Chapter 11

MARE: Mobile Augmented Reality Based Experiments in Science, Technology and Engineering

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Abstract

The average learner today, being quite exposed to information and communication technology tools, is less inclined to read books or manuals and prefers to carry out most of the communications on-line using new/modern electronic devices or gadgets. The traditional teaching styles built around using only face-to-face classroom based lessons no longer suit the learning styles of the average learner; introducing multimedia or other on-line content into teaching results in improved performance by the learners. Blended e-learning or other on-line teaching strategies tend to focus on the delivery of theoretical material; however the pedagogy/training of engineers, technologists and scientists involves a strong hands-on practical/laboratory training component as they are expected to create new things/technologies and not just repeat what previous generations did. The benefits of this hands-on or practical component include stimulating deep and reflective learning, thereby improving the creative problem solving capabilities while also providing exposure/insight into real world problems and challenges. This chapter introduces mobile augmented reality (semi-immersive 3D virtual reality) as a vehicle for the delivery of practical laboratory experiments in science, technology and engineering. Mobile augmented reality delivers multi-sensorial interactions with a computing platform over commodity hardware technology that is already widely accepted. Two illustrated examples in the fields of micro-electronics and communications engineering are presented to highlight the innovative features such as the ability to closely replicate an existing laboratory based hands-on experiment and use of the mobile augmented reality experiment as a blended learning aid for laboratory experiments or stand-alone off-line experiment for distance learning.

11.1. Introduction

The education of engineers involves an integral component of hands-on (interactive) work along with delivery of theoretical (sometimes abstract) concepts [1]. The curriculum of science based subjects, such as physics and chemistry, also includes a compulsory experimental component that is usually carried out in a controlled or laboratory environment, where learners are in direct contact with the laboratory/experimental apparatus and equipment.

In engineering, it has been reported that the laboratory environment also helps in developing other “soft" skills such as team work and in acquiring creative problem solving capabilities [2]. Additionally, learners within the engineering laboratory environment also develop insight into solving real world problems and challenges, sometimes by making relations and associations to their earlier (practical) experiences [3].

11.1.1. Online Laboratories

In the last twenty years, online laboratories including remote and virtual laboratories are increasingly being used in the training of engineers. In remote laboratories, the physical experimental apparatus or equipment is directly connected to a computer communication network such as the internet and used remotely by learners. In virtual laboratories, the experimental apparatus is replaced by a computer-software simulation based on mathematical model(s), all components and items used in the experiment are completely virtual or exist only within the computer application [4].

Remote laboratories play an important role in improving the efficient usage of laboratory apparatus as they can provide time-share access to the laboratory equipment even during hours outside normal laboratory time. Some types of experiments that involve manual activities such as mixing of chemicals and physically combining electrical circuits require within laboratory interventions by an operator employed to provide the necessary hands-on assistance to remote users [5].

In online experiments/laboratories, learners (users) are expected to provide the input/control information (sometimes through a web based interface) required by the remote equipment that runs the experiment, any output (from the equipment/experiment) is then returned to the remote learners or users [6]. Online laboratories are also used for distance learning as there is no need for the learner to be physically co-located with the laboratory equipment. Online laboratories are an example of the use of computer based aids in the training of engineers as they are typically available from computer based platforms.

11.2. Reality and Virtuality

Humans typically perceive, experience and relate with the world or environmental space around them using the five physiological senses of sight, sound, touch, smell and taste, although the former three are more readily used. According to [7], reality is a state of having existence or substance or alternatively an object that is actually experienced or seen. The same source goes further to portray reality as the opposite of an idealistic or notional view of objects; that is, having a “virtual” view of objects.

Fig. 11.1 shows an adaptation of the Reality-Virtuality Continuum from [8]. At the left-hand extreme of the continuum, there is the real environment and at the other extreme there is the virtual environment (virtual reality) and in-between them is the mixed-reality zone (augmented reality and augmented virtuality). Travelling along the continuum from left to right represents diminishing reality (or real objects) and increasing virtuality (virtual objects) and at the point of virtual reality, there are no longer real objects. That is, at the virtual reality end of the continuum, the environment (world) is completely made up of virtual objects or marked by a lack of real objects.

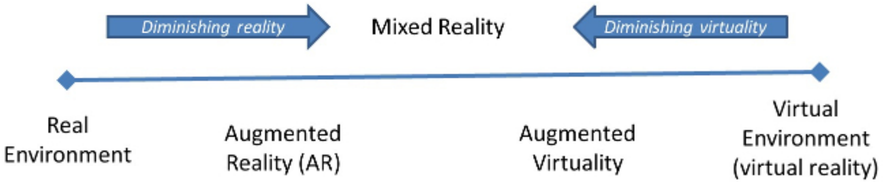


Fig. 11.1. Simple representation of a Reality-Virtuality Continuum.

The continuum identifies two different kinds of mixed-reality, which are augmented reality (AR) and augmented virtuality. In augmented virtuality, the environment has more virtual objects than real as the completely virtual surrounding environment has a few real objects in it. Naturally, the centre of the continuum represents a situation of balance between real and virtual objects, although, [8] reports this as a hypothetical situation where the real world is seamlessly blended with the virtual world. At the right-hand extreme end of the continuum, virtual reality (VR) may be described as a multi-dimensional computer generated simulation of an environment completely devoid of real objects.

11.2.1. Virtual Reality (VR)

In Virtual reality (VR), the term three dimensional (3D) is used to indicate a view of an object, system or environment capable of providing an additional dimension to the regular two-dimensional view of length and width. The additional dimension could refer to the display of object depths (x, y and z-axis) or the heightened stimulation of other human senses such as sight, sound or touch. VR technology permits a user to interact with a computer in a more natural manner than is normally supported by the traditional computer input devices of keyboard and mouse.

Actively engaging the user is vital to making virtual reality perceptually realistic as the user has an active and cognitively engaging role in the virtual environment where his or her natural behaviour produces an immediate and observable impact. In this situation, the user may undergo an immersion or the psychological experience of losing one’s self in the virtual computer/digitally generated environment, space or world.

The virtual (or computer generated) environment may or may-not be modelled after or based-on an existing real world, however, typical laws of physics such as gravity and time may or may-no-longer hold true as it is possible to allow the participants (within the confines of the virtual world) to overcome limitations that were previously imposed by the physical world [9].

VR systems are usually classified into the following three different levels according to the degree of immersion provided [10]

- **Non-immersive** VR systems generally do not provide a stereo view of the environment. For example, viewing a VR environment on a typical computer screen is a non-immersive experience as the virtual environment exists only inside the computer screen and interactions with the environment could be through the keyboard, mouse or sometimes joystick devices.
- **Semi-immersive** VR systems provide a bigger view of the computer generated environment. This is typically achieved through the use of a large screen device or through the use of special eye-wear or goggles. In semi-immersive VR systems, special input devices such as wands, special gloves or controllers are also commonly used. The user has a view of both the computer generated environment and the surrounding real world environment. A good example of a semi-immersive VR environment is a gaming station typically used for car racing, in which the output is a combination of one or more large-screen monitors and the input consists of a mock-up driving station complete with steering wheel and foot pedals.
- **Fully-immersive** VR systems eliminate completely any reference to the real world environment. This may be achieved by wearing special helmet devices with mounted displays or by housing the user in specially designed rooms called CAVEs (Cave Automated Virtual Environments) where all the walls (including floor and ceiling) are essentially replaced by large screen monitors. In both cases, the computer generated environment is projected on the displays or monitors all around the user. Fully-immersive environments also track the user movement particular orientation and may track the user's gestures and movement for input or optionally use wands, special controllers or special gloves in case tracking of individual finger movements is required for the simulated environment.

11.3. Augmented Reality (AR)

Augmented reality (AR) remains a growing research area, since its introduction in the 1960s era, although it was not considered as a research area until the 1990s. There are many definitions of AR and most of them reflect the use in a specific domain or context. For example, Milgram, positioned AR as a view of a physical or real world environment that is enhanced (augmented) through the use of computer generated or digital data [8]. Another definition portrays AR as the real-time integration of three dimensional virtual (computer generated) objects into a three dimensional real world environment [11]. Both definitions emphasize the visual or graphical aspect of the technology.

A third definition contextually speaks of augmenting the natural feedback to (equipment) operators (or users) with simulated cues [12]. As this last definition implies, there are other forms of AR such as auditory augmentation which involves the use of audible sounds via speaker devices (sometimes arranged spatially) and haptic augmentation which covers the delivery of tactile feedback (touch, pressure or vibrations) via small motors or similar devices.

In AR, visual, auditory and haptic augmentations may be used all together as outputs, although the visual form is more commonly encountered [13]. Both auditory and haptic AR systems have been used to support learning especially for the visually challenged learners [14].

A generalized definition, combining elements from all three definitions, is that AR is the real-time fusion of virtual or computer-generated objects and/or information into a multi-dimensional real-world environment. This definition reduces the emphasis on the visual or graphical nature and also encompasses visual, auditory and haptic inputs/outputs as the computer generated virtual object may include different types of media such as real-time video, audio or even digital data from various sensors.

Within the generalized definition and regardless of the target or subject domain and application, an AR system demonstrates three main characterizing features:

- **Real time:** AR systems typically run in real time and also the user is able to interact with the objects within the augmented environment in real time.
- **Blended environment:** AR systems combine real world environment with computer generated objects into a seamless virtual or real space. Practically, this is sometimes achieved by introducing special place holders known as markers for virtual objects within the physical environment. In many cases, Quick Response (QR) codes or other abstract objects are used as markers. The future appears to be towards marker-less AR systems.
- **Object Manager:** AR systems primarily manage the integration/interactions between the real and virtual objects as well as the interactions between user and virtual objects. For example, clashes between the placement of virtual and real objects have to be resolved and in some cases, shadows from virtual objects drawn or rendered over real objects. Also, when required, the AR system manages the interactions between the end-user and real objects. As shown in Fig. 11.1, AR is the first stage in the transition from reality to virtual reality or the point at which virtual objects begin to appear in the continuum, while in augmented virtuality systems, the environment is completely virtual (not related to the physical environment) and includes some real objects. For example, the typical satellite based navigation system for cars is an augmented virtuality system as it combines real location data with computer generated two dimensional or quasi-3 dimensional maps. In this example, the environment or surroundings (within the display) is a virtual map that may sometimes be out of phase (or outdated) from the real environment around, however the current position data is taken or interpreted from real location and movement sensors in real-time.

11.3.1. Visual Augmented Reality

In the visual form of AR, the user has a clear (transparent) view of the real world and the goal is to blend the virtual objects into the view of the real world in order to enhance or complement the real world objects. Visual AR systems may be classified into two broad categories, see-through and monitor-based.

In see-through visual AR system, the real world view of the surrounding environment is seen through the display medium, (for example transparent glass lenses) in order to maximize the presence of other objects in the real space [15]. Most visual AR devices that look like a pair of goggles are see-through AR systems. Another form of see-through visual AR systems used extensively in the advertising industry involves the projection (optically) of the computer generated information onto the real world objects or surfaces, sometimes using mirrors [11].

See-through visual AR is already considered a mature technology as it is used extensively by the military, even though there are still problems related to accuracy, precision, low latency tracking (of humans) and calibration. Video see-through AR [16] is a different form of visual AR where the real environment is composed of a live video feed from a camera and virtual objects are superimposed on this live video feed [17].

Monitor-based AR systems [18] are used to provide a window on the (mixed reality) world (WoW) experience [19]. In some monitor based systems, the augmentation happens in the visual display device (monitor), where two independent signal streams are mixed together for display. For example, computer generated information could be digitally or analogically placed over another video stream. This form of AR is used in the television industry for effects such as sub-titles in movies (the movie may be store and the sub-titles are added during broadcast, so the mixing of the signals is still real-time, as viewers can only choose to view or remove the sub-titles).

Monitor-based AR is also used for sports/racing broadcasts, where additional information such as biography, speed and performance data is directly overlaid on the live video stream. Typically in the case of sports/live broadcasts, the augmentation process is not under the control of the viewer (end user) and so cannot be turned on or off. The monitor-based visual AR systems are simpler to implement due to the fact that augmentation is only for a limited number of objects without the need to fully understand the real environment and is also without the need for user feedback or interactivity. Monitor-based AR is used in learning especially for augmenting video lessons such as in distance education or providing language based sub-titles to educational videos. A key disadvantage of the monitor-based AR systems is the lack of interactivity with the user [11].

11.3.2. Technological Advances

Augmented reality (AR) systems are dependent on enabling hardware technological devices such as audio-visual capture and playback devices and other haptic devices and technological improvements in these devices have given rise to notable advances in AR [11]; some examples in the areas of marker tracking, system calibration and photo realistic rendering, include:

- **Ability to use normal (arbitrary) objects as augmentation marker:** The AR marker is a type of place holder physically in the real world that acts as a reference point for insertion of virtual objects in the combined world or blended environment. Traditionally AR markers were composed of QR codes in 2 or 3 dimensions. With the new developments such as silhouette tracking, it is now possible to use arbitrary/normal patterns on paper, real physical objects, 3D models and photographs of objects. Marker-less augmented reality is also possible.

- **Advanced tracking of objects:** Accurate tracking of the objects from the view point of the user is crucial for good user experience in AR. New techniques such as single constraint at a time (Scaat) algorithm allows faster tracking with automatic calibration of different input devices such as camera devices with different resolutions. Tracking of objects inside a video stream is now sufficiently advanced and useable in real time.

- **Photo-realistic rendering:** Some applications require virtual objects to be indistinguishable from real objects when rendered. Several different techniques now exist that approximate the illumination and reflectance of virtual objects to the environmental illumination and reflectance values for a more photo-realistic effect on the virtual objects. Also, the ability to use photographs for texture surface (instead of computer generated surfaces) improves the realism of computer generated object and reduces computational requirements for rendering surfaces.

- **Automatic scalability:** Thanks to advances in hardware such as camera, display and many-core computational processors the augmented reality systems can now automatically scale and dimension the virtual objects based on the distance of the user from the marker. When 3D model data for virtual objects is available, the AR system also provides the ability to pan and rotate the virtual objects in real time and in relation to the user's perceived spatial position. For the user, all this is as simple as moving the tablet closer to the marker or change viewing angles.

AR applications are currently used in a wide range of fields, such as the reconstruction of heritage [20], the training of operators in specialized processes [21], the training operators in system maintenance [22] and the tourism sector, where it is used for augmenting visits to museums and historic buildings [23]. The health sector also uses AR for the visualization of complex human organs as well as for medical training [24].

11.4. Mobile Augmented Reality (mAR)

Mobile AR is a young technology that may be described as the application of AR via (or to) mobile devices. This description conceptually includes portable custom-gear, head-mounted devices (HMD), smartphones and tablets. Up till a few years ago, AR was considered an expensive technology used mainly by the military and entertainment industry due to the need for custom-gear, HMDs, other highly specialized hardware devices and equipment; the focus in this chapter is limited to the more cost-effective AR on smart-phones/tablet devices.

There is considerable interest in use of mobile platforms for learning as almost all learners own or use a mobile device (smart-phone or tablet) [24]. Mobile learning (m-learning), which can be described as learning on the move or learning through a mobile device positions the mobile-device as an effective and inexpensive tool for learning in new ways [25].

Closely related to m-learning is mobile science (m-Science), which involves the use of mobile devices for collecting (sensing), processing (computing) and disseminating scientific data [26]. For example, [27] reported how students used mobile devices and a customized application for gathering geometrical data that was subsequently used by the students to build a 3D model of a physical building.

The advent of powerful mobile devices with good quality touch-screen displays and an array of in-built sensors is a favourable development for AR on such devices [14]. The three basic feedback channels of mobile devices namely, loudspeaker(s), display-screen(s) and the ability to vibrate are directly useful for auditory, visual and haptic based AR respectively. Furthermore, mobile devices also carry one or more of the following in-built sensors: microphone, multi-touch input (display), camera, location/positioning, accelerometer (for acceleration, rotation or orientation), proximity, ambient light level, which are used to aid the augmentation process. The built-in camera in particular, is fundamental for video see-through augmented reality on mobile devices.

The majority of existing applications of mobile AR focus on providing passive information (text, audio and video overlays) to users, although based on real-time input from sensors about the user's physical location, movement and gestures. FitzGerald et al. [14] provide several examples of mobile AR applications from specific domains such as architecture and tourism that engage the user in an exploratory role (like in games) aimed at the discovery of additional material or content.

Research on technical issues affecting mobile-devices such as vision, interfacing [13] and sensor accuracy have been indirectly beneficial to mobile AR. For example, the available sensors in mobile devices have limited accuracy (±10 metres) in determining the position or location from the Global Positioning System (GPS); accuracy is further reduced by adverse ambient conditions such as tall buildings and weather [14]. However, modern mobile devices have improved on this through the use of Assisted GPS (A-GPS), where additional triangulation based on information from ground-based radio systems such as wireless (Wi-Fi) radio access-points and GSM radio towers, is to used improve location positioning to ±5 metres or less.

Mobile devices were designed for personal (or individual) use, even during their use in learning activities. However, in mobile AR some level of collaborative work is possible, as groups of learners may use their mobile devices for individual view points of a common physical object or marker [28]. Also, mobile devices depend on rechargeable batteries for energy to function; this may require learning activities that require them to factor in time for battery charging or changing.

11.4.1. Creating Mobile Augmented Reality (mAR) Applications

Fig. 11.2 shows the technical flow-chart for an AR app running on a mobile device or the sequence of steps implemented by the AR applications presented later in Section 11.5. As shown, several distinct and complex software processing steps/stages are required in AR applications; these include managing a hardware camera device (required for capturing a view of the real-world), image processing/detection (required for recognizing markers), image rendering/texturizing (required for introducing virtual objects into the view of the real world) and a real-time event-driven programming model, which is required for managing user input and interactions between real-objects, virtual-objects and end-user.

The process of creating AR application on mobile devices has benefited from the introduction of standard Application Programming Interfaces (API), frameworks and Software Development Kits (SDK) for various mobile-device platforms. For example, developing software for smart-phones running the Android Operating System (Android) depend on the free Android SDK tools available for various software development environments [29].

The software stack/architecture of most mobile platforms thanks to a UNIX heritage is composed of four main parts: the kernel, run-time libraries, frameworks and applications. Apart from providing low-level drivers for hardware components, the kernel also manages real-time scheduling and access to resources. The core run-time libraries and other third-party libraries interact with the kernel to access and use the managed resources. End-user software applications generally access hardware resources through various frameworks that may in-turn depend on run-time libraries as this is easier than using the kernel low-level direct access.

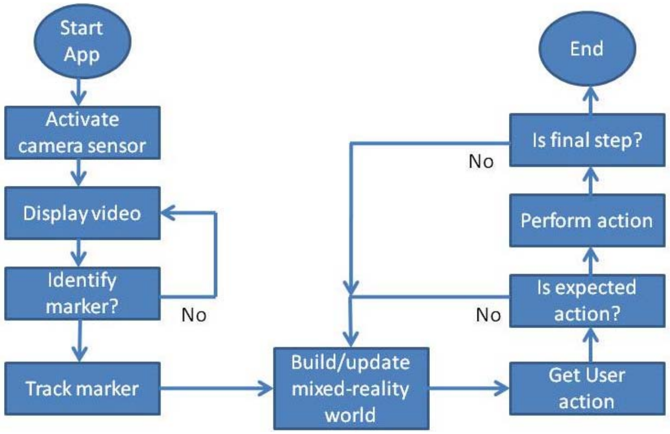


Fig. 11.2. Technical flowchart for video see-through augmented reality on mobile devices.

The Android SDK has simplified AR software development as it includes APIs for a wide range of hardware sensors including accelerometers, gyroscopes, proximity sensors, barometers, as well as for handling input/output from touch-screen displays [30].

The low-level programming required to manage the hardware camera is challenging as different camera devices do not behave consistently even for common problems such as poor resolution due to distance, motion blur and poor lighting/contrast situations. The Android platform provides a hardware-abstracted solution in the form of a high-level Camera API (in the SDK) that is capable of compensating for many types of problems [31].

The low-computational power of mobile devices has implications for high-speed image processing (detection) required for tracking a marker, the process may be slower for partially visible markers. In mobile AR, the marker image is decomposed into unique set(s) of simple shapes and angles, which is then registered or encoded within the AR application as the marker. At run-time, high-speed marker recognition is based on real-time decomposition of images followed by partial grey-scale pattern matching against the registered set(s). The inclusion of angles allows the identification of the marker at different distances, resolutions and angles from the camera. The Android SDK already contains some “limited” image processing functionality that is used exclusively for Face Detection, but this is not usable for AR as it lacks the ability to register arbitrary images/patterns for detection.

In AR, virtual objects are defined by shape-files that are rendered in 3D by a suitable graphics library or engine that also provide the ability to scale objects. The current generations or versions of Android SDK are limited in this respect but there are several libraries or engines that provide 3D capabilities on Android platforms. Typically, in rendering, the distance between the marker and camera lens, as well as the relative angular orientation of the mobile device (possible from accelerometer sensor) are used to compute a scale and perspective for rendered objects.

Nowadays, there are many commercial high-level SDKs for performing augmented reality on mobile platforms, although, some are free for non-commercial use. The Android applications presented in Section 11.5 were developed by combining the Android SDK with a 3rd party image-processing SDK and another 3D rendering library/engine. In future, it is possible that the free Android SDK would eventually grow to include both the image-processing and 3D rendering capabilities maybe as a dedicated framework/API for AR.

11.5. Augmented Reality in Education

There have been many projects about the use of virtual reality (VR) and augmented reality (AR) in education, although AR based environments for learning have not been systematically studied [32]. For example, the Magic Book uses head mounted (see-through) AR viewer to augment a normal story book. When viewed through the AR viewer, the characters from the story book are shown in 3D with animations [28]. Another example is the CREATE project, where a mixed reality (AR) framework was developed that enables the real-time construction and manipulation of photo-realistic virtual worlds from real data sources. According to [33] the CREATE framework was used for educating learners about cultural heritage, architectural design and urban planning. Also, [32] reported an AR application for mechanical engineering that allows users to interact with a web based 3D model of a piston.

The affordable nature of mobile devices has completely revolutionized AR and its research. The mobile device is now viewed as a powerful tool that can be deployed for both formal and informal learning in science and engineering. According to [27], mobile AR provides opportunities for combining learning and entertainment in new ways that are especially suited for both laboratory and classroom. A summary of 11 selected studies by [34], included none in engineering, 1 in biology, 1 in science (that used HMDs) and finds that the majority of mobile AR based learning systems have focused on role-playing/exploration educational games and other simulation using custom-gear, HMDs and cell-phones.

A key criticism of AR (both mobile and otherwise) is that learning may be driven more by the strengths and weaknesses of the AR tools rather than pedagogical content [34]. That is, the learners may focus on their shining new mobile devices (smart-phones and the AR application) rather than the intended learning objectives. For example, [14] reported that during outdoor learning activities, students prefer to work in a shaded area as they could not view the mobile device display-screen under sunlight. Another criticism reported by [24] is that AR could lead to overloading the learner with too much contextual information at once which may be counter-productive to the learning process.

Innovative research on mobile AR technology and applications is gaining ground in many academic environments worldwide. For example, Fig. 11.3 shows a Computer Aided Engineering Education (CAEE) concept, which was the result of research activity, between the University of Ulster [35] in Northern Ireland and the International Centre for Theoretical Physics (ICTP) [36] in Italy, on the use of computer aids in engineering education.

The CAEE scheme combines interactive video with virtual/mixed reality computing technologies for the enhanced, interactive delivery of educational materials in the field of engineering and science while also maintaining existing pedagogical contents and standards. The CAEE concept is composed of two separate components (one for classroom and the other for practical laboratories) related with a similar synergy to that which exists between classroom teaching and practical hands-on laboratory classes as shown in Fig. 11.3 (shaded rectangle).

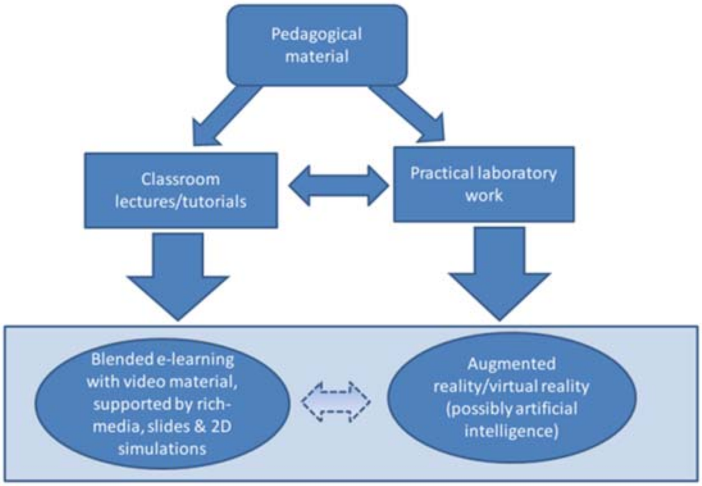


Fig. 11.3. Conceptual overview of a Computer Aided Engineering Education (CAEE) scheme.

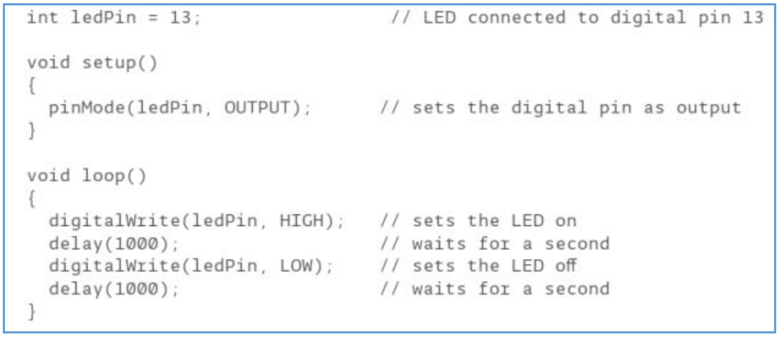
The CAEE component for hands-on laboratory practical work focuses on the use of video see-through AR on mobile devices/platforms (smart-phones and tablets) with the goal of replicating as much as possible the experience obtainable from an actual physical laboratory. The limited capability (computing & storage) of commodity mobile devices is overcome through a unique approach of simulating the experimental procedure rather than the experimental apparatus. The step-by-step procedures were coded as individual actions driven by events such as a touch action by the user, while the apparatus (virtual) were coded as three-dimensional shape files used in building the mixed-reality environment.

The innovative application of mobile AR technology is demonstrated by the following example implementations from the CAEE research work.

11.5.1. Experiment 1: Augmented Reality Based Experiment in Micro-electronics Engineering

The stalker line of the Seeding [37] group of pre-fabricated boards (an Arduino compatible board) is sometimes used to teach about embedded sensors in micro-electronics [38]. The board which may be powered from a +5 V source such as a universal serial bus (USB) port or a battery or from a solar panel device already includes a low-power programmable micro-processor (the AtMega328P), a real time clock (RTC) circuitry (crystal, chip and CR2032 battery) along with associated circuitry that allows the connection or addition of one or more modular/functional devices such as low-power sensors/wireless radio transmitters alongside basic components such as resistors [39].

At the Telecommunications/ICT for Development (T/ICT4D) Laboratory of the International Centre for Theoretical Physics (ICTP) [36] located in Trieste, Italy, the Seeding stalker v2 board is used in several practical experiments on wireless sensor networking including an introductory experiment where the intended learning outcome is to introduce the learner to using the pre-fabricated board in driving (pulsating) a Light Emitting Diode (LED). The hands-on experiment in the laboratory requires 2 additional components, an external resistor and a light emitting diode in addition to the pre-fabricated board, which is powered through a personal computer (or laptop), that also runs the integrated development environment (IDE) used for programming the board. The code-fragment shown in Fig. 11.4 may be used to pulse the LED at different frequencies.



```
int ledPin = 13;                  // LED connected to digital pin 13

void setup()
{
  pinMode(ledPin, OUTPUT);       // sets the digital pin as output
}

void loop()
{
  digitalWrite(ledPin, HIGH);    // sets the LED on
  delay(1000);                   // waits for a second
  digitalWrite(ledPin, LOW);     // sets the LED off
  delay(1000);                   // waits for a second
}
```

Fig. 11.4. Example Arduino software code for pulsating LED.

The intended learning outcome (goal) of the experiment to familiarize the user with the Seeding board is achieved when the learner is able to connect the resistor and LED to the right sockets of the board, power the board via a personal computer running the IDE and pulsate the LED.

Augmented Reality (AR) Version

An AR version of this experiment was developed that uses a low-cost 2D photographic mock-up of a Seeding stalker v2 board as a photo realistic marker alongside an application for android based mobile devices (smart-phones and tablets) that include a video-camera sensor used to capture and provide the real environment within the mixed reality world.

Fig. 11.5 shows the initial view of the android application at start up.

In Fig. 11.5, the two additional components (LED and resistor) are virtual (computer generated) objects built from 3D shape-files. The step-by-step experimental procedure of connecting the components to the board were coded as individual actions as shown in Fig. 11.2 activated by user touch-events.

The learner connects the components to the board by touching them within the augmented environment. Once both components are attached to the board, the LED begins to pulsate and a new window shows the example code programmer. Fig. 11.6 shows the completed running experiment with the pulsating LED. An additional slider control is provided that allows the learner to vary the LED pulse-rate.

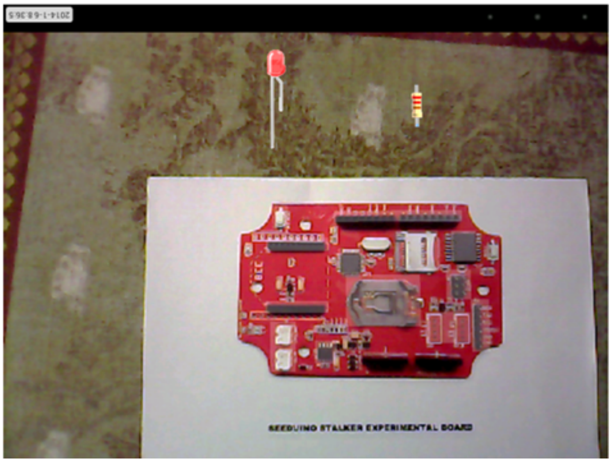
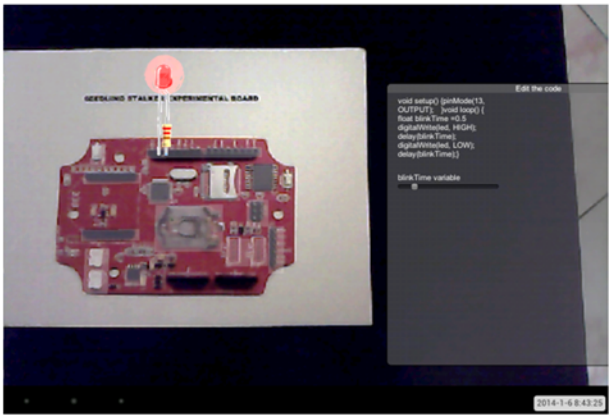


Fig. 11.5. Initial view of CAEE implementation.



```
void setup() {pinMode(13,
OUTPUT);    }void loop() {
float blinkTime =0.5
digitalWrite(led, HIGH);
delay(blinkTime);
digitalWrite(led, LOW);
delay(blinkTime);}
```

Fig. 11.6. View of completed augmented reality based micro-electronics experiment.

The AR application is also capable of acting as a smart interactive manual and showing a textual description (computer generated information) of the various components of the board whenever they are individually touched on the augmented display.

This smart interactive manual mode may also be used to seamlessly blend information from online resources such as data sheets or other experiments that use the individual component into the AR space.

11.5.2. Experiment 2: Augmented Reality Based Experiment in Communications Engineering

In communication engineering, the proper selection, design and use of antennae play a major role in all wireless radio based communication. During training, the communications engineer is often required to understand the sometimes subtle differences in various types of antennae from standard radiation patterns and how the design parameters affect the effectiveness of a particular type of antenna in relation to the surrounding objects or obstacles. Acquiring practical hands-on skills on antennae may be carried out in a laboratory setting or as part of a field exercise where the learner can practically use different types of antennae. For example, the learners are divided into groups (or teams) with the goal of establishing bi-directional wireless radio links between two groups. The intended learning outcome is that learners are expected to attain a better understanding of the effects of design characteristics on different types of antennae along with their relationship to the overall efficiency of an antenna.

At the Telecommunications/ICT for Development (T/ICT4D) Laboratory of the International Centre for Theoretical Physics (ICTP) [36] located in Trieste, Italy, learners are introduced to the following three different types of antenna:

- Yagi Antenna: The Yagi is a common directional antenna. The key defining characteristics of a Yagi are the length and number of elements in the antenna. The hands-on experimental procedure requires learners to understand the effect of changing the number of directional elements in a Yagi antenna from 3 to 9 and finally to 16 elements. Practically, this experiment involves the use of 3 separate Yagi antennae.

- Spider Antenna: The spider antenna is a simple Omni-directional antenna. During the hands-on experimental procedure, learners are required to vary the angle of the grounding pins between 5, 10 and 15 degrees. Practically, this experiment involves the use of 3 separate spider antennae.

- Cantina: The cantina is a special unit-directional antenna typically made from commonly available metal cans. During the hands-on experimental procedure, learners vary the signal frequency on cans of different diameters. Practically this experiment involves the use of cans with different diameters.

Augmented Reality (AR) Version

The experiments involving the three different antennae are implemented by a single AR application with three different marker objects (mock-up). All mock-ups are simple sketch diagrams of the individual antenna and the application only tracks a single marker at a time even when all three are present and visible.

The application has a button at the upper right-hand corner of the screen for switching between 2D and 3D mode. Changing antenna options or parameters are only supported in 2D mode.

The range of possible actions (step-by-step procedures for the experiments) were varied internally within the application based on the tracked marker. As shown in Figs. 11.7 and 11.8 on the Yagi antenna, three buttons labeled 3, 9 and 16 are provided at the bottom for changing the number of directional elements on the yagi antenna as the real experiment required different types of yagi antennae. As shown in Figs. 11.9 and 11.10 on the Cantenna, four buttons are provided, the first two (labeled +5 % and -5 %) are for changing the diameter of the can, the other two are for changing the frequency also by +5 % and -5 %. Similarly, the real experiment required several different cans of different diameters. As shown in Figs. 11.11 and 11.12 on the spider antenna, 3 buttons are provided at the bottom of the screen for varying the angle of the grounding pins between 5, 10 and 15 degrees. The experiment required physical manipulation of the angles of the grounding pins.

Fig. 11.7. A view of the Yagi antenna with 16 directional elements and radiation pattern in 2D.

Fig. 11.8. A view of the Yagi antenna with 16 directional elements and radiation pattern in 3D.

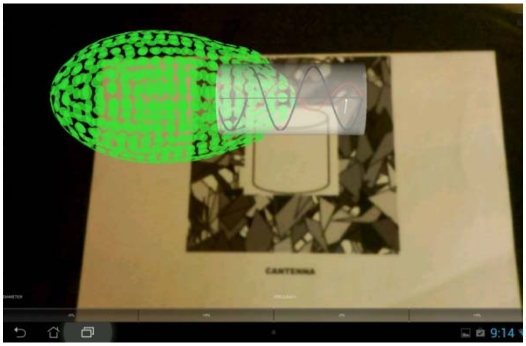


Fig. 11.9. Cantina with 3D radiation pattern.

Fig. 11.10. Cantina with 2D radiation pattern.

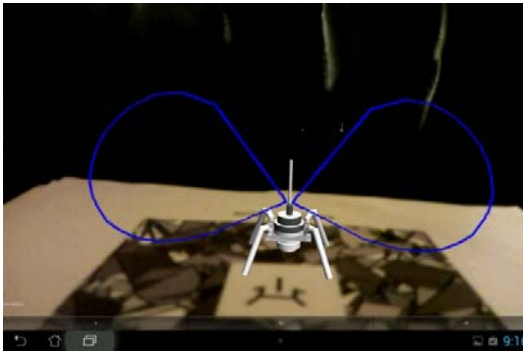


Fig. 11.11. Spider antenna with radiation pattern in 2D.

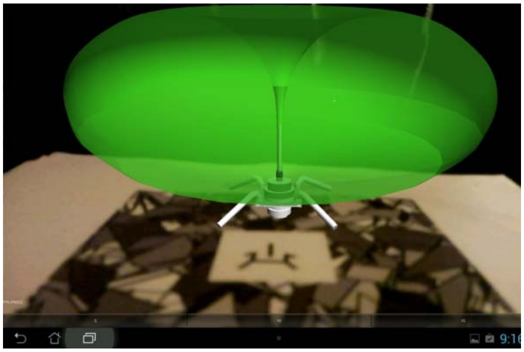


Fig. 11.12. Spider antenna with radiation pattern in 3D.

11.5.3. Evaluation

A hundred and forty-eight engineering and sciences students from two institutions, the Addis Ababa University, Addis Ababa, Ethiopia and the Obafemi Wallow University, Ile-Ife, Nigeria, were asked to anonymously evaluate both CAEE AR applications described in Sections 11.5.1 and 11.5.2. The survey collected voluntary subjective opinion from a random sample population about the effect on learning/grades and topics for which AR experiments would be built, using open questions. The mean age range of respondents was between 21 – 24 years, and for the majority of them, the presented tools represented their first contact with augmented reality technology.

At both institutions, a local contact was selected from the academicians that participated in a local pilot study carried out to establish conformance to both international and institutional standards. The authors and local contacts ensured only consenting volunteers (valid students) participated in the study, without incentives, risks and disadvantages. Participants in the survey could freely choose to respond to any of the included questions. An information sheet was used to inform participants of the purpose of the study, provide assurance of confidentiality, the intended use and end-of-life of the collected data.

The sample population was composed of 74 % undergraduate students (40 % from final year, 21 % from 1st year and the rest from 2nd and 3rd years) and 19 % female, from the departments of Computer Science & Engineering (41 %), Electronic & Electrical Engineering (27 %), Computational Science (10 %), Physics and Mathematics (22 %). The data analysis technique for the open questions was based on the constant comparative method [40], as commonalities in the responses were used to categorize them before counting.

The participants were satisfied with the CAEE approach as less than 6 % of the sample population had negative comments about the rendering quality and/or simulation technique (that is the technique of simulating the experimental procedure rather than the apparatus/components).

The results presented in Tables 11.1 and 11.2, show that within the diverse sample population, the CAEE AR versions made a positive impression with encouraging implications on learning. Specifically, over a quarter of the sample population found the CAEE AR experiments/tools helpful to their learning/grades and the collected requests for AR versions of practical laboratory experiments suggests that respondents potentially agree with implementing mobile AR versions of laboratory experiments in Engineering and Sciences as demonstrated by the CAEE concept/ applications.

Although about 44 % of the sample population responded to this survey item in Table 11.1, less than 28 % reportedly felt helped by the CAEE AR applications (discussed in Sections 11.5.1 and 11.5.2). This is expected as the CAEE AR applications covered topics/experiments that are directly relevant to Electronics and Telecommunications engineering. 19 respondents reported they were “helped” in their learning, while 13 others reported they were helped in their grades.

In Table 11.2, the respondents provided lists of several different topics that were grouped into disciplines. The percentages appear to be roughly aligned with the broad-disciplines of the sample population.

Table 11.1. Student's self-assessed impression of the effect of the AR versions on learning and grades.

Category	Frequency	Percentage	Notes
Cannot say	82	55.40	Declined answering
Did not help	26	17.57	Negative about it
Helped	32	21.62	Agreed grades/learning was better
Helped a lot	8	5.41	Felt helped substantively

Table 11.2. Student's requests for new AR versions of laboratory experiments.

Discipline/area	Frequency	Percentage	Notes
Engineering	24	64.87	Engineering and Computing
Sciences	12	32.43	Natural sciences
Other	1	2.70	Economics and management

11.6. Conclusion

Augmented Reality (AR) technology is a young and vibrant technology, with opportunities for innovative applications. Technological advances such as better hardware, photorealistic rendering and the ability to use photographic images as markers make mobile devices (smartphones and tablets) a cost effective augmented reality viewer platform capable of replicating existing hands-on experiments using photographic copies of existing laboratory apparatus.

AR on mobile devices is complemented by the innovative approach used in the Computer Aided Engineering Education (CAEE) research work that focuses on simulating step-by-step experimental procedures along with expected input and output values rather than modelling or simulating the complete experimental apparatus. The CAEE approach show-cases how augmented reality technology may be deployed as a computer based aid for hands-on laboratory experiments in Science, Technology and Engineering.

An evaluation by 148 students from engineering and sciences, most of whom had no prior experience with AR, shows the discussed mobile (CAEE) applications made a positive impression with encouraging implications on learning.

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