Reality + Virtual =

How physical environment interact with Augmented Reality

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ABSTRACT
Ninja! Shine is an ongoing mobile game project that integrates Augmented Reality (AR) into a stealth game with the modularized map. The player can control a character to escape a completely dark maze using his limited ability to light up part of the game world. To enhance the game mechanism with AR, this paper explores various approaches to create an interactive experience between AR technology and physical environment. Feasible approaches are discussed and shortlisted. New game mechanics of *Ninja! Shine* is then proposed.

Keywords
Augmented Reality, NUI, TUI, location-based, SLAM

1. INTRODUCTION
With the progress of recent Augmented Reality (AR) technologies, tracking and mapping of the physical world are now more accurate. Advanced AR interaction on a mobile device has become possible. On a latest Google developer conference, Google announced a new application, Google Lens, to integrate AR with the user experience. It can bring up relevant information from where the smartphone is looking at and even perform further actions on the information intelligently. You can find information about a shop by simply facing your camera to that shop. Router password printed on a label can be pick up and the user can instantly connect to the network [1]. On the other hand, Apple showcased the AR capabilities of their latest iPhone 8 and iPhone X with stunning tech demos, including a AR strategy game called *The Machines* which demonstrates its ability to display a battleground on an empty surface and correctly track the relative position between the phone and the surface without any noticeable drift [2].

While the great advancement of AR in the past decade has blurred the line between virtual and physical reality remarkably, the potential of AR games is still hidden behind a mask. –In order to research new game mechanics based on the AR technology, several approaches to combine AR with physical environment are discussed in this paper.

2. FIELD
Augmented Reality
Feiner et al. defined AR as a system that is able to 'combines real and virtual objects in a real environment; runs interactively, and in real time; and registers (aligns) real and virtual objects with each other' [3]. One example is the famous mobile game *Pokemon Go.* AR is being used to superimpose interactive virtual objects, such as monsters and special spots, on real-world locations. Players could catch the monsters and collect items on the special spots. Meaning of the places is literally redefined by this game. Although this example illustrates location as input and the mobile phone's screen as output, the combination of input and output could be anything. An iPhone app called RjDJ can detect ambient sound and transfer it into interactive music. Since ambient sound is generated differently when you are in different locations, environment, and even your own action, every music generated is unique [4].

3. KEY PLAYERS
Since there are many existing approaches, this paper will focus on three categories of approaches which are well studied.

3.1 Natural User Interface (NUI)
NUI is a user interface that allows users to interact with electronic devices with "natural" human actions, including gesture, speech, and gaze. Users should feel easy to use and intuitive. An example in AR hardware is the Microsoft Kinect.

Kinect is an RGB-D sensor which can detect the target environment and physically-based interaction by capturing color images, depth images and concatenated point clouds from multiple cameras [5]. With support from a few external libraries, a virtual ball can interact with user's bare hand and a physical paper can collide with the ball as depicted in figure 1.

Figure 1. On the top right, the hand model is represented as a collection of spheres in the Bullet physics engine. The virtual tennis ball would move with the hand model.

While the NUI is designed for intuitive user experience, its main shortcoming is the lack of precision and intuition. L. Heck et al. had experimented the effectiveness of using gesture and speech to browse a web page using Kinect. The result shows that around one-fifth of gestures being captured was unintentional and one-fifth of gestures was not captured. About 20% of word error is also recorded [6]. These input error could damage the user experience of the user and encourage frustration.

3.2 Tangible User Interface (TUI)

According to Billinghurst, TUI in AR are those in which "1) each virtual object is registered to a physical object and 2) the user interacts with virtual objects by manipulating the corresponding tangible objects [7] ". Two examples are selected to analysis this approach.

3.2.1 ARGroove [7]

ARGroove is a tangible AR musical interface that allows people to interact with physical LP records to compose electronic musical individually or in a group [7]. Players can pick up real LP records with AR markers on it. The markers will be captured by a camera and displayed as a virtual controller on a big screen. By moving the records as depicted in figure 2, players can play, remix and modulate musical elements which will be indicated on the virtual controller. By playing with different records, players can compose difference music sequence into a performance.

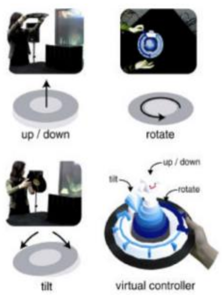

Figure 2. This picture demonstrates how different movements control the virtual controller in ARGroove.

3.2.2 Tangible Volume [8]

Tangible Volume was proposed by Issartel et al. to integrate the display of a virtual world and a tangible controller into one. This is achieved by giving an illusion that the box is displaying a virtual scene inside it, something very much like a fish tank.

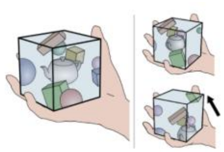

Figure 3. This image shows how a Tangible Volume is operated.

TUI enhances the user experience by relating the spatial manipulation of a true object with the presentation of a corresponding virtual object. Users could interact with the virtual content using the same skills they used in their everyday life [7]. As a result, the learning curve of a new user interface can be minimized. On Tanaya's study on comparing NUI and TUI, he found that although there is no considerable time difference in completing tasks between TUI and NUI, users "do perceive TUI to be significantly more "efficient" and "perspicuous" [9].

However, Tanaya also noticed that design of TUI showed some potential problems on the physical aspect [9]. For example, since Tanaya' s TUI prototype was not designed for the left-handed user, they might find the controller uncomfortable. Some users also reported that a component in the controller was not designed as intuitive as it should be.

3.3 Location-based Augmented Reality

Location-based Augmented Reality is a combination of AR with location awareness capabilities of a mobile device [10]. There are two vastly different approaches to recognize the surrounding area and the main differences are how and when the data is acquired.

3.3.1 GPS location

Using GPS (Global Positioning System), coordinates and altitude of the device can be obtained by a network of satellites. To integrate with the AR system, data from various sensors (e.g. the accelerometer and the compass sensor) is also processed to determine the orientation of the device [11]. The most famous example using this technique is *Pokemon Go* [12]. Players can search real-world locations to capture monsters spawned all over the map and acquire items on certain places of interest placed on the map as depicted in figure 4.

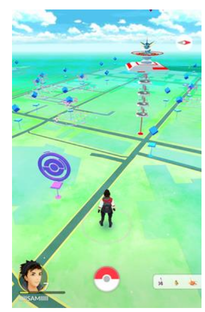

Figure 4. The screenshot shows how virtual places of interest are displayed on a geographical map based on player location.

Pokemon Go provides an engaging experience by relating real world to the game mechanics. Players can find different types of monsters depending on which landscapes they are in, to give an illusion of a virtual Pokemon ecosystem. The game also introduces a competing system where players are divided into teams of three and allows them to occupy real-world location and fight each other. This system encourages the communication of players and blends the game into social life.

Nonetheless, one of the limitations of this technology resides in the indoor environment where the GPS signal is weakened, and the other one is that environment itself is not interactive. The former limitation produced the most experienced problem in *Pokemon Go* - GPS drifting. When the player is underground or sometimes inside a building, the preciseness of the location tracking would be suffered where the character "drift" from the actual location frequently. The latter limitation is caused by the nature of the technology itself in the sense that only latitude and longitude is reflected in the gameplay, which could potentially be solved by the second approach.

3.3.2 Simultaneous Localization and Mapping (SLAM)

SLAM is defined as a problem of learning about an unknown environment by using sensor data to construct a map while tracking its own location simultaneously [13]. Unlike GPS, the tracking is entirely based on the device itself. Fusté et al. have demonstrated the area tracking capability of SLAM in their experimental project [14]. Their project can allow players to draw virtual highway on the floor and let a real remote car follow it. As the car moves along the track, the game world will be built around it, creating an atmospheric scene. By understanding the environment, a game can project the virtual objects on the real world much more precisely, and more interactive game mechanics can be developed as the engine can process data of the real-world terrain. On the other hand, the disadvantage of SLAM is the hardware requirement. Apple's ARkit provides excellent features on AR and SLAM, but it is limited to its products using the Apple A9, A10, and A11 processors [15]. Google's ARCore currently only supports Google Pixel and Pixel XL and Samsung Galaxy S8 [16].

Apart from learning the environment, a SLAM system can also be used on object recognition. ZSpace had developed a Ferrari AR Showroom App using this technology. Customers can choose to repaint the selected car, show the X-ray view, break down the car to show its component and customize the car components on the app [17]. Using object recognition, users and developers can change the virtual representation of a real object, producing a more interactive experience. Yet, such 3D reconstruction would require a pre-recorded video or scanning process to recognize a certain amount of feature points and store it locally or on the cloud, for example, Wikitude and Vuforia, two well-renowned mobile AR development tool [18] [19]. The reconstruction process cannot be done in real time dynamically, which greatly limit the usage.

By combining GPS and SLAM, the capability of an application can be further extended. Paula mentioned a development program from Senseable City Laboratory called Skycall. It provides tour guide to students in the MIT campus whenever a student "call" a droid on the Skycall mobile application [20]. Students can then follow the droid to navigate to wherever they want. The combing of technology removes the restriction of environment tracking, allowing the droid to move both indoor and outdoor [21].

3.4 Summary

A few elements from the above key players have been selected to summarize their advantages and disadvantages on a mobile platform in Table 1. Then, the feasibility of implementing the mentioned approaches in the game project, *Ninja! Shine*, will be discussed.

Table 1. Comparing approaches to interact with the environment

	NUI	TUI	Location-based AR
Added value	Intuitive player control	Easier interaction with virtual object	Interactive game mechanic with player location / nearby terrain
Hardware required	Depth sensing camera / microphone	Controller with marker(s), camera	GPS sensor, accelerometer, compass sensor, camera / Depth sensing camera
Technology required	gesture tracking / Speech recognition	AR marker recognition	GPS/ SLAM
Limitation	Lack of precision	Require good design on the controller, require a hand to hold the controller	GPS drifting / limited platforms depending on the tools

Ninja! Shine is a stealth game where players need to stay hidden from the enemies. It is expected to be challenging and requires skillful control to complete a stage. The limitation of NUI could be devastating when the player needs to perform an action precisely. The accumulation of input errors could bring tremendous frustration to the player in an already challenging game. On the contrary, TUI using marker tracking could provide a more accurate and intuitive control. Players can control a virtual object as if they are controlling a real object. However, the TUI controller would occupy a hand, causing inconvenience to the players. The third candidate, Location-based AR could enhance the game mechanic by interacting with the real-world environment. However, it requires to implement a more complicated system to be integrated into the gameplay and requires specific hardware depending on different AR software development kit.

3.5 Technologies/Approach

Based on the above findings, three new mechanics are proposed to enhance the current gameplay of *Ninja! Shine*.

3.5.1 TUI Controller

A TUI Controller which can control the main character is presented. It is a paper box consisted of six faces of AR markers and has a hole to be worn by a fingertip. It will be rendered as a small floating light ball on the screen, where other parts of a finger are hidden as the virtual content always render after the camera image does. The main character can be controlled by:

- Node your finger while point the light ball on the character to select, then swipe your finger to a direction to move the character
- Turned your finger and draw a symbol to use a special ability.

Comparing to touchscreen control where the finger could block the screen, players can see through the controller in this approach. Since this is a fingertip device, the design difficulty arises from right-hand and left-hand users can be addressed.

3.5.2 Terrain Transformer

This approach uses SLAM to detect surrounding environment and change the level setup accordingly. For example, objects on the desk, such as pen holders, books, and laptop, can be detected as simple cubes and cylinders. According to these 3D shapes and its coordinates, some modules in a predefined stage can be replaced by modules that fit into the 3D shapes. This approach provides a dynamic interaction with the physical space and improves the replay value of the game.

3.5.3 Keep Quiet

In a stealth game, the main character should remain undetected, but what about the player? It is only fair if the players also avoid getting attention. In this approach, a new enemy has a chance to be generated when a surrounding sound is detected. The environment noise will be canceled balance the difficulty. This encourages the players to stay quiet and helps them to immerse in the game easily. Generated enemies will emerge from where the sound is produced, so players can guess their locations and play strategically.

4. CONCLUSIONS

This paper described several approaches to combine physical environment and virtual contents. These approaches are analyzed and the result showed that TUI and Location-based AR are feasible to be integrated into the game project. Based on the result, three game mechanics are proposed. Further study on the proposed mechanics would be required to prove the actual result, where small prototypes could be built to test the technical feasibility and perform the user acceptance test.

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