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DISPLAY OF INTERACTIVE 3D MODELS IN AUGMENTED REALITY ON MOBILE DEVICES

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Abstract: *This paper study is related to two research areas, namely 3D computer graphics and augmented reality with a combination of their display on mobile devices. It presents the creation of three different interactive 3D models based on a realistically drawn image of domestic animals and can be displayed on mobile devices using augmented reality. The textured animals' models are displayed in the application Augmented animals (slo. Obogatene živali) with a simple user interface. The usability of the application is demonstrated by the detection of the image target, i.e., a printed interactive card, which proves the interaction between the mobile device and the augmented paper. When the mobile device camera recognizes the target, it displays the selected animal on the screen. The result is the enhancement of the real environment with animated 3D characters. By displaying a 3D character on the screen and interacting with the user interface, the presentation of each animal in three different animated movements is enabled.*

The first empirical part of this work was done with the help of the Blender program, in which we created all three animal 3D characters. First, we had to model all the animals from the initial templates into a recognizable 3D mesh, which we then mapped the textures on. This was followed by the construction of a system of bones and animation controls, based on which we could create the animal animations. After this step, we transferred the project to the Unity program. Then it followed the construction of an application that allows the representation of characters in augmented reality. The results of the entire work are appropriately made animal characters in the form of animated 3D models that can be displayed in augmented reality mode on mobile devices using interactive cards. The selected testing parameters showed that there are certain differences in rendering between the two tested mobile devices depending on the selected subdivision level of the 3D character. However, for recognition based on lighting conditions, distance and slope between the image target and the mobile device, the best user experience is obtained when the image target is captured from a distance of 15-20 cm and from a bird's eye view under good lighting conditions.

Keywords: 3D computer graphics, augmented reality, mobile devices, interactive 3D content, augmented paper.

1. INTRODUCTION

Mobile Augmented Reality - MAR stands for the display of augmented reality on mobile devices that adds computer-generated virtual content to the real world using a selected mobile platform. Mobile augmented reality systems usually include programs or applications. The combination of augmented reality and various mobile platforms allows the creation of various new mobile applications that include the use of augmented reality. Nowadays, the use of MAR is very wide, research is mainly focused on its use on devices such as smart glasses, smartphones, tablets, PDAs or even in some cases laptops. Mobile phones are considered the most typical MAR device because they contain a camera, sensors, powerful processors and specialized graphics hardware. This has made them the dominant mobile platform for MAR. Despite rapid advances, their capacity for real-time applications is limited. The most popular examples of MAR usage are Pokemon Go, Archeoguide, ARQuake, BARS, Snapchat, etc. (Kipper & Rampolla, 2012; Furht, 2011; Chatzopoulous et al., 2017; Craig, 2013; Shah, 2018) MAR system programs consist of the following three main components (Chatzopoulous et al., 2017; Shah, 2018):

- Input components that are part of the mobile device and have various sensors attached to them (camera, gyroscope, microphone, GPS) that serve as input for the MAR application;
- Data processing displayed on the mobile device screen, which requires access to data stored locally in the device or in a remote database;

- Output components where augmented reality content is displayed on the screen of a mobile device.

1.1 Examples of displaying 3D graphic content on mobile devices

We present some recent examples of research or market products that address the display of 3D graphics content in augmented reality in the MAR domain, using enhanced paper for the display. In the latter, interactive flashcards are usually used to display 3D models in augmented reality, with certain information on both sides. The main purpose is usually to facilitate familiarisation with the material or objects. Another alternative is various printed media, which are mainly used to facilitate the learning of the material. In addition to the graphic content it contains, the augmented paper also serves as an image target that enables the display of augmented reality on a smart device, such as a 3D model or other multimedia content (Wikipedia, 2021; Dijaya et al., 2018; Chow, & Sharmin, 2020; Subhashin et al., 2020; Andayani et al., 2019). On mobile devices, the thing works best via a developed application where the display is based on the model method of representing data (Kipper & Rampolla, 2012).

We summarize the research findings, focusing on functionality, usability, and user experience. Using medicinal plants as an example, systems for display and recognition were developed (Dijaya et al, 2018), with the goal of the application being to display 3D models using augmented reality technology. Interactive cards containing a graphical image of the plants were used for the display. The whole process was carried out in the Blender, Unity and Vuforia programming environments. The final testing focused on determining how long it took to load a given 3D model, the impact of camera quality on lighting conditions, screen response, receptivity, comparison between different devices, and user responses. The main findings were that the 3D model can be displayed correctly under conditions where the final display is strongly influenced by the quality and lighting of the camera, which has a very large impact on the display of 3D models.

A similar example is the use of interactive cards in an application from AR, designed to facilitate independent learning in neurobiology, cardiology, and structural biochemistry at the University of Alberta. An entire process was developed involving the display of 3D models in real time, and all of this required high levels of computer literacy, programming, and design (Chow & Sharmin, 2020).

Education is considered one of the most common application areas of augmented reality, since most of the content in books and textbooks is not interactive. Therefore, one of the research papers focuses on how to reduce the use of digital media during the pandemic and use traditional print media instead. As a solution, they propose the use of interactive books based on augmented reality, where the books would offer more interesting use through a AR application. Each page of the book would reflect certain rich content regardless of the type of graphic representation. So the goal is to understand the content of the book without needing further help from other electronic media. The whole thing is based on a mobile smartphone app created in Blender, Unity and Vuforia. The application on the smartphone ensures the connection with the classic book and helps in easier understanding of the content, testing different ways of displaying it more concretely (Subhashin et al., 2020).

The last example from the field of research is the 3D representation of models using the example of the digestive organs, which augment the content of the anatomy book. Based on the selected data from the book, the creators first selected images from which the corresponding pixels and 3D models with textures were created. This was followed by the design of the entire augmented system for the application in the Android environment, where everything was developed by showing the markers of the intestinal anatomy in detail. In addition to the content, the application also included a suitable user interface, where the opening menu includes the options Play AR, How to Play and Exit. The first option allows viewing the 3D scene and organ, while the second option informs about the full use of the platform. The tests in this research tested distance detection, which involves determining the image plane of a marker from a given distance. This type of testing is concerned with how far the camera can detect the image target in centimetres. A stable display is estimated to be possible between 15 and 45 cm. The test also included tilt detection to determine the distance with a camera tilt test. Research has confirmed that the most stable detection angle is between 45 and 150 degrees (Subhashin et al., 2020; Andayani et al., 2019).

There are many examples in the market where augmented reality is used on augmented paper to display various 3D models. The main purpose is to show the appearance or movement of various objects, and they are primarily intended as learning aids. Most often, content creators sell everything together via a mobile application and with the physical content of printed interactive cards or a book collection. First, we will highlight foreign examples, such as representations of animal images, cartoon characters, the solar system, historical images, learning the alphabet, etc. Such examples are Talking Cards (AR Talking Cards, 2021), Paparmali AR (Paparmali, 2021), Monopril Interactive, Experience Real History Alamo, Animal and Food, Shifu Space (Miller, 2018), Digoo Education Card AR Kaka (Digoo, 2021), the Red Chimpz series which offers a rich collection of different kinds of animals (RedChimpz, 2016), etc. We can also point to a self-learning project for Arabic letters, created using tools such as Blender, Illustrator, Unity and Vuforia, which includes different types of animation, such as outdoor animation, action animation and fun animation (Expose Academy, 2016).

On the Slovenian market, we can highlight the example of the retailer Lidl, which, in cooperation with the Dutch company BrandLoyalty, offers an example of wildlife presentation through its Incredible animals brand. The application works with the help of special interactive cards on which augmented reality can be used to show nine different wild animals in a 3D model in their natural habitat along with sound. The whole system is equipped with a simple user interface that also allows playing simple games (Lidl, 2021; BrandLoyalty, 2021).

The purpose of this paper is to present the manufacturing process and the final result of the properly produced animal figures in the form of animated 3D models that can be displayed in the application with the help of augmented reality on mobile devices using printed interactive cards, and to present the main final results of the tests according to various selected parameters performed on two selected mobile devices.

2. METHODS

The working methodology included idea generation, development of initial images with sketches and 2D illustrations of 3D animal models, and final applications. Based on 2D illustrations and sketches, we performed the first part of the task in the Blender program, where we fully created all three interactive 3D models of a cat, a horse, and a duck. The animal figures were designed in a non-photorealistic and stylized way, based on cartoon photos. For research and final performance testing on mobile devices, the animals were designed with a varying number of polygons and body anatomy. In Blender, we performed all steps from 3D modelling to texturing to placement of bones and controls. As part of the animation, we created three different movements for each animal. We created movements in a stationary state (idle), an example of walking, and an action state where we have a walking mode for a cat and a horse, and a flying mode for a duck. The augmented reality model method was used to represent the creatures in augmented reality mode. For this reason, it was also necessary to create physical interactive cards on paper for display, which the augmented reality application can use to recognize them, allowing the display of 3D models.

In the following, we also planned the design of the whole platform called Augmented Animals, talking about the appearance of the application on mobile devices. We carried out the preparation process in the Unity program, where we used prepared interactive cards and created 3D animal figures to set up the entire application platform, which allows it to be displayed in augmented reality mode. Another step was the preparation of the test parameters according to different criteria, which allowed us to confirm or refute the hypotheses established at the beginning of the task. We tested according to the following parameters:

- Playback according to the different degree of subdivision on both mobile devices,
- Display from the viewpoint of the camera and the image target in five different lighting conditions,
- Character recognition based on the distance between the mobile device and the image target according to different recognition ranges in two different ways,
- Character recognition based on the detection angle between the image target and the mobile device.

The following mobile devices, namely the Huawei Mate 10 Lite smartphone (year 2017) and the Samsung Galaxy A32 (year 2021), were the most helpful in the tests. Finally, a final analysis was performed. Figure 1 shows the entire work cycle from the idea to the final product.

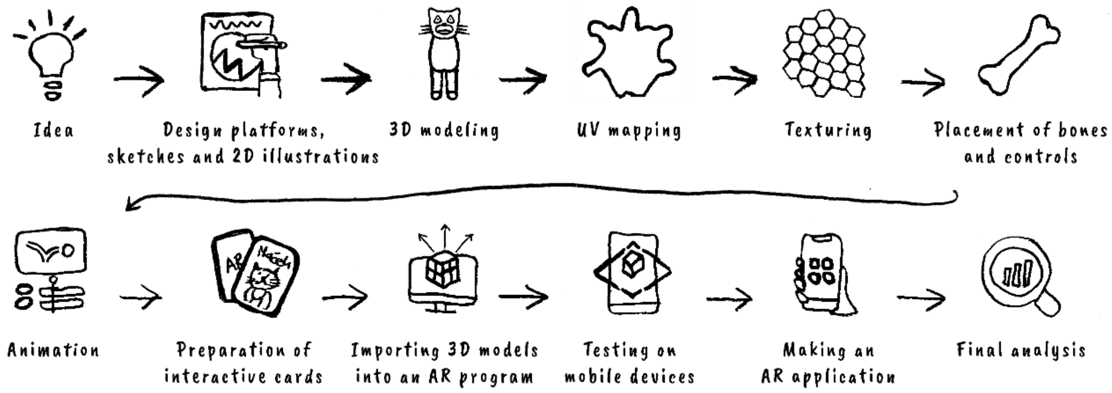

Figure 1: Showing the execution scope of production from idea to finished product

3. RESULTS

3.1 Presentation of the final results

The final result of the work is a mobile application called Augmented Animals, through which 3D animal models are displayed in augmented reality mode. After launching the platform from the desktop of the mobile device, it first takes us to the start menu, where we have the platform's trademark at the top and three buttons at the bottom, which are Start, Information and Exit. When you click on the Start button, the platform takes you to the application scene, where selected animal characters are shown in augmented reality mode with the help of image targets. In this mode, the user is greeted by three game buttons, which allow switching between three different animations when the selected character is displayed. Figure 2 shows the final result with all three animal models displayed on a mobile device.

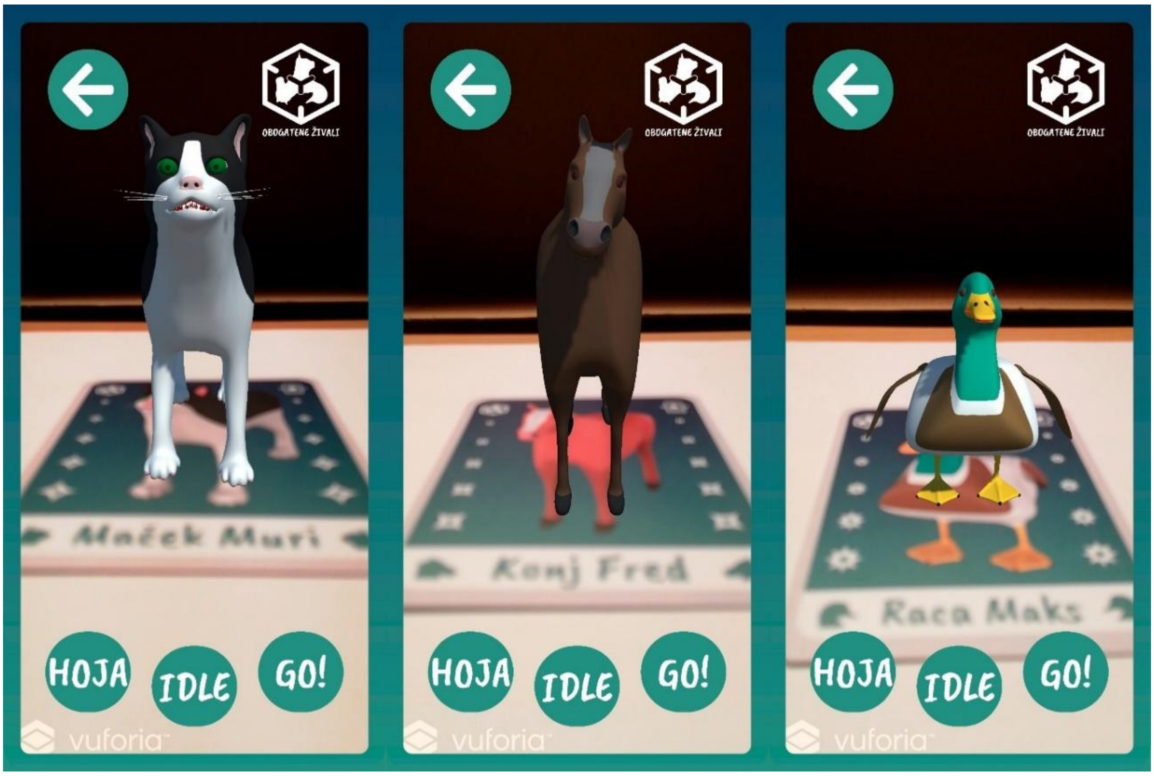

Figure 2: Display of all three animal characters on the image target from a mobile device screenshot

3.2 Final results regarding selected testing parameters

First, we analysed how animal characters play on two selected mobile devices according to different sharing levels (levels 0-3). Table 1 presents the playback performance results based on the degree of sharing between the two devices.

Table 1: Comparison of animal character playback by the level of subdivision between the two devices.

		Huawei Mate 10 Lite	Samsung Galaxy A32
Level 0	Static animation	There is no difference.	
	Dynamic animation		
Level 1	Static animation	There is no difference.	
	Dynamic animation		
Level 2	Static animation	No particular difference when playback animal characters. Playback quality looks better on a newer device.	
	Dynamic animation	Slightly slower playback, slight stuttering and less fluid playback.	Faster, better quality and smoother playback for a certain part.
Level 3	Static animation	No particular difference when playback animal characters. Playback quality looks better on a newer device.	
	Dynamic animation	Lower quality and slower playback.	Faster, better and smoother playback of action animations.

We also analysed the display of animal 3D models under different lighting conditions. Table 2 shows the final test results according to the lighting conditions.

Table 2: Test results according to lighting conditions.

	Image target	Character display
Sunny	Fast and successful recognition	
Cloud		
Artificial		
Light from another mobile device		
Darkness	Without success	

We also checked the detection according to different distances of the mobile device camera from the image target. In the first part, we checked detection when we did not have an animal character on the screen of the mobile device. Table 3 shows the final results of object detection according to the distance between the image target and the mobile device when starting the augmented reality mode in the application.

Table 3: Comparison of object detection by distance when launching augmented reality mode.

	Both mobile devices
Less than 10 cm	● Detection is rather difficult, as the camera is too close to the image target and consequently is not able to focus the card well enough. ● At a distance of 10 cm, it takes more time to detect than at a distance of 15 cm.
15–60 cm	● The light sensors of the camera quickly, qualitatively and successfully recognize the image target and display the selected animal character. ● The optimal distance for the best end-user experience is a detection range between 15 and 20 cm.
65 cm and more	● Due to the excessive distance, the mobile device camera is no longer able to detect all the details of the image target and does not display the character.

In the second part, we also checked how the animal figure is preserved depending on the distance of the image target from the mobile device. Table 4 shows the final results of described according to the distance between the image target and the mobile device.

Table 4: Comparison of keeping the animal character on the screen according to the distance between the image target and the mobile device.

	Both mobile devices
5 cm or less	● At a distance of 5 cm, the character remains visible, but we no longer see him in full, the character begins to shake. ● At an even smaller distance, the character disappears as expected.
5 cm or more	● The animal character remains visible even at a distance of more than 100 cm. ● However, the greater the distance between the device and the image target, the worse the final user experience is due to the lower visibility of the character on the screen. ● The ideal area of final use is a distance between 15 and 20 cm.

We ended the testing with an analysis that covers the recognition of the image target according to the inclination of the mobile device. Table 5 shows the test results in terms of the angle of capture between the imaging target and the mobile device.

Table 5: Results according to the angle of capture between the image target and the mobile device.

	Both mobile devices
Bird's perspective	● Fastest rendering, but we only see the character's back.
Sharp angle	● Still effective and fast rendering of the character, an intermediate level between the first and third views.
Right angle	● Characters did not want to appear in most cases. ● If we want to see the animal from the front, we have to put the mobile device in this kind of position, because it offers us the best end-user experience.

4. DISCUSSION

The following is a short commentary on all the results from the table of the previous point. First, we analysed how the animal characters are played on the two selected mobile devices according to the different levels of subdivision, namely 0 and 1. We noticed that animal characters and animations run equally well on both selected mobile devices. At Subdivision level 2, it has already been shown that the newer mobile device plays the action movements better and more fluidly when playing dynamic animations. While the tracking speed itself was still even between the two mobile devices. The difference was ultimately most noticeable at the Subdivision 3 level. It was shown that the processor of a newer mobile device plays selected action animations faster for a certain fraction of a second. Regarding the evaluation of static animation playback at a higher topology level, we can conclude that the differences were minimal, however, the playback quality was better performed on the newer mobile device. Subdivision testing has shown that animal 3D models with higher polygon count are considered more challenging to render on mobile devices. The main reason lies mainly in the more complex characters. The difference was most noticeable when playing dynamic movements.

We will continue with a comment regarding the analysis of perception under different lighting conditions, in which the influence of the choice of the mobile device had no particular effect on the final results. Perception analysis was performed under five lighting conditions. In very good lighting conditions, such as detection under sunlight, cloudy light or artificial light with the help of a table lamp, the camera recognized the interactive card very quickly and successfully displayed the selected animal model. When detecting in darker conditions, the latter is somewhat more demanding, as the camera's light sensors need a longer time to detect the image target and display animal characters. In this case, we tried displaying it against the light of the screen of another mobile device, where, surprisingly, the device displayed the animal character on the screen quite successfully and qualitatively. While the mobile device was not able to display the selected animal model in complete darkness as expected.

In addition to brightness, we also checked detection according to different distances of the mobile device camera from the image target. In the first part, we checked detection when we did not have an animal character on the screen of the mobile device. When detecting when the application is launched in augmented reality mode, the detection can be divided into three detection areas according to the distance. In the first class, we consider the detection of the image target at a very small distance, where we are talking about a distance of less than 5 cm and up to 10 cm. In this case, capture and detection are quite difficult. The reason lies in the fact that at a distance of less than 5 cm, the camera is not able to focus the interactive card well enough due to being too close. While at a distance of 10 cm, we can say that the light sensors of the camera manage to focus the image with sufficient quality to show the animal figure, for which they need a little more time. The most successful and appropriate way is to capture an image target at a distance of 15 to 50 cm, in which the mobile device recognizes the image target qualitatively and quickly and displays the associated selected animal character. While at a distance of 60 cm and more, the camera of the mobile device is no longer able to detect all the details on the interactive card and, as a result, it is not able to show the animal character. The most ideal detection distance is thus foreseen in the range between 15 and 20 cm.

In the second part, we also checked how the animal figure is preserved depending on the distance of the image target from the mobile device. It can be noted that during the testing of this part, problems appeared only in the part if we approached the image target to a distance of about 5 cm or less. At a distance of 5 cm, the animal figure is still present on the image target, but it is no longer visible to its full extent. A special feature when approaching is also the noticeable shaking, e.g., in animal legs. At an even smaller distance than 5 cm, the character always disappears, because the mobile device's camera is no longer able to recognize the details on the interactive card. When moving away from the character by more than 50 cm, the result surprised us, as the character remained visible even at a distance of up to 100 cm and more from the image target. Of course, the final quality and user experience at such a distance are useless or bad, because the selected animal character can only be seen as a single dot on the picture target.

We ended the testing with an analysis that covers the recognition of the image target according to the inclination of the mobile device. Perception of the interactive card from a bird's eye view was by far the most effective, as regardless of the lighting conditions, the animal character appeared the fastest in this view. Relatively fast rendering was also possible at a sharp 45-degree angle, which represents an intermediate angle between a bird's eye view and a right angle. There were more problems in detecting the characters at the right 90-degree angle, as the characters in the vast majority did not want to appear. The problem with this position is mainly in the fact that if we want to see the animal figure frontally, we have to set the position of the camera of the mobile device in this position most of the time.

5. CONCLUSIONS

At the end of this article, we can confirm that the main purpose has been successfully achieved, namely the creation of three different interactive 3D animal models that can be displayed on a mobile device using augmented reality technology. In the entire article, a short introduction and the methodology of the entire work are successfully presented, with the final results of the animal characters created and the final results of the tests carried out according to various selected parameters.

Finally, we will highlight the most important points of this article. When playing 3D models on mobile devices, we could see that animal characters with a higher level of subdivision or the number of polygons is considered more demanding when playing on mobile devices. The difference was best illustrated by the example between an older and a newer mobile device. The results of our tests also showed that the most successful detection between the image target and the mobile device is in the distance between 15 and 20 cm and from a bird's-eye angle position in good lighting conditions. The perception is worse at a smaller or greater distance outside this area and at a slope outside the bird's eye view. However, detection of an image target on a mobile device is also possible in much worse lighting conditions. To fulfil the detection conditions, only a small presence of light is sufficient for the mobile device to recognize the image target very quickly and efficiently and display the selected animal character. As an example, we will cite a successful detection attempt, where we illuminated the image target with the light of only another mobile device. Finally, we will evaluate the content playback according to the hardware. It turns out that a newer mobile device with better hardware and software OS equipment enables better playback of dynamic animations than an older mobile device. We can also mention that the newer mobile device allows better and higher quality use of animal characters. Regarding the playback of static animation on both devices, we can estimate that due to the small number of operations required by the animated character, the difference did not particularly affect the two mobile devices.

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