhanced with AR. Remote labs are commonly used for online education for distance or large class sizes. Lo, Qian, Quan, and Hong (2012) used a 3D information overlay to assist students in working remotely with an integrated circuit development board. Odeh, Shanab, Anabtawi, and Hodrob (2013) tested the suitability of AR for client user interfaces in remote labs by overlaying a live video stream with virtual objects, and found that this approach to training did help students develop skills for hands-on labs. Interestingly, Cubillo, S. Martin, Castro, and Meier (2012) had feedback from students that “The system avoids the fear of breaking the equipment of laboratory”, potentially showing students had more confidence to try activities in an AR enhanced remote lab setting at the beginning of their learning.

Skills based training at distance

In addition to the remote labs above, AR can also be useful in training hands on skills for distance learners. Vijay, Lees, Chima, and Chapman (2016) proposed an AR tutor for remotely simulating welding, finding that of the 10 experts surveyed “90% agreed that the proposed AR environment has demonstrated a high usability in enhancing practical skills of engineering distance learners and also for regular students in practicing the laboratory task when away from on-campus environment”.

Enhancing tools and instructions

One of the most interesting applications of AR is the enhancement of existing in-class or lab hardware tools to provide support for students in their hands-on learning. One example of this application is the AR magnifying glass system proposed by Benito, E. A. Gonzalez, Anastassova, and Souvestre (2014) for board discovery exercises with computer engineering students. By augmenting a common tool, the magnifying glass, students are able to have guided interactions with boards including instructions and explanations with freedom of movement and viewpoint around the board.

Another example of an augmented in-class learning experience is the assembly of a robot with an AR assistant providing in-situ instructions and tips. Alrashidi, Alzahrani, Gardner, and Callaghan (2016) found that "The assemblers who used the AR application outperformed the assemblers who used the paper-based approach in the post-test… the AR application provides real-time data for each component and enriches learners with a more sophisticated learning experience with respect to assembly."

Discussion

Technology

Hardware

An analysis of the 24 papers reviewed shows a trend for AR interaction towards using mobile and/or tablet displays for interaction. The reason for this is fairly straightforward – a mobile device integrates all the tools needed for a basic AR application (camera, display, operating system, method of interaction) at low cost and high availability and familiarity to students.

Only four of the reviewed papers used a Head Mounted Display (HMD). The reasons for the lack of engagement with this technology for developing AR are varied – the relative high cost of the hardware, lack of commercial availability (although many commercial prototypes are in open development, including the mixed reality Microsoft (2016) HoloLens) and the barrier a head worn device presents to natural communication and collaboration between students. This is not to say that HMD's are not a viable option, but they may be more suited to on-site use rather than classroom based instruction for engineering education.

Markers vs. markerless interaction

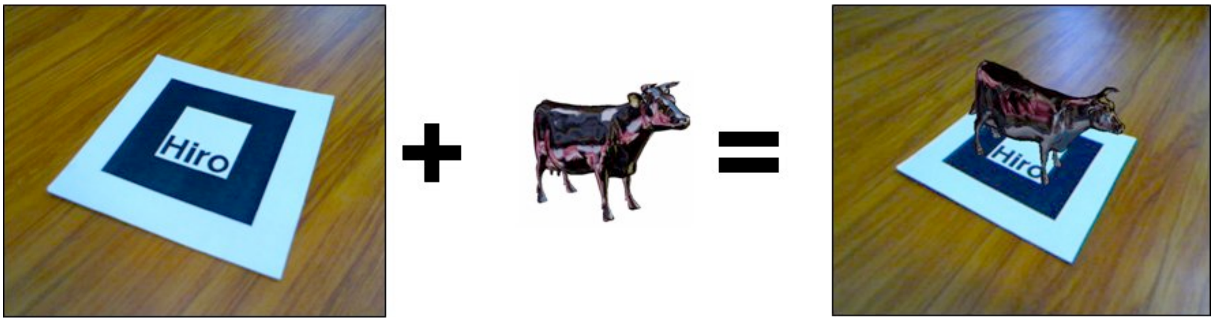

Figure 3: Marker based interaction example (ARToolKit, 2016)

Many earlier prototypes use marker based interaction, and indeed this is a very low barrier to entry method of developing an AR prototype as the marker recognition is usually built into the software framework. A more natural method of interaction is using markerless AR, which typically uses computer vision to recognise trained elements of an image or geolocation to provide the augmented content. This means a real environment can be more seamlessly augmented, without the use of imposed AR markers.

Software

Some of the reviewed papers specified an openly available software package or development framework rather than building a custom solution. The following software was used by authors in the development of their proof of concept, prototypes or final solutions. These may present options for your own development of AR teaching resources:

Table 1: Software solutions for AR, as specified in reviewed papers

Software	Website
BuildAR	http://www.buildar.org/
Augment	http://www.augment.com/
ARVita	http://pathfinder.engin.umich.edu/software.htm
Unity	https://unity3d.com/
ARToolKit	https://artoolkit.org/
Aumentaty	http://www.aumentaty.com/
Vuforia	http://www.vuforia.com/
OpenCV	http://opencv.org/

Issues with AR

Issues with implementing AR as an educational tool include some limitations of the technology itself and the resources required for implementation. Occlusion is still an issue under investigation in AR. When a real object comes between the camera view and the rendered AR object the view may be distorted, therefore a better understanding of the depth of the scene is needed. As with any screen mediated task, eye strain may also be an issue.

The programming skills required to implement an AR solution for teaching are still an issue, with an average engineering academic outside of specialist programming fields needing the support of a development team to bring their ideas to the classroom. However, this may be mitigated through the use of mobile devices and commercially available (or open source) software if the content can be customised appropriately for the intended educational use.

The cost of specialised hardware, particularly wearable devices, remains an issue. Therefore it is recommended that academics use the tools students have on hand, such as webcams and mobile devices, to implement AR enhanced teaching if the cost of the solution is a barrier.

Conclusion - Future Directions

This author's view is that the future of AR for education will be in augmenting tools, not textbooks. Many of the reviewed solutions used an augmented textbook as a classroom resource, which was generally well accepted by students. However, the real advantage of AR is for bridging the divide between the real world and classroom learning. The three examples that stand out in this review are the augmented magnifying glass for computer engineering students (Benito et al., 2014), the augmented welding helmet (Okimoto et al., 2015) and the visualisation of magnetic fields (Matsutomo et al., 2012).

As in Pokemon Go, geolocated AR interactions have the potential to provide in-situ and authentic learning experiences to students. Incorporating multisensory elements, such as sound and haptic feedback can also extend the learning experience further.

Finally, one of the biggest developments on the horizon for AR learning is the ability to render AR content in the browser using HTML5 and WebGL.

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