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We are on the verge of ubiquitously and unanimously adopting Augmented Reality (AR) technologies to enhance our perception and help us see, hear, and feel our environments in different and enriched ways. AR will support us in fields such as education, maintenance, design and reconnaissance, to name but a few. This paper describes the existing technological frameworks in the field of AR. It surveys the state of the art by reviewing some recent applications of AR technology as well as some known limitations regarding human factors in the use of AR systems that developers will need to overcome.

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\section{Introduction}

With the age-old human tendency of escapism, heightened in the recent years, it is only natural that humans develop a virtual world where things are modified and changed as they will it. Imagine a technology with which you could see and hear more than others, and perhaps even touch, smell and taste things that others can not. Augmented Reality is the technology to perceive completely computational elements and objects within our real world experience, entire creatures and structures even that help us in our daily activities, while interacting almost unconsciously through mere gestures and speech. Many of us use touch-based interfaces frequently. However, such devices do not consist of any physical sensation and involvement and rely on the user's sense of sight to complete certain tasks.

With such technology surgeons could see ultrasound scans of organs while performing surgery on them, mechanics could see instructions what to do next when repairing an unknown piece of equipment, soldiers could see positions of enemy snipers spotted by unmanned reconnaissance aircrafts, fire fighters could see building layouts to avoid otherwise invisible hazards, and we could read reviews for each restaurant in the street we’re walking into or battle 10-foot tall aliens on the way to work

This paper aims to analyze the existing frameworks that may allow the development of solutions using augmented reality resources, focusing on tools that enable the conception, design and implementation of mobile applications. As a result of this research, several development environments available on the market that facilitate working with augmented reality elements in mobile devices were discovered and examined. Among these platforms, eleven were selected to be analysed and presented in this paper. These were tested and compared to one another, and their main characteristics were indicated in a comparative table, as well as their resources that hold the potential to contribute with the construction of educational applications. All of this in favor of easing the development of applications that may assist educators in introducing augmented reality technologies in their classrooms.

Augmented reality (AR) is this technology to create a “next generation, reality-based interface” [2] and is moving from laboratories around the world into various industries and consumer markets. AR supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world. AR was recognized as an emerging technology of 2007 [9], and with today’s smart phones and AR browsers we are starting to embrace this very new and exciting kind of human-computer interaction.

\begin{figure}[htb]

\centering

\includegraphics[width=88mm]{tasks.png}

\caption{AR Framework Tasks}

\label{fig:app\_flowchart}

\end{figure}

\section{Literature Survey}

Augmented Reality consists in the integration of virtual resources with real world physical elements, in which computer generated graphical components are presented in users’ technological devices along with the real environment elements in loco. As established by Milgram & Kishino (1994), as an operational definition of augmented reality, this may be the term considered to refer to any case in which an otherwise real environment is “augmented” by means of virtual

objects (computer graphics).

Regarding the uses and applications of augmented reality resources, it’s possible to say that many studies are being conducted and that there are several computational solutions already assisting society, in many fields. Among these are areas like entertainment, marketing and advertising, tourism (Chung, Han & Joun, 2015), automobilism (Rameau et al., 2016), health care (Jamali et al., 2015), training and education (Kysela & Štorková, 2015), (Majid, Mohammed & Sulaiman, 2015) and (Akçayir, Akçayir, Pektaş, & Ocak, 2016), along with other areas (O’Shea & Elliott, 2016), all of which are converging to the development of content and interactive solutions, allowing them to offer a pleasant and enriching

experience to their users.

\section{Problem Statement}

Due to huge variety of enabling technologies present for AR,a field experiencing a growth boom, this topic was chosen.

\subsection{Objectives}

\begin{itemize}

\item Survey existing AR frameworks

\item Survey existing AR enabling technologies

\item Compare existing AR frameworks and enabling technologies

\end{itemize}

\section{Survey}

\label{section:methodology}

\begin{enumerate}

\item \textbf{Aural display:} Aural display application in AR is mostly limited toself-explanatory mono (0-dimensional), stereo (1-dimensional) or surround (2-dimensional) headphones and loudspeakers. True 3D aural display is currently found in more immersive simulations of virtual environments and augmented virtuality or still in experimental stages.Haptic audio refers to sound that is felt rather than heard [75] and is already applied in consumer devices such as Turtle Beach’s Ear Force5 headphones to increase the sense of realism and impact, but also to enhance user interfaces of e.g. mobile phones [44]. Recent developments in this area are presented in workshops such as the international workshop on Haptic Audio Visual Environments6 and the international workshop on Haptic and Audio Interaction Design [15].

\item \textbf{Visual display: } There are basically three ways to visually present an augmented reality. Closest to virtual reality is video see-through,

where the virtual environment is replaced by a video feed of

reality and the AR is overlaid upon the digitised images.

Another way that includes Sutherland’s approach is optical

see-through and leaves the real-world perception alone but

displays only the AR overlay by means of transparent mirrors

and lenses. The third approach is to project the AR overlay

onto real objects themselves resulting in projective displays.

True 3-dimensional displays for the masses are still far off,

although [140] already achieve 1000 dots per second in true

3d free space using plasma in the air. The three techniques

may be applied at varying distance from the viewer:

head-mounted, hand-held and spatial (Fig. 4). Each combination of technique and distance is listed in the overview

presented in Table 1 with a comparison of their individual

advantages.

\item \textbf{Display positioning:} AR displays may be classified into three categories based on

their position between the viewer and the real environment:

head-worn, hand-held, and spatial.

\begin{figure}[htb]

\centering

\includegraphics[width=88mm]{img1.jpeg}

\caption{AR application}

\label{fig:app\_flowchart}

\end{figure}

Visual displays attached to the head include the video/optical

see-through head-mounted display (HMD), virtual retinal

display (VRD), and head-mounted projective display

(HMPD). Cakmakci and Rolland [40] give a recent detailed

review of head-worn display technology. A current drawback

of head-worn displays is the fact that they have to connect to

graphics computers like laptops that restrict mobility due to

limited battery life. Battery life may be extended by moving

computation to distant locations (clouds) and provide

(wireless) connections using standards such as IEEE 802.11

or BlueTooth.

Hand held- This category includes hand-held video/optical see-through

displays as well as hand-held projectors. Although this category of displays is bulkier than head-worn displays, it is

currently the best work-around to introduce AR to a mass

market due to low production costs and ease of use. For

instance, hand-held video see-through AR acting as magnifying glasses may be based on existing consumer products

like mobile phones Möhring et al. [110] (Fig. 7a) that show

3D objects, or personal digital assistants/PDAs [161] (Fig.

7b) with e.g. navigation information. [148] apply optical

see-through in their hand-held ‘sonic flashlight’ to display

medical ultrasound imaging directly over the scanned organ

(Fig. 8a). One example of a hand-held projective display or

‘AR flashlight’ is the ‘iLamp’ by Raskar et al. [134]. This

context-aware or tracked projector adjusts the imagery based

on the current orientation of the projector relative to the

environment (Fig. 8b). Recently, MicroVision (from the

retinal displays) introduced the small Pico Projector (PicoP)

which is 8mm thick, provides full-colour imagery of 1366 ×

1024 pixels at 60Hz using three lasers, and will probably

appear embedded in mobile phones soon.

Spatial

The last category of displays are placed statically within the

environment and include screen-based video see-through

displays, spatial optical see-through displays, and projective

displays. These techniques lend themselves well for large

presentations and exhibitions with limited interaction. Early

ways of creating AR are based on conventional screens

(computer or television) that show a camera feed with an AR

overlay. This technique is now being applied in the world of

sports television where environments such as swimming

pools and race tracks are well defined and easy to augment.

Head-up displays (HUDs) in military cockpits are a form of

spatial optical see-through and are becoming a standard

extension for production cars to project navigational directions in the windshield [113].

\item \textbf{Tracking sensors and approaches:}

Before an AR system can display virtual objects into a real

environment, the system must be able to sense the environment and track the viewer’s (relative) movement preferably

with six degrees of freedom (6DOF): three variables (x, y,

and z) for position and three angles (yaw, pitch, and roll) for

orientation.

There must be some model of the environment to allow

tracking for correct AR registration. Furthermore, most environments have to be prepared before an AR system is able

to track 6DOF movement, but not all tracking techniques

work in all environments. To this day, determining the orientation of a user is still a complex problem with no single

best solution.

\item \textbf{Tangible UI and 3D pointing:}

Early mobile AR systems simply use mobile trackballs,

trackpads and gyroscopic mice to support continuous 2D

pointing tasks. This is largely because the systems still use a

WIMP interface and accurate gesturing to WIMP menus

would otherwise require well-tuned motor skills from the

users. Ideally the number of extra devices that have to be

carried around in mobile UIs is reduced, but this may be

difficult with current mobile computing and UI technologies.

Devices like the mouse are tangible and unidirectional,

they communicate from the user to the AR system only.

Common 3D equivalents are tangible user interfaces (TUIs)

like paddles and wands. Ishii and Ullmer [76] discuss a

number of tangible interfaces developed at MIT’s Tangible

Media Group14 including phicons (physical icons) and sliding instruments. Some TUIs have placeholders or markers on

them so the AR system can replace them visually with virtual

objects. Poupyrev et al. [131] use tiles with fiducial markers,

while in StudierStube, Schmalstieg et al. [142] allow users to

interact through a Personal Interaction Panel with 2D and 3D

\begin{figure}[htb]

\centering

\includegraphics[width=88mm]{img2.jpg}

\caption{AR application}

\label{fig:app\_flowchart}

\end{figure}

\item \textbf{Haptic UI and gesture recognition: }

UIs with bidirectional, programmable communication

through touch are called haptic UIs. Haptics is like teleoperation, but the remote slave system is purely computational, i.e. “virtual.” Haptic devices are in effect robots with a

single task: to interact with humans [69]. The haptic sense is divided into the kinaesthetic sense

(force, motion) and the tactile sense (tact, touch). Force

feedback devices like joysticks and steering wheels can

suggest impact or resistance and are well-known among

gamers. A popular 6DOF haptic device in teleoperation and

other areas is the PHANTOM (Fig. 11). It optionally provides 7DOF interaction through a pinch or scissors extension.

Tactile feedback devices convey parameters such as roughness, rigidity, and temperature. Benali-Khoudja et al. [27]

survey tactile interfaces used in teleoperation, 3D surface

simulation, games, etc.

Data gloves use diverse technologies to sense and actuate

and are very reliable, flexible and widely used in VR for

gesture recognition. In AR however they are suitable only for

brief, casual use, as they impede the use of hands in real

world activities and are somewhat awkward looking for

general application. Buchmann et al. [37] connected buzzers

to the fingertips informing users whether they are ‘touching’

a virtual object correctly for manipulation, much like the

CyberGlove with CyberTouch by SensAble15

.

\item \textbf{Visual UI and gesture recognition: }

In stead of using hand-worn trackers, hand movement may

also be tracked visually, leaving the hands unencumbered. A

head-worn or collar-mounted camera pointed at the user’s

hands can be used for gesture recognition. Through gesture

recognition, an AR could automatically draw up reports of

activities [105]. For 3D interaction, UbiHand uses

wrist-mounted cameras enable gesture recognition [14], while the Mobile Augmented Reality Interface Sign Interpretation Language 16 [16] recognises hand gestures on a

virtual keyboard displayed on the user’s hand (Fig. 12). A

simple hand gesture using the Handy AR system can also be

used for the initialization of markerless tracking, which estimates a camera pose from a user’s outstretched hand [97].

Cameras are also useful to record and document the user’s

view, e.g. for providing a live video feed for teleconferencing, for informing a remote expert about the findings of AR

field-workers, or simply for documenting and storing everything that is taking place in front of the mobile AR system

user.

Common in indoor virtual or augmented environments is

the use of additional orientation and position trackers to

provide 6DOF hand tracking for manipulating virtual objects. For outdoor environments, Foxlin and Harrington [60]

experimented with ultrasonic tracking of finger-worn acoustic emitters using three head-worn microphones.

\item \textbf{Gaze tracking:}

Using tiny cameras to observe user pupils and determine the

direction of their gaze is a technology with potential for AR.

The difficulties are that it needs be incorporated into the

eye-wear, calibrated to the user to filter out involuntary eye

movement, and positioned at a fixed distance. With enough

error correction, gaze tracking alternatives for the mouse

such as Stanford’s EyePoint17 [94] provides a dynamic history of user’s interests and intentions that may help the UI

adapt to the future contexts.

\item \textbf{ Aural UI and speech recognition:}

To reach the ideal of an inconspicuous UI, auditory UIs may

become an important part of the solution. Microphones and

earphones are easily hidden and allow auditory UIs to deal

with speech recognition, speech recording for human-to-human interaction, audio information presentation,

and audio dialogue. Although noisy environments pose

problems, audio can be valuable in multimodal and multimedia UIs.

\item \textbf{ Frameworks:}

AR systems have to perform some typical tasks like tracking,

sensing, display and interaction (Fig. 13). These can be supported by fast prototyping frameworks that are developed independently from their applications. Easy integration of AR

devices and quick creation of user interfaces can be achieved

with frameworks like the ARToolKit19, probably the best known

and most widely used. Other frameworks include StudierStube20

[152], DWARF21 , D’Fusion by Total Immersion 22 and the

Layar23 browser for smart phones.

\item \textbf{ Networks and databases:}

AR systems usually present a lot of knowledge to the user which

is obtained through networks. Especially mobile and collaborative AR systems will require suitable (wireless) networks to

support data retrieval and multi-user interaction over larger

distances. Moving computation load to remote servers is one

approach to reduce weight and bulk of mobile AR systems [25,

103]. How to get to the most relevant information with the least

effort from databases, and how to minimise information

presentation are still open research questions.

\item \textbf{ Global positioning systems:}

For outdoor tracking by global positioning system (GPS)

there exist the American 24-satellite Navstar GPS [63], the

Russian counterpart constellation Glonass, and the

30-satellite GPS Galileo, currently being launched by the

European Union and operational in 2010.

Direct visibility with at least four satellites is no longer

necessary with assisted GPS (A-GPS), a worldwide network

of servers and base stations enable signal broadcast in for

instance urban canyons and indoor environments. Plain GPS

is accurate to about 10-15 meters, but with the wide area

augmentation system (WAAS) technology may be increased

to 3-4 meters. For more accuracy, the environments have to

be prepared with a local base station that sends a differential

error-correction signal to the roaming unit: differential GPS

yields 1-3 meter accuracy, while the real-time-kinematic or

RTK GPS, based on carrier-phase ambiguity resolution, can

estimate positions accurately to within centimeters. Update

rates of commercial GPS systems such as the MS750 RTK

receiver by Trimble10 have increased from five to twenty

times a second and are deemed suitable for tracking fast

motion of people and objects [73].

\item \textbf{ User movement tracking:}

Compared to virtual environments, AR tracking devices must

have higher accuracy, a wider input variety and bandwidth,

and longer ranges [17]. Registration accuracy depends not

only on the geometrical model but also on the distance of the

objects to be annotated. The further away an object (i) the

less impact errors in position tracking have and (ii) the more

impact errors in orientation tracking have on the overall

misregistration [18].

Tracking is usually easier in indoor settings than in outdoor settings as the tracking devices do not have to be completely mobile and wearable or deal with shock, abuse,

weather, etc. In stead the indoor environment is easily modelled and prepared, and conditions such as lighting and

temperature may be controlled. Currently, unprepared outdoor environments still pose tracking problems with no single best solution.

\end{enumerate}

\begin{figure}[htb]

\centering

\includegraphics[width=88mm]{img3.jpg}

\caption{AR application}

\label{fig:app\_flowchart}

\end{figure}

\section{Frameworks}

\begin{enumerate}

\item \textbf{Vuforia:}

Being a complete SDK for AR applications development, Vuforia supports:

the detection of several kinds of targets (including objects, images, English text)

target tracking

2D and 3D recognition

scanning real objects for recognition

virtual buttons

mapping additional elements via OpenGL

Smart TerrainTM, a capability to reconstruct a terrain in real time, creating a 3D geometric map of the environment

Extended Tracking, a capability that delivers a continuous visual experience even when the target is out of view

In particular, using Vuforia for detecting images, AR applications can appeal to the data that are either local on the device or in the Cloud.

The main advantages of the framework include the support of virtual reality devices and a test app with comments showing the Vuforia abilities.

However, the absence of a complete framework manual leads to complications for the developers working with Vuforia for the first time. Although there are many specific instructions and short tips, they are in random order and cannot replace the required documentation.

The use of cloud recognition has limitations in the free version of Vuforia. Also, a watermark appears in this version once a day.

\item \textbf{ARToolKit:}

ARToolKit is a set of augmented reality software tools that can be used in AR apps. Its main benefit is an open-source code that implies free access to the library.

ARToolKit supports:

2D recognition

mapping additional elements via OpenGL

The library allows tracking known in advance object markers through a mobile device camera and reproducing their location on a device screen. Then a developer can create an app interface using received data.

ARToolKit serves for different platforms: Android, iOS, Windows, Linux, Mac OS X, SGI. Each operating system needs its own development environment. Development environments are free for all the mentioned platforms.

Despite free access to this AR library, the development documentation is quite limited. It includes the test apps, but not all of them can be easily built. The examples are very poor, and there is no information about any plans for the framework update.

\item \textbf{Wikitude:}

Wikitude library supports:

2D and 3D recognition

scanning real objects for recognition

3D model rendering and animation

location tracking

HTML augmentation

Using Wikitude, developers can create apps to reconstruct places at the virtual map or in the list, to do a search of events, tweets, Wiki articles, or to get the recommendations from other users. Besides a Wikitude-based app allows to receive mobile coupons, information about current specials, and also to play in AR games.

Wikitude can be used for Android and iOS, as a plugin for PhoneGap, a module for Titanium and a component for Xamarin. The Wikitude SDK includes SLAM (markerless tracking) and supports Unity programming language. This framework is available for smart glasses Google Glass, Epson Moverio, Vuzix M-100 and ODG R-7.

There is a free trial version for developers. When you want to use a complete version, be ready for regular payments. As for the documentation, it is well structured and detailed.

\item \textbf{LayAR:}

As follows from the framework name, you can watch the terrain through the layers, that are mapping on the mobile device screen.

LayAR supports:

image recognition

mapping additional elements on the base of user location and recognized images

Each of the framework layers could include the data about the location of specific places or social net users. Besides, the LayAR functionality allows considerably expanding the abilities of printed products. For example, using the LayAR-based app, you can make an order in a printed catalog or listen to a song that was mentioned in a magazine.

All the work takes place on a server through JSON, including the logic of mapping additional elements in recognition. For this reason, the work with LayAR is not flexible.

Turning to the benefits, we should say that the documentation is very detailed and well-structured. Although, the framework manual is available only online.

\item \textbf{Kudan AR:}

The Kudan functionality consists of:

image recognition

mapping additional elements on the base of user location and recognized images

markerless tracking (instead of fiducial marks it relies on the use of natural features like the edges, corners, or textures)

mapping additional elements via separate component over OpenGL

Kudan is faster than other frameworks. This library helps mobile AR apps to map multi-polygonal models in reality and import 3D models from one of the modeling software packages. In addition, the number of recognizing images is not limited and it requires less memory to store files in a device.

Developers can use the basic documentation but the framework manual is short and needs additional information. Also, there is a chance that you can suffer from the limited built-in functionality without a direct access to OpenGL.

In general, the described above augmented reality libraries have a wide range of opportunities for app development from the support of different platforms and to the set of tools for recognizing and tracking objects.

Nevertheless, when it’s time to choose a particular framework, a developer needs to understand what he gets. Some of the tools you can use for free, simply going to the website or downloading the software program. Other tools require signing a contract and paying a fee, but they provide more features with higher quality. Choosing one of the AR tools, think of your project tasks and results you want to achieve, and, after all, match them with the abilities of the AR libraries.

\end{enumerate}

\begin{figure}[htb]

\centering

\includegraphics[width=88mm]{fw.png}

\caption{AR Framework Comparison}

\label{fig:app\_flowchart}

\end{figure}

\section{Conclusion}

We surveyed the state of the art of technologies, applications

and limitations related to augmented reality. We also contributed a comparative table on displays (Table 1) and a brief

survey of frameworks as well as content authoring tools

(Section 2.4). This survey has become a comprehensive

overview of the AR field and hopefully provides a suitable

starting point for readers new to the field.

AR has come a long way but still has some distance to go

before industries, the military and the general public will

accept it as a familiar user interface. For example, Airbus

CIMPA still struggles to get their AR systems for assembly

support accepted by the workers [163]. On the other hand,

companies like Information in Place estimated that by 2014,

30% of mobile workers will be using augmented reality.

Within 5-10 years, Feiner [57] believes that “augmented

reality will have a more profound effect on the way in which

we develop and interact with future computers.” With the

advent of such complementary technologies as tactile networks, artificial intelligence, cybernetics, and (non-invasive)

brain-computer interfaces, AR might soon pave the way for

ubiquitous (anytime-anywhere) computing [162] of a more

natural kind [13] or even human-machine symbiosis as

Licklider [99] already envisioned in the 1950’s.

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