CHAPTER 1

INTRODUCTION

This is the world with lots of digital technologies, which are widespread throughout this world, the technology such as computer graphics, virtual reality, augmented reality together are used to create a world of virtual objects superimposed into the real world with the real objects. These technologies enhance the visual experiences of the audience. Augmented reality is exactly what the name suggests, it is when a different reality is over-layered onto your pre-existing reality using certain devices such as smartphones and smart-glasses. Computer-generated images of the different setting are superimposed on your device to alter your perspective of reality. Augmented reality is a technology through which uses real-time view is enhanced by superimposing computer-generated graphics on the viewing screen in real-time. Over the years, augmented reality has been used in many domains for a multitude of purposes. In most fields, AR is used as an assistive system for performing human tasks.[7] AR has proven to be useful in increasing the efficiency and accuracy of the tasks especially in the domains related to surgery and aeroplane manufacturing. In the case of surgery, it can be used as a tool to render 3D models of the patients operated area/organ that can help doctors perform surgeries with minimum risk and complications. In aeroplane manufacturing, AR can be used as a tool to assist wiring the electrical harness of a plane which is a long and tedious task and is still done manually. Augmented reality works in synchronization with other technologies such as IoT (Internet of Things), Artificial intelligence and many others to give people a richer view on their reality. Yelp app is already using AR to show things like reviews simply by pointing your phone camera at restaurants. Games such as Pokémon Go opened the doors to implement AR elements to mobile gaming. Also on Instagram and Snapchat, there are various fun filters like the dog filter, bunny ears, pig filter, etc. which are based on consumer-facing applications which use AI and AR in combination.[10]

As artificial intelligence develops rapidly, a virtual agent will finally possess an independent mind similar to that of humans. Based on Minsky's analysis of the human's mind, a virtual agent could develop its own independent mind and live successfully in the virtual world as humans can do in the physical world. For this reason, a virtual agent can have equal status with real humans. But the basic frameworks for augmented reality (AR), mixed reality (MR) and virtual reality (VR) were proposed by Milgram et al. These paradigms are designed for the human-centered world. The well-known augmented reality can transfer from a human-

centered framework to a virtual agent-centered framework. When the virtual agent is the center of the system, it can observe both virtual objects in the virtual world and real objects in the physical world. This is called inverse augmented reality (IAR), because it uses an exactly opposite observing direction compared to the traditional augmented reality.

The idea of IAR is originally inspired by the concept of the parallel world in the discipline of physics. Based on the consideration of physics, IAR requires that the virtual world exists with similar structures and interaction roles to that of the physical world. These similar structures and interaction roles have been applied to virtual reality in order to define inverse virtual reality (IVR). In this report, it would talk about inverse augmented reality using the similar methodology.

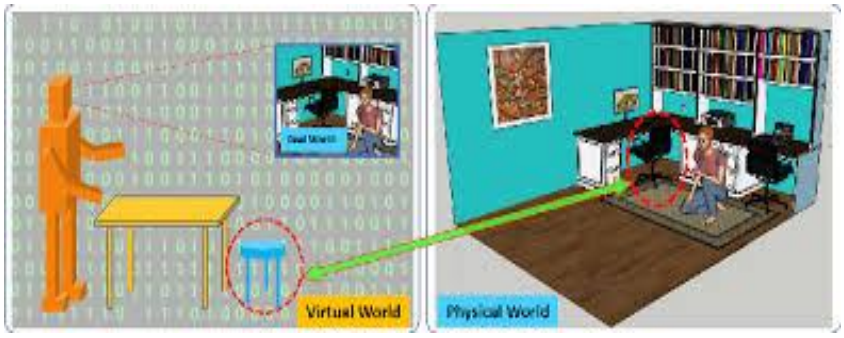

Figure 1.1: A typical scene of inverse augmented reality.

In the figure 1.1, in left side, the virtual agent is represented as an orange avatar. A real chair is registered into the virtual world, so that a virtual one corresponds to a real one. Meanwhile, the virtual yellow table in the virtual world can exist independently with no relationship with the desks in the physical world. The physical world can be observed by the virtual agent, but only the registered real objects are available data which can augment the virtual world.

The study about IAR is significant for the two following reasons. First, it figures out the relationship between the virtual world and the physical world under the background of IAR, promoting the development of the scientific architecture of virtual agent-centered inverse augmented reality. Second, it lays the foundation of inverse augmented reality applications which do not treat the human as the system center, increasing the diversity of augmented reality systems. For these reasons, the upcoming IAR is expected to make a breakthrough in boththeory and practice. This report studies the emerging concept of IAR, and concretely shows the relationship between the virtual world and the physical world.[1]

CHAPTER 2

LITERATURE REVIEW

AR technology exists since the 1960s when the first AR prototype was created by computer graphics pioneer Ivan Sutherland and his students at Harvard University and the University of Utah. They used a see-through to present 3D graphics. The research was continued by Massachusetts Institute of Technology and the University of North Carolina at Chapel Hill during the 1970s and 1980s. At the same time, mobile devices like the Sony Walkman (1979), digital watches and personal digital organizers were introduced.

Today, AR technology is growing and has been applied in various fields such as telecommunication. Recently, many mobile platforms exist that may support AR, such as personal digital assistants (PDAs), tablet PCs and mobile phones.

It took about ten years when in the early 1990s, the term "augmented reality" was coined by Caudell and Mizel. In fact, true mobile AR was still out of reach. However, a few years later a GPS-based outdoor system that presents navigational assistance to the visually impaired with spatial audio overlays was developed. In 1997, the earliest prototype of a mobile AR system (MARS) was created. It registers the 3D graphical tour guide information with buildings and artifacts the visitor sees.[2]

By 2001, AR became an interesting area of research when it was first applied in the field of cultural heritage. ARCHEOGUIDE is actually a new system bringing state of the art visualization technology and mobile computing in cultural heritage. The 3D reconstructions of artifacts and monuments are presented to the user through a special augmented reality interface while he has constant visual contact with the natural environment and listens to audio commentary. This feature renders the system more user-friendly and avoids the weaknesses of other alike systems where the user is isolated or immersed in a purely synthetic world. In order to help visitors and scientists better appreciate and enjoy the past glory of these sites, it provides personalized augmented reality tours and reconstructions of ruined cultural heritage sites.

In 2007, a research was conducted on emulation of the human feelings and behaviours in an animated artwork. The researchers used the behavioural control technique which is actually developed to control the mobile robots Cassinis, 2007. Meanwhile, in 2008, an investigation has made on how mobile technologies can be designed to facilitate the practice of collaborative inquiry for two contrasting outdoor settings. The suggested study proved that

the groups were also able to integrate the accessed digital information with their observations and begin to make generalizations from them. Another study was conducted on how to augments mobile learning by applying web page adaptation techniques in the same year. This study was experimented by applying web page adaptation to facilitate mobile learning on the blackboard learning system and the results show that the method provides effective and efficient delivery of web-based learning material over the mobile internet.

AR technology is continually growing. In 2009, a new method was introduced to encode the context-dependent information in cultural heritage collections. The advantage of this technique is users can have a thorough picture of the collection since information concerning the past and all the states which the collection has passed through time is provided to them. Cultural heritage research is not only stopping there when a study is done on semantic-based retrieval of cultural heritage multimedia objects. This study discussed two important issues regarding the suggested solutions based on a rich semantic model. Firstly is, the study indicated how semantic transitions can be ordered to the user in a user-friendly and efficient way and secondly it discussed how a user may be navigating between objects.

By 2012, mobile AR application has been introduced for library uses and next-generation library services. This application usage was include augmenting physical book stacks browsing, library navigation, optical character recognition, facial recognition, and building identification mobile software for compelling library experiences.

Recent technological developments in AR are:

i) Head-Worn Display: These devices are worn on head providing image display in front of their eyes. Generally, two types of HWD's exist optical see-through (AR spreading over a transparent display) and video sees through (captures videos from a head-worn camera shown on an opaque display).

ii) Handheld display: such devices provide video see-through augmentation by using handheld devices or flat-panel LCDs with attached camera.

iii) Projection display: These devices project virtual objects directly on the object to be augmented.

iv) Head-Mounted Display: (HMD) devices are paired to a headset.

v) Spatial Augmented Reality: It augments real-world scenes without using special display devices such as monitor, HMD's etc.

vi) Input devices: Augments real word using speech recognition (translation of speech into

computer instruction) or gesture recognition (interpretation of body movements through sensors).[4]

As discussed, in the past a lot of related researches about augmented reality have been presented. Before the IAR, some novel styles of reality have been proposed. For example, Lifton et al. proposed the "dual reality" system to make the virtual world and the physical world corresponding to each other. Rooetal proposed the "one reality "system, which contained a 6-level mixture of virtual and real contents ranging from purely physical to purely virtual world. But they all describe the mixed reality from the perspective of humans, ignoring the view from the virtual world.

Since the virtual environment is expected to be the same intelligent as our natural environment in the physical world, it should be created with some virtual smart brains using current techniques in artificial intelligence. Luck et al. applied artificial intelligence into virtual environments to make the virtual environments intelligent. This work inspires us to add some intelligence to IAR, making the virtual world be driven by intelligence besides human's manual design. The intelligence of the virtual world can be accumulated by learning from the human's behaviours in some special cases. Note that intelligence plays an important role in constructing IAR for the reason that the intelligence-driven self-development can make the virtual world act as the physical world does. If the intelligence is missing, the virtual world may suffer from low spontaneity, which can be harmful to the equivalence of the virtual world and the physical world.

To make the virtual world intelligent, Taylor et al. discussed the possibility of making a virtual world evolve by itself. The evolution of the virtual world took advantage of the principle of biological evolution in the physical world. Though the self-learning is not simple, there are still many learning frameworks that can be used to obtain the self-learning ability, such as evolutionary computation, reinforcement learning, and deep learning.

CHAPTER 3

FRAMEWORK OF INVERSE AUGMENTED REALITY

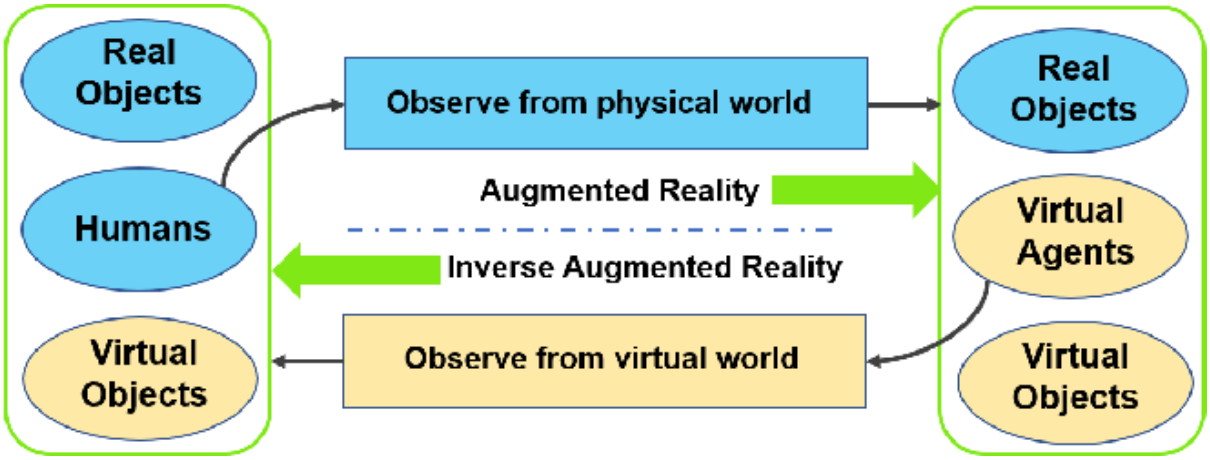

Figure 3.1: Relationship between AR and IAR

In the right rounded rectangle of the figure, it shows the typical scene of the traditional augmented reality, which can be observed by humans. In the left rounded rectangle of the figure, it shows the typical scene of the inverse augmented reality, which can be observed by virtual agents. Augmented reality and inverse augmented reality share the same structure except that they have opposite observing directions and different observers.

3.1 Dual-World Structure

The proposed inverse augmented reality and the traditional augmented reality, as shown in Figure 3.1, are under the unified dual-world structure. The traditional augmented reality (human-centered observation) is to augment the physical world with virtual objects, while the inverse augmented reality (virtual agent-centered observation) is to augment the virtual world with real objects. There might be a misconception between the proposed “inverse augmented reality” and another well-known concept called “augmented virtuality”. Even though the two concepts are all describing using real elements in the physical world to augment virtual elements in the virtual world, their positions are definitely different. The augmented virtuality means that it is the human who can see a scene where the virtual elements are augmented by real elements, and the human himself is located in the physical world. Conversely, the inverse augmented reality means that it is the virtual agent who can see a scene where the virtual

elements are augmented by real elements, and the virtual agent itself is located in the virtual world.

3.2 Mathematical Model

Take the visual AR and IAR as an example, the formulation for AR and IAR can be as follows.

Let O_R denote the real objects, O_v the virtual objects, H the humans, A the virtual agents, then we get equation 1 as,

$$\begin{cases} AR \Leftrightarrow S_H(O_R, O_V, A) \\ IAR \Leftrightarrow S_A(O_R, O_V, H) \end{cases}$$

where S_H denotes the observation function of humans, and S_A denotes the observation function of virtual agents.[1]

CHAPTER 4

PHYSICAL PERSPECTIVE OF INVERSE AUGMENTED REALITY

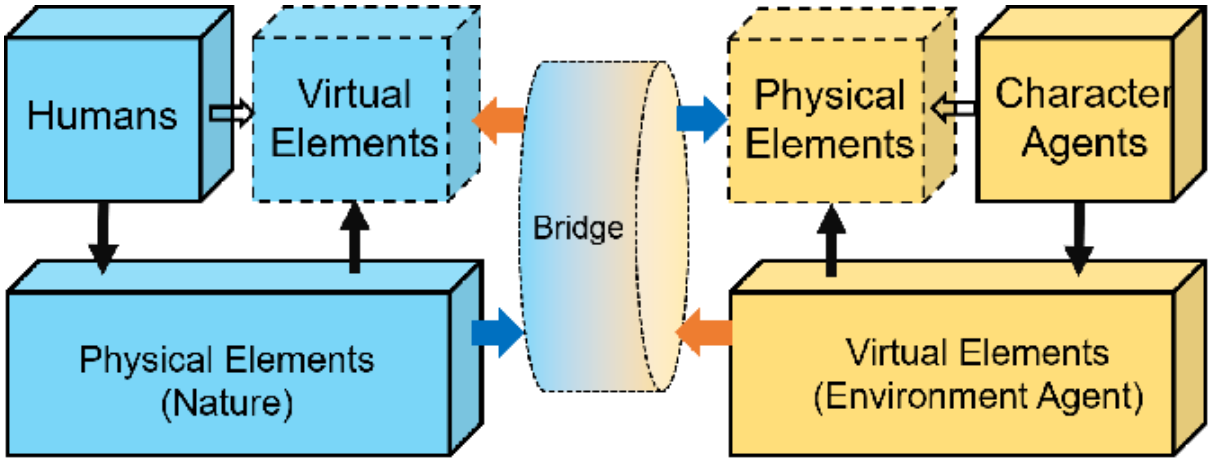

Figure 4.1 Interaction between physical world and virtual world.

In this work, emphasize is on the equivalence of the virtual world and the physical world regarding the structure in physics. The referred physics here contains both the physical world and the virtual world, i.e., the virtual world is treated as a kind of existence in physics, which possesses the same structure with the physical world. In this way, IAR has the same important role as the traditional AR. It uses a definition called physical equivalence to elaborate the equivalence of the physical world and the virtual world. This means the two worlds should be the same when talking about the physical structure, which can also be seen in Equation 1.

4.1 Spatial Structure

In the traditional augmented reality, there are three key components, i.e., the humans, the physical world and the virtual contents added to the physical world. As a correspondence, the same structure applies to inverse augmented reality. Concretely, inverse augmented reality also contains three key components, i.e., the virtual character, the programmable virtual world and the physical contents added to the virtual world. It emphasize the spatial structure rather than the appearance, because the difference regarding appearance is obvious. For example, all objects in the virtual world are data that are first created by human and then develop independently. Though the appearance is different, the spatial structure can be similar, especially the physical roles and interaction ways.

4.2 Self-Development

As a common knowledge, the physical world we live in is keeping developing all the time. It seems to be driven by a kind of energy with the form of physical roles. Meanwhile, humans are born with intelligence, so they can actively interact with the physical world. Since the virtual world is expected to be developing by itself, it should have two kinds of agents, i.e., the character agent and the environment agent. The character agent can be treated as a virtual human in the virtual world, while the environment agent determines how the virtual environment can develop automatically. The two agents are created by our physical world, then they construct the virtual world and develop independently without being directly controlled by the physical world. The agents can not only learn from physical world but also evolve by themselves. Notice that only the character agents can observe things in the proposed framework of inverse augmented reality.

4.3 Equal-Status Interaction

Considering the traditional AR and the proposed IAR, the physical world and the virtual world are equal to each other regarding interaction. As we often see in the traditional AR, a human can interact with both real and virtual objects that have been observed by him. Similarly, the character agent in the virtual world can interact with both virtual and real objects that have been observed by the agent. The two interaction processes are dual processes with the exactly symmetrical interaction style, as shown in Figure 4.1. The interaction from virtual world to physical world means the virtual agent can control some physical power in order to change the physical state of real objects, e.g., if the virtual agent want to put a real box on a virtual table, it is required to find a certain physical way to support the real box so that it seems to be on the virtual table. And the physical way to realize this physical effect is expected to be controlled by the virtual agent. This is surely very hard for the current technology, but it is an essential part for IAR to support an equal interaction process compared with the traditional AR. Therefore, the equal-status interaction may need to be further studied and realized in the future.[1]

CHAPTER 5

PROOF OF CONCEPTS

5.1 System setup

It utilizes Microsoft HoloLens as the basic platform to demonstrate the concept of IAR. Both AR and IAR are implemented by Unity3D and the Vuforia software development kit.

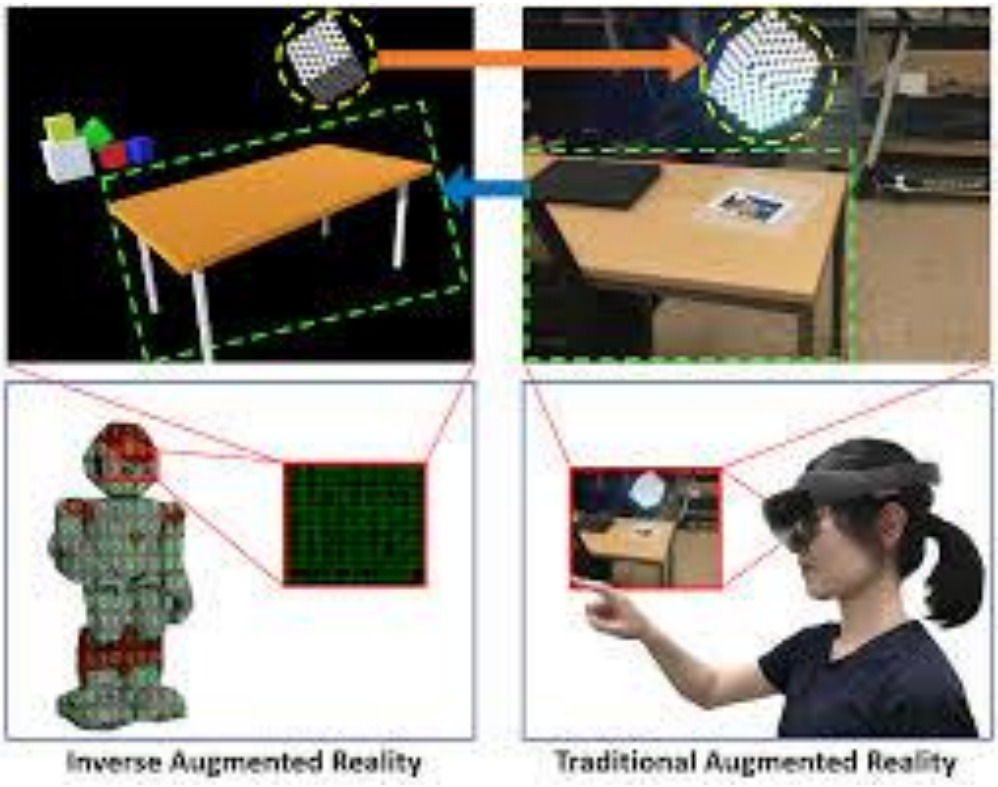

Figure 5.1 Concept demonstration.

The left side is the view from the virtual world, while the right side is the view from the physical world. Some objects exist in both worlds, such as the cube with yellow dashed circle and the table with green dashed rectangle. Some objects only exist in one world. For example, some colourful cubes only exist in the virtual world, while a chair and a laptop only exist in the physical world.

5.2 Framework Representation

Since the basic framework has been illustrated above, it presents a typical demonstration of IAR using an office environment. It adds a virtual cube floating above the table, which is located by a small photo. The small photo is fixed on the top of a

table, which serves as a bridge connecting the physical world and the virtual world. After the environment is constructed, two views from the different worlds are shown in Figure 4. In the traditional augmented reality, the user can see the physical environment and the virtual element (a cube with the checkerboard pattern), and she can also interact with the virtual element. In the inverse augmented reality, a virtual agent is constructed, and it can behave like a physical human. Though what can be "seen" by the agent is absolutely some data, we can still figure out the meaning of these data. Usually, these data include the virtual cube that is connected with the physical world, the virtual table that corresponds to the real table in the physical world, and some other virtual objects that do not exist in the physical world.[1],[3]

CHAPTER 6

CHALLENGES

6.1 Lack of Augmented Reality App Design & Development Standards

Standards are something of a universal language for a software application. It is one of the ways to secure its compatibility and contribution to the overall development of the technology. At the moment, this is the thing that is under construction for Augmented Reality. The reason is simple - it's too soon. The technology is too new, and it is still coming to its own both in hardware and software terms (despite "technically" being around for a while.)

So what's the problem? Without standards, every augmented reality-related project is a thing of its own barely compatible with the others and complicates the process of unifying solutions to the greater whole which makes the overall development of the technology much slower than it could have been if everyone had been on the same page. However, implementation of technical standards is a question of time, and its adoption will signify the final stage of establishing the technology as a real deal.

6.2 Security & Privacy Issues with Augmented Reality

Privacy & Security also pose significant challenges that the AR industry. Due to inconsistencies in augmented reality programming, oversight, and negligence, there is a legitimate chance of getting into trouble without meaning to do so.

The biggest issue is that no actual regulation designates what is allowed and what is not in the augmented reality environment. Which means the technology can be used with malicious intent just as it can be used for entertainment. For example, "try before you buy" option for clothing, but instead of overlaying the cloth on your body someone may overlay another nude body and spread to damage your reputation or blackmail. Or AR can be used to hijack accounts via surveillance and mining data output by slightly manipulating and overlaying AR content (just as in ad stacking fraud schemes).Part of the problem is lack of awareness about these problems. People don't understand how sensitive the subject is. The other part of the problem is the reluctance of the developers to take action before there is any heat on the corner.[9]

6.3 The Possibility of Physical Harm

While long-term effects of using augmented reality are much better documented than

ones for Virtual Reality (uh-hm), there is still a significant possibility of harming yourself and the surroundings due to nature of the application and lack of attention.

The thing is - Augmented Reality operates in the real world and adds a little bit of digital into it. These elements are driving attention away from reality which may cause a potentially dangerous situation.For example, remember all those news about people hurting themselves while playing Pokemon Go? Well, it is just the tip of an iceberg.

6.4 Social Issues of Augmented Reality: Public Acceptance & Retention

While Augmented Reality seems to be a relatively popular topic in the media and frequently mentioned as one of the most exciting emerging technology - its overall public reception is, for the lack of the better word, mild.Part of the reason for that is that the quality of the majority of AR content is mostly hit and miss. Out of this comes the notion that AR applications are nothing more than an unnecessary addition. However, the situation will probably revert with a couple of "killer apps" that will prove the worth of technology in one swift sweep.

The other part of the problem is that the public, for the most part, is not aware of the benefits of augmented reality in various fields. It is still perceived as zany science fiction by a significant portion of potential users. Then there is a retention problem. Despite the popularity of the Augmented Reality technology steadily growing over the past few years, there is still a significant problem in keeping an audience using Augmented Reality applications in a long-term perspective.

The current state of affairs with AR apps looks like this: users download the app because they saw some advert that excited them uses it a couple of times until the goal is realized or interest is satisfied and then abandon the app due to lack of long-term use cases.

6.5 Augmented Reality Technology Problems & Limitations

Another big problem with implementing AR solutions is the technological gap between AR devices. It is one thing to design an app for a fully-fledged AR gear, and it is a completely different thing to do it for a smartphone. The latter case got many limitations that make the whole experience not really user-friendly and somewhat redundant to the activity it augments. Considering that the majority of the target audience will not likely purchase AR gear due to its impractically and high prices - smartphones remain a preferred function and since they have certain augmented reality app design limitations - it neuters the whole point of implementing

AR solution to the mix. What's the solution to this problem? It is a question of time when the price for AR gear will drop to a mass consumer acceptable level. The thing is - Augmented Reality Technology is in its early stages, and it is too soon to expect that its gear will be available for a regular Joe from the get-go.[5]

6.6 Other Challenges to IAR

The remaining challenges in the field of inverse augmented reality mainly include three aspects:

(1) Physical construction of virtual objects in the physical world.

(2) Specific design of virtual-to-physical bridges.

(3) Intelligence and knowledge for the self-driven virtual world.

Future work will be unifying the proposed IAR and the previous IVR into a more general framework in order to represent the reality at a higher level than what we have done currently. In this way, what the virtual agent could experience in both the virtual and the physical world can be well illustrated.[1]

CHAPTER 7

AR: THE LIMITLESS POSSIBILITIES

Technology usually evolves through two pathways – someone "builds" a new technology out of necessity to solve a particular problem, or someone "discovers" an existing technology and finds ways in which it can be used to solve new problems (which the original technology may not have been designed for). Augmented Reality (AR) is one field that owes its evolution to both aspects equally. As new information demands emerged, new ways of adding information to reality were found. Each passing day sees an increasing number of applications of augmented reality, and its potential seems endless.

Augmented reality is not just about fun and games. There are some substantially beneficial uses for the technology in everything from engineering and medicine to sports, education and more. And when it comes to inverse augmented reality, the applications today are beyond our imagination.[6]

CHAPTER 8

CONCLUSION

The equivalence between the virtual world and the physical world is proposed regarding the structure. As for the structure, it is already illustrated by introducing all essential parts of the traditional augmented reality and the inverse augmented reality. Though the specific expression forms are different, the two paradigms possess the same structure with each other. Our demonstration is about the concept verification, and all the results are shown directly by images observing from different worlds. This is a clear way to show the concept of IAR.

In this seminar, big framework of the traditional augmented reality and the inverse augmented reality is proposed. Then it illustrate the main properties of this framework. Under this framework, we emphasize that the self-intelligence would play an important role in the virtual world, which contributes greatly to building an inverse augmented reality system.it also present a typical implementation of an inverse augmented reality system, which shows the inverse augmented reality can be realized with most current techniques.

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