CHAPTER 7

Mobile Augmented Reality

INTRODUCTION

One trend is certain. People, more so than any other time in history, are on the go, and while they are on the go, they carry technology with them. The notion of having to “go to” a specific place to do something that could potentially be done via technology they carry is very unappealing to people today, especially young people. Augmented reality (AR) exists in the world, and people are in the world wherever they are. Consequently, there is a very strong trend toward mobile augmented reality applications that can be used anytime, and anyplace, with technology that is considered mobile enough that it is with a person all the time, no matter where (or when) he or she is.

WHAT IS MOBILE AUGMENTED REALITY?

Simply put, mobile augmented reality is AR that you can take with you wherever you go. Most specifically, this means that the hardware required to implement an AR application is something that you take with you wherever you go. There is an important distinction between mobile augmented reality and portable augmented reality.

Portable augmented reality uses technology that you can move from place to place. A desk-side computer with a monitor is somewhat portable in that it can be moved from one place to another relatively easily. A laptop computer is even more portable. If the batteries are charged you can carry it easily from place to place. You can even operate the laptop while you are walking, but it is awkward and not something you want to do on a regular basis.

A smartphone, however, is a truly mobile device. It fits in your pocket and is easy to operate wherever you are, even if you are walking or otherwise engaged. Likewise, most tablet devices are mobile devices in that you can carry them easily wherever you go. They are lightweight and you can operate them while walking. For the purpose of this chapter, I consider smartphones and smart tablets to be mobile technology, but anything larger and
more encumbering than that to be either portable or permanent technologies, where permanent technologies are those that are virtually impossible to move to a new location.

There is another class of devices that needs to be considered. Handheld gaming consoles and e-readers are easy to carry around. They may or may not provide the technological support for AR at the current time, but these and portable tablets seem to be encroaching on each others’ territory in terms of the applications they run. That is, tablets are running e-reader applications and games, and game consoles are evolving toward doing more things than just games. E-readers are doing more things than just serving as e-readers and are becoming more “tablet like.” The big distinction between these types of devices and smartphones and tablets comes down to whether people would likely be carrying the devices with them anyway or not. That is, many people would carry a smartphone whether or not it had anything to do with augmented reality. Some people might carry a gaming console on a day-to-day basis, and some would not. These are clearly portable devices, but the real win in mobile augmented reality comes when the participant is not required to carry anything more than he or she would have been carrying anyway (Figures 7.1 and 7.2).

Many head-mounted displays are mobile in nature but are still rather cumbersome, and most people do not wear them on a daily basis. Newer

**FIGURE 7.1**
Devices such as e-readers are becoming more like smart tablets, and smart tablets are able to run e-reader software on them, making the distinction between the two more blurry. This particular e-reader does not contain the sensors required for augmented reality applications, but some do. Hence, an e-reader might someday serve as a mobile AR device. *Photo courtesy of Alan B. Craig.*
glasses-oriented displays are more likely to be worn on a daily basis and thus make a mobile AR system that provides the capabilities of a head-mounted display a possibility. With contact lens displays or lightweight glasses displays, the mobile AR experience can become totally seamless with your everyday life. Applications that currently require you to “look through” a tablet or a smartphone become much more compelling when you are not required to “do something” to experience the AR and that “remind you” that you are doing something special in order to experience the augmented content.

Even though personal projectors are available for around $300, and some phones have built-in projectors, portable projected augmented reality systems are not commonplace. However, it will not be too long before mobile projection becomes a practical reality and, along with it, portable projected augmented reality applications. Projection systems are especially sensitive to ambient lighting conditions where they are deployed due to the possibility of bright light “washing out” the projected image. It is also possible for bright lights to wash out the display on smartphones and tablets, but it is an especially serious consideration with mobile projectors.

---

**FIGURE 7.2**
The difference between mobile augmented reality and portable augmented reality is treated somewhat differently from person to person. Camille Goudeseune of the Beckman Institute at the University of Illinois, shown here, was participating in an outdoor augmented reality environment that required a hefty amount of technology to experience. Most of the technology was built onto a bicycle helmet, and the computer portion of the hardware was carried in a backpack. Note that the shuttering stereoscopic glasses were not required for this particular application but are seen in the place where a stereoscopic head-mounted display would normally be. This application used both visual and audio components that were placed in the environment. Photo courtesy of Beckman Institute for Advanced Science and Technology at the University of Illinois.
ADVANTAGES AND DISADVANTAGES OF MOBILE AUGMENTED REALITY

As with most things, there are advantages and disadvantages to using mobile devices for mobile augmented reality applications. The advantages are related primarily to the fact that AR applications can be experienced anywhere and at any time. The disadvantages are related primarily to constraints that are imposed in exchange for mobility, although there are sometimes advantages to using a permanent or semipermanent installation at a particular location. There are also other special considerations for those planning to create mobile augmented reality applications.

Advantages of Mobile Augmented Reality Applications
There are many advantages to using mobile technology to support AR applications. Many of them are obvious, but some are less obvious. First and foremost is the fact that augmented reality, as seen in earlier chapters, exists in the real world, wherever that might be. That is, in general it does not make sense to house the AR application in a purpose-built “facility” much like a virtual reality CAVE, video teleconference facility, or other major infrastructure. By using mobile technology, the AR application can be experienced at the location where it makes the most sense. This is not to say that, for example, there is never an occasion for an AR application to be limited to a specific geographic place. Indeed, if one builds an AR application around the (real) Eiffel Tower, then the participant(s) would need to be at the Eiffel Tower. However, mobile augmented reality allows people to bring the required technology with them. In fact, in many cases of mobile augmented reality, they would already be carrying the required hardware with them whether or not they were planning to experience augmented reality at any given moment.

Mobile augmented reality is especially well suited to ideas such as “ubiquitous learning” in which the plan is that every person learns all the time, wherever they are, when they need to. One example might be that if someone is visiting Gettysburg and wants to learn more about the Battle of Gettysburg that (assuming the fields have been AR enhanced) he or she can use his or her mobile phone or tablet to gain additional information about the battle, perhaps to see the field as it was at a historic point in time, to see the battle taking place, and also to see overlays on the fields to show how the terrain was used in the battle strategy.

One advantage of mobile technologies that might not be obvious on first blush is that they are often very low cost compared to more permanent or special-purpose technologies. In this case, I am referring specifically to smartphones and tablets. These technologies are gaining power and features on a daily basis, while at the same time their costs are dropping.
Advantages and Disadvantages of Mobile Augmented Reality

Some AR applications are only possible with mobile technology. For example, if one wants or needs to “see” simulated airflow over the wings of a (real) jet airplane, it is reasonable to take a tablet to a parked jet, but it is not possible to bring the airplane to an AR facility (Figure 7.3).

At the same time, however, as shown in an earlier chapter, it is sometimes advantageous to have a semipermanent “kiosk” at a point of sale in order to use the AR experience as an enticement to bring customers into a retail setting. In this case, it might be advantageous to have something that can be done with mobile AR but also something important that can only be done at the point of sale. Perhaps, there could be an AR application that could be used anywhere to see an example of a product in three dimensions, but only by coming to the point of sale could you see the interior of the product, and when you see the interior, you see an image of the prize you won.

Probably the key advantage of mobile AR is that in addition to being inexpensive, many people already own the necessary hardware. Current smartphones and tablets already contain the sensors, processing, and displays necessary for mobile AR applications. Having a large number of potential users already in possession of the required hardware is a very compelling attribute. As AR software improves, it is likely that there will be a handful of “master” AR client software programs (i.e., you only need to download one or two “apps” to your device to experience many different AR applications). In this case, it is likely that you would need to be connected to a network of one sort or

FIGURE 7.3
Some things are just too big to bring to an AR laboratory. Consequently, if one needs to use AR in conjunction with such a large thing, it is necessary to have a portable or mobile AR system. In this case, one could conceive of a mobile augmented reality application that allows you to see wind flow over the wings of this airplane. Photo courtesy of Clarita on morguefile.com.
another in order to retrieve the content for those different uses, but many smart devices like these are already connected to a network that would be suitable for this purpose (Figure 7.4).

**Disadvantages of Mobile Augmented Reality Applications**

Of course, along with advantages, there are a number of disadvantages with mobile augmented reality and using mobile technology to implement augmented reality applications. The most serious disadvantages are those related to constraints that must be placed on mobile AR applications due to the mobile technology itself, as well as the lack of control over the environment in which the mobile application will be experienced.

**Constraints of Mobile Augmented Reality Applications**

There are a number of constraints that limit what can be done with mobile AR applications and/or additional things that the application developer must address to overcome those constraints. The primary constraints fall into two broad categories: (1) technological and (2) environmental. These are clearly interrelated. The constraints are generally related to the limited capabilities of mobile devices, and that the application must be workable in a very wide variety of environmental conditions.

**Technological Constraints**

One of the key constraints on mobile augmented reality applications is that the resources on most devices are limited. These are manifested primarily as limited memory and limited computational capability, as well as limited graphics capability, limited input and output options, and, especially in
Advantages and Disadvantages of Mobile Augmented Reality

the case of nonprojection environments, limited screen real estate. Even if the mobile system includes some type of head-based, display such as glasses, they often have a limited field of view and limited resolution. Memory is a primary limitation on the amount of content that can be resident on a mobile device at any given moment. In real-world, practical terms, this means that there is an upper limit on the number and/or complexity of graphical and/or sound objects that can be kept on the device. There are two primary ways to overcome the limited memory available on a device. The first is to use clever schemes to limit the amount of memory that the content occupies. One way to do this is to limit the number of polygons and size of textures that are associated with visual objects and to limit the applications in the number of objects that are expected and/or required. The other way to overcome the issue of limited memory is to create a scheme by which content is loaded onto the device when needed and off-loaded when not needed. In this scenario, though, there is still a maximum amount of content that can be resident on the device at any given moment. There is more detail on this issue later in this chapter in the Architectures for Mobile Augmented Reality Applications section.

Environmental Constraints

Beyond the technological constraints imposed by the devices themselves, there are often environmental constraints that the mobile AR application developer must consider. It is often the case that there is no way a priori for the application developer to know what lighting, humidity, noise, and other environmental conditions might exist where the end user will experience the application.

In all cases of augmented reality applications and devices that use computer vision for tracking, it is essential that there is enough ambient light of the appropriate wavelength in the environment for the vision system to “see” the world (Figure 7.5).
Likewise, if an application is used outdoors, in particularly sunny areas, it is important to use screens that can be seen even in harsh glare if screens are used. Shadows in sunny spaces can also be problematic, especially when using vision-based tracking. Bright spaces are particularly difficult for projection AR environments.

For AR applications that rely on any kind of client server architecture or other means for downloading content or relying on a server system in any way, there must be an adequate network available in the area in which the system is planned to be deployed. If the system relies on the network, the end users must be made aware of this constraint, as otherwise they may take the application to an area with no network available and be disappointed when the application fails to perform as expected. One could question whether this is an environmental constraint (something essential is missing in the environment) or a technological constraint (no network available), but the presence or absence of a network can make or break the success of an AR application if a network is required.

Ambient sounds and noise are also a concern for the mobile AR application developer. If the application generates sounds, it is necessary that the participant is able to hear those sounds. Conversely, if the application is to be deployed in an area where extraneous sounds are not welcome (e.g., a church or funeral service), then it is important that the application not create unwanted sounds. Sound can be controlled more or less by a volume control and/or using headphones or earbuds, but it may be that neither of those tools can solve the sound problem in certain circumstances.

If an AR application requires sound (speech or other sounds) as an input to the system, then it is important that there not be extraneous sounds in the environment that might mask those signals.

In some circumstances, such as perhaps in medical applications that will be run in a hospital, electromagnetic interference can be problematic. Many hospitals insist that cellular phones not be used in certain areas because of the possibility of interference with medical testing and/or treatment systems. Hence, if an application requires use of a cellular telephone for communication, network, or other functions, then it is prudent to learn any appropriate restrictions or technical specifications that the system must adhere to.

Other locations might restrict the types of devices that you are allowed to carry/use. For example, many devices are restricted in some courthouses. Some industrial facilities limit the types of devices or emissions (such as radio frequency emissions) that are allowed. Computer rooms in data centers often have restrictions on the types of equipment that can be used in them. Virtually all devices are restricted on commercial air flights during takeoff and landing, and only certain devices are allowed while the plane is at altitude.
Many devices have a temperature below which they don’t operate correctly. This can be an important consideration if the application might be deployed in very cold regions. This can be a concern if an application is for collecting science data on the North or South Pole, at great altitudes, or in other areas (walk-in freezers?) that are very cold. The converse is also the case; there are technologies that cannot be used effectively in very hot environments—your potential “Desert Cactus Identification” AR application might be affected adversely if you are in a particularly hot area of the planet.

All other environmental measures, such as humidity, pressure, and magnetic fields, can have an effect on mobile devices and consequently on mobile AR applications. If you are planning to deploy AR systems in any kind of extreme area, it is important to know the limits of the technology you are using. These concerns will primarily be important to military, science, and other similar application areas but can be important to other groups as well. For example, a mobile AR application to assist firefighters could potentially help save lives and property, but only if the technology doesn’t fail under severe conditions.

**User Understanding**

In fixed location augmented reality, it can be made obvious that there is AR content at the location and what to do with it. There can be signs pointing this fact out, personnel who make it obvious to visitors what to do to make the AR work, etc. Mobile augmented reality presents the challenge that there could potentially be content anywhere. In one scenario we can imagine people walking through the world pointing their AR device at everything and everybody they see just to see if they happen to be “activated” for AR. It is likely that every person will have more than one AR application available to them at any time. How do they know which application they need for content that they may or may not know exists at any specific location? What about multiple, different competing sets of content at any given location? One could consider a scenario much like over-the-air radio and television in which one “tunes in” to different “channels” of information. Much like over-the-air broadcasts, such a scenario would require coordination and the ability of participants to make informed choices of what content they want to tune in to.

It is easy to imagine that spam could overwhelm the augmented world with unwanted advertising or unwanted information of any kind. Of course, one person’s spam may be another person’s treasure. How do we allow users to choose which content to participate with and which to filter out?

In the same way that all AR applications require intuitive, easy-to-use, perhaps standardized interaction schemes, it is especially important to have these schemes for mobile AR applications because of the potential for them to be so open ended in so many different environments. How is a participant supposed to know how to interact with new content at a new location unless
it is reasonable to figure out what to do based on a history with other content at other locations? Embedded, contextual help systems in AR applications can provide one solution to this problem.

ARCHITECTURES FOR MOBILE AUGMENTED REALITY SYSTEMS

As shown in Chapter 3 (Augmented Reality Hardware), we learned that there are different architectures that an AR application can use. As a review, these included:

1. Application run on handheld system such as smartphone
2. Application run on handheld system connected to remote server(s)
3. Application run on desktop/laptop computer
4. Application run on desktop/laptop computer connected to remote server(s)
5. Application run as a web application
6. Application run on a cloud with a thin client
7. Other combinations of local and remote systems

The same can be said basically for mobile augmented reality applications [except for #3 (application run on a desktop/laptop computer) and #4 (application run on a desktop/laptop computer connected to remote server(s))]. However, there are (as seen earlier) certain constraints that a mobile AR application must consider. Except for architecture #1 (application run on handheld system such as smartphone), each of the other mobile architectures requires some type of network connectivity. Does this mean that there is no possibility for mobile AR applications that require more resources than are on your mobile device if the Internet is not available? Of course not. There are some applications that need to be connected to the Internet at large, and some that only need to be connected to a server system for the purpose of additional computational power and/or additional memory for content and content management.

In the event that you need to deploy a mobile AR application in an area that has no network coverage, and if you need to be connected to a server, but not the Internet at large, you can install a network [most likely wireless for maximum mobility of the participant(s)] for the express purpose of connecting the mobile devices with the server.

It is not a very significant hurdle to set up a wireless network that will communicate within an area you would like to allow the mobile AR application to communicate with a server. In order to do this you only need power, the server(s), and some basic networking equipment. If you need to extend the range of the network, there are commercial, off-the-shelf solutions for that
purpose as well. If the area you are working in is outdoors and/or accessible by the public, you will need to take precautions to protect all of the equipment from weather and vandalism/thievery.

An example application that might make use of such a network and server is one where a public park (that is not covered by the Internet) might provide an AR application to show how the park looked in the past or to assist visitors in identifying flora and fauna in the park. The possibilities are endless.

This solution (building a network to allow the mobile AR application to communicate with a server) is very useful for mobile applications that take place in a specific area, but that area is not necessarily too mobile itself. That said, though, it is possible to install a network as described earlier on a bus or on a truck such that the bus or truck could travel from school to school to allow schoolchildren to experience that particular AR application. There would need to be provisions made to provide power to the server(s) and network hardware. As long as there is power available, there is no reason that such an application could not be made functional on a bus or on a train while it is in motion. Such an AR application might be considered a “mobile mobile augmented reality application.”

**SUMMARY**

Mobile augmented reality is one of the most explosive growth areas for AR applications currently. Mobile AR takes advantage of the widely distributed base of hardware such as smartphones and tablets. Because AR exists in the world, it makes sense for AR applications to be mobile and that people can experience them wherever makes the most sense in the world, whether it is at a specific exhibit in a museum or in an open field in Africa. Mobile devices that can support AR are becoming more powerful and less expensive at a very rapid pace. Additionally, new hardware possibilities are emerging, such as mobile projection devices that will allow new types of mobile AR applications to function and make sense. There is a difference between “portable” and “mobile” augmented reality applications. Some people are more willing to accept the requirements of carrying additional technology for AR applications than others. Some mobile technology is very obvious to others in the environment, whereas some is “stealth” in the sense that others in the area might not even realize that someone is engaged in an AR experience. If necessary, a computer network can be deployed if there is not already suitable connectivity in the area that the mobile AR application is intended to be used in. As computer vision algorithms become better, there will be less need to “set up” an area to be AR enhanced ahead of time in any way by utilizing natural features of the area, such as skylines or famous landmarks, to aid the AR application to determine where the device is in the environment (Figure 7.6).
The next chapter addresses augmented reality applications in general, what makes a compelling AR application, how to evaluate AR applications, AR application styles, how to apply AR to a problem, and collaborative AR applications and illuminates several AR application “case studies” to show some ideas that are currently being used in AR applications as well as applications that were created for differing purposes and technologies.