Towards Design Principles for Low-cost Virtual Reality Games

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ABSTRACT

Virtual Reality (VR) games resurfaces once again as plausible products due to the maturing of computing technologies. However, this technology is still prohibitive in terms of costs, since most devices are more expensive than gaming consoles. Several initiatives attempt to offer minimally viable head-mounted displays (HMDs) at low costs. These consist of goggles endowed with lenses specially designed to be attached to an adjustable helmet. In this work, we investigate about low-cost VR games in a pursuit to unveil elements useful for the construction of cost-effective, but compelling titles. We carried out two sets of evaluations with volunteers by adopting focal group interviews. Representative VR applications were run on a modest Android smartphone model and experimented through a low-cost HMD to determine both key aspects of the user experience and design solutions applicable for assuring the quality of VR games built on top of this platform.

Keywords: Game design, virtual reality, immersive games.

1 INTRODUCTION

The gaming market has made significant advances in both underlying technology and its value as an industry. This market consolidates its position with one of the largest and most profitable in recent decades [5], while VR has been battling for its space, presenting the recent maturation of its technologies and demonstrating several potentialities of its applications. Heavyweight companies demonstrate intense mobilization in the search for space in this promising market of VR for the wide public [3]. Recent advances on hardware and software finally enables the development of of VR applications for a variety of purposes, and has considerable economic attention as well as software tools providing means for development and research [7].

VR technology has become more cost-effective and increasingly independent of expensive tools for development and execution, which allows for analyzes and studies in this area within the usual development spaces. Our investigation finds space in the current academic environment due to the lack of research focused on VR used in the area of digital games. This can be partially explained by the unfeasible costs of conducting such research. The studies found in the literature are mainly focused on the areas of psycho-social and therapeutic studies [1], medicine [12] and simulation [10]. Moreover, guidelines found in similar works do not present details on empirical evaluation [14]. Finally, the data collected and analyzed in this work are not necessarily restricted to the development of games.

Our investigation aims to understand the particularities inherent to the application of low-cost VR in video games with a special focus on how these products can be constructed. Other applications of VR will not be addressed in this work, except for comparative purposes as we approach this technology as an emerging platform for digital electronic games.

These are the main contributions of this work: (1) we examine low-cost VR software and hardware products which are representative of this new market niche; (2) we scrutinize the aspects explored in existing products based on evidence obtained from the literature; (3) we conduct experimentation with user groups based on gameplay of three selected game titles which are executed on a reference hardware setup; and (4) we evaluate results in the process of determining empirical, general guidelines for building low-cost VR games since an evaluation is not found in literature for this specific case [14].

2 BACKGROUND

2.1 Electronic Games

Crawford [2] draws a parallel with the arts, thinking of the game as an indirect construction of the individual experience of each player. Thus, the author defines games as a formal closed system, having a set of rules defined and contained in itself, which represents, subjectively, a subset of reality, having interactivity as an intrinsic element, differentiating and characterizing every experience of playing.

Other authors resort to a broader definition, in which a game is a problem-solving activity approached with a playful attitude [13]. The mechanics are the unique characteristics that distinguish games from other entertainment media [8]. In fact, game mechanics and the underlying programming methods invoked by agents to interact with the game world are intrinsically related [15] [11].

2.2 Virtual Reality

Conceptually, Virtual Reality aims to facilitate and intensify the "immersion" of users in an alternate reality in order to experience an interactive existence in a universe built as a computer simulation [6]. For this end, a technological system is built around the sensory and physiological perceptions of users in order to mediate interaction.

Although "presence" is about a more specific element in which the user feels mentally connected to the mediated space, simulated in VR, instead of being connected to our "ordinary" reality. This aspect, however, requires a certain degree of persuasion for the user. VR immersion does not necessarily depend on a highly detailed environment, but a certain level of quality is required in its graphical construction. So, advances on VR walk alongside the evolution of Computer Graphics, being proportionally affected by the latter's economic, technological and market developments.

The inconvenience of physiological effects such as *nausea* and *malaise* are caused by sudden movements or poor display of information on the screen. This is a fundamental problem to overcome for the continuity of both research and market development. Such limitations reflect the bleeding-edge technologies developed by one of the leading companies at that time.

2.3 Low-cost Virtual Reality

For the purposes of this work in order to consider a material as low-cost Virtual Reality, we take into consideration the acquisition value of the stereoscopic visualization piece, i.e. the glasses, together

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with the cost of the part needed for any processing, graphics display and overall execution of the application as a VR software.

Google Cardboard, developed by Google company and aimed at mobile viewing launched in 2014. This device has the cost of the base product, available on a company website at a value of US $ 15.00 [1]. The device compatible with the VR applications for this platform must necessarily contain accelerometer and gyro sensors, elements present in various models of modern, affordable smartphones that most users probably already possess. It is also possible to find a variety of devices based on Google Cardboard technology, with a wide range of aesthetic variations, offering wrappings of other materials (the original is made of cardboard) and may not contain the magnetic interaction button in the base piece.

We advocate that low-cost VR technologies deriving from Cardboard offer an interesting trade-off between cost and benefit for those who want to experiment and get started in the development of this technology. However, in spite of support for essential immersion elements such as spatial sound and head tracking, limitations of this type of platform should be taken into account due to the reduced processing of execution platforms, less optimization of stereoscopic visualization and few input methods available for user interaction.

3 Related Work

Hilfert and König [7] presented an approach to build a low-cost, highly immersive VR environment for engineering and construction applications using a hand-tracking device. They claim better collaboration and understanding during the planning, construction and maintenance phases was obtained.

Vishwanath et al. [16] employed VR for motivating students. These authors suggest that representational fidelity arouses curiosity and results on deeper engagement with the studied topics. However, they do not provide clear design guidelines for this kind of applications.

Works on game design are either too general [13] or too centered on traditional game development process [4]. Insights deriving from investigations performed by Jesse Schell [14] are useful for the purposes of this work. However, it is worthy to mention that Schell's results are not (a) specifically targeted to the low-cost VR experiences nor (b) empirically evaluated.

In his work entitled "*Making Great VR: Six Lessons Learned From I Expect You To Die*", Schell [14] discusses the challenges involved in the development of an actual VR game title. He highlights the main problems concerning the development process and the parameters necessary to obtain a quality product by taking advantage of the interactive potential that VR technology can offer.

Schell has a concern essentially related to the user experience within the application. On the other hand, little concerns are taken about the specifications of hardware and software that are not directly influencing factors or intrinsically linked to the results presented to the user.

The physiological effect probably most common in relation to the use of VR, the so-called *motion sickness*. Schell states that presence can be used to improve the experience, so building up interactions must consider players are feeling *present* in the virtual place. Actions and encounters may reinforce this sensation, such as picking objects and performing interactions closely to non-player characters. The author suggests that immersion must even overcome gameplay in VR titles, so he also enumerates "immersion breakers" to be avoided. On the other hand, designers may adopt mechanics that can lead to exploration.

Finally, Schell states that VR games are projects filled with many unknowns. This, however, does not necessarily mean an intractable obstacle since there are some discoveries to be found about the title being developed besides the usual problems to be solved as a product. Moreover, real-world prototypes can be built using paper craft to pre-validate designs on user interactions and to anticipate problems related to a close-up examination of objects manipulated by players.

We conclude that the fundamentals found in Schell's seminal work cannot provide clear game design guidelines concerning the specific case of low-cost VR. What could be avoided and why? Besides, a general understanding that building VR games requires a proper way of thinking in order to maintain the objectivity of the investigated elements for understanding both the qualities and the users' perception on low-cost VR.

4 Methodology

We aim to tackle the following questions in the context of low-cost VR: (a) elucidate what would be the positive and negative decisions for the construction of existing experiences [14, 9]; (b) assess personal immersion and physiological effects on its use; and (c) obtain guidelines for further research and development. Results are analyzed in order to confirm or refute Schell's predicitons [14].

The research involved user evaluation and occurred according to the following methodology. Three Android VR games compatible with a low-cost VR headset were chosen for evaluation, because each experiment takes a lot of time. In addition, the number of evaluated titles was kept low because VR can cause some discomfort to users, so we avoided long gameplay sessions.

4.1 Games Evaluated

The choice of specific game titles was based on parameters intrinsic to their proposals. *Titans of Space Classic* has a simple approach, more focused on the visualization of key elements. This application is intended to teach about astronomy and pivots around space exploration with a greater use of non-interactive textual interfaces. Its exploration and movement take place like the use of a button that advances the ship to the next predefined point.

We also have an exploratory theme in *InMind VR* but with a more intense level of interaction than the previous example, which is an application, since the proposal of *InMind VR* is to be an actual entertaining, electronic game. In the game, we must move forward with a railing ship by abstracting a human brain, correcting defective neurons responsible for mental disorders, using available mechanics, as debated in later topics.

Finally, *Sinister Edge* offers a much more traditional gameplay experience compared to previous ones, thus resorting to mechanics and interactions which are more common in games with similar proposals. The game unfolds through the user's exploration of the scenario, seeking solutions to "key-and-lock challenges", using specific scenario objects to advance in initially non-viable areas in the game. This game adopts narrative and ambiance focused on the suspense, terror, and horror.

4.2 Evaluation Process

First, each user chose one among two titles made available according to their personal interest. The user was allowed to try two games in cases there was interest on her part and the availability of time for it. Evaluations were divided into two sessions, and the game *InMind* VR was present on both occasions, while *Titans of Space Classic* and *Sinister Edge* were alternated in the first and second evaluations, respectively.

After the test session, the user was submitted to a semi-structured interview, comprising topics that explored aspects of the user experience and its relation to the game design decisions contained therein. The choice of this structure was intended to take advantage of the most varied impressions of the users while pointing out in the essential aspects of this research: Understanding about the user experience based on user's own reports; Revisit the actual utilization of low-cost VR in game titles; Perform comparison between the

[1] https://vr.google.com/cardboard/get-cardboard/

evaluated titles, which also includes suggestions from the public; and Observe discomforts and physiological symptoms.

4.3 Interview Topics

These were the topics presented to the users during the interviews. **T1.** *Do you have any prior experience with Virtual Reality? Could you please tell us about it?* This question was introduced in the second evaluation since all users from the first session had some experience with VR. **T2.** *Strong points*. **T3.** *Negative points*. **T4.** *What is actually added by using VR?* **T5.** *Could you please give us your personal feedback?* **T6.** *Does the application justify the adoption of VR? Why?*

4.4 Experimental Setup

The ColorCross[2] VR headset derived from Google's Cardboard technology was adopted for experimentation. This model is compatible with all the features of the base product, except for interaction. The headset allowed the game titles to be executed on an affordable smartphone compatible with the technology.

Games were executed in a 2nd generation Moto G mobile phone with the following technical characteristics: 5s̈creen; Qualcomm MSM8226 Snapdragon 400 1.2 GHz Quad Core processor; 1 GB of RAM; Android 6.0 Marshmallow; GPU Adreno 305 series 6 @ 450 MHz with graphical functions equivalent to the DirectX 9.0c model; accelerometer and gyroscope, the latter two being the sensors used to estimate the pose of the user's head for interaction purposes.

5 Focal Group Interviews

We analyzed each user's reports in the two evaluation sessions in which each game was experienced during 2 to 5 minutes while the player was sat down in a swivel chair. All gaming sessions were carried out in a room lit by both natural and artificial light, without sound insulation. Most players participating in the evaluation are very familiar with games and gaming consoles, i.e., they consider themselves as "gamers", play at least 5 hours a week and are regular customers of popular game platforms.

Five users were introduced to Titans of Space Classic® during **Session 1**. Only 3 users actually were interested and played this title. All users played InMind VR®. The interviews in the first analysis session were carried out according to the following topics: T2, T3, T4, T5, and T6.

For **Session 2**, four users were invited to play InMind VR®. After this experience all of them also played Sinister Edge®. Evaluations took more time in the second game due to its suspense-themed exploratory nature. Some users in particular were more comfortable due to their previous experiences and provided their opinions in detail.

6 Discussion: User Experience and Low-cost VR

6.1 Motion Sickness

In the examination we performed with users of a Cardboard variant, issues related to frames per second and camera movement issues, also predicted by Schell, were not mentioned by users in the interviews. However, our results can be considered inconclusive on the matter. Nausea and dizziness reported by users have two main factors: how the application handles movement, and the user's personal sensitivity to motion sickness. Of all participants, 3 presented dizziness or nausea after the session of use, 1 for each application. All of these users pointed to movement or some movement-related factor as a cause of discomfort.

For *InMind VR*, dizziness was pointed at the moment when the ship in which the user is in the game accelerates. In *Titans of Space Classic*, the difference in motion seen in relation to the immobile body was noted together with slight weariness by the user. Finally, dizziness has been described together with a sense of imbalance and differentiation of movement within the game and that of the user's body in *Sinister Edge*. The motifs of these cases are linked to the accelerations in motion within the VR environment, either from a constant motion to a faster motion (InMind VR), or in a motion from the resting at a constant speed at the next moment (Titans of Space Classic and Sinister Edge). We confirmed Schell predictions for this problem. A constant speed can work better, despite the inner ear being sensitive to minor accelerations.

6.2 Heads-Up Display

It was possible to observe in the experiments that some of the elements needed for a good VR experience contradict elements of more traditional game designs, such as HUD (heads-up display). The evaluated applications did not make a continuous use of HUDs. However, the less interactive experience of *Titans of Space Classic* was the only one among them that got a bad impression of a user's use of HUD. It was described as uncomfortable in its positioning, besides displaying extensive texts as an element that degrades the immersion, as foreseen by Schell.

6.3 Head Tracking and Spatial Visualization

In the return given by the interviewees, the impressions with the head tracking were unanimous regarding the response time of the virtual movement of the head. Thus, users presented a consistency in the description of this item as a positive point, absent from contrary opinion. However, in spite of the good responsiveness, VR visualization brought divergent results, mainly related to the intrinsic body movement for visualization. However, it can not be ruled out that longer sessions may reveal discomfort by users.

Regarding the movement only to the spatial visualization, it is possible to observe a discomfort of some users with the movement of the head in the sense of performing a full movement. This limitation is basically analogous in rhythm to the natural counterpart for the visualization of the elements in the session of use. This feedback was present in *InMind VR* and *Titans of Space Classic*. On the other hand, there was substantial praise for the possibility of using 360-degree visualization, most often with the feeling of immersion and participation in the environment.

During most of the points raised and discussed above, significant elements were pointed out regarding how cameras are used and their impact on the player experience, such is the importance of this aspect of VR platforms. As stated before, head tracking might be considered as the default option for camera control when designing an immersive, low-cost VR game.

6.4 Controls and Interactive Elements

An extremely simple VR viewer model was chosen for user experimentation, even though it did not have any type of external controller and was thus maintained during the overall research. The importance of the visualization of the user within the games has gained the weight of having to contain, by itself, solutions for the interaction of the user with the environment. The mechanical solutions developed by each application for this purpose appeared in the interviews in several points, highlighted by their good or poor performance for the user.

It should be noted that this approach is clearly perceived by the user as a "slow interaction", which was mainly reflected in the mechanics involved in targeting that should be avoided by game designers when an intense shooting experience comes into play.

[2] https://www.amazon.com/AGPtek%C2%AE-Cardboard-Universal-Virtual-Smartphones/dp/B00O1WJ1D0?th=1

7 Design Choices in Evaluated Titles

7.1 Titans of Space Classic

All the interaction in this game was about a virtual control panel which displayed, for the movement inside the environment, only a single button that could be pressed (planet, star, and moon, among others) to be explored.

User feedback pointed this issue in this application were reasonably mixed, much due to the individual perception of their own experience. From a more positive perspective, the comfort of a more paced rhythm, the sense of participation and the intuitive interface are all good points highlighted by users. On the other hand, users felt the absence of an external control or of more interaction that, in this case, remained only to the abstracted menu in the simplistic control panel of a spaceship.

7.2 InMind VR

In this first-person shooter, interaction is related to reaching target objects in the course of player's journey through the human brain. The movement happens completely on rails, so users only controls the visualization of the environment, and focus on the target objects for a short period of time to destroy them.

It is curious to observe the dichotomy reported in the interviews regarding perception as a VR experience and as a game. In general, this game's ambiance received praise related to the good visual, the narrative mode of the game's exploratory possibilities, having, in that same aspect, received punctual criticisms related to the misuse of 3D space, limited by the playful aspect of being positioned inside a ship Interactive as a negative and limiting aspect. In its proposal as a game, there were repeated almost unanimously rejections to the simplicity in its game design, seen as simple and uninteresting.

The isolated game mechanics obtained more interpolated criticisms between positive and negative. The aim control mode and its responsiveness were considered beneficial by adding challenge and feedback. Some users felt discomfort combining head and body movements to achieve goals, along with the imbalance of the speed of the ship in relation to the time necessary to aim and destroy some of the target objects.

7.3 Sinister Edge

This game features more complex interactions, requiring the user's attention for control and movement since no external controls were used. Movements are based on the inclination of the gyroscope which is activated when looking down in relation to the "height of the eyes". This solution is relatively common in VR for more authentic and paced movement. However, there was a point of consensus in the critics due to the consequences of this mechanics: the compulsory nature of the movement during environment exploration when looking below. A similar positioning issue occurred when one of the users, inside an internal environment, had to climb stairs.

Users felt the lack of an auxiliary control, despite positive feedback about the mechanics for interacting with game objects. Both mechanics and interaction consisted basically in focusing on the interaction element in order to visualize it (contributing to the narrative) or in order to add it to your inventory for later use. This function, in general, obtained very positive feedback, mainly by the design decisions in the visual clues attached to the elements endowed with interaction. The elements that were no longer relevant for interaction continued to stand out for the user, which delayed their exploration of other spaces within the environment.

8 Conclusion

Experimental results suggest that immersion is the key element in low-cost VR games, so game designers may consider pivoting around how immersion affects the user experience and *vice-versa*. Low, fluctuating frame rates did not affect the user's experience. Despite the input latency, head tracking was proven to be a good choice for handling both camera movements and user interaction. However, deeper investigations must be performed on this subject, and these should include at least an evaluation of longer gameplay sessions.

HUD in fact breaks immersion: visual clues are important for inducing player's curiosity and panoramic examination of scenes, and for assisting players while keeping immersion. Low-cost VR games have an inherent cost for users (eye wearing, discomfort, discharged batteries may be recharged before playing again, etc), so designers might try to challenge players without necessarily confusing them (too much). Finally, developers should consider simplification on game mechanics in order to achieve an optimal user experience for low-cost platforms, especially in the case of smartphones.

Future works include case studies about the user experience for specific genres or applications, the evaluation of new hardware, especially interaction devices, and the development of guidelines, heuristics and tools for more effective design and evaluation of VR game mechanics.

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