Augmented Reality and Virtual Reality Web Environment to Visualizing the Planets of The Solar System

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Abstract

This paper shows the development of a webpage environment created to visualizations of the Solar System planets with Augmented Reality and Virtual Reality. With the objective to show the Solar System closer to reality, the measurements used in this paper involve distances between the planets and the Sun, limits of minimum (perihelion) and maximum distances (aphelion), rotations, inclinations and eccentricities of the elliptical orbits. To improve the orbits visualization, distances, diameters and rotations metrics were adapted with proportional circles areas and geometrical mean, smoothing the differences of magnitudes. The developed environment can be used in the classroom to visualize the Solar System in Augmented Reality, with the possibility of manipulations of the planets representations by the students with the environment created in Virtual Reality, besides studies of the laws of Kepler and properties of inclinations and rotations of the planets. This work serves as a way to encourage teachers to develop materials with the technology shown in order to propagate and popularize the use of Augmented Reality and Virtual Reality in classroom programmed as in a web environment.

Keywords: Augmented Reality, Virtual Reality, Solar System, Graphical Visualization

1. Introduction

Disciplines that involve three-dimensional (3D) concepts almost always require auxiliary resources for a better comprehension and spatial abilities development of the students. Manipulation of objects by students is important to help understanding these contents. Concrete materials can currently be produced with 3D prints for classes of Biology [1], Geometry [2] or others courses involving 3D shaped objects. The development of web-based teaching environments or applications also helps in visualization and manipulation of contents about Biology [3] and Geometry [4] and is shown as an attractive alternative to student learning aid. The digital planetarium presented in [5] assists in the learning of middle school students in understanding the relations of distances between planets and in the study of eclipses occurrences.

Another alternative to aid teaching classes that involve 3D objects is the use of modelling with virtual technologies. The Virtual Reality (VR) serves to create an immersive environment with manipulation of objects through controls and immersive goggles [6]. Environments developed in VR can help in the visualization of physical or biological phenomena, educational games, simulations of training situations, planet surface views, construction simulations, and other areas of education. The work shown in [7] describes the construction of a VR environment for the Solar System made by the high school students, with orientations of the Astronomy teachers. The contents applied by the authors involve distances and rotations of the planets, as well as studies of eclipses of the Moon and the Sun.

The Augmented Reality (AR) uses a camera device to place it together with the camera image environment, creating virtual layers of 3D objects and text on the camera image in real time. Students can interact with real and physical camera objects and virtual models are added to this environment [8]. Recent works show very interesting applications of AR to aid in the educational areas, such as Geometry [9], Engineering [10], Medicine [11], Architecture [12], Chemistry [13] and others [14], [15], [16]. The contributions of AR in educational area demonstrate that it is a powerful tool to use in classrooms because it allows many interactive visual forms of learning Astronomy [17], [18] and other disciplines [19], [20]. The basic concepts of Astronomy are not easy to teach, since they are contents distant from the students' daily reality. Therefore, the use of auxiliary materials is fundamental to the students' better understanding of these concepts. The use of concrete materials in the representations of each planet to show sizes, distances and basic concepts of the Solar System was used by the authors of the work shown in [21]. In a simpler way, the use of analogies with objects is also a good alternative of methodology for the teaching of initial concepts of the Solar System [22].

1.1. Objectives

The representation of the Solar System involves concepts of Euclidean Geometry, such as distances, diameters, rotations and eccentricity of elliptical orbits. The AR resources can be used to study and visualization of each planet separately [23], [24] or with relations of Earth's orbit with the Sun [25].

The use of AR can complement the use of traditional didactic materials in teaching of astronomy concepts, as students can interact and visualize the planets and their properties more effectively and significantly. The VR can assist in the interaction of students with the virtual representations of the planets, allowing astronomy contents to be taught as field lessons, through the virtual visit of planets separately or individually [22].

This paper presents the elements that allow the construction of an environment that uses VR and AR technologies to representation of the Solar System using webpage resources. The main idea is to use a webpage with HTML resources encoded for AR, creating links to the webpages developed in VR. With access to the webpage encoded in AR, students visualize the Solar System through various viewpoints and access the sites developed in VR to manipulate the graphical representations of planets and orbits with mobile devices, computers or can even immerse in the scene with the available VR goggles.

The modelling proposed in this paper modifies the relations of values of orbital diameters and distances to improve visualizations in VR and AR. Instead of using direct proportional measures, the concept of proportional circles areas and geometric means is used, making it possible to smooth the distribution of measurements without losing the proportions of real distances.

The environment proposed in this paper illustrates only one application, but can be developed in several areas of teaching involving Euclidean Geometry. As the programming is done in webpages, the loading is practically immediate and does not require installation of applications, it is enough that the device has camera and access to internet. As can be seen in this paper, the used commands to building the proposed environment AR/VR are quite intuitive, and require only a basic understanding of HTML codes. It is an excellent and simple programming tool that allows applications in the classroom without the difficulties pointed out in the use of some AR technologies [26].

1.2. Organization

This paper is organized into 6 sections, including this introduction. Section 2 describes the data used to create the VR models with the proposed changes in the distances and diameters proportions. Section 3 shows the main tags used in the VR models in webpages environment. Section 4 presents the modifications of the VR models to operation in the AR environment. Section 5 shows some possible applications of the system developed in the classroom. Finally, section 6 presents concludes the paper and shows some suggestions to future works with VR and AR technologies in the educational area.

2. Modeling data

The data used to modelling the Solar System in VR and AR environments were obtained from National Aeronautics and Space Administration - NASA [27] and involve distances, diameters, orbital rotation periods of planets around the Sun and rotation periods of planets and the Sun around their own axes. Using the data shown in this section, the proposed model will have the necessary elements for the graphical representation of the Solar System closest of reality and applicable in the classroom for exploration of Astronomy, Geometry and Physics concepts.

2.1. Distances e diameters

The distances informations used to each planet are: diameter (*d*), distance from the Sun (*r*), and the limits of distances to the Sun perihelion (*ph*) and aphelion (*ah*). The data are shown in Table 1, including the 5 dwarf planets Ceres, Pluto, Haumea, Makemake and Eris.

The modelling of planets distances of the Sun can be made using a planet as reference, calculating the other relative distances through rule of three. Considering the Pluto's distance from the Sun as a reference p_{dist} = 100%, the proportional values of other planets distances from the Sun are shown in Table 1. It can be observed that the distance from Mercury's orbit to the Sun represents only 1% of the distance between Sun and Pluto's orbit. The planets Venus, Mars and Earth have orbits very close to Mercury, all percentages p_{dist} below 4%, damaging the VR visualization of these orbits.

Considering a reference distance R = 26 m used in VR as the distance from Pluto's orbit to the Sun, the other distances are found by multiplying each percentage p_{dist} by the measure R:

$$r_p = p_{dist}R/100.$$

However, as shown in Table 1, the shortest distances have very closest values, all smaller than 1 m, making it difficult the visualization of these orbits. To improve the visualization of the planets in their orbits without losing the distances proportions, we can use the notion of circles areas centred on the Sun as if they were approximations of the planets orbits. In this way, the radius of a circle of an orbit r_o is considered with proportional area p_{dist} in relation to circle area of Pluto's' orbit, that is:

$$\pi r_o{}^2 = p_{dist}\pi R^2.$$

Isolating the radius r_o gives:

$$r_o = \sqrt{p_{dist}R^2} = R\sqrt{p_{dist}} \tag{1}$$

that is, r_o is the geometrical mean between $p_{dist}R$ and R.

Table 1 shown the values of radius r_o calculated with equation (1) for all the planets. This methodology makes the orbits distances well defined, without losing the proportionality, which instead of being applied directly to the radius, can be used in circles areas. The orbits of Venus and Mercury have direct proportional distance r_p = 0.23 m, and using the circles areas this distance becomes r_o = 0.95 m. Figure 1 shows the representations of orbits from Mercury to Pluto using the proportional radius r_p and the radius with proportional areas r_o. It can be verified that the orbits visualization with radius r_o is much more clear and comprehensible to apply with the students in classrooms. The orbits representations to the last three dwarf planets were omitted in Figure 1 so as not to impair the orbits visualization of planets near to the Sun.

The planets diameters can also be calculated by equation (1), using as reference the diameter of the Sun. Table 2 shows the percentages p_d of planets diameters compared to diameter of the Sun, the proportional diameters d_p and proposed diameters d_{prop} through equation (1), considering Sun's diameter D = 4 m to be used in VR environment. Note that diameters that would have insignificant sizes become more representative, for example, Mars has proportional diameter d_p = 0.02 m and proposed diameter d_{prop} = 0.28 m.

According to Kepler's first law, also called the Law of Ellipses, the planets orbits are elliptic, and the Sun occupies the position of one of the foci of each orbit [28]. To correctly position the orbits ellipses, we consider the distances aphelion (ah) and perihelion (ph) that represent, respectively, the largest and the shortest distances from planets orbits to the Sun [29]. For example, the aphelion and perihelion of Mars measure 249.2 x 106 and 206.6 x 106 km, respectively, and one of these distances can be used to represent the orbit of Mars with a translation Δ of the ellipse's major axis relative to the orbit center.

Table 1. Distances and translations

planets	distances to the Sun				aphelion		perihelion		translations	
	r (10^6 km)	p_{dist} (%)	r_p (m)	r_o (m)	(10^6 km)	*ap* (m)	(10^6 km)	*ph* (m)	(10^6 km)	Δ (m)
Mercury	57.9	1	0.25	2.57	69.8	2.83	46	2.29	11.9	0.28
Venus	108.2	1.8	0.48	3.52	108.9	3.53	107.5	3.51	0.7	0.011
Earth	149.6	2.5	0.66	4.14	152.1	4.17	147.1	4.1	2.5	0.035
Mars	227.9	3.9	1	5.11	249.2	5.34	206.6	4.86	21.3	0.245
Jupiter	778.6	13.2	3.43	9.44	816.6	9.67	740.5	9.21	38.1	0.234
Saturn	1,433.5	24.3	6.31	12.81	1,514.5	13.17	1,352.6	12.44	80.9	0.367
Uranus	2,872.5	48.6	12.64	18.13	3,003.6	18.54	2,741.3	17.71	131.2	0.419
Neptune	4,495.1	76.1	19.79	22.68	4,545.7	22.81	4,444.5	22.55	50.6	0.128
Ceres	413	7	1.82	6.88	445.41	7.14	382.6	6.62	30.38	0.258
Pluto	**5,906.4**	**100**	**26**	**26**	7,375.9	29.05	4,436.8	22.53	1,469.6	3.466
Haumea	6,452	109	28.4	27.17	7,701.86	29.69	5,976.8	26.15	475.18	1.02
Makemake	6,847	116	30.14	27.99	7,904.8	30.08	5,773	25.7	1,074	2.289
Eris	10,125	171	44.57	34.04	14,602	40.88	5,723	25.59	4,402	8.448

Observation: the translations Δ were calculated using the values of the orbits perihelion distances.

Table 2. Diameters

planets and Sun	d (km)	p_d (%)	d_p (m)	d_{prop} (m)
Sun	**1,391,016**	**100**	**4**	**4**
Mercury	4,879	0.35	0.014	0.237
Venus	12,104	0.87	0.035	0.373
Earth	12,756	0.92	0.037	0.383
Mars	6,792	0.49	0.02	0.28
Jupiter	142,984	10.28	0.411	1.284
Saturn	120,536	8.67	0.347	1.177
Uranus	51,118	3.67	0.147	0.767
Neptune	49,528	3.56	0.142	0.755
Ceres	952	0.07	0.003	0.105
Pluto	2,370	0.17	0.007	0.165
Haumea	1,240	0.09	0.004	0.119
Makemake	1,430	0.1	0.004	0.128
Eris	2,326	0.17	0.007	0.164

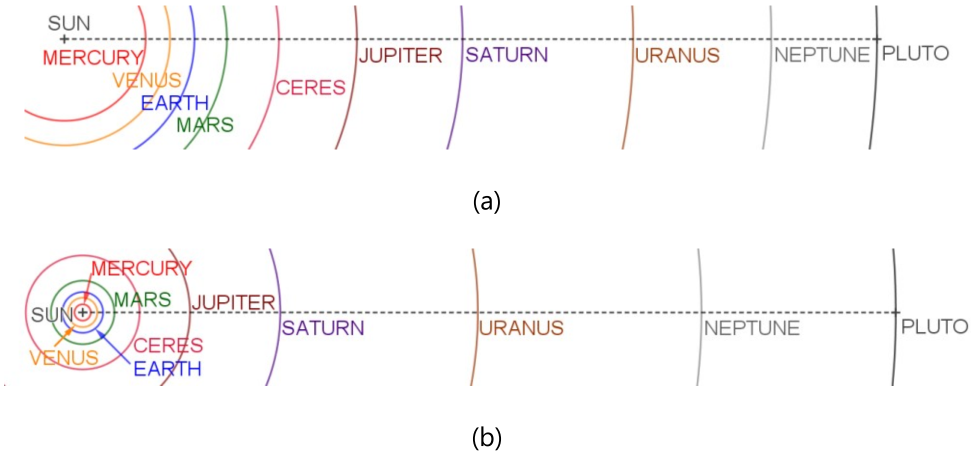

Figure 1. Distances between orbits: (a) with proportion of circles areas; (b) with direct ratio of the radius.

The proportional values of the distances aphelion and perihelion of each planet were calculated using the same methodology of the distances and diameters shown previously. These values are used to calculate the translation Δ of each planet in relation to the center of Sun finding the difference between the distance of each orbit r_o with the respective perihelions (or aphelions). Therefore, each orbit suffers a translation Δ of the elliptical orbit from the center of Sun towards the aphelion of each planet. All these values are shown in Table 1, where it can be noted that the accentuated values of the dwarf planets translations stand out.

2.2. Rotation periods

For a complete representation of the Solar System, orbital and rotation periods can be represented in VR and AR environments. The orbital period t_o is the number of days it takes a planet to complete a full 360° rotation around the Sun. The rotation period t_r represents the number of days it takes a planet to complete a 360° rotation around its own axis [27], [29]. The values of these periods of the Solar System planets are shown in Table 3.

The Mercury's orbital period represents only 0.1% of Pluto's orbital period, that is, while Mercury gives 1,000 turns around the Sun, Pluto complete only 1 turn. These great differences also occur with periods of rotation. For example, Jupiter takes just over 9 hours to complete a rotation around its own axis, while Venus has the rotation period of 243.02 days. Therefore, since the values of orbital and rotation periods also have large variations of values, the visualization of the Solar System proposed in AR and VR can use equation (1) to represent a smoothing of these differences between the planets periods, thus avoiding viewing problems caused by very slow or fast rotations. The proposed values of periods are showed in Table 2 with unit of seconds to direct application in models of AR and VR. Pluto's orbital period was used as a reference with duration of 5,000 seconds. Using the same unit seconds, the period of rotation of Mars was used as reference, with duration of 259.01 seconds.

2.3. Angles, inclinations and orbits' eccentricities

The representation of planets orbits can be made through an imaginary line that passes through the center of each planet and describes an ellipse around the Sun. This ellipse's center has positioned with translation Δ shown in section 2.1 from the Sun's center, with an inclination i relative to a plane of reference. The intersection of this plane with the ellipse is called line of nodes, and the axis d with origin from the Sun's center is used as a reference for all planets [28].

Table 3. Periods of planets and the Sun

planets and sun	orbital period t_o			rotation period t_r		
	days	**%**	**(s)**	**days**	**%**	**(s)**
Sun	-	-	-	35	14.4	98.3
Mercury	88	0.1	155.88	58.65	24.13	127.24
Venus	224.7	0.25	249.06	**-243.02**[a]	**100**	**259.01**
Earth	365.2	0.4	317.52	1	0.41	16.62
Mars	687	0.76	435.49	1.02	0.42	16.78
Jupiter	4331	4.78	1,093.44	0.41	0.17	10.63
Saturn	10,747	11.87	1,722.44	0.45	0.19	11.15
Uranus	30,589	33.78	2,905.93	-0.72[a]	0.3	14.1
Neptune	59,800	66.03	4,063.05	0.67	0.27	13.57
Ceres	1,680	1.86	681.01	0.375	0.15	10.17
Pluto	**90,560**	**100**	**5,000**	-6.39[a]	2.63	42
Haumea	104,025	114.87	5,358.8	0.167	0.07	6.78
Makemake	111,325	122.93	5,543.7	0.938	0.39	16.1
Eris	203,305	224.7	7,491.6	1.08	0.44	17.26

Observation: [a]Negative values indicate that the planet rotates in the opposite direction to that of its orbit around Sun.

The position of perihelion and aphelion of the planets is possible with the determination of two angles: the longitude of the ascending node Ω, determined between the axis d and the line of nodes; and longitude of the perihelion ω, formed between the line of nodes and the perihelion point. The angles Ω and ω are shown in Figure 2, whose values for all planets are showed in Table 4.

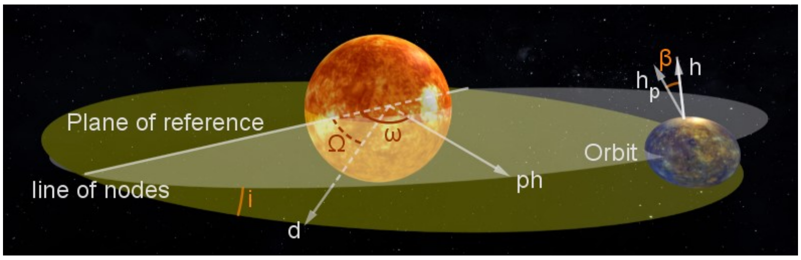

Figure 2. Angles used to position the planets' orbits.

Considering the axis h orthogonal to the orbit plane, each planet has an axis passing through its poles called h_p. The angle β formed between the axes h and h_p is called the inclination or obliquity of the planet [28]. Figure 2 shows an example of this angle, and the values for all planets are shown in Table 4. The inclinations not available for Haumea, Makemake and Eris were considered null. Again, the tilt values of the dwarf planets are accented. Full VR modelling with all angles allows an immersive exploration with all these differences in orbital slopes of the planets in the Solar System.

Table 4. Reference Angles and Orbits' Eccentricities

planets and sun	***ω***	***Ω***	***i***	***β***	***e***	**minor semi-axis**	
						***b* (m)**	**b_p (%)**
Sun	-	-	-	7.25°	-	-	-
Mercury	77.4°	48.3°	7°	0.03°	0.206	2.519	97.9
Venus	131.5°	76.7°	3.4°	177.3°	0.007	3.519	100
Earth	102.9°	-11.3°	0°	23.26°	0.017	4.137	100
Mars	336°	49.6°	1.9°	25.19°	0.093	5.085	99.6
Jupiter	14.7°	100.6°	1.3°	3.13°	0.048	9.429	99.9
Saturn	92.4°	113.7°	2.5°	26.73°	0.056	12.789	99.8
Uranus	170.9°	74.2°	0.8°	97.77°	0.047	18.112	99.9
Neptune	44.9°	131.7°	1.8°	28.32°	0.009	22.681	100
Ceres	157.85°	80.7°	10.6°	4°	0.076	6.855	99.7
Pluto	224°	110.3°	17.2°	312.9°	0.248	25.188	96.9
Haumea	2°	121.9°	28.96°	-	0.189	26.685	98.2
Makemake	16.6°	79.4°	28.9°	-	0.156	27.638	98.7
Eris	286.9°	35.9°	44.2°	-	0.441	30.569	89.8

Observation: *ω* – longitude of the perihelion, *Ω* - longitude of the ascending node, *i* - inclination of the orbit, *β* - inclination of the axis, *e* - orbits' eccentricities.

Despite the small values of eccentricities, the planets' orbits have elliptical shapes. The ellipse's semi-major axis of a planet orbit is the distance r_o to the Sun (Table 1). The value of semi-minor axis *b* of a planet orbit can be found by using the ellipse's eccentricity definition with semi-major axis r_o and considering *c* as the distance to each focus to the ellipse's center:

$$e = c/r_o, \text{ where } c^2 = {r_o}^2 - b^2,$$

$$\text{that is, } c = \sqrt{{r_o}^2 - b^2}.$$

Substituting the value of *c* in the first equality yields the value of the semi-minor axis *b*:

$$b = r_o\sqrt{1 - e^2}. \quad (2)$$

Table 4 shows the values of semi-minor axis *b* in meters, calculated through equation (2), and in percentages b_p in relation to semi-major axis r_o to each planet. Venus, Earth and Neptune have approximate representations by circles, because their eccentricities have values close to zero. Section 3 presents the commands to planets modelling in VR environment with all elements of the Solar System presented in this section.

3. Virtual Reality

The programming of the Solar System elements was done in both Virtual Reality and Augmented Reality. In both cases, we used the A-frame libraries, an environment developed by the Mozilla VR team [30]. A-frame uses functions from the Java Three.js library with pure HTML tags, which allows all VR or AR programming as a webpage, which follows the tags composition with inheritance and hierarchy principles [31].

The main tags used to modelling a part of the Solar System in VR are shown in this section, placed in Figure 3. The reference tag to the main library of A-frame is placed between lines 3 and 5, which represent the HTML page header. All references of libraries can be inserted within the page header tag.

```
1 <!DOCTYPE html>
2 <html>
3  <head>
4   <script src="https://aframe.io/releases/0.8.2/aframe.min.js"></script>
5  </head>
6  <body>
7  <a-scene cursor="rayOrigin:mouse">
8  <a-entity camera look-controls position="0, 2, 8"></a-entity>
9  <a-assets>
10   <img id="milkyway" src="imagens/milky_way.jpg">
11   <img id="sun" src="imagens/sun.jpg">
12   <img id="mercury" src="imagens/mercury.jpg">
13 </a-assets>
14 <a-sky src="#milkyway"></a-sky>
15 <a-sphere src="#sun" radius="2">
16  <a-animation attribute="rotation" dur="98300" easing="linear" repeat="indefinite"
17   from="7.25, 0, 0" to="7.25, 360, 0"></a-animation>
18 </a-sphere>
19 <a-entity id="i" rotation="7, 48.3, 0" scale="1, 1, 0.979">
20  <a-entity id="i_ph" rotation="0, 77.45, 0">
21   <a-entity id="desl" position="-0.28, 0, 0">
22    <a-sphere src="#mercury" radius="0.12" position="2.57, 0, 0" scale="1, 1, 1.021">
23     <a-animation attribute="rotation" dur="127240" easing="linear" repeat="indefinite"
24       from="0.03, 0, 0" to="0.03, 360, 0"></a-animation>
25    </a-sphere>
26    <a-text id="label" value="MERCURY" position="2.57, 0.3, 0"></a-text>
27    <a-torus id="orb" rotation="-90, 0, 0" radius="2.57" color="cyan"
28      radius-tubular="0.008"></a-torus>
29    <a-animation id="p_orb" attribute="rotation" dur="155880" repeat="indefinite"
30      to="0, 360, 0" easing="linear"></a-animation>
31   </a-entity>
32  </a-entity>
33 </a-entity>
34 <tags of the solar system planets>
35 </a-scene>
36 </body>
37 </html>
```

Figure 3. HTML code in A-frame to visualizing solar system in VR.

The elements of the Solar System modelling are defined in tags of body's page. Before placing them, it is necessary to define the user interactions with the mouse or VR controls (a-scene) and the scene's camera (a-entity) with initial position at the coordinates x (right/left), y (height) and z (depth), as shown in line 8 of Figure 3. The initial values proposed are as follows: x = 0 to place the camera in the center of screen; y = 2 to the observer have a more privileged viewpoint with a height of 2 m to watch the planets; and z = 8 to move the observer away 8 meters from the origin of the modelled environment. With the value z = 8, the observer will be positioned between the orbits of Saturn and Uranus (Table 1), with the Suns' representation at the origin of the coordinate system.

The tags defining the textures used on the planets are placed within a-assets (between lines 9 and13 of Figure 3), and the images were taken from a free online model of Solar System [32]. The Milky Way image is referenced as a 360° background image of the scene through the a-sky tag. The Sun and Mercury tags will be shown as an example, and the other planets have similar tags. The images of the textures of Sun and Mercury are referenced below, placed in a folder called images.

The Sun is the first star modelled in A-frame (between lines 15 and 18 of Figure 3), with the texture referenced as #sun and radius equal to 2 meters (Table 1). The animation of Sun's rotation period is 98.3 seconds (Table 3), whose value is placed in the duration property of the a-animation tag. The unit of A-frame is milliseconds, that is, the duration of the animation will be t_r = 98,30 ms. In this animation tag, we define the angle of axis inclination $\beta = 7.25^{\circ}$ (Table 4) in relation to the x-axis and the complete rotation that varies from 0 to 360° around the y-axis.

Note that the A-frame coordinate system has the y-axis orthogonal to the orbit's plane of reference (the most common and intuitive is to use the z-axis orthogonal to the plane of reference). The repeat property is set to indefinite, and the easing property, which controls the acceleration of the animation speed, is set to linear so that the rotations do not have speed variations during animations.

The Mercury's orbit tags are between lines 19 and 33 of Figure 3, with major axis on the x-axis and minor axis on the z-axis of the A-frame coordinate system. The first tag with id="i" (line 19) has the properties to define the inclination of the orbit's plane using a rotation of $i = 7^{\circ}$ around the x-axis and the line of nodes inclination through the longitude of the ascending node with a rotation of $\Omega = 48.3^{\circ}$ around the y-axis. The eccentricity was used as a scaling factor $b_p = 0.979$ (Table 4) on ellipse minor axis.

The tag with identifier id="i_ph" (line 20) rotates the orbit with inclination across the longitude of perihelion $\omega = 77.45^{\circ}$ around the y-axis (Table 3). After doing the inclinations, the tag with id="desl" (line 21) moves the orbit's plane with the value $\Delta = 0.28$ meters (Table 1) relative to the x-coordinate of the ellipse's major axis of the orbit.

The tag in line 22 define the sphere with reference to the texture defined in assets #mercury, radius $d_p/2$ = 0.12 m, distance of the orbit r_o = 2.57 m (Table 1), inverse scale of eccentricity $1/b_p$ = 1.021 on minor axis, angle of axis inclination $\beta = 0.03^{\circ}$ (Table 4) and rotation period t_r = 127,400 ms (Table 2). The animation of the rotation period must be inside the sphere tag so that only the planet rotates around own axis.

The a-text tag with id="label" (line 26) serves to position a label on the planet. The tag with id="orb" (line 27) shows the orbit as a torus with a larger radius equal to the planet's distance from the Sun r_o = 2.57 m and the tubular radius with 0.008 m. A rotation of -90° around the x-axis was made to leave the orbit contained in the plane defined by the x and z-axes.

The last tag with id="p_orb" (line 29) is used to define the animation of orbital period. This tag is inside the tag with id="trans", that is, it serves to rotate all the elements of the planet Mercury with duration of t_o = 155,800 ms (Table 3). After the closing of the Mercury tags, the other planets tags can be inserted, closing the following tags in sequence: scene </a-scene>, body </body> and webpage </html>.

One way to create interaction with the scene elements is to use orbits functions [33], which allows students to move the camera around the objects of the scene according to the best visualization of the Solar System. When using the VR goggles, moving the camera with orbit function is automatic. On computers, tablets and smartphones, moving the camera around objects can be done using the mouse, keyboard or touch.

Figure 4 illustrates a wide region of VR modelled orbits with A-frame HTML codes. This visualization shows the orbital inclinations and relative positions of the planets in relation to the Sun. With the metrics proposed in the previous section, it can be see that the proportions of circles areas used allow a good visualization of each planet in relation to the Sun. If direct proportions were used, many planets would have irrelevant sizes and could not be visualized in the VR system properly. The perihelion and aphelion points can be easily located in the VR modelled system.

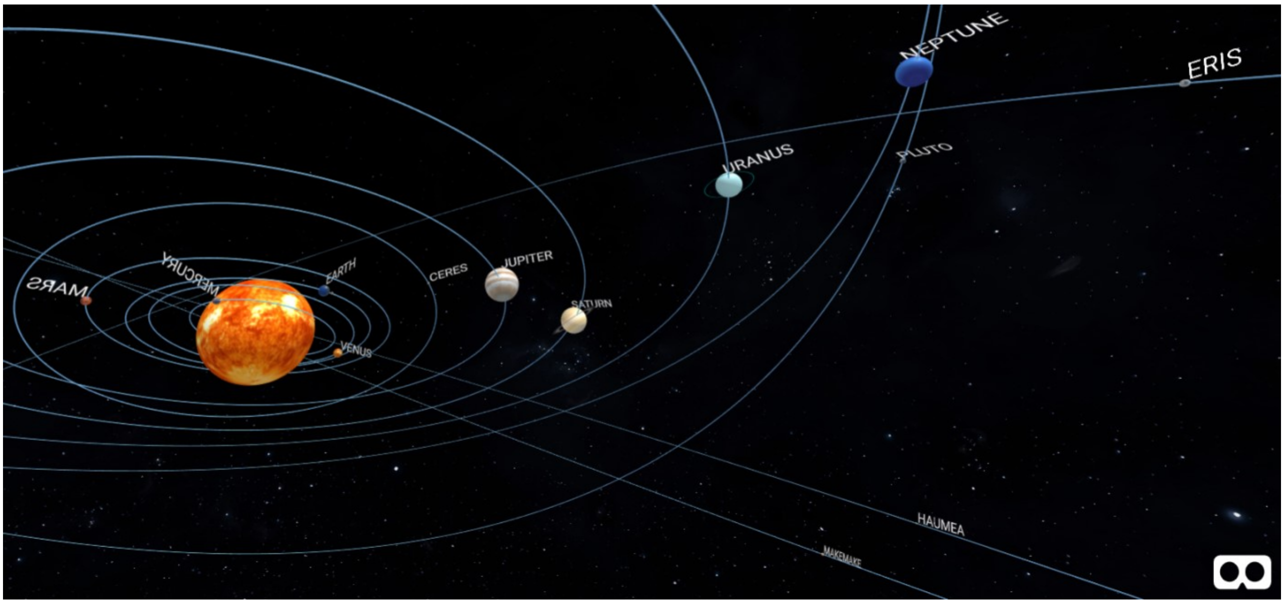

Figure 4. Enlarged view of solar system orbits modeled in VR with A-frame.

Figure 5 shows a part of the Solar System modelled in VR, the planets closest to the Sun and also the great slope i = 10.6° of Ceres orbit in relation to the others. Figure 6 shows the system modelled from another point of view, the most distant orbits of the Solar System and the great orbits inclinations of dwarf planets Pluto, Haumea, Makemake, and Eris in relation to the orbits of Uranus and Neptune.

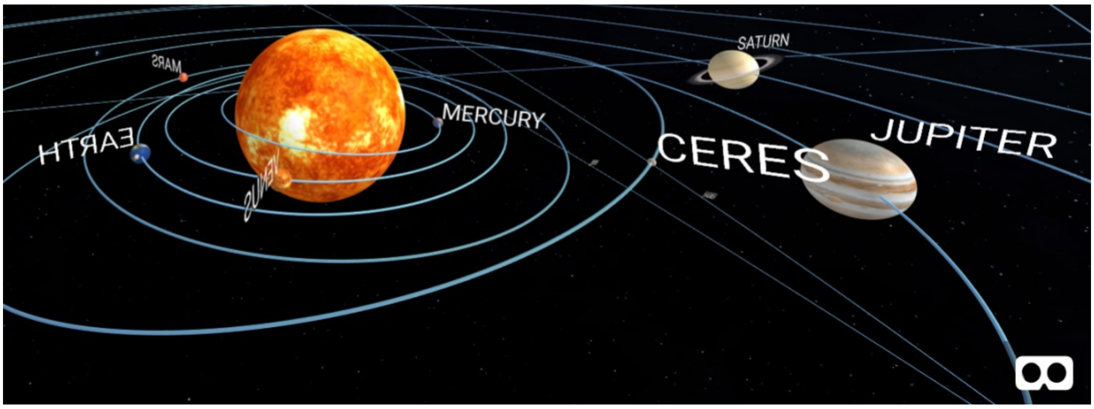

Figure 5. Visualization of orbits planets of solar system with VR using A-frame. Detail of the planets closest to Sun, standing out the 10.6° inclination of Ceres orbit.

For being a webpage, users have options of visualizations in tablets, computers, smartphones, besides oculus Rift, oculus Vive, Daydream and gearVR. To use the goggles and get the full immersion in the scene, simply press the goggles that appear in the lower right corner of the webpage's screen. Enabling this icon on smartphones, tables or computers, the effect is maximizing the browser screen. The interactions commands with the planets can be modelled in the immersion of the VR scene for individual manipulations of planets [34] or teleportation [35] in scene regions. In this project the interaction used was to orbit elements of the Solar System.

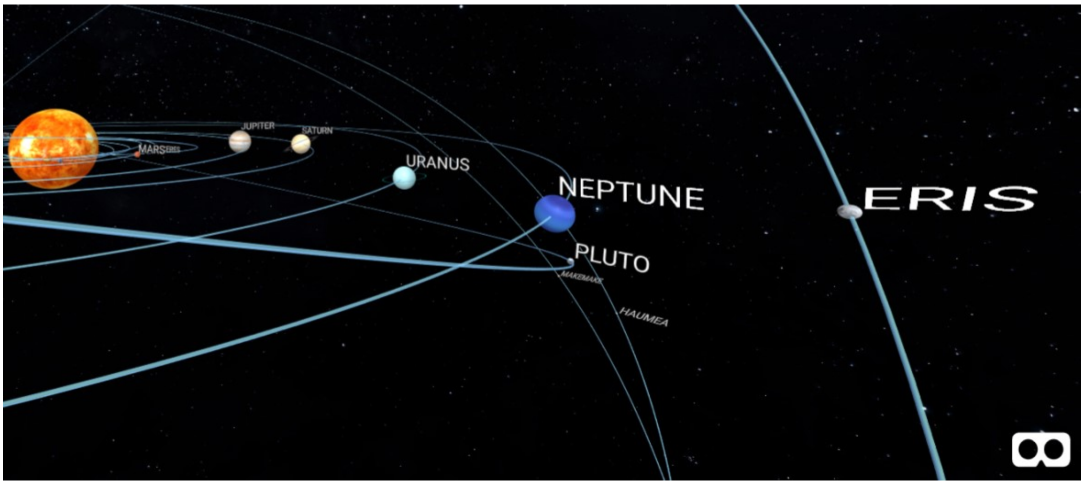

Figure 6. Detail of the view of orbits planets farther from the Solar System, highlighting the inclinations of dwarf planets orbits Pluto, Makemake, Haumea and Eris.

4. Augmented Reality

In an environment programmed in Augmented Reality, elements modelled in Virtual Reality can be mixed with physical objects shown through the device's camera. The webpage programming of the Solar System in AR uses the same structural VR tags showed in Section 3.

One of the modifications of VR webpage to work in AR is the inclusion of referential tag of AR visualizations, developed by Jerome Etienne [36] and that should be placed in header of webpage along with referential tag of the A-frame, shown in Section 3. The RA tags for visualization of the solar system are in Figure 7.

The scene tag in AR has the inclusion of webcam image, embedding properties and capturing interaction with mouse or raycaster controls on objects with links. In addition, the AR scene has the inclusion of markers, which work with 0 and 1 bits of an images matrix that are recognized in the scene through the webcam [37]. The properties for capturing the marker data for the modelling appear in the webcam image are detectionMode and matrixCodeType (lines 7 and 8 of Figure 7). Markers work as reference points, where you can set specific positions for the virtual objects that appear in the actual webcam image. The AR image background is the webcam image, and there is no need to set the a-sky tag.

```
1  <head>
2   <script src="https://aframe.io/releases/0.8.2/aframe.min.js"></script>
3   <script src=" https://jeromeetienne.github.io/AR.js/aframe/build/
4      aframe-ar.min.js"></script>
5  </head>
6  <body>
7  <a-scene embedded cursor="rayOrigin:mouse" raycaster="objects:[link];"
8     arjs='sourceType:webcam; detectionMode:mono_and_matrix; matrixCodeType:3x3;'>
9  <a-marker preset="hiro">
10   <a-link href="solarsystem.html" title="VR"></a-link>
11   <a-entity position="0 0.5 0" scale="0.2 0.2 0.2">
12    <tags of the solar system planets>
13   </a-entity>
14 </a-marker>
```

Figure 7. HTML code in A-frame for visualizing solar system in AR.

When the image of a marker is recognized in AR scene, the VR element modelling will be activated. There are more than 80 options of markers already programmed in the library developed by Jerome Etienne, and markers are defined as parent tags that contain the elements programmed into VR that are activated. Common A-frame markers are called hiro, kanji and barcodes. In the same scene, several markers can be used, each with a modelled object to be activated. In this paper the 3 markers illustrated in Figure 8 will be used: hiro, kanji and the barcode code #20. With the printed markers, students can access the webpage from their tablets, smartphones, or computers and viewing the programmed markers, the objects programmed in VR appears on the devices' screens in AR.

The hiro marker was used in this paper to enable visualization in AR of all planets of the Solar System. The webpage tag with the hiro marker gets all the tags on the planets, and their structure is shown between lines 9 and 14 of Figure 7.

Figure 8. Markers used in A-frame: hiro, kanji and barcode #20.

In these tags, a-entity serves to group elements of Solar System, position them on the marker, and use scales. To better visualize the complete Solar System, the scale of 0.2 was used, with a distance y = 0.5 from the marker paper plane. Figure 9 shows Solar System with a-frame AR and hiro marker. The kanji marker was programmed to show 8 planets of Solar System, without the dwarf planets. Figure 10 shows this visualization Solar System with kanji marker.

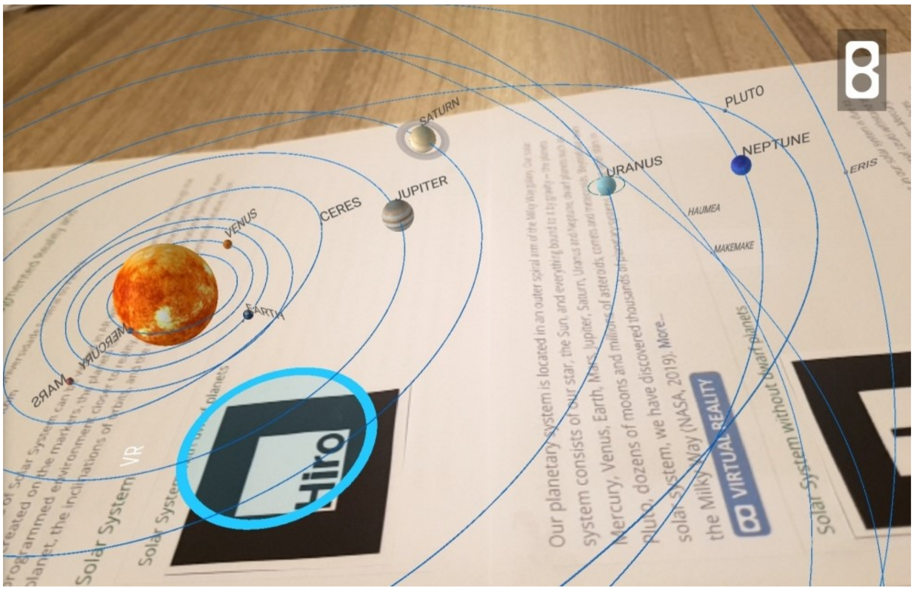

Figure 9. Visualization of 13 planets of Solar System (including the dwarf planets) with Augmented Reality using A-frame with hiro marker.

Individual visualizations of the planets can be done on the same page through the barcodes markers. With this view, the aphelion and perihelion boundary points can be showed, also the line of nodes, the inclination of axis, and the orbital and rotation periods of each planet. The use of the barcode marker #20 is illustrated in

Figure 11, with the example of the Mars elements. The other planets can also be programmed and displayed with other barcodes, all on the same webpage.

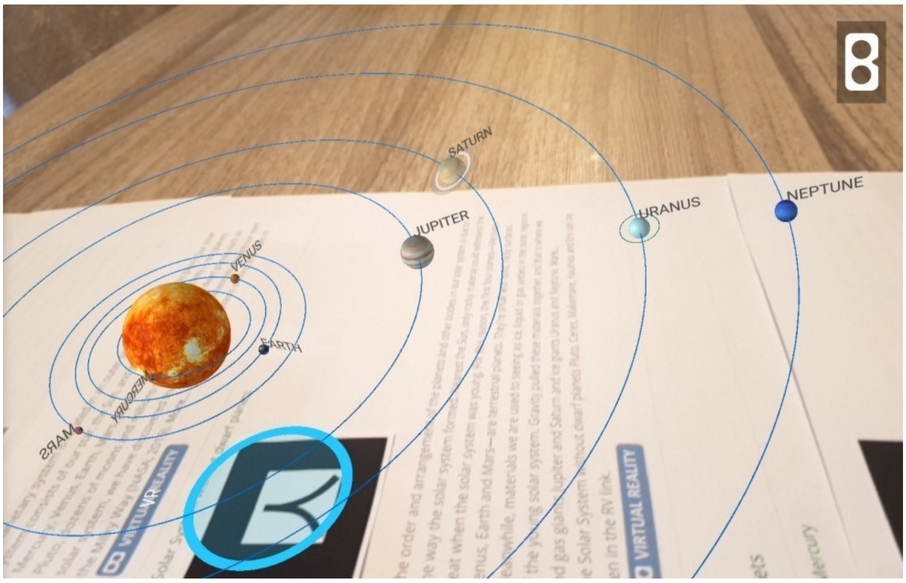

Figure 10. Visualization of the 8 planets of Solar System with Augmented Reality with A-frame using the marker kanji.

Access is instant because webpages have all pure HTML tags referenced with A-frame functions. Students do not need to download applications and it is only necessary that the device has internet access and webcam. When students access the Solar System with AR, the planets appear with all the rotational animations and metrics shown in the previous sections.

Using the link tag, we can create the interaction with the students to access the webpages programmed in VR. In this way, students view the system in AR and can manipulate visualizations with VR resources. In Figures 9, 10 and 11, the blue circle above the marker works as a link: just focus the device camera to marker or click on the marker to access the webpage in VR. The link tags are inside the respective marker, as shown in line 10 of Figure 7.

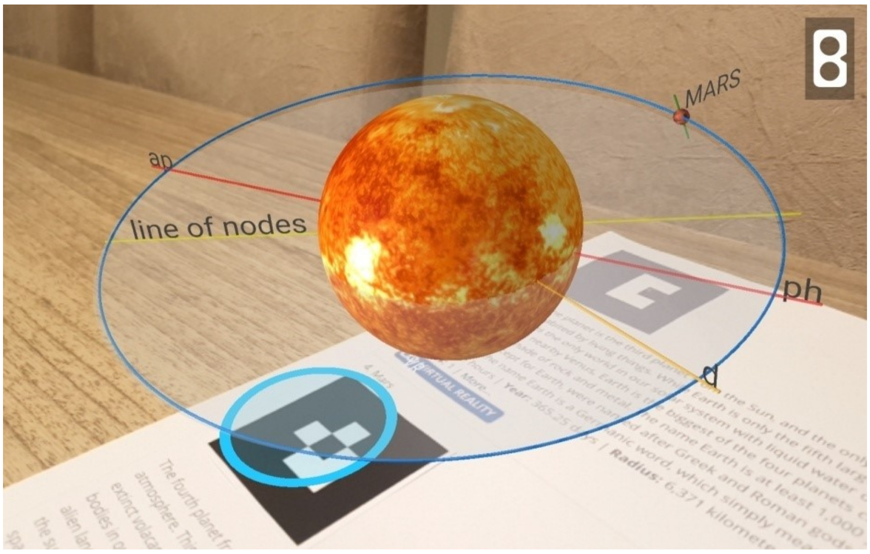

Figure 11. Visualization of Mars orbit in Augmented Reality using A-frame with barcode marker # 20.

The proposal is very interesting for use in the classroom for being practical, inexpensive and works on all types of smartphones and tablets. Another advantage is the use of several markers in a single HTML page, which allows the editing of didactic material with various themes programmed in AR and VR.

The Augmented Reality webpage developed in this paper is available at:

https://paulohscwb.github.io/solar-system/

At this webpage address developed in AR are all links to views of the elements in VR indicated.

5. Applications of the proposed environment

This section presents a list of some possible applications of the modelled environment in AR and VR to aid in the orbits and planets visualizations of the Solar System. The environment presented in this paper can be used to show the orbits, planetary inclinations and planets distances to the Sun, as well as the involved contents of Astronomy, Geometry and Physics.

The basic notions of distances between orbits, simple proportions and rule of three can be explored in the classroom with the complementation of visualization with proposed environment of AR and VR. Unit conversions can also be proposed in the classroom, such as transforming given distances from kilometres to astronomical units. The construction of a prototype of the Solar System with the direct proportions, shown in Section 2.1, can also be applied in the classroom to comparison with use of geometric means and circles proportional areas.

The applications of Kepler's Laws in the study of the planets orbits can make classes on ellipses more interesting and motivating. The concepts of eccentricity, relations between the semi axes and areas make more sense to the students when one has a real application to be studied, leaving aside the purely algebraic applications of these concepts. In this case, Kepler's three laws can be explored in the classroom with the aid of visualizations in an environment of 3D graphical representation.

The Kepler's law of Harmonies guarantees that the ratio of the square of orbital period by the cube of the distance from the planet to the Sun is constant for all planets orbits of the Solar System. The application of this law can be shown in the classroom as a complement to Kepler's first law with the distances and periods shown in Tables 1 and 2.

The constructions of the ellipses of the orbits and calculations of the laws of the Ellipses and the Harmonies can be made in through materials such as pencil, paper and ruler [38], [39], [40] or using free software for drawing ellipses, such as Geogebra. The contents of ellipses, eccentricities and comparisons of the constructed elliptical orbits can be explored and visualized in the environments modelled in AR and VR.

The eccentricity concepts can be used to calculate the measurements of the semi-minor axes of the ellipses representing the planets orbits with the distances aphelion and perihelion, applying all the concepts of Kepler's first law. The visualization of the geometric elements of each orbit can be done as shown in Figure 11, showing to students some real applications of basic concepts of ellipses. Exploiting these content makes more sense to students with real applications and their views in an environment of 3D graphical representation, such that proposed in previous sections of this paper.

Properties of angular momentum and orbit conservation can also be applied in Physics classes with orbital models designed by students [41] or calculated through a programming language [42]. In these cases, the visualizations of orbits developed in AR and VR can be used as complements to the learning of these concepts.

The angles shown in section 2 of this paper can also be used in the classroom for a larger Solar System building made by students. An interesting exercise may be to construct one orbit relative to another [43], using as parameters the angles shown in Table 3 as a top view of orbits around the Sun.

In this case, students would use the angles of ascending nodes Ω and longitude of perihelion ω to position the semi-major axes of the ellipses and the orbits distances shown in Table 1. Some contents that can be approached are relative to scales and proportions, which can be used in comparison with the direct proportions and the geometric means shown in section 2 of this paper.

The inclinations concepts of the planets and the Sun axes in relation to an axis orthogonal to the reference plane can be shown to the students with the modelled environment of each planet (Figure 9). Each planet or the Sun representation shows the axis passing through the poles, making it possible to see all angles of inclination β.

The orbital and rotation periods concepts can be explored for studies of alignments of some planets with the Sun, velocity calculations, conversions of measurements, and the law of the Kepler Harmonies already mentioned.

The properties and calculations of exoplanets orbits through an application for classroom use are presented in [44]. Exoplanet visualizations can be programmed in an AR and VR environment similar to the one shown in this paper, in order to aid in the visualizations of exoplanets' orbits, angles and eccentricities.

All classroom applications listed in this section are possible because the proposed A-frame environment works on any smartphone, tablet, or computer [31]. The practicality of showing students the representations in AR with markers printed in didactic materials creates students' interactions with three-dimensional objects that would only be possible with the use of concrete materials.

This technology is simple, functional, has low cost and requires no installation of applications, since it is all programmed as an HTML page. The performance of a page modelled with A-frame in AR is over 60fps on any smartphone, with almost instant loading, open source code and quite intuitive [36].

The development of this paper is intended to encourage teachers of disciplines involving Euclidean geometry to create similar environments for use in the classroom, helping to propagate and popularize AR and VR technologies in web environments for simple classroom applications [45] .

6. Conclusions

This paper shows a web-based system for visualizing the Solar System in Virtual Reality and Augmented Reality. Through the view of printed markers, students can visualize with any device with internet access and webcam the planets of the Solar System in AR, with links to their VR visualizations.

The metrics proposed in this paper use proportional circles areas and geometric means, with the aim of improving the visualizations of orbits and planets with a smoothing of magnitudes. The direct proportional scale has large differences in measurements of orbits, diameters and rotations, making it impossible to represent properly all elements of the Solar System in AR and VR.

Planets that have diameters smaller than 1% of the Suns diameter, or very distant orbits such as Neptune, Pluto or Eris have impaired views. The results show that this is a helpful tool for use in classrooms because it allows students to visualize and manipulate the graphical representations of the planets and orbits with their devices or to use the Virtual Reality goggles for complete immersion in the scene.

To make the orbit’s representation more realistic, inclinations, eccentricities, aphelion and perihelion thresholds were programmed, in addition to the orbital and rotation periods. With all these properties, this environment can be explored in classes involving contents of ellipses eccentricity, angles, proportions, and Kepler laws. All of these elements can be viewed in AR and VR and students can move the camera from the scene to find the best views of the Solar System in VR with tools developed to orbit the camera around the objects in A-frame.

Some advantages of creating AR and VR environments as web pages for classroom use are practicality, low cost, great performance and simplicity of programming. Another great advantage of this system with AR and VR technologies is the almost immediate loading of the webpage as it is built in HTML with references from VR libraries developed in Java to A-frame. This system AR/VR can be used in applications of courses of Geometry, Calculus, Statistics, Biology, Chemistry, Engineering and other areas that use graphic representations in 3D.

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