

Fundamentals of auditing in mixed reality



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SUMMARY

Supported by information collected from the website of the National Aeronautics and Space Administration–NASA and the Jet Propulsion Laboratory–JPL, we analyze the computer graphics techniques employed in the project OnSight–NASA and how they can be applied to the audit of public works. Based on this theoretical reconstruction, the foundations of a new audit modality called MRA – Mixed Reality Auditing are established. This consists of a remote audit procedure in real time that uses images from digital cameras at the place of the audit, transmitted to Head-mounted Displays-HMDs, or special mixed reality glasses, used by an observer who is at a separate location.

Keywords: Computer graphics. Mixed reality. Rendering. Frustum. Quadtree. Game engine. Audit of public works.

1. INTRODUCTION

The Jet Propulsion Laboratory–JPL, a technological center for research and development in partnership with NASA, has been offering to the public a guided tour of an area on planet Mars since March, 2016 (JPL, 2016). This is the mission Destination: Mars, an interactive exhibit using mixed reality glasses, one of the recent advances in virtual reality. Visitors can explore



various locations on Mars, reconstructed from real images sent to Earth by Curiosity, a motorized robot jeep that explores the surface of the red planet since August 2012 (Ibid., 2016).

Destination: Mars is an adaptation of the project OnSight, a software tool for missions on Mars. The data and images transmitted daily by the vehicle Curiosity are picked up on Earth by three giant 80-meter antennas. Then, using a mixed-reality device, this information is transmitted from the surface of Mars to a laboratory on Earth. Scientists are enveloped by the images captured in the vicinity of the vehicle on Mars and may wander around rocky surfaces or crouch down to examine geological formations at different angles. OnSight provides scientists with a way to plan and, together with the vehicle Curiosity, conduct operations on Mars, exploring the planet directly from their offices in Pasadena, California (Ibid., 2016).

2. HMDS AND DIGITAL REALITY

HMD or Head-mounted display is a video device used over the head like a helmet, containing a wide display, headphones and an interface through which the user can experience a virtual reality environment (MELZER; MOFFITT, 2011). It consists of a transparent display mounted on the head of the observer, where the information is presented without requiring the user to look outside of their normal field of vision, as shown in Figure 1 (CANON, 2016). Since its pioneer studies, re-

searchers in the field of virtual reality have used HMDs as essential devices for visual display.

Virtual reality consists of an immersive multimedia or computer-generated reality that replicates an environment, simulating physical presence in real-world or imaginary-world locations, allowing the user to interact within that world. In other words, it is a generic

Figure 1:
HMD device



Source: CANON (2016)

term, applicable to all kinds of immersive experiences, created using only real or synthetic world content, or a hybrid of both (LACKEY; SHUMAKER, 2016). Examples of virtual reality goggles include Oculus Rift, by Facebook; Gear VR by Samsung; and Project Morpheus by Sony.

According to Lackey and Shumaker (2016), augmented reality is a direct or indirect view of a physical real-world environment whose elements are augmented or supplemented with entries generated by sensors, such as sound, video, graphics or GPS data. It is synthetic content superimposed on the real world, where that content is neither attached to nor part of it. The content of the real world and the computer graphics are not able to interact with each other. Examples of augmented reality glasses are Google Glass, the Daqri Smart Helmet and the Moverio by Epson.

Mixed reality, also referred to as hybrid reality, consists of a fusion between real and virtual worlds to produce new environments and visualizations where physical and digital objects co-exist and interact in real time. It is a synthetic content superimposition on the real world of the user, the world connected to him or with which he interacts (Ibid., 2016). Among the mixed reality glasses are the HoloLens, the Canon MREAL Display MD-10 and the Magic Leap.



Modernly, it is admitted that virtual, augmented and mixed realities can be gathered under a more generic name: digital reality.

3. LEVEL OF DETAIL AND RENDERING

Computerized stereoscopic vision (stereovision) consists of the extraction of 3D information from images such as those taken by a digital camera. Comparing the scene from two selected points, 3D information can be extracted by examining the relative positions of objects in both scenes. The information collected from these stereoscopic images is projected onto a free surface, created for this purpose (AKENINE-MÖLLER; HAINES; HOFFMAN, 2008).

Two cameras, spaced horizontally from each other, are used to obtain two different views of a scene, in a way similar to human binocular vision. Comparing these two images, relative depth information can be obtained in the form of a disparity map, which encodes the difference between the horizontal coordinates of the corresponding points in the images. The values in this disparity map are inversely proportional to the depth at the corresponding location of the pixels (Ibid., 2008).

With the use of computerized stereoscopic vision, for each image that reaches the observer's HMD a completely new 3D model is generated through automated algorithms that construct a mathematical and statistically accurate model of the analyzed surface, referred to as stereoscopic correlation (COLANER, 2016). Observing two images and finding the differences between them with the aid of a disparity map and the use of a particular model of camera, the distance between each point is ascertained and these images' range maps are generated.

In order to speed up image processing, all objects that are outside the observer's field of vision are removed in the rendering process (the process of generating an image from a 2D or 3D model through digital processing, consisting of three basic steps: determining the virtual camera, visible surface and light sources). Only the pixels that are visible in the *frustum* need to be rendered. All objects that are visible from a particular point are precomputed, whereupon all non-visible objects are immediately removed, thus reducing the number of objects that intersect the *frustum* (Ibid., 2016).

The *frustum* is the field of vision from the eye of the beholder and can be represented by an imaginary spatial volume containing all that is visible in a three-dimensional scene. It can be represented by a truncated

pyramid, consisting of six planes. Four of these planes correspond to the sides of the screen, called the right, left, top and base *frustum*. The two remaining planes are called the near and far planes of the *frustum*, and define the minimum and maximum distances that the objects of a scene are visible to the observer (DUNN; PARBERRY, 2002). Figure 2 illustrates the geometry of the *frustum*.

To manage the level of detail, the surface of the scene is divided into tiles of different sizes, each with a certain level of detail, following a partition in the surface (2D space) known as the quadtree (COLANER, 2016).

The quadtree consists of a tree data structure in which each internal node has exactly four children, used to partition a two-dimensional (2D) space; for example, a surface with recursive subdivision into four quadrants, regions or adaptable cells. Each cell or reservoir has a maximum capacity. When this capacity is reached, the reservoir is divided. The following tree structure follows the spatial decomposition of the quadtree, i.e. each node undergoes a division into four sub-nodes (LENGYEL, 2004).

Figure 3 shows a quadtree built for an area containing a single object. The illustration on the right shows how the corresponding data structure is organized. Each node has four sub-nodes. If no geometry of world intersects a quadrant, then this quadrant is not subdivided. Any quadrant that does not contain objects is removed from the tree. It is also assumed that any missing quadrants are empty.

According to Lengyel (2004), organizing the geometry in a quadtree brings the benefit that whenever a node of the tree can be determined as not visible, it becomes immediately known that all its sub-nodes are

also not visible and can be eliminated, therefore improving management of the level of detail.

4. GAME ENGINE

An engine for creating video games such as Unity¹ creates software for integration with the hardware involved, proving to be appropriate for user interaction with mixed reality, as the available glasses have an interface with the aforementioned engine. A frame rate of 60 fps (frames per second) is used. Frame rate is the rate at which an imaging-processing device consecutively displays images called frames.

The Unity game engine employs the technique of mipmaps, which consist of sequences of 3D world textures, optimized and pre-calculated, each of them a representation with progressively lower resolution of the same texture, which increases rendering speed. High resolution mipmap textures are used for high-density samples, such as objects close to the camera. Low-resolution textures are used when the object appears farther away. The mipmap technique can improve rendering performance by up to 33% in Unity.

Thus, for the tiles closest to the observer, resolution is maximized. For tiles farther away from one's field of vision, the resolution decreases exponentially. When the observer turns his gaze further ahead, lower resolution textures are superimposed over higher resolution textures. With this technique, images captured on location by cameras on the vehicle Curiosity can be combined with images from satellites orbiting Mars over the place of observation, considering that their resolution is constant in the region (COLANER, 2016).

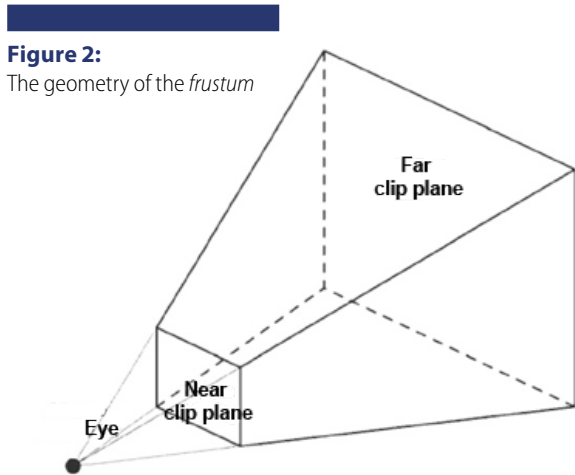


Figure 2:
The geometry of the *frustum*

Source: Dunn e Parberry (2002)

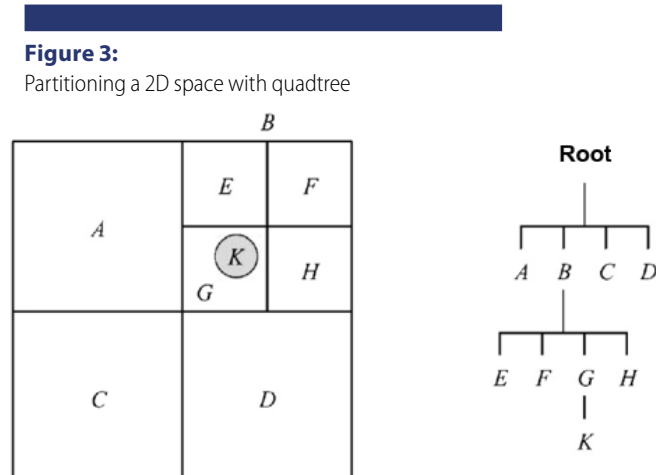


Figure 3:
Partitioning a 2D space with quadtree

Source: Lengyel (2004)

Additionally, if the viewer clicks on a detail in the image, other zoomed-in images can be displayed, taken from a different angle or even from a satellite in orbit. For their part, mixed reality glasses (HMDs) support the viewer's gaze, gestures and voice commands.

5. AUDITING IN MIXED REALITY

Auditing in mixed reality consists of performing an audit in which the auditor is not physically present at the construction site, but at another distant location. Electromagnetic signals from the surface images captured by digital cameras on site are transmitted to the HMD of the auditor who receives those images and can browse through the site virtually and in real time, although at a distance; for example, in a room at the headquarters of TCU (Federal Court of Accounts of Brazil). In this way, TCU Auditors can perform audits of public works at locations far away from Brasilia without ever having to leave the headquarters building in the federal capital.

The auditor is enclosed by multiple images taken in the vicinity of the work site, all with high levels of detail. He is also able to take various vantage positions and look around at different angles as he browses through a given surface area, even crouching down to examine details from different perspectives and gather audit-related findings.

Audits of road works the following flaws on highways can be observed remotely, using Mixed Reality Auditing –MRA: pothole formations, dips, embankment

slippage, worn-down and cracked coating, ruptured drainage components, exudation on curved stretches, patches, degradation, ruptured and eroded road edges, etc.

In regard to audits of railway works, visual observation in MRA can detect the following flaws both in the construction of earthworks, bridges and flyovers, train station platforms as in the railway itself: rot, fractures or excessive holes in wooden railway ties; burns, corrosion or buckling of steel rail tracks. Longitudinal displacement (or drag) of railway tracks, unevenness in the joints, disappearance of clearance between them, contraction, as well as track misalignment can also occur.

As for building audits using, irregularities can be found in the faulty positioning of the construction; in the earthworks (excavation, transportation and landfills); in the foundation (cracks in pipes or in support columns); in reinforced or prestressed concrete structures (inaccuracies of bobs in external corners, columns and elevator shafts); in masonry (cracks or fissures, the use of damaged bricks, inaccurate wall and frames positioning); on the roofing (leaks, broken tiles, roof slope and gutters), as well as in the coverings (i.e. loose boards).

All information relating to basic and executive projects can be inserted into mixed reality software, such as amount of materials, quality and prices per unit to be conferred with the visual findings of the works being audited, simply by staring at a target object and using gesture-based controls to select the commands on the menu bar. Similarly, a virtual measuring ruler



can be inserted to measure the distance between two points.

Internationally, the audit of aid resources in the event of major natural disasters is a recurring theme in the *International Journal of Government Auditing* of INTOSAI. With audit techniques in mixed reality, experts from all over the world, among them SAI auditors, geologists, seismologists, physicists and environmentalists, can monitor occurrences *in loco*, without leaving their countries, simultaneously and in real time.

6. CONCLUSION

This study aimed to analyze computer graphics techniques employed in the project OnSight– NASA, applying them to the audit of public works. Based on this theoretical reconstruction, the foundations of a new audit modality is established called MRA – Mixed Reality Auditing.

The creation of this new auditing concept by the Federal Court of Accounts of Brazil is a major breakthrough in the field of public works and environmental auditing. It will have an immense impact on how this work has been being carried out so far because it eliminates the need for specialists to travel long distances to construction sites or the location of natural disasters, with obvious economy of time and resources for traveling and other related expenses.

The groundwork launched in this study would be a guideline for the TCU to establish a partnership with NASA, initiating a joint project in the area of interest. TCU could also possibly initiate its own project, including the development of the necessary software as well as the selection of the most suitable HMD and the consequent integration with the hardware to be used.

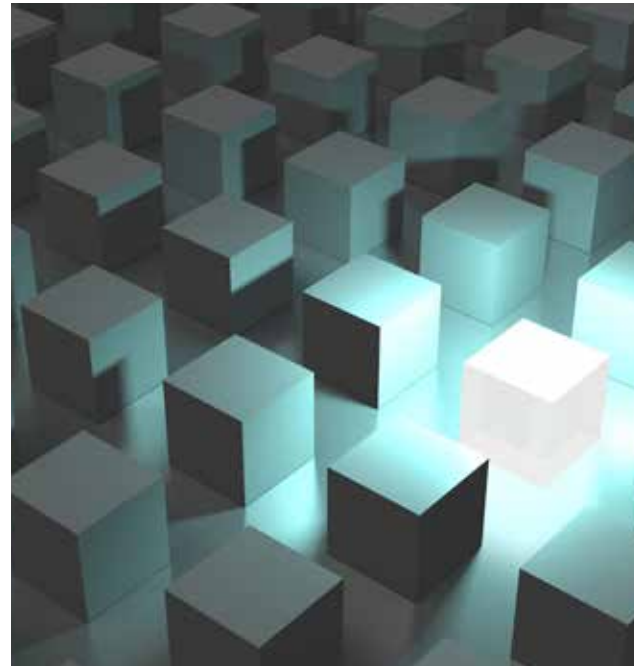
NOTES

1 Available at: <<http://unity3d.com>>..

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