Using Unity 3D to Facilitate Mobile Augmented Reality Game Development

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***Abstract*— Mobile augmented reality (mobile AR) enables virtual content such as 3D models, animations and annotations to be placed on top of a real world objects in any context. We applied mobile AR to develop the Calory Battle AR exergame to tackle worldwide childhood obesity. In this game the player finds and defuses virtual calory bombs in a real world environment. Specifically, we present the development of two game versions. First prototype was created without a third party game engine and it led to many challenges. To explore solutions to these challenges, we created a new version of game with the Unity 3D game engine. Using the Unity 3D, the game development process was simplified. A mixed-method usability evaluation on children and university students indicated that especially interaction with AR content and user interface clarity were improved in the Unity 3D version. This study produced three important contributions: 1) a novel mobile AR exergame to motivate children to move; 2) reimplementation of the game using the Unity 3D; and 3) results of a usability evaluation comparing two game versions. We expect that game engines such as the Unity 3D will become essential for AR game development in the future.**

Keywords—exercise; mobile game; game engine; augmented reality; usabilty

I. Introduction

Today, ubiquitous technologies develop rapidly and are widely spread. As a consequence, many citizens in developed countries use the smartphones in which making phone calls has become a secondary function. Smartphone platforms, such as iOS and Android, provide not only highly sophisticated computing and context sensing infrastructure but also open markets which contain a variety of applications and services for users to benefit from. With the prevalence of smartphones, the interaction between humans and the context through ubiquitous technology has been given more attention. One of the means to enrich this interaction is augmented reality (AR) in which virtual content is placed on top of a real world camera view. AR can provide additional contextual information and enable more realistic interaction experience with virtual content. At the moment of writing this paper, there are hundreds, if not thousands, AR applications available for smartphones. Many researches have been conducted on augmented reality in the fields such as tourism[1], shopping[2], education[3] and entertainment[4]. Early AR applications required the user to carry a computer and a Head Mounted Display (HMD) but in this study we focus on mobile augmented reality (mobile AR) which is enabled by handheld devices such as smartphones. Mobile AR enables unobtrusive gathering, managing and utilizing contextual information and providing AR-enhanced services based on the user's context.

One of the great challenges in developed countries such as UK, South Korea and New Zealand is that obesity rates in all age groups have been on the rise while physical activity rates have been declining[5-7]. According to the World Health Organization, the worldwide obesity has nearly doubled since 1980 and more than 40 million children under the age of five were overweight in 2011[8]. To tackle this challenge, we have set to harness the power of smartphones and mobile AR to develop exergames (exercise games) for children and young adults which aim at making exercise more fun. Exergame is video games that are provide player with physical exercise. There are many ways to participate in exergaming through systems such as Nintendo Wii, Xbox Kinect, PlayStation EyeToy. In this paper we will focus on mobile exergame such as GeoBoids[9], Walk2Build[10], SmartRabbit[11].

In this paper we explain our experiences and challenges in developing Calory Battle AR, a mobile AR exergame. Specifically, we present the development of two prototypes of the game: one without an existing 3D game engine and one with the Unity 3D game engine. Second prototype was created by undergraduate students on an animation production course to alleviate the challenges met in the development of the first prototype. We also analyze previous studies on AR systems, perform a usability study between two versions of Calory Battle AR and discuss the findings.

II. Background

A. Augmented Reality Systems

In early augmented reality systems the users carried a computer and/or some form of Head-Mounted Display (HMD). MARS, Studierstube, AR Quake, AR Pacman are examples of such early AR systems. MARS (Mobile Augmented Reality Systems)[12] consist of a computer with 3D graphics acceleration, GPS, See-through HMD, wireless LAN and other components. Studierstube[13] is wearable augmented reality system that makes user to interact with the augmented object

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by a pen and pad. User equips laptop on his back, a helmet with video output device and webcam and use pen and pad which are track optically by markers and camera. AR Quake[14] and AR Pacman[4] are examples of games that use augmented reality technology. Specifically these are adaptations of augmented reality to popular Quake FPS and Pacman arcade games, respectively. Both game use wearable computers for data processing and require See-through HMDs to show information to the user.

AR Phone, MobiAR and GeoBoids are examples of mobile AR that are based on handheld devices instead of wearable computers and HMDs. As a consequence, the user does not have to carry special hardware which improves mobility. AR Phone[15] is study where a mobile phone with limited processing capabilities is used to provide an augmented reality interface in smart environments. In the AR Phone system high-processing tasks such as image processing are performed on the AR server and the phone merely performs the role of viewer. MobiAR[16] is Android application that provides tourist information with augmented reality. When users observe the real world through the MobiAR, the view is augmented with information of their location. With multimedia content, users can access useful information to plan their routes in the city. GeoBoids[9] is an exergame that uses AR on smartphones. The game provides Field and Arcade modes where the player has to search and capture virtual GeoBoids creatures in an outdoor real world environment. Interaction between the player and augmented reality objects is simple which is just touch or swipe on the smartphone screen. To our knowledge GeoBoids and Calory Battle AR are the only research outcomes of exergames utilizing mobile AR.

B. Challenges in AR Development and Use

Past augmented reality systems suffered from limitations of mobile technology and IT infrastructure. These limitations cause the developers and users to experience several challenges as described below.

Firstly, using special AR hardware such as HMD has some problems. HMD disrupt the view of vision and may cause inconvenience to the user. In addition, if HMD has low resolution, it causes difficulties to recognize augmented object and distortion of the sight that differ from real world. Moreover, special hardware is less accessible than common device such as smartphone. The latest example of special hardware for AR is Google Glass, which is wearable computer with an optical head mounted display. Although its technology is sophisticated and design unobtrusive, Google Glass is currently too expensive to normal users. Another problem of Google Glass is that the current version cannot be used by people who wear ordinary glasses.

Secondly, implementing augmented reality and building mobile computing interfaces require much time and effort from the developers. In the past, memory and data processing capabilities of mobile devices were significantly lower than today. As shown in AR Phone system, high data processing tasks can be delegated to an external server which performs necessary computations. This issue requires developers to build an infrastructure for external data processing and communications which, in turn, inflict latency to user experience.

Because of these limitations smartphones containing a camera, high performance processing unit, high resolution display and context sensing capabilities have emerged as potential platforms for implementing mobile augmented reality. Yet, implementation of AR can still be a complex task. Today there are many AR libraries, such as Qualcomm's Vuforia, to alleviate this problem but they often lack direct support for processing of and interacting with virtual objects for the purpose of gaming. This, in turn, can increase time required for the development of mobile AR games.

In next section, we introduce a mobile AR exergame Calory Battle AR that overcomes the aforementioned limitations. Additionally, in second iteration of the development process we explore the combination of Unity 3D game engine with AR to speed up the development and enrich 3D environment.

III. Calory Battle AR Development

A. Concept and Implementation of the First Prototype

Calory Battle AR is an Android-based augmented reality mobile game which aims at promoting physical activity among children but it can also be enjoyed by adults. It is different from console-based exergames (e.g. some of Nintendo Wii games) in that it is based on the real world context, thus including an additional motivation through context exploration. The game can be easily deployed at different locations because it does not require any special equipment other than an Android smartphone and printed image targets representing augmented reality content.

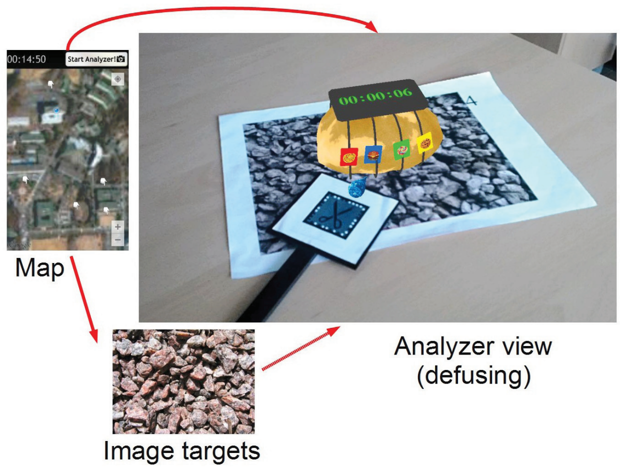

Fig. 1. Basic concept of first prototype's game flow

The Calory Battle AR story features the Dews, the good guys, and the Caloroids, the bad guys. The Dews extract energy from our sweat and with that energy, they cast spells on us that make our bodies healthier and mind sharper. The Caloroids hate sweat and thus want to stop us from sweating and to become unhealthy. The player's role is to help the Dews by finding and defusing calory bombs that have been placed around a geographical area by the Caloroids. There is a global time limit for finding the bombs so the player must go from one bomb to another one.

Figure 1 shows basic concept of game flow. The player begins by locating the bomb using GPS map. After finding an image target in real world, the player start the analyzing screen and AR bomb model is appears on the top of image target. Then the bomb's local countdown timer is started at a random time from 10-60 seconds during which the player must defuse the bomb. A bomb should be defused by careful removal of virtual fuses in correct order with the Multitool which is another AR model representing a dewdrop. The fuses have appearance of unhealthy food such as pizza and hamburger. The player earns points by defusing the bombs and for remaining time at the end of the game (i.e. when all bombs have been defused or exploded). After finishing the game, the player can upload score to a hall of fame website where they can be compared against other players' scores.

B. Challenges in the First Prototype

The first prototype of Calory Battle AR was created using the Vuforia AR library but without any third party rendering or game engine. This design decision caused various challenges related to loading, processing and presenting AR content.

When a 3D model is loaded manually in Vuforia it must be given several parameters such as coordinates and factors for translation, scaling and rotation. These parameters affect how the model appears on top of the image target. If one wants to, say, rotate a model after the user has interacted with it, this has to be done manually by the programmer. Thus, making dynamic changes to the content on-the-fly is tedious at best. Furthermore, there is no physics engine to support realistic game object manipulation effects.

After a model has been loaded, it is rendered by the programmer using OpenGL library calls. Lack of rendering engine means there is also no direct support for shaders which are required for drawing special effect on the models. As a result, model appearance lacks the final artistic touch that would make it look more realistic. Finally, scene backgrounds are not used – the only 3D content is the game objects drawn on image targets.

There is no support for animations in the vanilla Vuforia AR library. To create animated countdown timer and bomb explosion, the programmer had to manually swap images to cause animation effects. For simple and repeating animations this is not a big issue but dynamic animations are not feasible.

The only way of interaction in the bomb defusing screen is to use the Multitool (or back button). Adding more interaction modalities would require programming each of them into the game. Collision detection, which is a prerequisite for game object interaction, is done manually by checking whether bounding boxes of two game objects intersect. Due to our lack of experience in 3D game programming, this solution, together with loading and rendering 3D content, makes the game loading and rendering performance suboptimal.

C. Calory Battle AR with Unity 3D

To solve aforementioned challenges, we created a new version of game by Unity 3D and Vuforia AR Extension for Unity. Unity 3D is a feature rich, fully integrated development engine that provides out-of-the-box functionality for the creation of interactive 3D content. Using Unity, you can publish to multiple platforms such as PC, Web, iOS, Android and Xbox[17]. Complete toolset, intuitive workspace and on-the-fly play testing and editing feature of Unity makes developers to save the time and effort. The Vuforia AR Extension for Unity enables vision detection and tracking functionality within the Unity and allows developers to create AR applications and games easily[18].

The first prototype Calory Battle AR and the new Unity version share the same basic frame as shown in Figure 2. Players have to find virtual bombs indicated by a map and defuse them by AR interaction. The way of interacting with the bomb is different. In the first prototype, the bomb is defused with the Multitool. This interaction uses two different augmented reality objects. However, it was confirmed in user feedback that the distance between two objects is not clear and defusing require high precision. The Unity version of game uses virtual buttons to provide more intuitive and more user friendly interaction. A virtual button is a virtual object that is drawn on a marker and it can be pressed by finger directly. Additionally, by placing the floating food images on each buttons, it made user to distinguish button objects more clearly. Finally, static indoor map was used instead of GPS map to demonstrate the game.

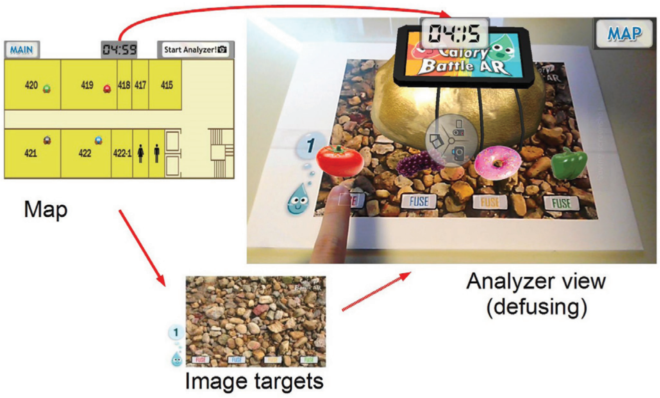

Fig. 2. Basic concept of Calory Battle AR with Unity 3D's game flow

Using Unity 3D enabled several visual improvements. The graphical expression of the augmented objects became more precise by using Unity's built in shaders. As result, augmented 3D model appearance looks more realistic and graphic modification was quick with on-the-fly play testing and editing feature. We can also express more realistic manipulation effects by Unity's built in physics engine. Although animation was not implemented in this game, it would be possible to create animated bomb explosion or other effects.

There are some added values with Unity 3D to the development work. Complete toolset feature of Unity makes writing the code more intuitive. Developers can see the relations between programming code and game objects visually.

Developers also do not have to assume and adjust values just by code and they can check how an object reacts to property changes immediately. In addition, communication between programming part and graphic part was smooth because Unity enhances the link between both parts. These properties of Unity speeded up the game development process greatly. Unity 3D also supports various formats such as .max, .mb, .fbx, .obj, thus allowing detailed and systemic interoperation with other programs.

IV. USABILITY EVALUATION

Table I shows the evaluation setting with demographic information. We used a mixed-method questionnaire (in Korean) that included open-ended and multiple choice questions with Likert scale (5 = strongly agree, 1 = strongly disagree). Pre-test part of the questionnaire collected participant's background information about feelings toward sport and games. Post-test part of the questionnaire measured participant's perceptions on motivation, usability, game activities and game's appropriateness. In this evaluation we only analyzed statements related to usability. Evaluation started by researchers explaining the game concept and how to defuse bombs after which the players filled in the pre-test questionnaire. In the first prototype evaluations, the players were divided into two teams and they were given 20 minutes to play in university campus. In Unity version evaluation the players played individually for 5 minutes inside a university building. Researchers observed and took notes on gameplay. After playing game, players filled in the post-test questionnaire.

TABLE I. EVALUATION SETTING

	First prototype		***Unity version***
	Primary school students	**University students**	**University students**
Date	October 2012	March 2013	September 2013
Sample size	11	18	11
Male/Female	7 / 4	16 / 2	11 / 0
Average age	13	24	24
Location	Outdoor university campus in Korea		Indoor classrooms in Korea

Compared to the first prototype, the Unity version received more positive answers in usability as shown in Figure 3. Difficulty of defusing bomb was improved in the Unity version by using virtual buttons instead of the Multitool. Using the Multitool was seen as a challenge in first prototype by several players, for example:

- When the bomb is on ground, it is hard to push the fuse exactly. It would be better if the fuse is a little higher. (M21)

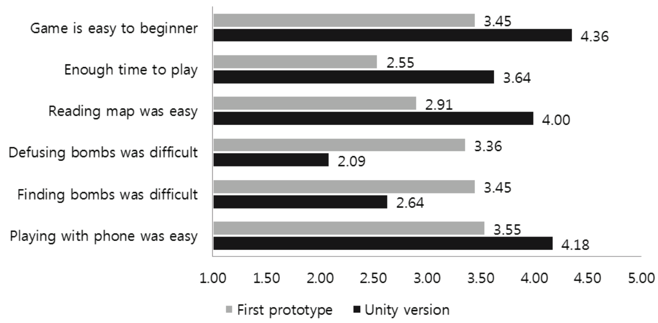

Fig. 3. Evaluation of usability

Majority of players agreed that playing with phone was easy in the Unity version, but still there remain some problems that were identified by the players:

- Holding phone with one hand, it was difficult to matching finger's position though the screen. (M24)
- Reflected light on the image target causes error in operating virtual button. (M24)

Figure 4 shows evaluation of clarity. First two statements were only used in evaluation of the Unity version. The map clarity was considered of poor quality in the first prototype. This was due to temporary problem with Google Maps tile resolution. Qualitative feedback also suggested this:

- Map resolution is not good so it was a little bit hard. (M29)

However, the Unity version received high score regarding map screen. This is possibly because the Unity version uses a static indoor map with a very simple design. This also explains difference between easiness of map reading in Figure 3.

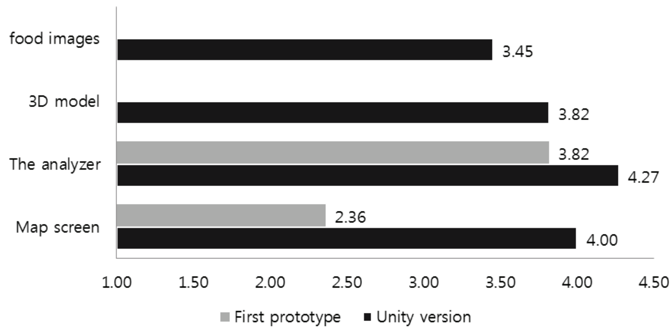

Fig. 4. Evaluation of clarity

3D model of Unity version's clarity received positive scores from the players but some were still not satisfied with the bomb's shape both in the first prototype and Unity version:

- Design bombs more realistic. (F13, the first prototype)
- I think bomb's shape should be more like a real bomb. (M25, Unity version)

We added questions to the Unity version questionnaire for evaluating whether players liked virtual buttons. All game control functions were appreciated by majority of players as shown in Figure 5. As we mentioned earlier, the Unity version diminished the difficulty of defusing bombs of the first prototype by virtual buttons.

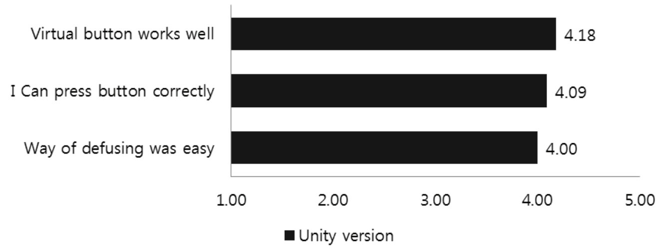

Fig. 5. Evaluation of Game control

Overall, the Unity version outperformed the first prototype especially in aspects of interaction with AR content and user interface clarity according to player's feedback from the Unity version's questionnaire:

- Interaction with invisible thing was enjoyable. (M23)
- The way of interaction with augmented reality was interesting. (M24)

V. DISCUSSION

We solved some of the first prototype's challenges by using Unity 3D. Other challenges, such as interaction with the bomb, were solved by re-design of game interaction. Virtual buttons made it possible for players to have more intuitive interaction by using their fingers directly. Another improvement was made on the graphical expression with Unity's built-in shaders. Moreover, its Unity's complete toolset made programming more intuitive and fast. However, there are still some challenges to be solved in future.

First, both versions of the game have the same challenge related to the way Vuforia handles locations of different targets. All targets tracked by Vuforia have their own coordinate system, with the origin being in the center of the target. In regular 3D games the coordinate system is typically uniform for all objects which make for example collision detection easy. In the first prototype we had to take the model view matrix of target A, invert it, and then multiply it with the transposed model view matrix of target B. This created an offset matrix with which one can multiply by points in 3D space to produce the coordinates in the other target's coordinate space. This entails more calculations that are required for something as common as collision detection, so the matrix calculation algorithms should be highly optimized.

Second, as shown in the user feedback on clarity, the calory bomb's design should be changed. The bomb's texture quality was improved in the Unity version but its design is still unsatisfactory to some users. Users hardly recognized that the bomb's shape is similar to fat (as the game story suggests). We should also emphasize the background story of the game to convey the meaning of the bomb's shape.

Third, two usability challenges identified by players' qualitative feedback related to difficulty of defusing the bomb while playing alone and virtual button error caused by reflected light. First of these challenges can be solved by encouraging the players to form teams. As one player holds the mobile device, the other can perform defusing with greater stability. The second challenge relates to augmented reality's inherent requirement for suitable light condition. This can be remedied by careful positioning of image targets to locations with sufficient light levels and no reflections.

Fourth, high scores are wiped out whenever the game is restarted. So instead of saving high scores in the game, the game calculates a rank (A, B, C or D) so that players can compete against each other but this competition can only be done locally. To solve this problem, a web server with a database is needed for persistent and shareable high scores.

Lastly, map is too inflexible to play in other places. There is no GPS or indoor positioning feature in the Unity version, so the player's location is not indicated on the map. The map's image is static so it should be customized for every game location. A solution is to make the map adaptable to the player's location using GPS, for example.

VI. CONCLUSION

Smartphone-based mobile AR solves challenges that past AR systems had, including inconvenience of head-mounted displays and computer backpacks as well as requirement of external data processing infrastructure. We described two versions of Calory Battle AR exergame that utilizes mobile AR as a means of visualization and interaction. In Calory Battle AR, the player's role is to find and defuse virtual calory bombs in a real world environment. First prototype of the game was created without a third party rendering or game engine. This led to many challenges related to 3D data processing and presentation. To solve these challenges, we designed a new version of game with the Unity3D game engine. The game development process was significantly faster and required far less programming than the first prototype development. Usability evaluation indicated that the Unity version outperformed the first prototype especially in aspects of interaction with AR content and user interface clarity. One of aspect that improved user experience is virtual buttons. They made it possible for players to have more realistic interaction by using their fingers directly. Graphical expression was also enhanced by using Unity's built-in shaders.

This study produced three important contributions. Firstly, we presented a mobile AR exergame. This is significant because up to date there are only few exergames that utilize the affordances of augmented reality. Secondly, we utilized Unity 3D to implement a version of Calory Battle AR. In the process we analyzed the challenges of developing a mobile AR game and how Unity 3D can solve some of those challenges. These experiences can be beneficial to other AR game developers who seek to facilitate AR game development process while enriching AR content visualization and interaction. Thirdly, we presented the results of a usability evaluation comparing two versions of Calory Battle AR. The usability evaluation drew interesting results such as defusing with a finger is more comfortable than defusing with a multitool. These results indicated points of success and failure which form the basis for future improvements, but a deeper comparison should be done in the future to understand underlying reasons for improve usability.

Despite of solving many challenges by using Unity 3D, several issues remain to be addressed in future research as suggested in discussion. Unity version of the game was developed from scratch as a proof-of-concept, thus it lacks some features such as GPS, collision detection between multiple AR objects and, most important of all, flexibility in terms of game content management. In future research we seek to integrate these two versions but this task will require significant efforts as underlying systems are quite different. Finally, user evaluation should be widened to cover larger sample sizes and deepened with more detailed instruments.

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