Introduction to Augmented Reality Concepts and Technologies

Juliet Chukwuemeka[6862196]

[1] Paderborn University, Paderborn 33098, Germany
[2] Warburger Str, 100, 33098 Paderborn, Germany
juliet@mail.uni-paderborn.de

Abstract. Abstract. Augmented reality is a technology that layer's computer enhanced graphics on a person's view of the physical world. The main reason of this paper is to present an introduction to Augmented Reality assist-ed robot programming, its technologies and concepts. This paper presents the idea of augmented reality assisted robot programming, a brief look at the past to see where some of the ideas supporting augmented reality came from. Augmented reality appeals to many senses, however currently it is mainly visual. Augmented Reality can be used in many different application areas like manufacturing, medicine, education and other areas which are dis-cussed in this paper.
A number of Augmented Reality components will be discussed and an overview of them will be provided. Many technologies can be used to implement augmented reality assisted robot programming and this paper talks about the different methods and types of technology that can be utilized. Future works relating to Augmented Reality assisted programming are dis-cussed.

Keywords: Augmented Reality · Robot Programming · AR Application.

1 Introduction

1.1 Background

Augmented Reality (AR) is a recent upcoming technology coming from Virtual Reality. Augmented reality is a process that involves overlapping computer-generated information, this can be audio, images or video over a real-time environment. The AR computer interface have three characteristics which were suggested by Azuma (1997) [1]: (1) Combination of virtual and real world, (2) Interactivity in real time and (3) Registration in 3D. AR amplifies on the real world by superimposing virtual objects and enhancing the user's perceptions and their interaction between virtual and real environments. Thus, AR supplements reality instead of completely replacing it. Therefore, AR can be said to the a "middle ground" or a combination between a completely manufactured and a completely real environment. A continuum containing these environments is shown in Figure 1.

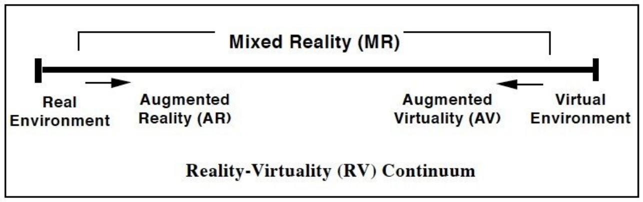

Fig. 1. Reality - Virtuality Continuum.

1.2 Brief History of AR

This section outlines some brilliant people and some of the remarkable contributions they brought in terms of Augmented Reality development. In 1968 Ivan Sutherland and Bob Sproull created the first Augmented Reality system called The Sword of Damocles. This was a head-mounted display. In 1975 Myron Krueger created a Video-place, which is an artificial reality laboratory. The Video-place allowed users to inter-act with virtual objects for the first time. In 1990 the term "Augmented Reality" was established by David Mizell and Thomas Caudell - Boeing company researchers. In 1999 Hirokazu Kato developed ARToolKit to provide an efficient method for AR system construction.

1.3 Robot Programming

Augmented Reality (AR) research has been active in robot applications and various works have also addressed robot programming. Current robot programming approaches lack the efficiency and intuitiveness needed for fast and easy applications. There are several robot programming methods namely: (1) Online programming, there are two different types of online programming: teach pendant and lead-through. Teach pendant are like touchscreen tablets, in order to program the robot, the operator moves from point-to-point, with the aid of the buttons on the pendant to move it around and save each position individually, once the entire program has been learned, the robot can play back the points at full speed. The teach pendant method is unintuitive and slow. Lead-through involves physically guiding the robot around the work-space, moving the robot to desired positions and recording the points. This method is very intuitive but it is less precise and it poses safety concerns for the users within the robot's work-space.

In spite of reducing the need of manually writing programming code, present day conventional robot programming methods are still time-consuming. This results in the robot programming process being costly and time-consuming for programming complex tasks. Robots have to be re-programmed regularly for high-mix low-volume products. Therefore, the cost of employing robots is high for the small and medium enterprises (SMEs).

(2) Offline programming/simulation: Offline programming is performed without the need of the actual robot. Offline programming method is the construction of a robot and its work-space in a virtual environment. This is done with teaching and simulating tasks through a virtual prototype of the robot. Path planning optimization algorithms with crash avoidance can be used of offline programming. Therefore, decreasing the effort needed by developers and increasing the quality of the robot programs. In offline programming, high fidelity *Computer-aided design* (CAD) models of the actual robot and their kinematics have to be modelled to depict the actual robots so as to generate a realistic simulation. It is computationally intensive and time-consuming to model the actual robot with high fidelity. These models and kinematics may need to be modified many times after they have been applied to the real robots [16]. This simulation needs to be tested on the actual robot before offline programming can be executed. These tests may need more effort to refine the method to reach high fidelity. Offline programming is inflexible when it comes to unknown environments because it needs to model the physical entities in these environments. Also, offline programming packages requires the users to know complex programming languages that are software specific. Offline programming is less intuitive as compared to online programming.

To overcome the constraint of conventional robot programming methods, An augmented reality-assisted robot programming system can be implemented. Augmented reality has been used to generate applications that provide guidance or electronic user manuals to assist developers in manufacturing processes like maintenance and robot path planning.

1.4 AR-assisted Robot Programming

AR can enhance robot programming in two ways. First, AR interfaces can allow developers to access computer software and data straight from the actual work-space of a robot, therefore increasing information perception. Second, virtual reactive objects can be overlaid on real objects to increase user interaction with the robot programming system. Zaeh and Vogl [17] reported a the use of projection-based AR interfaces for robot programming. A laser projector is used to project an AR user interface, that contains user-defined end-effector paths and menus on work-space surfaces and work-pieces for the developers to edit the robot's motion parameters. A stylus is used to interact with the menus on the AR user interface, it traces the necessary end-effector paths and defines the orientation of the end-effector tracked using an optical tracking system. Projection-based AR interfaces are only seen on surfaces. To solve this problem, Gaschler et al. [18] combined a computer monitor with video projection to enable the visualization of robot tasks in a virtual work-space.

This method, nevertheless, caused extra mental load for the developers as they had to concentrate on two different displays (the display on the monitor and the

AR projection on the actual work-space). Fang et al.[19] introduces a marker-based AR-assisted system that uses a see-through head-mounted display (HMD) with a handheld pointer to define the robot paths and end-effector orientations manually. As this system relies on the trusty markers in the robot work-space for tracking and registration. There are dead-zones in the AR environment where tracking is not achievable. Using marker-based tracking and registration limits the positions and viewing angles in the robot work-space. AR assisted robot programming is designed to allow users will little robot programming skills and knowledge to program tasks for a robot. The system converts the work-space of a robot into an AR environment.

2 Augmented Reality Today

Augmented Reality has continuously developed over the decades and it has worked its way into the modern technological scene of today. This chapter looks at the different application areas where AR is being used.

Medical Training From operating Magnetic resonance imaging (MRI) equipment to performing complicated surgeries. A medical operation using robotics and AR is shown in Figure 2. Neurosurgery is one of the top areas when it comes to surgical applications of AR. The capability to image the brain in 3D on top of the patient's actual anatomy is very important for the surgeon. Medical students at Cleveland Clinic at Case Western Reserve University will learn anatomy using an AR headset which allows the user to explore the human body in an interactive 3D environment. Also, visualizations helps in explaining complicated medical conditions to patients. AR has the potential of improving the effectiveness and accuracy of medical training.

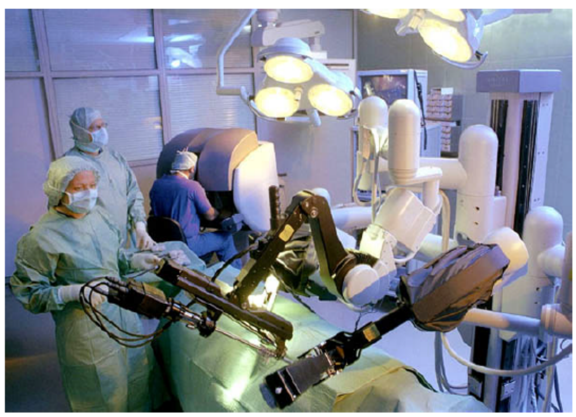

Fig. 2. Robotics using AR for medical operation.

Maintenance and Repair A mechanic making repairs to an engine can use a head-worn display. The mechanic sees a superimposed imagery and information in his actual sight. The system is presented in a box in the corner and an image of the needed tool demonstrates the exact motion the mechanic has to perform. The AR system labels all the important parts of the engine. Simulations can be used in the training of technicians and this can reduce training expenses.

Education Information technology is modifying education in numerous ways. Firstly, from the amount of information that is readily available for everyone that has access to the internet to online learning and teaching methods. Secondly, Technologies like tablets are now being used in many schools, which is boosting up student's learning experience with AR. For example, students learning about astronomy can see an entire map of the solar system, music students might be able to see some musical notes in real time while learning how to play some instruments and medical students can use AR technology to practice surgery in a controlled environment.

Military Heads-Up-Display (HUD) is an example of AR used in military. A transparent display is placed directly in the fight pilot's view. Data that is usually displayed to the pilot includes horizon line, airspeed, altitude and other important data. The term "heads-up" applies due to the fact that the pilot doesn't have to look down at the aircraft's instrumentation to get the required data. Head-Mounted Display (HMD) is used by troops that are on the ground. Important data like enemy position can be displayed to the soldier within their line of sight. This technology is also utilised for simulations for training purposes.

Entertainment Mobile application is the most common implementation of augmented reality, this is where virtual objects appear over an image on a device. For example, SnapChat adding dog ears and tongue to a person's face. AR games like Pokémon Go superimposes mythical creatures over a person's everyday landscape.

Navigation One of the biggest uses for Augmented Reality is navigation. Enhanced GPS systems use AR to make it easier to get from one point to another. City guides and maps like Maps.me and Google Maps helps people to locate places to eat, drink, shop or relax have Augmented Reality capabilities that offers users real-time visual directions to the particular places they were looking for [3]. TapNav uses the smartphone's camera in combination with the GPS to show the user the selected route over the live view of what is in front of the car. An image of the TapNav application is shown in Figure 3.

Advertisement Nowadays companies like BMW, Toyota and Nissan are using magazine advertisements and AR to offer viewers 3D view of the cars. Harley Davidson developed an application that lets their customers view a motorcycle in store and customize it on their smartphones. Lego companies use AR systems to provide children with an animated version of the completed Lego set which is inside the box. Another company that has also taken advantage of Augmented Reality is the motion picture industry. It does so by promoting movies like Avengers, Transformers, and Star Trek.

Robotics Robots can be programmed with the aid of Augmented reality. A robotic operator uses a visual image of the work-space to direct the robot. when

Fig. 3. TapNav Application

the operator attempts a motion, it is first practiced on a virtual robot that is visualized as an augmentation to the real one. After seeing the results, the operator can decide to proceed with the motion on the actual robot (Figure 4).

Fig. 4. AR assisted robot programming

3 Augmented Reality Concepts

This chapter looks at the components of Augmented reality (AR) and the wide categories of concepts required to implement Augmented Reality and also shows how Augmented Reality works.

3.1 How AR works

In this section a brief introduction to how Augmented Reality works will be given. Firstly, Augmented Reality applications can be described as a two-step process. Secondly, more details of what is in each of these two steps will be discussed.

Sensors. Sensors are used to determine the state of the real world where the application is positioned. So in order to be able to respond correctly to the real world, an Augmented Reality application must have knowledge about the physical world in real time. Cameras on devices scans the environment and with this information, the device finds physical objects and generates 3D models. This device can be special duty cameras like in Microsoft Hololens or ordinary smartphone cameras to take pictures or videos. Sensors collect data about the user's interactions and sends it for processing.

Process. At the center of any Augmented Reality system is a *processor* that coordinates and examines senor inputs, stores and retrieves data. The processor carries out the tasks of the Augmented Reality application program, and generates the suitable signals to display. That is to say, every Augmented Reality system includes a computer of some kind. Computing systems for Augmented Reality may range from handheld devices like smartphones and tablets to laptops, computers and workstation class machines. In all these cases, the device must have sufficient computational ability to carry out the tasks it has been assigned in *real time*. Figure 5 shows a person pressing a virtual button on a tablet.

Display. A display is the component that causes a suitable signal to influence on a user's senses [8]. There have been different trends in Augmented Reality display, from static to wearable and then handheld displays. The most trending display is the **optical see-through (OST)** technology. The idea of seeing the real world through a semi-transparent screen and projecting some virtual content on the screen still remains. The blending of the physical and virtual worlds happens directly on the retina of the human eyes rather than on the computer screen. Figure 6 depicts this action.

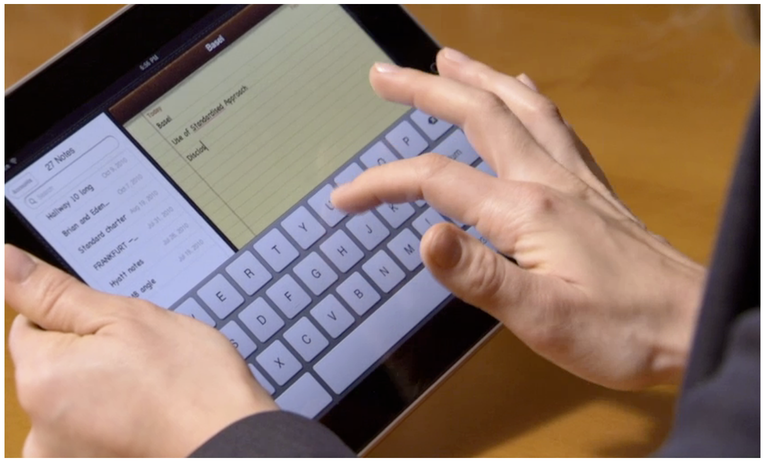

Fig. 5. Person pressing a virtual "button" on a tablet

The other trending Augmented Reality display is **video see-through (VST)** technology. Imagine perceiving the world indirectly through a video on a monitor. The video image is combined with virtual content, which is sent back to a display like a computer screen, smartphone or the impending head-mounted displays as shown in figure 7. A HMD is used to display the AR user interface and provide a view of the augmented work-space, so as to allow users to recognize augmented 3D graphics with depth perception [15]. Figure 8 shows an Oculus Rift DK2 HMD for User-interaction and display.

Interaction with the environment. In order to build an Augmented Reality application, interaction between environments are required. Augmented Reality interaction applies to choosing and controlling digital and physical objects plus navigating in the augmented scene. High level Augmented Reality applications allow users to utilise objects that can be on a table all the way to moving virtual characters, using their hands to choose some floating virtual object while taking a stroll down the street. Also speak to a virtual agent that is appearing on a smart watch to set up a meeting later during the day.

Registration in 3D. Augmented Reality needs more knowledge about virtual and real content. AR needs to know where things are in space (registration) and follow where they are going (tracking). **Registration** is aligning real and virtual content in the same space. In movies and sports 2D or 3D graphics are superimposed onto scenes of the real world. AR is based on aspects which were earlier mentioned in chapter 1 section 1.1.

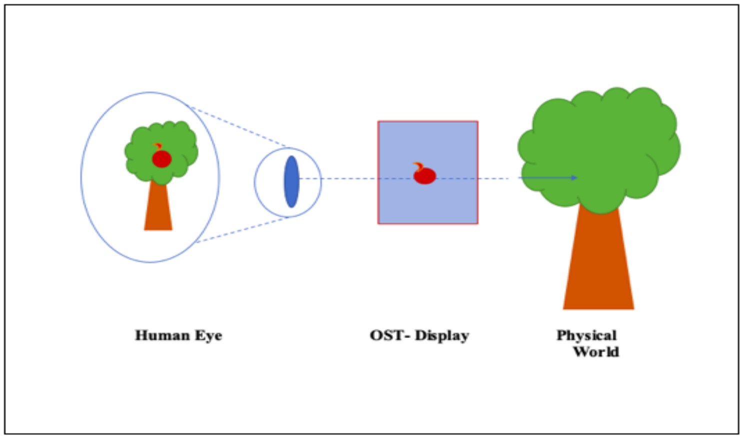

Fig. 6. Optical See-Through (OST)Technology

3.2 Types of Augmented Reality

Marker-based AR. This can also be referred to as image recognition, cause it needs a visual object and a camera to scan it. This can be ordinary images or little objects. The AR device calculates the orientation and position of a marker to place the content in some cases. Therefore, a marker starts digital animations for users to view, and that's how images in a magazine can turn into 3D models figure 9.

Marker-less AR. This is location-based AR, it uses GPS to give data based on the user's location. The data then decides what AR content you find or get in a particular area. With smartphones, this type of AR normally produces maps and directions, close by businesses information.

Projection-based AR. This involves projecting synthetic light to physical surfaces, it may also allow for interacting with it. It notices user interaction with a projection by its adjustments. These are the holograms in science fiction movies like Avengers and Star wars.

Superimposition-based AR. This replaces the original view with a partially or fully augmented view of that same object Figure 10. Object recognition plays an important role because without it, the entire concept is impossible. An example of superimposed augmented reality is in robot programming, it allows users to place virtual information in their work-space.

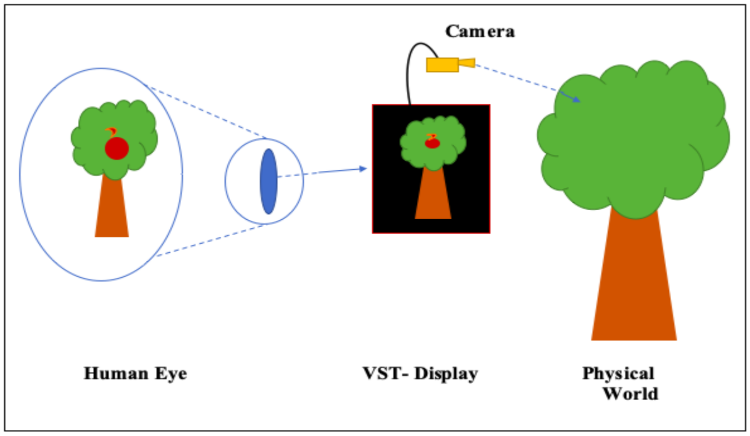

Fig. 7. Video See-Through (VST)Technology

4 Augmented Reality Technologies

This chapter presents some of the software development kits used to perform the task of fusing digital content and information with the real world. Software libraries for developing the AR Apps are also presented. A review is given evaluating their strengths and weakness.

4.1 AR Software Development Kits (SDKs)

ARToolKit. ARToolKit is one of the first AR SDKs, it is an open-source library used for developing augmented reality applications based on marker identification. The principle of ARToolKit is that it processes graphic data which are received from the mobile camera in run-time mode lead by initial known square object markers. Then the objects are displayed on the smartphone's screen considering their location in space. Nevertheless ARToolKit allows for plugin integration with Unity. Apart from Android and iOS, ARToolKit is used for AR apps on Windows, Linux, and Mac OS. Variety of functions makes it challenging to integrate the library and it is time consuming to explore all options and settings.

Vuforia. Vuforia uses computer vision to recognize and track image and 3D objects in real-time. This functionality enables AR developers to place virtual objects, in relation to the physical world environment. 3D models are then overlaid on top of the physical world scene and viewed in relation to the environment through an AR-enabled smartphone or tablet. At the core of Vuforia lies a QCAR library which is written in C++. Vuforia allows for development of

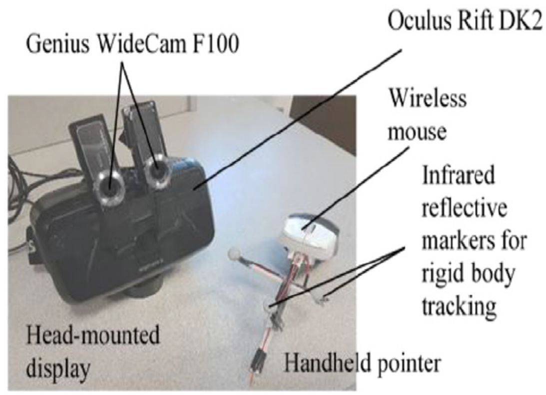

Fig. 8. Interaction and display device

iOS and Android and the development of AR apps in Unity Editor. One of Vuforia 's strength is that it is simple to setup. This makes it easy to generate a development environment, install the right SDK version and then build an app.

Apple ARKit. ARKit is a framework that enables developers to design and generate unique experiences for iOS 11+ iPhone and iPad devices. ARKit enables 3D objects and and digital information to be merged with the physical world. ARKit works with third-party graphics engines like Unity. One of ARKit's strength is that it offers mostly unique accessibility in terms of the number of existing devices that it supports. One weakness is that ARKit can only run on devices that are equipped with an Apple A9, A10, or A11 processor.

Google ARCore. ARCore replaces Tango toolkit which was initially meant to develop AR apps on hardware equipped with depth measuring sensors. ARCore is a Google software development kit (SDK) which was designed for Android 8.0+ app creation. One main advantage of ARCore is that as opposed to Apple ARKit,it supports developing AR applications for both iOS and Android. ARCore has three notable Features that enables developers to blend virtual content into the physical environment: environment understanding, light estimation and motion tracking. ARCore supports a wide range of Development Plugins: Android NDK, Unity for Android, Unity for iOS and Unreal.

Wikitude. Wikitude is a cross-platform AR SDK that fuses 3D Markerless tracking technology (SLAM), object identification and tracking, image recognition and tracking, cloud recognition and Geo-location features for apps. Wikitude supports these platforms: Android, iOS, Unity Editor, Smart Glasses, JavaScript.

Fig. 9. Marker-based AR

Wikitude supplies Wikitude Studio which makes the development process easier, programming skills are not needed. The app can be created by dragging objects on the studio screen.

Table 1. Augmented Reality SDK Comparison

	ARToolKit	Vuforia	ARKit	ARCore	Wikitude
Supported platforms	Android, iOS, Linux, Windows, macOS	Android, iOS, UWP	iOS	Android, iOS	Android, iOS
Licence Type	Free	Free, Commercial	Free	Free	Commercial
Smart glasses support	+	+	+	+	+
Unity support	+	+	+	+	+
Cloud recognition	-	+	-	-	+
3D recognition	+	+	+	+	+
Geo-location	+	+	+	+	+
SLAM	-	-	-	-	+

4.2 Development Tools

Unity. Unity is a strong, cross-platform 3D environment with a user-friendly development editor [13] which is used to develop applications 3D content (It is a Game Engine). It contains a combination of different modules for rendering and managing 3D objects, animations, lighting, audio etc. The Unity modules have programmer interface, with plenty sets of functions and classes. The whole system can be accessed via scripts which are written in C# programming language.

Fig. 10. Superimposition-based AR

Visual Studio. when Unity is installed, there is an option of installing Microsoft visual studio tools for Unity as the default script editor. Visual Studio is a powerful integrated development environment (IDE) for all kinds of projects. It is used to develop computer programs, web apps, websites and mobile apps. Visual studio is used to write code and run the HoloLens Emulator. First the the latest version of Visual studio is downloaded, with the Universal Windows Platform (UWP) and the game development with unity.

HoloLens Emulator allows the user to run Holographic applications without a physical HoloLens. The HoloLens Emulator contains a HoloLens development toolset. To install the emulator, the user's system must support Hyper-V. HoloLens Emulator needs Visual Studio to function.

4.3 Implementation

The operating system for Microsoft Hololens is Windows 10. *Universal Windows Platform* UWP serves as a development platform for the Windows 10 applications. Visual Studio is used for the development of Hololens applications, together with the game development software Unity3D for which Microsoft already supplies fundamental functions like speech recognition and gestures. The basis of the application is the final product, which has to be assembled virtually by the developer as well as in reality by the robot. To have the product displayed holographically, the computer-aided design (CAD) model the product has to be transformed to a mesh model and then imported into Unity3D.

During this process, the structure described in the CAD model is kept. Nonetheless, it can be changed in Unity3D as required. The program logic is generated by scripts which are designed in a manner that allows them to be used on any model and therefore facilitates the exchange of different models. For user interface a toolbar with buttons is implemented. Every function of the program can be selected and settings can be made. Additionally, a voice control allows control of the application and the developer gets feedback and instructions through a voice output.

5 Future Work

In spite of the many recent advances in Augmented Reality and AR assisted robot programming, there is still a lot of work that remains to be done. AR application developments can be assisted by the usage of the available software development kits. The most popular SDK being ARToolKit provides computer vision techniques to compute a camera's orientation and position relative to marked cards so that 3D objects can be overlaid on the markers.

6 Conclusion

There is still hope for Augmented Reality and AR assisted robot programming. Even though augmented reality has not become part of every-day's life, it is on the edge of potentially doing precisely that. The required technologies are in order and are daily being upgraded. Application development is the present hold-up, but developers are creating powerful applications and producing platforms. Augmented Reality will expand its reach from its present place in robot programming, medicine, advertisement, education and a few other essential areas to virtually all areas of everyday life.

It is an exhilarating time to be part of the developing medium of AR. So far the biggest limitation in Augmented Reality is our imagination for the endless possibilities amalgamated with a lack of largely easy-to-use, available development tools.

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