Study on VR Application Efficiency of Selected Android OS Mobile Devices

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Abstract: Currently, the number of scenarios for using VR (Virtual Reality) technology grows every year. Yet, there are still issues associated with it, related with the performance of the mobile device itself. The aim of this work is to perform an analysis of the effectiveness of virtual reality applications in case of mobile platforms. We put the main emphasis on examining the performance and efficiency of four different hardware and software platforms, evaluated in a number of research scenarios, related with typical user activities. The performance of various consumer devices running Android OS was assessed using selected benchmark applications. Additionally, a custom-build environments was also created to facilitate further testing, including an enhanced HCI (Human-Computer Interface) linking the mobile device, head-mounted googles, and a powerful desktop PC. The performed tests and obtained results can aid any interested individual when choosing the right mobile device, as well as configuring the VR environment, for various UX (User Experience) purposes.

1 INTRODUCTION

Nowadays, there are many definitions of VR (Virtual Reality) that more or less overlap in different areas and fields of study. When we use the word VR today, it refers precisely to computer-generated images that have been specifically designed to provide us with the most immersive experience possible.

Many definitions also say that VR must be interactive. This would distinguish it from applications such as: 3D movies, 360 videos and other similar enhanced media (Fan et al., 2019). The problem is that many computer-generated VRs are not interactive at all. In practice, a 360 video may not be computer-generated and functionally not different from a non-interactive VR experience.

In the historical context, what is perceived as or adjacent to VR should be widened. Some of the milestones were therefore precursors to other forms of media and entertainment (Dixon, 2016). The aim of this paper is to perform an investigation of VR application efficiency on selected mobile devices running Android OS.

2 BENEFITS OF VR TECHNOLOGY

Research conducted by PricewaterhouseCoopers (PwC, 2021) shows that the use of virtual reality technology in conducting training and education (Kamińska et al., 2019; Radianti et al., 2020) brings many benefits:

- Employees using VR were able to complete training in 4 times less time than people who chose the lecture and about 30% faster than people using distance learning.
- People who completed training via VR showed 40% more confidence in using new abilities than remote students.
- VR users felt 4 times more emotionally attached to the tasks performed than during remote learning.
- The use of VR in learning, almost 5 times, reduces the number of distractions during classes, which significantly improves the user's focus.

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So why are virtual reality classes not conducted in every school or university? According to a survey conducted by VR First in 2017 (Graham, 2017), VR laboratories were present only in 26 out of 553 surveyed universities. Others (Getting smart, 2020) show that approx. 97% of students would like to attend such classes. So the demand greatly exceeds the supply.

Of course, there are several advantages of using VR in education (Huang et al., 2019), but the cost of such a solution seems to be the most important factor. While browsing for VR goggles offered in the most popular electronics stores, it was noticed that the prices range from a couple of hundreds to thousands of Dollars or Euro. Now do assume a scenario where the school would like to purchase 30 sets to conduct classes with a group of students simultaneously at the same time.

Yet, there are affordable devices, costing less than 100 Dollars/Euro. So where is the catch? Such a device requires a smartphone to operate that will generate and present the entire image that we see through the lenses.

Since by 2022 almost every person has a mobile phone, and consumes multimedia content on a daily basis (Falkowski-Gilski and Uhl, 2020), nothing prevents from using it with such goggles. If a significant part of the costs were eliminated in this way, many institutions could start classes with the aid of virtual reality. The question is whether VR on smartphones is effective enough to meet the needs of modern-day users.

3 VR ON MOBILE ANDROID OS DEVICES

The target image that we see on mobile devices is rendered using the theme. Usually there are several independent parts that generate images, e.g., SystemUI responsible for creating the status bar and tools, and foreground applications rendering the image within their own buffers. Then, such a buffer is absorbed by the client, who is responsible for their proper distribution and finally for displaying the appropriately arranged final effect on the screen. In case of the Android operating system (Gilski and Stefański, 2015), this is usually a system application called SurfaceFlinger (Android Developer, 2020), as shown in Figure 1.

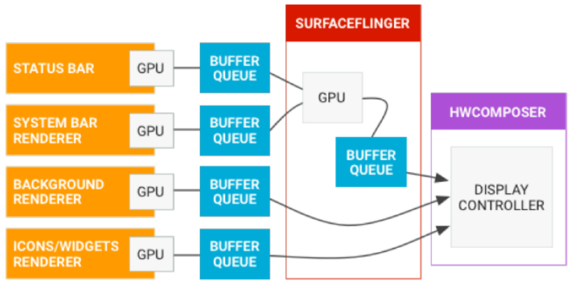

Figure 1: Flowchart of graphical data in Android OS.

Both parts are highly independent. In fact, they are different processes that, thanks to inter-process communication, talk to each other and synchronize their actions. Incorrect synchronization may lead to corruption on the screen. An example of such corruption is called tearing, when the display shows information from more than one frame. Such a phenomenon is easy to identify thanks to the visible cut line. This happens when the client renders to a buffer that is currently displayed to the user. In this case, one part of the screen shows the old content and the other shows the new content.

To prevent image tearing, in addition to synchronization, double buffering is also a key element. It allows the producer to render new content while the old content is still used by the client. When rendering is finished, the buffers are switched over and the new content can be presented. This mechanism is necessary for a smooth and comfortable image reception in the Android system. Unfortunately, it has its cost, which is additional delay, therefore optimization is very important, especially in the case of VR technology (Shi et al., 2019).

4 VR PERFORMANCE

Reaching the target number of frames is a particularly important element to provide the user with a comfortable experience in virtual reality. VR is computationally more expensive compared to other projects, mainly due to the need to render per each eye separately. In case of mobile platforms, this task is particularly demanding not only because of the VR overhead, but also because the power of mobile devices is much lower than that of desktop PC units (Ba et al., 2013).

4.1 Optimization Methods

The most common optimization methods include:

- Static batching – combines static objects into one large mesh. Thanks to this, when we have, e.g., 100 models of chairs made of the same material, we can combine them into one draw call. This significantly reduces the amount of memory used, compared to drawing each such object in a separate draw call.
- Light baking – this technique refers to the initial calculation of the lighting of a scene prior to its launch. Usually, Unity renders each object separately for each light that shines on a particular object. This means that if an object has, e.g., three lights on it, it will be rendered three times in a given view. Thanks to the earlier preparation of the scene, and the preparation of textures with lighting, we significantly reduce the number of drawing calls.
- Occlusion culling – another optimization technique is based on the fact that objects outside the field of view of the camera are not rendered at all.

4.2 Common Problems

The most common problems of VR technology, in case of mobile devices, include:

- Limited power – the most obvious and well-discussed challenge facing mobile virtual reality applications is a much more limited power budget and thermal constraints compared to the desktop PC. Moreover, the proximity of the processing equipment to the user means that the thermal budget also cannot be higher. By comparison, mobile devices typically run below 4 W, while a single desktop GPU can easily consume 150 W or even more.
- Device overheating – when the device detects that it is getting too hot, it begins to intentionally limit the amount of energy the app can use. This will obviously result in slower computation and will negatively affect the FPS (Frames Per Second). Thermal limitation is an important factor to keep in mind when developing mobile VR applications. This is a common problem, mainly due to the fact that mobile virtual reality often pushes devices to their limits. Devices enclosed in goggles, while designed to be handheld, also contribute to the increased thermal impact. Optimizing CPU and GPU processing, reducing the use of network and location services, e.g., related with the handover mechanism, could improve energy efficiency.
- Delay – it is very important to minimize the delay of the head movement to its actual representation on the device screen to give the user the impression of real-time presence, and being physically connected to the virtual world. It is recommended to obtain 20 ms or less motion latency.

In this experiment, different aspects were tested and examined, including: obtained framerate, device temperature and RAM consumption.

5 TEST ENVIRONMENT

The investigation was carried out using a laboratory stand composed of a desktop PC as well as a set of 4 mobile devices.

5.1 Desktop Stand

The laboratory stand included a desktop PC with the following configuration:

- Processor – Intel i9-9900K, 8-core, 3.60 GHz.
- GPU – NVIDIA RTX 2080Ti.
- RAM – 16 GB.
- Operating system – Windows 10.
- Googles – DreamzVR 2.0.

Next, we have performed an evaluation of a selected group of mobile devices, namely 4 smartphones running Android OS.

5.2 Tested Mobile Devices

The tested set was composed of 4 devices, including different manufacturers, hardware components and version of the operating system. Their principle technical specification is described in Table 1.

Those devices included a multi-core configuration, either 4 or 8 units, with more than 1 GB of RAM, as well as a version of Android OS equal to 5.1 and higher. Those models were released on the market as a medium segment, just to meet the needs of a typical user. It should be mentioned that none of them was advertised as a flagship model when being released on the market, with high-end integrated hardware.

Table 1: Principle technical specification of tested mobile devices.

No.	Model	CPU, GPU, RAM	Android OS
1	Huawei Y5	4-core, 1.10 GHz Adreno 304 1 GB	5.1
2	Xiaomi Mi9 SE	8-core, 2.30 GHz Adreno 616 6 GB	9.0
3	Xiaomi Mi6	8-core, 2.45 GHz Adreno 540 4 GB	7.1
4	Xiaomi Note 10	8-core, 2.20 GHz Adreno 618 6 GB	9.0

Next, each device was subjected to a number of benchmarks and stress test, in order to determine their performance under rich multimedia rendering and 3D image processing.

6 RESULTS

As shown, the most important element of virtual reality technology is the image itself. For this reason, at the very beginning, it was decided to investigate how efficient the devices are in rendering 3D scenes in relation to each other. On each smartphone, the Android Sling Shot test was launched in the 3DMark application (3DMark, 2022). The results are shown in Figure 2.

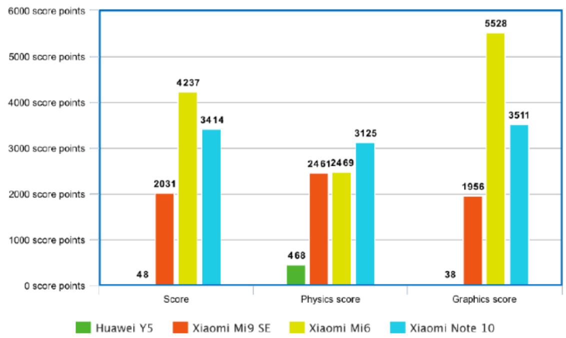

Figure 2: Performance in Android Sling Shot.

As shown, the performance of each device differs significantly. We have chosen this particular software, because 3DMark is currently the top benchmark for both computers and mobile devices and has a public database of results for virtually every device.

Next, we have decided to check the performance in case of the most popular VR-compatible mobile games. They were selected on the basis of top recommended Android games (Hughes, 2022). In case of every application, the test lasted 5 minutes.

In order to minimize the influence of other apps running in the background, the only application opened on the smartphone, apart from system applications, were Gamer Bubbles and the tested game itself. The results, describing framerate in FPS, obtained temperature and consumed RAM resources, are shown in Figures 3, 4 and 5, respectively.

At first glance, a typical smartphone is feasible of obtaining a stable framerate of 60 FPS, giving a feeling of a smooth and uninterrupted playback. However, a noticeable difference may be observed in case of heating of the device itself. It should be noted that different manufacturers utilize various materials for building the chassis as well as case.

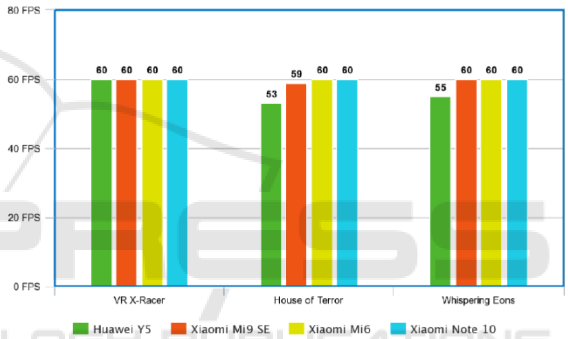

Figure 3: Framerate in selected mobile games.

As we know, some provide a more sturdy grip, whereas on the other side they may affect the heat dissipation capabilities. In some cases, the placement of the user's hands may cause additional attenuation of the signal, leading to an interruption in wireless communication. Yet, this aspect was not the topic of our study.

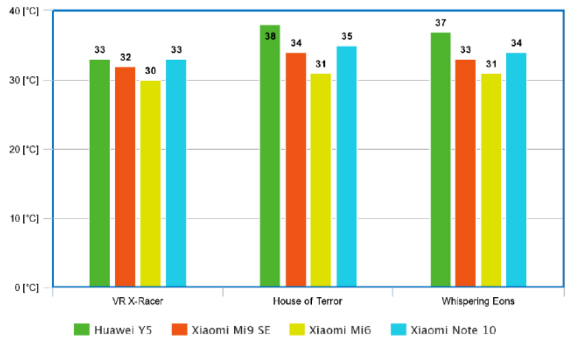

Figure 4: Temperature in selected mobile games.

As shown, the typical temperature of a device put into stress has raised to a level between 30°C and 38°C. Such a temperature will not cause discomfort to the user.

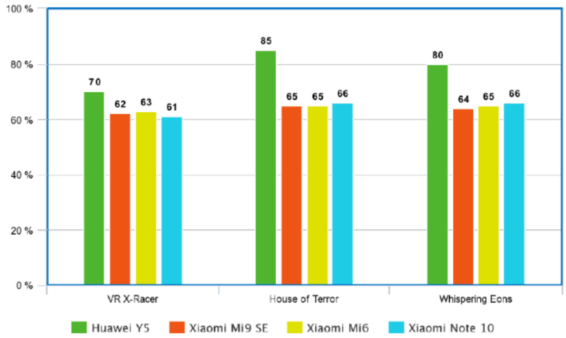

Figure 5: RAM consumption in selected mobile games.

Surprisingly, the amount of integrated memory proved to be sufficient when it comes to handling complex graphical content. As noticed, neither device did not occupy 100% of available RAM resources. One of the reasons, aside from the mere size of this memory, may be the upgrades made in newer releases of the Android OS.

7 DISCUSSION

After carrying out the main objective of this study, we have started to wonder whether there is another way to enhance the user experience (UX) when it comes of VR technology (Kim et al., 2020). Each and every person can appreciate high-quality resolution, smooth framerate, especially when one desires to stare at the screen for a long period of time. Eventually, we have decided to investigate what are the possibilities of enhancing the gaming experience.

After preliminary examinations, we have agreed to check VRidge, according to which gaming is one of the most important needs of VR technology users. With this software we tried to create an environment in which we would be able to play games available only on stationary VR-compatible PCs.

At first, it was necessary to have the RiftCat client installed on a desktop computer (Riftcat, 2022). The software also required a mobile client downloaded from Google Play (VRidge, 2021).

The next step was to configure the LeapMotion camera. For this purpose, it was necessary to download the SDK (Software Development Kit) from the manufacturer's website (Leap Motion SDK, 2022). For the camera to work with SteamVR, the Leap Driver (Leap Driver, 2022) driver and modification of the configuration file were also required.

Thanks to the combination of the above software and hardware configuration, along with some custom modifications, it was possible to run one of the most popular VR games, namely Half-Life: Alyx, in 60 FPS, and with the possibility of hand and gesture tracking. The photo report from the research is presented in Figures 6-8.

Figure 6: DreamzVR 2.0 googles with an installed smartphone and a front-mounted Leap Motion camera running Half-Life: Alyx.

Figure 7: Half-Life: Alyx VR application with gesture detection – gesture 1.

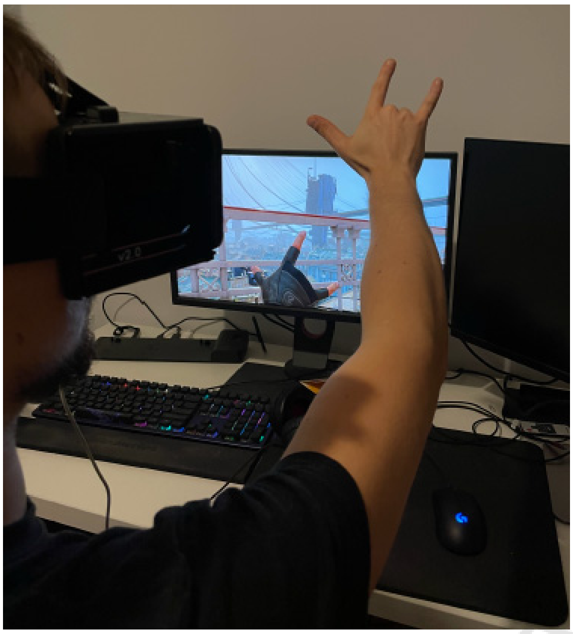

Figure 8: Half-Life: Alyx VR application with gesture detection – gesture 2.

This hardware and software configuration worked very well, especially when the user was in a static sitting position. Therefore, several additional applications were tested using the described configuration, enriching it with supplementary input devices, as shown in Figures 9 and 10.

Figure 9: Assetto Corsa car driving simulation VR application with Leap Motion enabled.

Figure 10: VTol flight simulation VR application with Leap Motion enabled.

It is worth mentioning that streaming delays related with generating image sequences as well as interpreting gestures were imperceptible. This aspect becomes even more important in 5G networks (Krogfoss et al., 2020).

8 SUMMARY

When analyzing the effectiveness of the set of user terminals, it was found that mobile VR technology still has a great potential for development. With the use of appropriate software solutions, one can create a full-sized virtual environment, thus fulfilling the most important user needs. In addition, thanks to mobile VR, in the nearest future we could, i.e., organize a mass show in virtual reality at a much lower cost. Furthermore, mobile VR could serve as a good introduction for the newest and most up to date technologies in a very simple way. Compared to desktop stationary solutions, it does not require additional wiring, etc. As shown, current capabilities offer a smooth rendering of high-quality images.

Of course, there are still other aspects, namely problems with gesture control, high battery consumption, heat dissipation, etc. Another issue is the inability to use the phone when it is fixed inside the head-mounted goggles. However, many of these problems could be solved in the near future, with a set of compatible wireless accessories. We do believe that with the right support, this technology will have its so-called second youth.

This research investigation has shown that even a typical mid-range smartphone is able to provide stable VR image rendering. It is also possible to relieve the mobile device from the rendering process, as the whole handling of complex image sequences may be realized with the aid of VRidge. Thanks to this we were able to show any virtual reality composition on the smartphone. Streaming delays were practically imperceptible.

Recently, cloud gaming technologies are also being developed, where computers bear the burden of rendering the image. In this case, the mobile device becomes only the stream recipient. In such a scenario, delay plays an even more important role (Soliman, et al., 2013; Huang et al., 2014; Laghari et al., 2019).

As shown, VR technology is very capable of enhancing the user experience, even with a portable mobile device. With the aid of appropriate goggles, even a mid-range device becomes a good replacement for expensive dedicated accessories. Undeniably, a broader range of consumer application could speed up the whole process and make VR even more popular among people.

Future studies may and should include a broader range of consumer devices, googles, as well as test scenarios, including rich 3D graphics and multimedia content. Additional source of inspiration may be found in (Kopczyński, 2021; Langer et al., 2021; Sermet and Demir, 2022; Cheng, 2022).

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