Augmented reality, the future of contextual mobile learning

Roopesh Kevin Sungkur, Akshay Panchoo and Nitisha Kirtee Bhoyroo
Department of Computer Science and Engineering, Faculty of Engineering, University of Mauritius, Réduit, Mauritius

Received 8 July 2015
Revised 2 December 2015
4 February 2016
5 March 2016
Accepted 11 March 2016

Abstract

Purpose – This study aims to show the relevance of augmented reality (AR) in mobile learning for the 21st century. With AR, any real-world environment can be augmented by providing users with accurate digital overlays. AR is a promising technology that has the potential to encourage learners to explore learning materials from a totally new perspective. Besides, the advancements made in information technology further broaden the scope for educational AR applications. Furthermore, the proliferation of wireless mobile devices such as smartphones and tablets is also introducing AR into the mobile domain.

Design/methodology/approach – This discussion paper gives an insight of the different potential fields of application of AR and eventually proposes an AR application that will give a completely different learning experience for learners. This AR mobile application will not only provide learners with supplementary information but will also assist lecturers in their teaching process. There are certain concepts in computer science at the tertiary level that are at times difficult for learners to understand using the traditional classroom approach. Through this AR application developed, the learners are able to see what is happening and experience a different form of learning where the focus is more on "learning by doing" and on the ability of visualizing the complete set of steps involved for a particular operation. Finally what is proposed is a generic framework/process for the development of AR applications for learning purposes.

Findings – The AR application developed and tested has proved to be helpful in understanding complex concepts of computer science that average students have much difficulty in understanding. Through AR, learning has been brought to a new dimension where the students can easily visualize what is happening and easily understand complex concepts. This low-cost system that has been proposed can track and detect both markerless and marker-based images. A number of experiments have also been carried out to determine a set of best practices for the development and use of such AR applications.

Originality/value – Learners have been able to have a more interactive and enriching learning experience through two-dimensional and three-dimensional digital augmentations. The AR mobile application has been enhancing the cognitive skills of learners through enabling them to scan images from printed materials with their smartphones. Then, informative digital augmentation has been overlaid in real time on the mobile screen with the image preview still in the background.

Keywords Augmented reality, Smartphones, Marker, Mobile learning, Overlay

Paper type Conceptual paper

1. Introduction

The business of the mobile industry has known considerable growth since its emergence and it continues to bloom into a lucrative endeavor offering more fascinating features. One of the most captivating advancements that have been made over the years in the mobile industry is the development of smartphones equipped with new software, clever

Interactive Technology and Smart Education
Vol. 13 No. 2, 2016
pp. 123-146

1741-5659
DOI 10.1108/ITSE-07-2015-0017

applications and enhanced Web interactivity. The beginning of the twenty-first century has seen a technological shift and a continuous progress toward powerful mobile and handheld computer devices as well as intelligent software applications. Most of these systems are GPS-enabled and location-aware and provide wireless access to the internet. High-quality video cameras and audio functions provide the basis for future learning and instruction. These new technologies are and will be shaping how people learn in the beginning of the twenty-first century in formal and informal settings (Ifenthaler, 2010). Besides, another technology that has become a topic of interest for many application developers is augmented reality (AR). AR technology is gaining popularity within society and becoming more ubiquitous in nature (Johnson *et al.*, 2010). The use of AR systems has been investigated in a range of industries since the early 1990s, including medicine, manufacturing, aeronautics, robotics, entertainment, tourism and, more recently, social networking and education (Azuma, 1997; Billinghurst, 2001; Hincapie *et al.*, 2011; Shelton and Hedley, 2002; Shin *et al.*, 2010; Shuhaiber, 2004). Examples from the industry include driver training (Regenbrecht *et al.*, 2005), practising aspects of complex surgery (Cristancho *et al.*, 2011) and learning how to change a filter on a space station (Regenbrecht *et al.*, 2005). AR improves a user's insight of the real world, as it enables users to see information that cannot be automatically detected with their own senses. Users can improve their performance in carrying out their tasks through the help of information provided by virtual objects. With the advent of computers, smartphone, tablets and the internet, new ways of communicating information to the world have been developed. Recent improvements in mobile computing power and functionality have led to larger resources being directed to the development of mobile AR systems (Johnson *et al.*, 2010), and thus, AR is now widely available to regular consumers rather than limited to high-end laboratory research and industry. These devices can easily merge various types of content such as text, audio, video and three-dimensional (3D) media to reduce opacity of information. Today, there is a transition occurring from paper to digital print, as digital media can provide additional useful details for better understanding purposes. Some publishers are assessing the advantages of publishing over the use of new digital media. Nevertheless, the integration of AR is being considered, as it can enable users to be exposed to a visual display to boost their interest in traditional printed materials. Moreover, AR can reduce many drawbacks of print media. For instance, books, newspapers and magazines provide static contents that do not usually encourage interactivity with readers. Information transmitted by printed paper is merely passed to the recipient in a passive way, as the latter cannot respond to the sender during this communication process. By integrating AR in books, a dynamic content is presented that promotes a bi-directional flow of communication. The act of reading can turn into an active task for the reader, as the latter can learn more about a particular context.

AR can also exploit other human senses beside vision, including the sense of touch and hearing. Not only can AR be used to integrate virtual objects in the real surrounding but it can also hide certain parts of a real surrounding. This characteristic is mostly exploited in animation films. Besides the use of video, AR can also be designed to include audio segments. Through the use of headphones equipped with external microphones, additional 3D sounds can be integrated through the headphones. Moreover, AR can be used for haptic technology. For instance, special hand accessories can be designed such that tactile feedback is provided. This feature is being exploited in the medical field to aid visually impaired patients.

Numerous researchers have identified AR as having immense potential to enhance learning and teaching (Billinghurst and Duenser, 2012; Dede, 2009; Dunleavy *et al.*, 2009; Johnson *et al.*, 2012; Kaufmann and Schmalstieg, 2003; Shelton and Hedley, 2002; Squire and Jan, 2007). Besides, Garret *et al.* (2015) describe AR implementation as a relatively low-cost innovation and that experimentation with AR applications is easily within the reach of most schools. Normally studying in a class where there are more than 50 students is sometimes uncomfortable, as the lecturer cannot respond to queries of all the students during a lecture session of two hours. Sometimes, students at the back can hardly see what the lecturer is writing on the board. Besides, in large classrooms without microphone facilities, hearing difficulties are also common. In most educational institutions, some students experience difficulties to learn complex concepts in the classroom. These students may need specialized attention to understand new topics conveyed by their lecturer. Nowadays, most students have a smartphone in their possession and this can be used as a learning tool in our institutions. Thus, the traditional means of teaching need to be revisited, as learners now want to be independent and no longer want to be confined within the four walls of the classroom. What learners now expect from the learning experience is one that is enriching and effective, whilst focusing on the concept of student-centered approach.

2. Literature review

2.1 Augmented reality

Azuma *et al.* (2001) in their definition of AR talk about computer-generated virtual information superimposed on the real-object image. AR can be described as live view of a physical environment whose elements are augmented by computer-generated input such as video, sound, images, graphics or GPS data. AR is a technology that allows the real-time merging of the digital data processed by a computer with data from the surrounding environment through specific computer interfaces. It involves the real-time immersion of digital augmentations in a physical space and it allows the merging and connection of the latter with the digital world. AR enables information pertaining to a specific context to be directly accessible by means of an interactive AR interface.

2.2 Pedagogic theory and augmented reality

Understanding how learners learn is of primary importance to teachers who eventually calibrate their teaching practices to have the best-desired effect. As a cognitive tool and pedagogical approach, AR applications and tools are primarily aligned with situated and constructivist learning theory, as it positions the learner within a real-world physical and social context while guiding, scaffolding and facilitating participatory and metacognitive learning processes such as authentic inquiry, active observation, peer coaching, reciprocal teaching and legitimate peripheral participation with multiple modes of representation (Dunleavy and Dede, 2015). Situated learning theory posits that all learning takes place within a specific context and the quality of the learning is a result of interactions among the people, places, objects, processes and culture within and relative to that given context (Brown *et al.*, 1989). Within these contexts, learning is a co-constructed, participatory process in which all learners are "transformed through their actions and relations in the world" (Driscoll, 2000). Situated learning builds upon and extends other learning theories such as social learning theory and social development theory, which posit that the level of learning is dependent upon the quality of the social interaction within the learning context (Bandura, 1977; Vygotsky, 1978). Our conception of the way in which AR helps us to confront reality aligns with an essentially student-centered conception of learning. An AR is a flexible space, containing learning opportunities that the learner can grasp at will. Learning is liberated from traditional spaces such as classrooms, lecture theaters and labs and instead envelops the students wherever they are (Munnerley *et al.*, 2012). What is interesting to highlight is that there are studies that demonstrated that AR games can be applied in informal learning environments, a recent trend in reform recommendations in education (Koutromanos *et al.*, 2016).

2.3 Augmented reality for mobile devices

Over the past couple of years, AR applications have emerged into the market in parallel with the deployment of the new smartphone with multiple features. Some applications enable users to view augmented images of their surrounding environment on their mobile phone's screen. AR applications capture the background scenery with the camera and then present the information layers related to that context in the physical system of the user. Thus, this enables users to have ubiquitous access to contextual information.

2.4 Augmented reality in education

Mobile AR applications can enhance students' learning and understanding capacities. Students also have the possibility to browse through information based on their current environment. Kerawalla *et al.* (2006) stated that AR has the ability to make learners more dedicated and motivated in exploring resources and applying them to the real environment from various new perspectives. According to Chang *et al.* (2010), many researchers have proposed that AR can contribute to strengthen the motivation for learning in students. Lecture notes are the most used teaching medium in all educational institutions. However, lecturers and students are now progressively exploring the adoption of new technology that can be of great help to explain technical concepts related to computer science, architecture, geometry, national geography, astronomy and science. Images from books can be overlaid with digital data. The concept of augmented books provides additional illustration and reflection for a deeper understanding of the context through additional perspectives. AR aims at extending the user's senses so that users can perceive more information. This can be achieved by manually identifying objects with the use of markers such as QR codes. Thus, enhancement of two-dimensional (2D) static media with dynamic 3D media can be implemented. In 2009, Dias, a computer science professor, identified that augmented books could improve the notion of traditional books used in schools. He pointed out that a better understanding of the topic learned could be achieved by augmenting integrated educational sketches (Figure 1).

AR can transform a book by supplementing it with digital information in the form of additional videos and animations and helpful overlaid information on the related concepts.

Billinghurst *et al.* (2001), a computer researcher found that:

> People, especially young children, can read books in more interactive and realistic ways by superimposing 3D rendered models onto books with AR technology.

This statement describes the essence of how AR would provide a completely new technological experience. The learner can go through the book and look at the pictures and the text without any interactive assistance. However, with AR hand-held displays, the learner can experience something completely different.

AR books have the ability to make people become part of a specific story. The mobile device uses its camera feature to scan the pages of the books and the relevant digital information can be visualized on its screen. This enables students to read books and obtain additional information about pictures and text in an interactive way. These books can better assist and guide students for an improved effectiveness in learning. In 2010, Johnson *et al.* explained that augmented books can be implemented specifically as an AR edition after publication. This can be done by installing software packages (e.g. AR tool kits) on the users' computers and directing an integrated camera of their computers at the book to see the digital and virtual 3D models appear out of the book. 3D real-time tracking is an extremely important technique of most AR applications. Accelerometer and gyroscope enable the augmented virtual objects' positions and orientations to be precisely synchronized with the real object. The alignment should be correct even when users move the mobile device quickly. The use of AR in academic institutions such as universities and colleges is also very effective, as this can boost the cognitive skills of students and share contextual knowledge on intricate theories or complex mathematical equations. In 2004, a demonstration was carried out by Liarokapis *et al.* which showed that AR has the ability to simplify complicated topics in higher education. Students can better understand and grasp a specific concept when exposed with context-based interaction via AR.

Various educational AR applications have been developed for location-based information and games; this technology has been analyzed and used only recently in the educational field. However, the adoption of AR in education is still considered a challenge. This is mainly because of the difficulty to integrate AR with traditional learning methods and little financial income from the government for the development and maintenance of the AR applications. There are already numerous interesting AR applications. However, the AR technology needs to evolve to a higher extent so that innovatory AR tools for education purposes are designed. Professionals and researchers

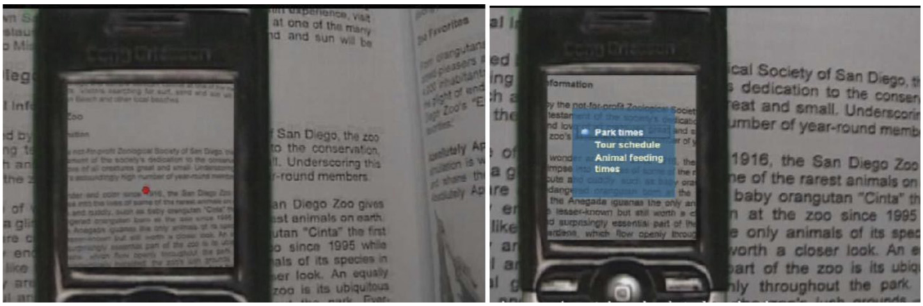


Figure 1.
Information overlaid to a book via AR

in the educational domain predict that more educational AR applications will be developed in the near future.

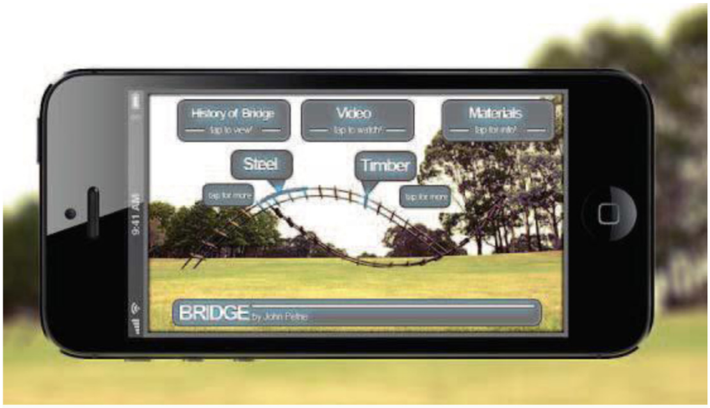
2.5 Benefits of augmented reality in education

2.5.1 Interactive education. AR can definitely transform educational environments into a more lively, productive, pleasurable and, hence, interactive experience for students (Lee, 2012). With AR, the students are engrossed in innovative and different ways that can provide a unique learning method enriched with relevant content from digital models (Figure 2).

2.5.2 Simplicity. A number of previous studies carried out by professionals have shown that AR has the ability to simplify many educational concepts. AR provides a way of connecting users to education in an easier and more focused manner. These results have shown that AR is expected to boost the interest of learners with 3D simulations. Furthermore, the recent innovations in computer and mobile devices and information and communication technologies and the developments in the internet wired and wireless technologies are expected to provide a more effortless and concise approach to use AR in the education sector.

2.5.3 Contextual information. According to experts in the field of educational AR, the introduction of AR in education can enhance the scope and standard of information in both schools and in business organizations. Research studies have shown that AR helps the training environment to be more educational, responsive, productive and contextual. Educational AR applications are thus integrated with several contextual characteristics in an attempt to provide a better quality of education. An example of an AR application is the use of geotag information and relevant comments to provide constructive information about historical places and rare artifacts to visitors (Figure 3).

2.5.4 Efficiency and effectiveness. Besides, AR has the potential to provide a more efficient education in academic institutions, as AR can present users with information corresponding to a particular location and time. AR enables student to learn constructively in a new authentic way through motivating and captivating



Source: Bower *et al.* (2014)

Figure 2.
The student design of the "Bridge" AR interface

Figure 3. Annotations provided about a place of interest using an AR application

environments. Besides, it is very likely that students will find it more appealing and stimulating to learn with the support of this revolutionary technology.

2.5.5 Compensate for the dearth in education conditions. AR can help to present information in a more natural and intuitive way to students by providing more realistic environments for learning purposes. For instance, many students are unable to carry out important educational experiments due to unavailability of equipment, lack of laboratories and other associated educational costs. In this case, an AR system can be implemented to enable students to visualize and conduct experiments with the help of virtual models to represent a physical system or specific scenario in a real environment. In this way, students can manipulate distant equipment by controlling the computer-generated complements (Figure 4).

2.5.6 Improves interpretation skills of students. AR can visualize the outline of characters by displaying the silhouette of historical individuals and other famous personalities to present users with a more constructive learning environment. Besides, this can even encourage intercommunication of students and the virtual characters and thus improve the awareness of students.

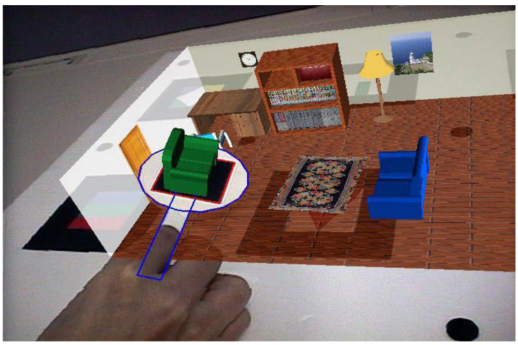


Figure 4. User wields real paddle to pick up, move, drop and destroy models

2.6 Main categories of AR systems

According to Johnson *et al.* (2010), AR systems are classified into two main categories, namely, marker-based and markerless.

2.6.1 Marker-based systems. Marker-based tracking for AR environments is designed by calibrating the environment, specifying landmarks, adjusting lighting and curbing the operating range to facilitate tracking. This is a very successful technique and one example is the ARToolkit library of Billinghurst *et al.* (2001). The marker-based application consists of three main components that include a booklet that provides the marker data, a gripper for retrieval of data from the booklet and changing it to another data type and a cube for augmenting the data on a screen.

Drawbacks of marker-based systems:

- perspective distortions occur;
- some markers are not implemented to view large fields; and
- not enough points are provided to enable 3D pose calculation.

2.6.2 Markerless systems. In contrast, markerless AR applications require a tracking system that is equipped with GPS, a compass and an image recognition device. As markerless AR applications have the ability to function in any location and without reference points, it can be more widely used.

2.7 Augmented reality technological components

AR incorporates three technologies: image recognition, interactive controls and computer graphics (Cawood and Fiala, 2007). When applied to learning, AR creates a more integrated learning environment, thus providing more opportunities for young learners to collaborate. AR applications provide virtual objects and backgrounds, which are simultaneously projected on the real world, to create the sensation of immersion. This simple means of interaction creates a new mode of learning, which is easily used even by students who have no experience in using computers (Su-Ju and Ying-Chieh (2015).

Registration is the accurate superimposition of real and virtual objects. Registration is one of the issues to be considered when developing an AR system. In recent years, AR has migrated from research laboratories to the market in several applications. Its use has been exploited for marketing, entertainment, maintenance, medicine and publishing purposes. AR makes use of several appropriate displays and interaction devices to enable users to access information related to specific contexts directly by associating layers of digital information to the physical space.

Appropriate devices integrated with sensors are required for the development of AR applications. Some examples of sensors are the webcam, GPS, compass, accelerometer and gyroscope. For instance, the webcam is used along with complex computer vision algorithms so that the required characteristics can be obtained from the video recorded. As AR includes the rendering of computer-generated graphics, many people associate it with costly equipment such as wearable computer devices and overhead monitors with remarkable processing powers. However, nowadays, there are numerous substitutes that can be designed more simply. For instance, latest mobile devices such as smartphones and tablets, personal computers equipped with a webcam and laptop computers with integrated webcam. The increasing popularity of smartphones has promoted the development of AR mobile applications. Therefore, innovative learning methods can be implemented in real surroundings to enable users to explore new AR experiences. Besides, AR is a technology that enhances a user's visual, aural and tactile senses with virtual information that is made visible through digital methods. Some examples of virtual information that are used in AR applications are geo-located metadata, 3D enhancements and visual or audio overlays.

Like context-aware systems, AR applications make it possible to filter information and present information overlays relative to the user's current context. (Zimmermann *et al.*, 2005, 2007). Therefore, information can be sorted according to various contextual parameters. The direction, object in focus, time and environment are used to synchronize and augment a particular context with digital information. Moreover, sensors are also essential for the connection of media and real-world objects. Some important processes that form part of the development of an AR application are aggregation, enrichment, synchronization and framing (Specht, 2012).

2.7.1 Aggregation. Sensor data should be aggregated to achieve a relevant contextual learning experience. For instance, it is important for the location of a GPS mobile device of a user to be connected to the user's environment. Aggregation is merging various sensor information such as the location of a GPS sensor with the actual time. However, it is not necessary to obtain the device location if the AR application is implemented to examine the camera feed with computer vision to establish the exact location of the digital overlay. Computer vision works by acquiring and processing the required information from the scanned images.

2.7.2 Enrichment. Relevant objects and potential users should be enriched with aggregated sensor information. Enrichment involves a mapping of a specific attribute to a raw data. This process enables users and devices to identify the appropriate sensor data and information related to their context.

2.7.3 Synchronization. Synchronization of enriched objects and users is derived from a matching process whereby a particular user location is matched with location metadata of the objects and channels.

2.7.4 Framing. The framing process involves vital feedbacks enabling the synchronized channels to be displayed according to relevant reference data (Figure 5).

2.8 Embedded vision enhancements

While inertia (accelerometer, gyroscope) and location (GPS, Wi-Fi, magnetometer, barometer) data can be used to identify the pose (i.e. position and orientation) of a mobile

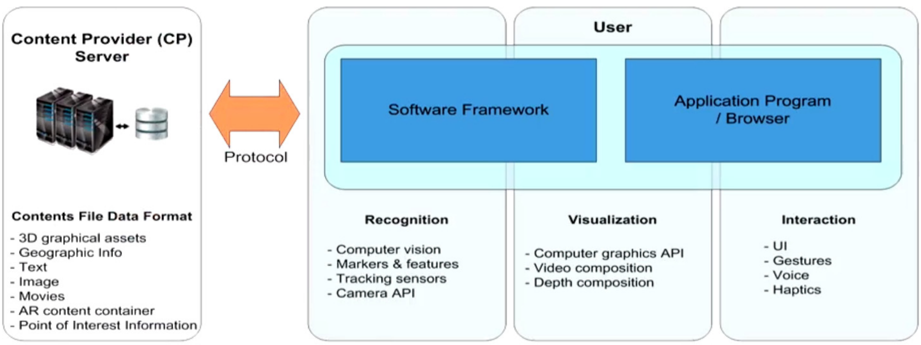


Figure 5.
AR technological components

electronics device with reasonable precision, camera-captured and embedded vision-based information is also a common and increasingly important aspect of AR systems. Various approaches to vision-based pose estimation exist, becoming more sophisticated and otherwise evolving over time. The most basic technique uses pre-defined fiducial markers as a means of enabling the feature tracking system to determine device pose. Figure 6 shows a basic system diagram for marker-based processing in AR. The tracking function, the essence of the system, outputs an estimate of the pose of the camera in real time based on what it "sees" (Silthanen, 2012).

2.9 Real-time object identification

The matrix method, also known as "cybercode", is a technique for AR that identifies real-world objects and estimates their coordinate systems simultaneously. The 2D matrix code used in our method is a square-shaped barcode that can identify a large number of objects. It is also used as a landmark to register information on the real-world images. As matrix codes are printable, it is virtually costless to produce and attach codes on various kinds of real-world objects (Rekimoto, 1998) (Figure 7).

2.10 Interesting AR projects

This section highlights some projects having made use of AR in an interesting way.

2.10.1 Boeing's AR in assembly line. An interesting AR application successfully used is by Boeing in 2015. The latter has been using AR projects to unite its research and development, IT and manufacturing teams. Boeing sees the future of AR in its assembly line. Looking through the tablet, a mechanic can see the real-world torque box unit as the assembly is being performed. To supplement the real-world view, digital parts, arrows

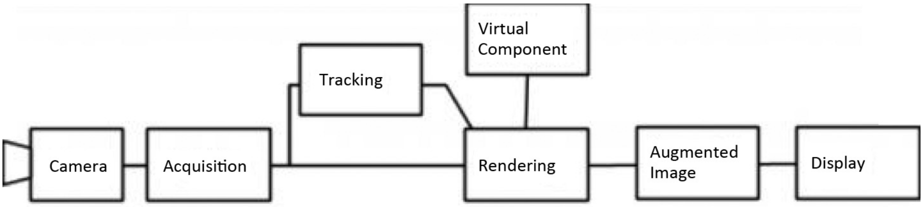


Figure 6.
This system flow details the multiple steps involved in implementing marker-based augmented reality

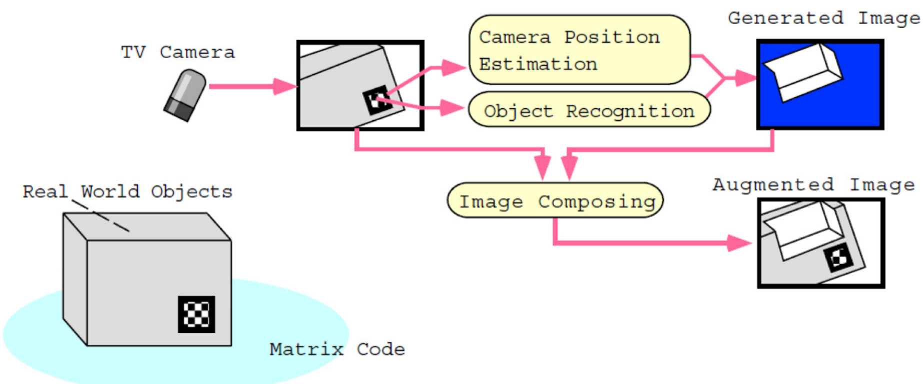


Figure 7.
MATRIX method for real-world object identification

and instructions can be seen. Ted Colbert, CIO at Boeing, sees AR as an emerging new level of tech innovation that has the potential to significantly improve Boeing's operations and financials.

2.10.2 System of Augmented Reality for Teaching. Freitas and Campos (2008) developed an educational system called SMART (System of Augmented Reality for Teaching) that makes use of the AR technology. It involves the superimposition of 3D objects on the real-time video that is displayed to the class. As it is obvious that children have a huge interest in playing digital games, game-based learning through AR is an effective way to inspire children through their learning journey. Freitas and Campos (2008) have carried out numerous experiments with 54 students in three distinct institutions in Portugal. The results obtained showed that SMART has a favorable impact on the learning process and performance of academically average and poor students.

2.10.3 ALIVE project. The MIT Media Lab added clever virtual creatures that can respond to user stimuli into an environment. AR technology has been exploited in remote education, thus promoting the use of ARERE. ARERE can design a collaborative and interactive AR-based education system that enables educational works to be performed through distance learning. Once the necessary educational concepts have been virtualized as 3D geometric models, AR enables remote collaboration between teachers and students. Interpretation and handling of the virtual models occurs through AR interfaces in the same AR environment. Users can make use of various signals in the form of gestures, speech and other nonverbal cues to provide a clear communication with one another.

The combination of real and virtual worlds forms the AR platform which is transmitted to all the students. The proper synchronization of the shared augmented video is essential to obtain a uniform display of the shared environment. In ARERE, markers with several designs are used and each marker is connected to a specific virtual model. Markers are also used to track signals by the software and enable users to replicate features that naturally occur in the learning space. Therefore, markers offer the possibility for users to control the 3D digital prototypes just as real entities. Four basic parts in the system are:

(1) *Formation of augmented video*: Augmented video information is produced by determining the location of the 3D model on the real video.

(2) *Transmission of augmented video*: The augmented video information is transmitted and shared with every concerned student.

(3) *Scene synchronization*: Scene synchronization ensures that the users view the entities as being synchronized at all the locations.

(4) *Communication and collaboration*: TAR modeling improves remote collaboration by providing gaze and nonverbal communication signals. These features ensure that the sense of presence of distant students is remarkably higher.

2.10.4 The Science Center To Go project. The Science Center To Go (SCeTGo) project has as objective to implement the AR technology into both formal and informal science subjects (Davidsson *et al.*, 2012). It helps to develop sustained learning techniques by allowing users to have access to daily science. In this approach, AR is used to reinforce the learning process and to demonstrate concealed scenarios. SCeTGo combines with the benefits of AR to present a merged reality illustration of a science center into a school classroom. The portability of the minuscule demonstrations makes it easier for users to use this technology independent of the time and place (Figure 8).

2.10.5 Augmented astronomy. Astronomy students study the different features of planets which include their relative position with respect to other planets in the solar system and the planet size and color. Therefore, AR applications with 3D-rendered planet shapes can be used in astronomy classes to improve the learning experience of students. Shelton and Hedley's (2002) study showed the use of AR in astronomy. It described that students could adjust the viewing angle and performs rotation of the 3D-rendered planets. This way of learning is better, as the students are more likely to retain a visual 3D display of information rather than pure theoretical notes and 2D pictures (Figure 9).

Moreover, Johnson *et al.* (2010) described yet another AR application known as Google's SkyMap. SkyMap overlays additional details about the stars and the constellations as users scan the sky with the camera on their smartphones.

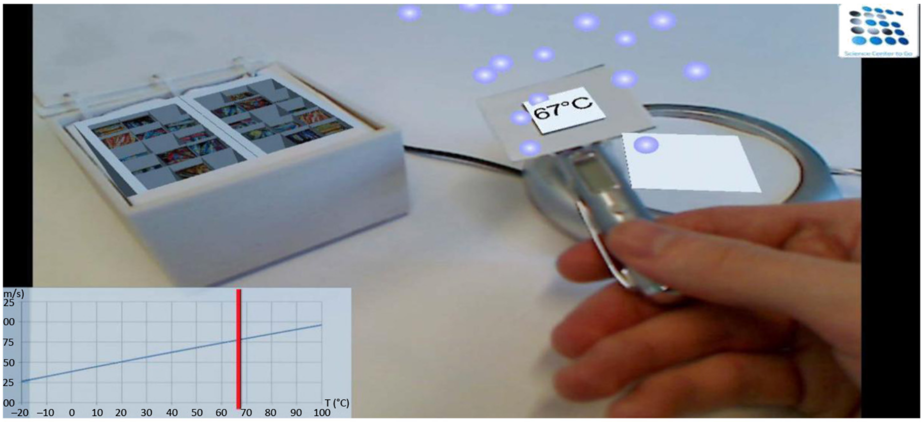


Figure 8.
One of the SCeTGo miniatures illustrating heat as the motion of molecules: moving slower or faster if put on top of the fridge (left) or heater (right)

Note: An augmented thermometer shows the "virtual" temperature

Figure 9.
An AR book featuring astronomy contents showing how a virtual model of a planet is displayed

2.10.6 Augmented chemistry. Augmented chemistry involves the interactive demonstration of the structure of atoms, molecules and elements to students. This enables students to determine the correct place to connect elements to molecules by directly manipulating virtual objects. Moreover, chemical reactions can be demonstrated via AR whereby animations and videos are used as supplementary information to help students retain the color changes and specific gas formed during a particular reaction. Several existing applications enable the representation of molecules in 3D on a 2D screen by allowing rotation and movement of the 3D objects. However, these applications are not very intuitive.

A study carried out by Maier and Klinker (2013) showed that the AR provides a better understanding of molecular structures than a 3D user interface with mouse and keyboard. "Augmented Chemistry" and "Augmented Chemical Reactions" are examples of AR systems with a 3D interface that enable users to directly control virtual objects by changing their positions and orientation. The latter makes use of a physical cube equipped with a handle that is covered with black-and-white designs. When two molecules undergo a chemical reaction, the cube can also vibrate with changing intensity. The user has to hold the cube and it is captured by a webcam. The system uses a marker tracking algorithm to identify the designs on the cube (Figure 10).

2.10.7 Augmented biology. AR can further be employed to analyze and observe different organs within the human body. AR can also be used to demonstrate several chemical reactions that occur during digestion and absorption of food in the stomach and intestines. An experiment carried out by the Specialist Schools and Academies Trust (SSAT) demonstrated that AR technology could be used to display a detailed view of human organs in terms of their size, appearance and location in the body by watching 3D digital prototypes in the class. Students also had the possibility to study humans' organs independently with their laptops integrated with webcam and AR markers that link PCs with the required biological digital information (Figure 11).

3. Methodology and proposed solution

This section describes how an AR application was implemented after identifying a suitable platform for development. Usability testing with 25 students of the Computer

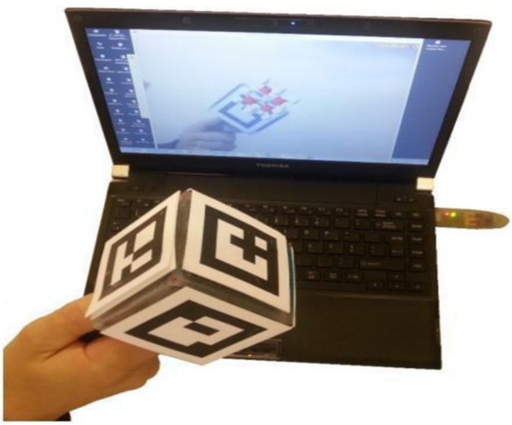


Figure 10. Augment reality application and haptic prototype system

Science and Engineering Department was also carried out. Their feedback was recorded and the application was modified following some interesting suggestions obtained. This is further described below.

3.1 Choice of development tools

3.1.1 Android operating system. Apart from the remarkable features depicted in the evaluation part, the Android operating system (OS) has been chosen, as it can be more easily released in the Google Playstore. Besides, it targets a larger audience, as there is a huge variety of smartphones running on the Android OS for distinct price ranges that users can select from. In contrast, the iOS devices are much more expensive, making them less accessible to students.

3.1.2 Android Studio (for Windows). Apart from the list of advantages mentioned in the evaluation part, the main reason for choosing Android Studio is the fact that it already integrates the following features:

- Android Studio IDE;
- Android SDK tools;
- Android 5.0 (Lollipop) platform; and
- Android emulator system image with Google APIs.

Thus, this option removes the need to download and install plug-ins separately, which can be a time-consuming and cumbersome task. Besides, Android Studio is a clever code editor whereby developers can begin new projects using sample codes. Furthermore, application projects and resources can be more efficiently managed. There is also no need to previously configure the emulator image with Android Studio, as it is already optimized.

3.1.3 Eclipse IDE. Apart from the various advantages mentioned during the evaluation, the Eclipse IDE will also be used concurrently, as its graphical user interface is easy to use and it has been extensively used for implementing codes in the past with no problem encountered. Eclipse IDE can be used for any programming language that includes an available Eclipse plug-in. Besides, even though the supplementary plug-ins have to be added manually, they are readily available and free.

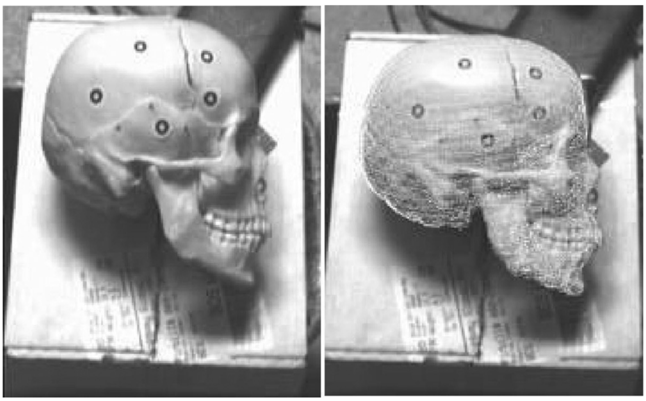


Figure 11.
Real skull with five fiducials (left), virtual wireframe skull registered with real skull (right)

3.1.4 Metaio SDK. The Metaio SDK is a library that supports object recognition, advance tracking configuration for both 2D images and 3D objects. It also supports QR codes and location-based tracking. Documentation and tutorials are available online for assistance to develop AR applications. A number of impressive projects have been produced using Metaio tools, one of which is where Ferrari gives the potential buyer an AR tour of the car. In May 2015, Apple acquired Metaio, and at the time of writing, this AR platform is no longer available.

3.1.5 Blender. Blender can be used to generate markers. The marker enables detection and tracking. It involves color space filtering and accurate calibrations. Besides, 3D texts and 3D models can be created using Blender for digital overlays.

3.2 Proposed solution

The main features of the proposed AR application for contextual mobile learning are described below.

3.2.1 Scan objects in real time. One of the main features of the application will be the capability to scan specific contents from the printed materials in real time with a mobile phone equipped with the application. This means that it should be possible to scan a figure from a book while moving the mobile phone.

3.2.2 Augmentation of scanned image by displaying digital information. The digital information consists of AR content that can be in the form of 2D images and animations, 3D-rendered models, texts and hyperlinks. These overlays enhance the learning process of students by providing useful tips, worked solutions to complex questions or simply additional information to improve students' understanding capabilities of a particular area of study. Besides, videos can also be linked to printed materials to provide supplementary educational information to students or to convert a static diagram into a dynamic one.

After the particular content has been scanned, the application shall be able to identify the content scanned from the user's printed material and augment it by displaying the digital information linked with it. This function shall be possible by previously scanning the content and storing it in a database. When that same image is scanned at a later time by another user, the application shall identify the existence of a similar image from its database. Upon successfully locating the stored image, the digital information related to that specific image will be superimposed on the screen of the mobile phone. For this functionality to be achievable, it should be ensured that the appropriate digital information associated to that specific scanned image is first uploaded in the database. Afterwards, the augmented information shall appear on the screen simultaneously with the image being scanned in real time still in the background view. These steps are depicted in Figure 12.

Figure 13 shows how the AR application was successfully used to demonstrate the "Tower of Hanoi" and binary search trees, concepts that many students of computer science have much difficulty in understanding. The feedback collected from students was very much positive and below is one such example:

> When the Tower of Hanoi was explained in Lecture, the Lecturer made his best to explain the concept to us but unfortunately we could not grasp the concept. Eventually we were asked to write a program to implement the Tower of Hanoi, which was impossible because I had not grasped the concept. With the AR Application developed, everything suddenly became clear because I was able to visualize what was happening just by using my Smartphone to scan the static image in my lecture notes. The steps became clear and I am sure I will now never forget

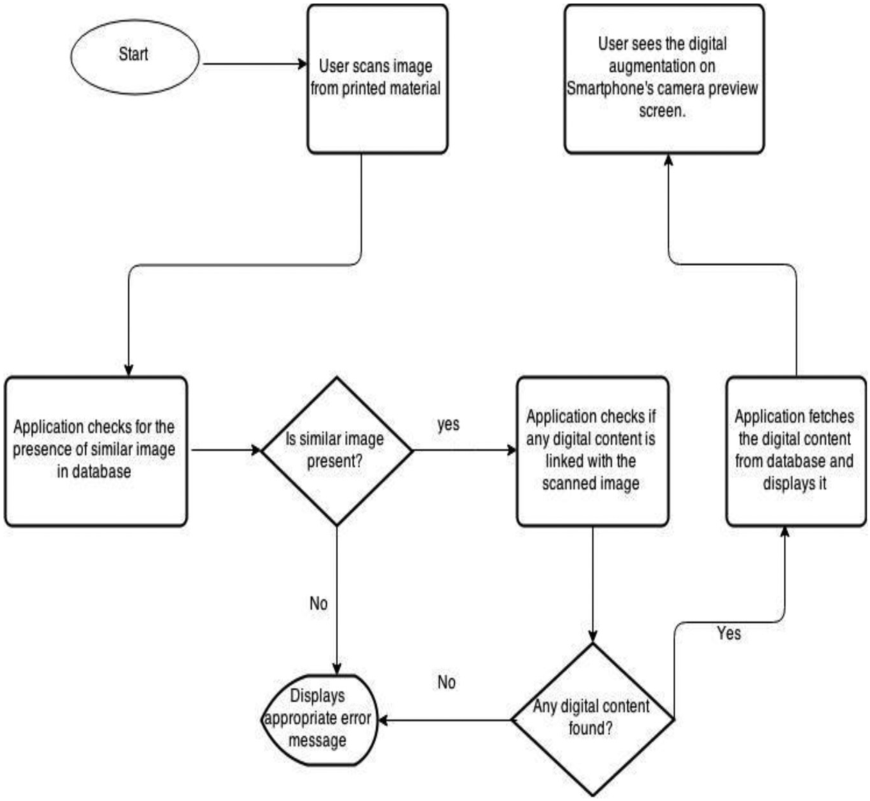


Figure 12.
Flowchart of operations

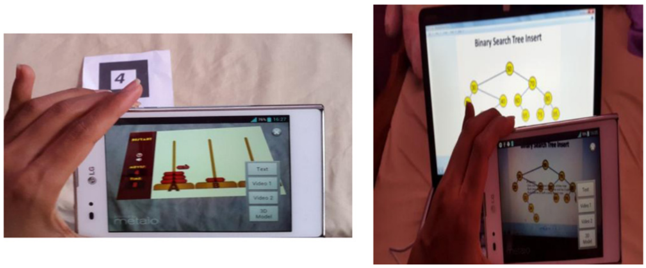


Figure 13.
Understanding complex computing concepts using AR

the concept. With the AR Application, learning the concept was fun and it can be said that learning was definitely brought to a new dimension.

3.2.3 User interface. The application shall consist of a simple and user-friendly user interface that will enable all categories of users to easily navigate throughout the application. The overall user interface shall be designed in a consistent way keeping in mind an appropriate clarity and good organization of related functions. The design of the user interface is aimed to convey clear and concise information to the users, so that every user can have a satisfying experience while using the application (Figure 14).

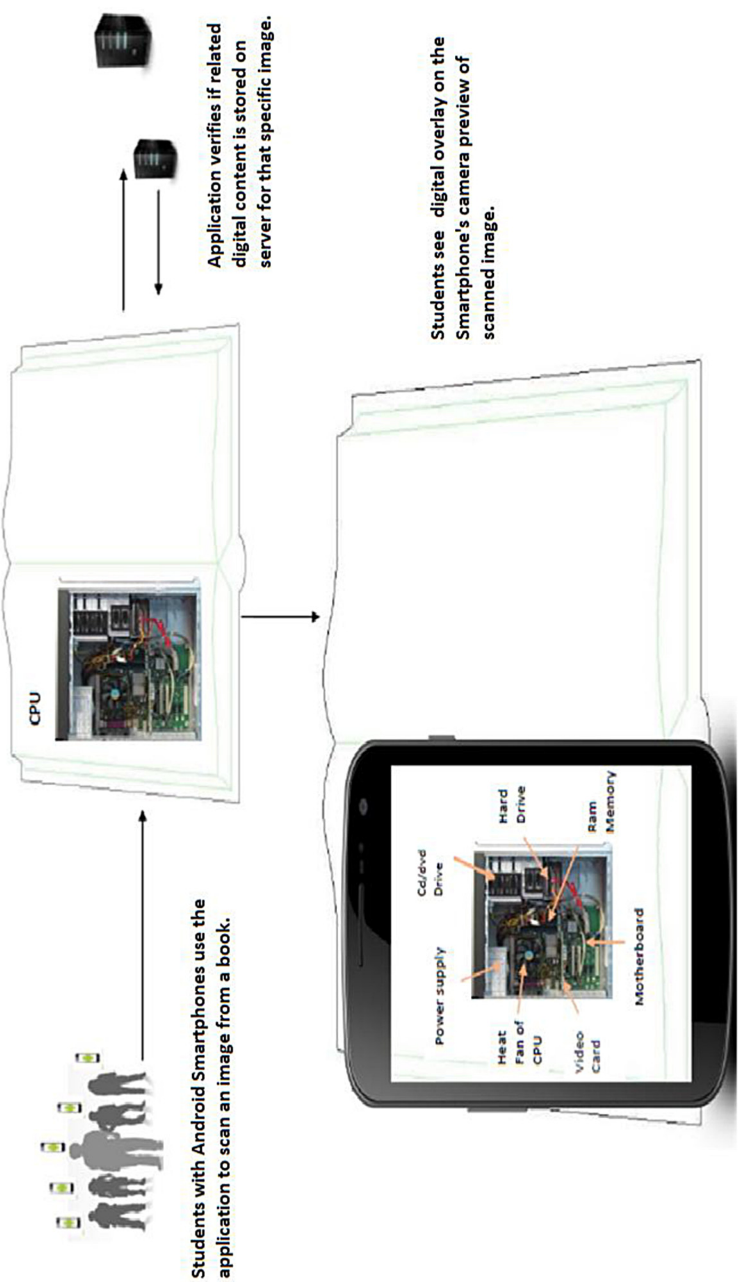


Figure 14.
The scanning
process in action

3.3 A proposed framework/process for the development of AR applications for learning purposes

After developing the AR application using a set of best practices, what is proposed in this paper is a generic framework/process for the development of AR applications for mobile learning. The generic mobile framework includes the following:

- hardware requirements in the form of smartphones;
- authoring tools for the development of the AR application, which includes Eclipse Luna, OpenGL, Blender and Android APIs, but other platforms can also be used;
- a remote database server to keep track of markers and corresponding augmentations;
- access to the internet for retrieval of augmentations; and
- general logic for the matching and retrieval of the augmentations (Figure 15).

3.4 Factors to be considered when using the application

Factors to be considered when using the application include:

- The application searches through each frame of all the square shapes detected.
- When a square shape is detected, the application uses a mathematical formula to find the orientation and position of the camera relative to the marker.
- Once the orientation and position is found, the graphic overlay is superimposed on the marker.

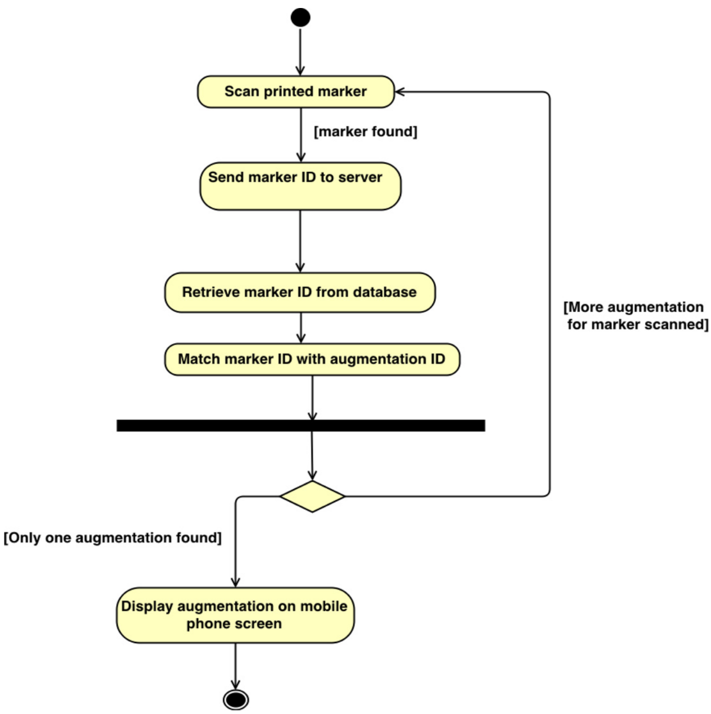


Figure 15.
Generic process

- Digital overlays can be a text, a video or a 3D model.
- When the camera orientation changes, the augmented material disappears, as the camera can no longer track the marker.

4. Results and interpretation

4.1 Experiments carried out

A number of experiments were carried out to test the robustness of the application developed and to be able to eventually come up with a set of best practices for the use of such applications. These experiments coupled with the feedback obtained enabled the carrying out of the application performance review. Two such experiments are described below:

(1) *Experiment 1*: To check if augmentation still appears when the device is moved further from the marker. The results are shown in Table I:
   - *Distance**: Refers to the distance between the marker being scanned and the phone used for scanning (Table II).
   - *Discussion*: It is noted that the distance between the marker being scanned and the phone used for scanning has to be in the range of 6-35 cm.

(2) *Experiment 2*: To check if augmentation appears when the marker is rotated at different angles. The results of this experiment are shown in Table III:
   - *Discussion*: It can thus be concluded that the algorithm tracks and records specific coordinates on the marker while scanning. The augmentation is then linked with distinct coordinates of the marker. Hence, this explains why the augmentation also changes its orientation when the marker is rotated.

(3) *Experiment 3*: Tracking of marker-based image (QR code) to check if it is detected. This is shown in Figure 16:
   - *Discussion*: The application has been able to detect the QR code and display the text overlay in different positions and orientations.

5. Proposed solution

When a user covers part of the marker with their hands or with other objects, the augmentation disappears on the phone's screen. Tracking and recognition is affected by the marker's orientation and position relative to the mobile device.

Solution: User should avoid moving the mobile device repeatedly while tracking.

Tracking is also affected by lighting conditions. Lights may create some kind of reflection on markers, thus making image recognition difficult.

Orientation	Expected results	Results	Comments
0° (no rotation)	Augmentation displayed	Passed	Augmentation appears as expected
90° clockwise	Augmentation displayed	Passed	The augmentation also rotates itself with respect to the marker's orientation
180° clockwise	Augmentation displayed	Passed	The augmentation also rotates itself with respect to the marker's orientation
270° clockwise	Augmentation displayed	Passed	The augmentation also rotates itself with respect to the marker's orientation

Table I. Rotation of marker by different angles

Table II.
Distance from marker and scanning device

Distance*	Expected results	Results	Comments
0-5	Augmentation not displayed	Passed	As the phone is too close to the marker, only part of the marker's pattern is detected. Hence, tracking is not successful
6-10	Marker tracked and augmentation displayed	Passed	Optimal distance for tracking
11-20	Marker tracked and augmentation displayed	Passed	Optimal distance for tracking
21-25	Marker tracked and augmentation displayed	Passed	Optimal distance for tracking
26-30	Marker tracked and augmentation displayed	Passed	The size of the augmentation is smaller because of the decreased size of the marker as the distance is increased. Hence, the augmentation also resizes accordingly
31-35	Marker tracked and augmentation displayed	Passed	The size of the augmentation further decreases
36-40	Marker tracked and augmentation displayed	Failed	If the phone is placed in the range of 36 to 40 cm upon first scanning of marker, tracking is unsuccessful However, if the marker has been previously tracked with a distance range of less than 35 cm and the user moves the device away from the marker, the augmentation continues to appear up to a maximum distance of 40 cm
41-45	Marker not tracked and augmentation not displayed	Passed	Neither is the marker tracked nor does the augmentation appear. The augmentation disappears if the phone with displayed augmentation is moved between 41 to 45 cm from the marker

Table III.
Tracking of marker-based image (QR code)

Objective	Check for supported orientation to scan QR code
Test data	Printed QR code, text in .obj format, video in .3g2 format
Expected test result	Application should detect QR code and display text overlay in different positions and orientations
Actual test result	Text is augmented on QR code in both landscape and portrait view
Conclusion	Test successful

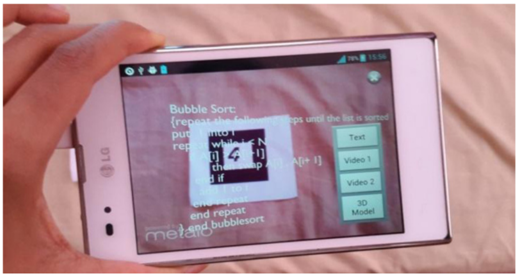


Figure 16.
Text overlaid on QR code

Solution: Tracking should be carried out in dim lighting conditions.

Tracking is affected by the distance of the marker from the mobile device.

Solution: The mobile device must be placed perpendicular to the marker and moved further away to note the maximum supported distance.

The size of markers also affects tracking. Large markers cannot be detected from the same distance as compared to small markers, as part of the image is not detected when scanning.

Solution: The larger the marker, the further away the mobile device needs to be placed for detecting it.

Complex markerless images with several patterns and intricate details cannot be easily tracked.

Solutions: Use simple images with well-defined outlines as markers for better results. Markers in the form of QR codes with large black-and-white regions are more effective.

6. Discussion

The first part of the paper has enabled us to summarize existing knowledge and interesting projects concerning AR. The research has also demonstrated that there are limited mobile AR applications as far as learning of computer science concepts is concerned, with the majority of AR applications focusing on learning of science subjects and others being used in the industry. An overview of the essential underlying technology has been described. The AR application that has been implemented for this study is also different from the ones described in the Literature Review section in the sense that it has been adapted to the local context and much more personalized for the university in question. The AR application implemented also allows marker-based images such as QR codes to be tracked. This is essential nowadays, considering the immense potential of QR codes in various aspects of life.

7. Conclusion

7.1 Achievements

The aim of this study was to come up with innovative and effective means of learning in this new era of learning through the use of AR applications for contextual mobile learning. The AR application has proved to be helpful in understanding complex concepts of computer science that average students have much difficulty in understanding. Through AR, learning has been brought to a new dimension where the students can easily visualize what is happening and easily understand complex concepts. With this learner-centered approach, students are encouraged to become more independent learners who can learn at their own pace. The low-cost system that has been proposed can track and detect both markerless and marker-based images. To further help the students, textual and video overlays are displayed on the marker scanned where the students have the option to pause and resume the video as and when required.

7.2 Difficulties encountered

While developing the AR application, a number of difficulties were encountered but solutions have been developed. Some issues that were identified were that videos in the format of mp4 could not be used and for graphical overlays, only file formats of MD2, OBJ and FBX could be used. The FBX format should however first be converted to a binary format first using an appropriate converter.

7.3 Future works

AR is a vast topic which is still under research. There are various ways to implement AR for mobile learning. The work accomplished is only an apercu of what we assume is a helpful learning tool to assist students to reduce the monotony of traditional learning methods. However reliable a system can be, improvements are always welcomed. One feature that could be considered is the use of advanced augmentations in the form of 3D models and animations, which are more appealing. However, this requires much time. Another aspect that needs to be investigated is location-based AR applications that can be used where students would be encouraged to engage in critical thinking.

References

Azuma, R. (1997), "A survey of augmented reality", *Teleoperators and Virtual Environments*, Vol. 6 No. 4, pp. 355-385.

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S. and MacIntyre, B. (2001), "Recent advances in augmented reality", *Computer Graphics and Applications*, Vol. 21 No. 6, pp. 34-37.

Bandura, A. (1977), *Social Learning Theory*, Prentice-Hall, Englewood Cliffs, NJ.

Billinghurst, M. and Duenser, A. (2012), "Augmented reality in the classroom", *Computer*, Vol. 45, pp. 56-63.

Billinghurst, M., Kato, H. and Poupyrev, I. (2001), "The MagicBook: a transitional AR interface", *Computers & Graphics*, Vol. 25 No. 5, pp. 745-753. doi: 10.1016/s0097-8493(01)00117-0.

Bower, M., Howe, C., McCredie, N., Robinson, A. and Grover, D. (2014), "Augmented reality in education– cases, places and potentials", *Educational Media International*, Vol. 51 No. 1, pp. 1-15.

Brown, J.S., Collins, A. and Duguid, P. (1989), "Situated cognition and the culture of learning", *Educational Researcher*, Vol. 18 No. 1, pp. 32-42.

Cawood, S. and Fiala, M. (2007), *Augmented Reality: A Practical Guide*, Pragmatic Bookshelf, Raleigh, NC.

Chang, G., Morreale, P. and Medicherla, P. (2010), "Applications of augmented reality systems in education", in Gibson, D. and Dodge, B. (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2010*, Association for the Advancement of Computing in Education (AACE), Chesapeake, VA, pp. 1380-1385.

Cristancho, S.M., Moussa, F. and Dubrowski, A. (2011), "A framework-based approach to designing simulation-augmented surgical education and training programs", *The American Journal of Surgery*, Vol. 202, pp. 344-351.

Davidsson, M., Johansson, D. and Lindwall, K. (2012), "Exploring the use of augmented reality to support science education in secondary schools", *Proceedings of the Seventh IEEE International Conference on Wireless, Mobile, and Ubiquitous Technology in Education WMUTE 2012, Takamatsu*, 27th-30th March.

Dede, C. (2009), "Immersive interfaces for engagement and learning", *Science*, Vol. 323, pp. 66-69.

Dias, A. (2009), "Technology enhanced learning and augmented reality: an application on multimedia interactive books", *International Business & Economics Review*, Vol. 1 No. 1.

Driscoll, M. (2000), *Psychology of Learning for Instruction*, Allyn & Bacon, Needham Heights, MA.

Dunleavy, M. and Dede, C. (2015), "Augmented reality teaching and learning", in Spector, J.M., Merrill, M.D., Elen, J. and Bishop, M.J. (Eds), *The Handbook of Research for Educational Communications and Technology*, 4th ed., Springer, New York, NY.

Dunleavy, M., Dede, C. and Mitchell, R. (2009), "Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning", *Journal of Science Education and Technology*, Vol. 18 No. 1, pp. 7-22.

Freitas, R. and Campos, P. (2008), "SMART: a system of augmented reality for teaching 2nd grade students", *Proceedings of the 22nd British Computer Society Conference on Human-Computer Interaction (HCI 2008)*, *Swinton*, pp. 27-30.

Garret, B.M., Jackson, C. and Wilson, B. (2015), "Augmented reality m-learning to enhance nursing skills acquisition in the clinical skills laboratory", *Interactive Technology and Smart Education*, Vol. 12 No. 4, pp. 298-314.

Hincapie, M., Caponio, A., Rios, H. and Mendivil, E.G. (2011), "An introduction to augmented reality with applications in aeronautical maintenance", *13th International Conference on Transparent Optical Networks (ICTON)*, *Stockholm*, pp. 1-4.

Hsu, C. and Shiau, H. (2013), "The visual web user interface design in augmented reality technology", *International Journal of Advanced Computer Science & Applications*, Vol. 4 No. 2.

Ifenthaler, D. (2010), "Learning and instruction in the digital age", in Spector, J.M., Ifenthaler, D., Isaías, P., Kinshuk and Sampson, D.G. (Eds), *Learning and Instruction in the Digital Age: Making a Difference Through Cognitive Approaches, Technology-Facilitated Collaboration and Assessment, and Personalized Communications*, Springer, New York, NY, pp. 3-10.

Johnson, L., Adams, S. and Cummins, M. (2012), *NMC Horizon Report: 2012 K-12 edition*, T.N.M. Consortium, Austin, TX.

Johnson, L., Levine, A., Smith, R. and Stone, S. (2010), *Simple Augmented Reality. The 2010 Horizon Report*, The New Media Consortium, Austin, TX, pp. 21-24.

Kaufmann, H. and Schmalstieg, D. (2003), "Mathematics and geometry education with collaborative augmented reality", *Computers & Graphics*, Vol. 27, pp. 339-345.

Kerawalla, L., Luckin, R., Seljeflot, S. and Woolard, A. (2006), "'Making it real': exploring the potential of augmented reality for teaching primary school science", *Virtual Reality*, Vol. 10 Nos 3/4, pp. 163-174. doi: 10.1007/s10055-006-0036-4.

Koutromanos, G., Sofos, A. and Avraamidou, L. (2016), *The Use of Augmented Reality Games in Education: A Review of the Literature*, International Council for Educational Media, Taylor & Francis, Routledge.

Lee, K. (2012), "Augmented reality in education and training", *TechTrends*, Vol. 56 No. 2, pp. 13-21.

Liarokapis, F., Mourkoussis, N., White, M., Darcy, J., Sifniotis, M., Petridis, P. and Lister, P. (2004), "Web3D and augmented reality to support engineering education", *World Transactions on Engineering and Technology Education*, Vol. 3 No. 1.

Maier, P. and Klinker, G. (2013), "Evaluation of an augmented-reality-based 3D user interface to enhance the 3D-understanding of molecular chemistry", *5th International Conference on Computer Supported Education – CSEDU 2013*, *Aachen*, pp. 294-302.

Munnerley, D., Bacon, M., Wilson, A., Steele, J., Hedberg, J. and Fitzgerald, R. (2012), "Confronting an augmented reality", *Research in Learning Technology*, Vol. 20.

Regenbrecht, H., Baratoff, G. and Wilke, W. (2005), "Augmented reality projects in the automotive and aerospace industries", *IEEE Computer Graphics and Applications*, Vol. 25, pp. 48-56.

Rekimoto, J. (1998), "Matrix: a realtime object identification and registration method for augmented reality", *Proceedings of the 3rd Asia Pacific Computer Human Interaction*, *Shonan Village Center, Japan*.

Shelton, B. and Hedley, N. (2002), "Using augmented reality for teaching earth-sun relationships to undergraduate geography students", The First IEEE International Augmented Reality Toolkit Workshop, Darmstadt.

Shin, C., Kim, H., Kang, C., Jang, Y., Choi, A. and Woo, W. (2010), "Unified context-aware augmented reality application framework for user-driven tour guides", International Symposium on Ubiquitous Virtual Reality (ISUVR), Gwangju, pp. 52-55.

Shuhaiber, J.H. (2004), "Augmented reality in surgery", *Archives of Surgery*, Vol. 139, pp. 170-174.

Silthanen, S. (2012), "Theory and applications of marker based augmented reality", *V. Science*, VTT Technical Research Centre, Finland, available at: www.vtt.fi/inf/pdf/science/2012/s3.pdf (accessed 31 May 2016).

Specht, M. (2012), "Mobile augmented reality for learning: a case study", *Journal of The Research Center For Educational Technology*, Vol. 7 No. 1.

Squire, K. and Jan, M. (2007), "Mad city mystery: developing scientific argumentation skills with a place-based augmented reality game on handheld computers", *Journal of Science Education and Technology*, Vol. 16, pp. 5-29.

Su-Ju, L. and Ying-Chieh, L. (2015), "Integrating augmented reality technology to enhance children's learning in marine education", *Environmental Education Research*, Vol. 21 No. 4, pp. 525-541. doi: 10.1080/13504622.2014.911247.

Vygotsky, L.S. (1978), *Mind and Society: The Development of Higher Mental Processes*, Harvard University Press, Cambridge, MA.

Zimmermann, A., Lorenz, A. and Oppermann, R. (2007), "An operational definition of context", *Modeling and using Context*, Springer, pp. 558-571, available at: http://link.springer.com/chapter/10.1007/978-3-540-74255-5_42 (accessed 31 May 2016).

Zimmermann, A., Specht, M. and Lorenz, A. (2005), *Personalization and Context Management*, User Modeling and User-Adapted Interaction, Springer, Vol. 15, pp. 275-302.

About the authors

Roopesh Kevin Sungkur, Akshay Panchoo and Nitisha Kirtee Bhoyroo are from the Computer Science and Engineering Department, Faculty of Engineering, University of Mauritius. Roopesh Kevin Sungkur is lecturer in the same department and his research interests include technology-enhanced learning. Roopesh Kevin Sungkur is the corresponding author and can be contacted at: r.sungkur@uom.ac.mu