Stereoscopic Interactive Objects: Acquisition, Generation and Evaluation

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Abstract: Three-dimensional objects suffer from inaccuracies in the format of computational representation and artistic drawing, losing visual acuity. On the other hand, photographs offer visual acuity, but they are not interactive, that is, they do not offer the possibility of changing the perspective of visualization as a three-dimensional model does. Thus, we have created a device capable of scanning a real object, allowing for the production of interactive contents and visual acuity. In addition, the model created allows stereoscopic visualization, that is, with a notion of depth. We produced a learning object from the scans of a real object, assessed by teachers and students who work at medium, technical, and higher school levels. The interactive stereoscopic learning object with visual acuity seems promising for the responses to a questionnaire and interviews showed it motivated teachers and students due to its more realistic visualization and rich details. By allowing the visualization of the piece from several angles, it can foster and satisfy curiosities.

1 INTRODUCTION

The study of artworks, anatomical pieces or botanical items is just an example of visual analyses of real objects common in scientific research, education, or in the production system, among others. These visual inspections are a means for solving issues such as museum restoration or quality control in the production chain, among other applications.

However, it is not always possible, or even interesting, for the observer to be in direct contact with the item he studies. For example, a middle-level student does not need to enter into a human anatomy laboratory, where there are chemical agents that make this environment unhealthy, to study anatomy.

On the other hand, imprecise, inaccurate or static models may not faithfully represent the objects to be studied and hamper the teaching-learning process. Research has been done to obtain visual anatomical models that offer high visual acuity, such as the Visible Human Project (Ackerman, 1998), in which two human bodies were sectioned with intervals of 1mm and 0.33mm and these sections were photographed to generate image bases of the whole human body.

In his paper, Ackerman describes that there are two forms of image representation: those based on photos and three-dimensional models (3D). Three-dimensional models suffer from imprecision of both artistic design and graphical representation, which are based on geomorphic forms and mathematical formulas to represent volumes and structures. These, however, do not faithfully represent biological forms, which are irregular in nature.

As for the content in photographs, Ackerman argues that a set of two-dimensional static images are limited because they do not offer the possibility of changing the view perspective of the photograph as does manipulation of the real object.

According to the author, the understanding of tridimensional structures is essential in many areas, but the learning of them is a challenge. Photographs are two-dimensional in nature and force the viewer to a mental exercise of constructing a 3D visualization, which can lead to inaccuracies in the understanding of structures.

Besides anatomy, the same difficulties in understanding three-dimensional structures occur in other areas of education, such as the study of artworks, botany, design, among others. In order to overcome these problems, a device that can scan real objects

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for the generation of Learning Objects (LO) was developed. The generated LOs can be visualized on different devices, such as screens, projectors, and augmented reality, and include the notion of three-dimensionality, depth, and volume, preserving visual acuity, displaying details that are not visible to the naked eye.

The educational contents produced in this research have interactivity and stereoscopy (depth perception). To these contents will be added data such as information, definitions and characteristics present in the real objects, which were scanned. It is believed that the minipulation of an interactive and stereoscopic content can attract the interest of the students, contributing to the learning.

This paper introduces a solution for the digitization of real objects that allows an interactive, stereoscopic visualization and preserves visual acuity (Section 2). Section 3 addresses LOs and how the device can be used for this purpose. Section 4 presents the assessment of an LO generated from such digitization. Section 5 contains our final remarks.

2 FULL FRAMES SEMI-SPHERICAL SCANNER

Considering Ackerman's notes on the need for interactive digital models with fidelity to real objects, we worked out a method of digitization based on a set of photographs with visual acuity, which enables the generation of interactive and stereoscopic models. We define visual acuity here as the possibility to visualize in the digital model the same details found in the real object, that is, preserving its color, shape, and textures.

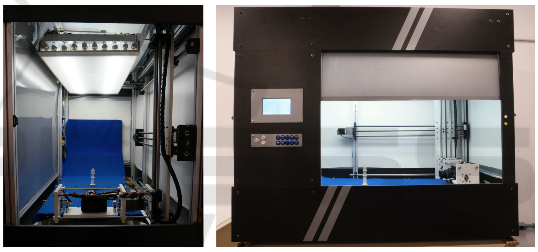
Visual acuity is achieved through the appropriate use of photographic techniques, correction of intrinsic problems in the digital photography process, enhancement of the acquired images (Krasula et al., 2017), and the use of quality metrics for these images (Cheng et al., 2017). Fidelity is also guaranteed for the acquisition of the colors of the real object (Yu et al., 2016).

Moreover, according to Ackerman, for the understanding of three-dimensional structures, it is desirable that one can interact with the model. In this paper, interaction is defined as the possibility of observing the digital model from different angles, manipulating and rotating it as if the object were in hands.

However, we used two-dimensional photographs; in order to allow for a spatial and volume-based understanding of the scanned object, we used stereoscopic techniques to create depth perception in the visualization. On the other hand, the work of (Weber et al., 2016) presents equipment for the acquisition of photos with a camera, an arm and a turntable, where the camera can be attached at different points in the arm, which have vertical movement.

This process is completely manual and generates problems in the acquisition for the generation of stereoscopy. In the works of (Solav, 2018) (Zhang et al., 2017) (Xu et al., 2017) multiple fixed cameras are used for the acquisition, which may entail the need for adjustments in the images, with the application of geometric transformations due to distortions.

In order to enable the scanning of real objects in accordance with the mentioned characteristics, we developed a Full Frame Semi-spherical Scanner - F2S2. The term "semi-spherical scanner" refers to the fact that the F2S2 takes pictures while moving the camera such that it forms a semi-sphere around the object, covering all the angles according to a predefined range. The term "Full Frames" refers to the photographic acquisition of all angles of the object. Figures 1(a) and 1(b) show F2S2.



(a) (b)

Figure 1: Full Frame Semi-spherical Scanner: (a) internal view; (b) side view.

Until the visualization process is reached, three steps are taken: initially, the photographs of all the angles of the object being scanned are acquired; these photos are then corrected, processed and organized into a file called Stream2D; finally, Stream2D is used to generate the visualization. Figure 2 shows the complete process.

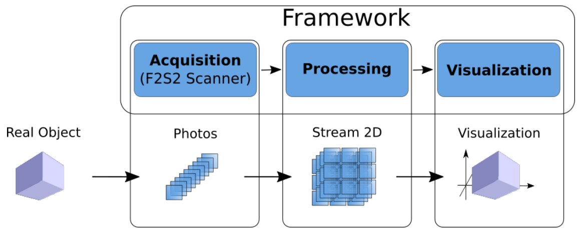
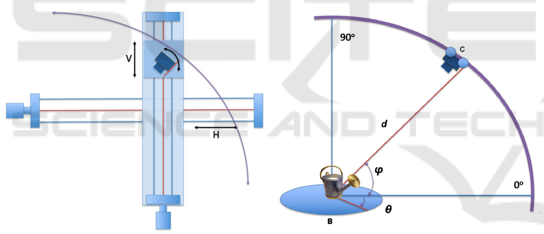


Figure 2: F2S2 framework.

Acquisition

The acquisition process occurs by photographing all the angles of the object in ultra-high definition (UHD), 4k (3840×2160 pixels) or 8k (7680×4320 pixels) pictures. Scanning takes a predefined angular range and a minimum scanning accuracy of 0.9° into account. In order for the camera to acquire the photographs, it is moved by a mechanical bracket that has two axes (Axes: H – responsible for the horizontal movement of the camera, and V - vertical movement). The H and V axes move the camera along an arc-shaped path with a predefined radius and with the object positioned in the center of the arc. Picture 3(a) shows the motion and the axes.

The C axis tilts the camera so that it maintains the focal point in the center of the sphere, that is, on the object. In addition to the movement of the camera, the object is positioned on a turntable that revolves around its own axis (Axis B), so that it is possible to obtain images from all sides of the object for each angular position of the camera. The arc motion (angular variation φ) and the object's rotation (angular variation Θ) cause the camera to move in a semi-sphere around the object, as observed in Figure 3(b). The acquisition process can be seen in videos[1].



(a) (b)

Figure 3: Acquisition process.

Processing

After the acquisition, the images are adjusted automatically, starting with the correction - by software - of imperfections intrinsic to the process of digital photography, such as deformations caused to the image by the optical set of the camera, removal of chromatic aberrations and the vignette. The colors of the pictures are corrected to match the actual colors of the object. These problems occur in all photographs, digital or analogical, and are not usually perceived in photographs of common use. For scientific and educational applications, however, aiming for greater fidelity to the real object, these characteristics should be corrected.

[1] Acquisition: https://www.youtube.com/channel/UCXEFzyZGrGlLANNrCawNgWQ anonymous link

Then, the context is reduced and the background removed. These steps remove parts of the scanned image, such as the infinite background where the object is positioned, so that the resulting image is the scanned object only. Figure 4 shows the acquired image (Figure 4(a)) and the final image (Figure 4(b)).

(a) (b)

Figure 4: Image processing: (a) image as scanned by F2S2; (b) final image.

Finally, the Stream2D is created, in which the processed images are organized so that for each image of the set it is possible to know the position of the camera during the scanning. The organization of Stream2D is based on a matrix with two structures: Streams and Frames. A Stream is a set of images for a given position of the camera, i.e., a set of photos with angular variation Θ but without angular variation φ. A Frame is a photograph from a certain point of view of the object. Each Frame has a unique angular variation φ and Θ.

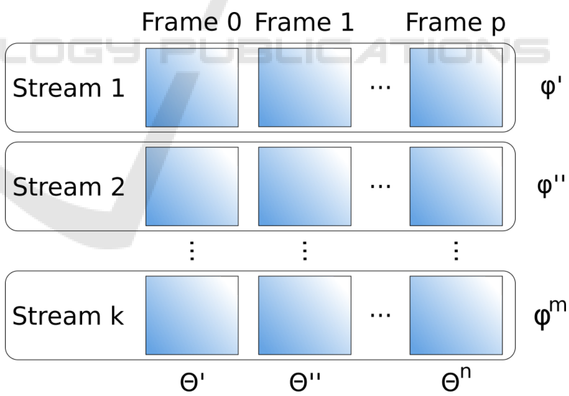


Figure 5: Stream2D.

Considering a maximum scan accuracy of 0.9°, the number of Frames in a Stream is defined by $0 < Frame \leq 400$, 400 being the multiplication of the angular variation Θ by the scanning precision ($360^\circ \div 0.9^\circ$).

The number of Streams in a Stream2D is defined by $0 < Stream \leq 100$, 100 being the multiplication of the angular variation φ, which is 90°, by the scan precision ($90^\circ \div 0.9^\circ$). Hence, the number of Frames in a Stream2D is $0 < Frame \leq 40,000(400 Frames \times 100 Streams)$.

Visualization

Stream2D visualization takes place in graphics computing environments using, among others, three-dimensional Cartesian coordinate systems (X, Y, and Z axes). In Cartesian coordinate systems, a point P is defined by a set of three values: $P = (X,Y,Z)$, where the values of each axis indicate the displacement on the axis. Figure 6 shows this coordinate system.

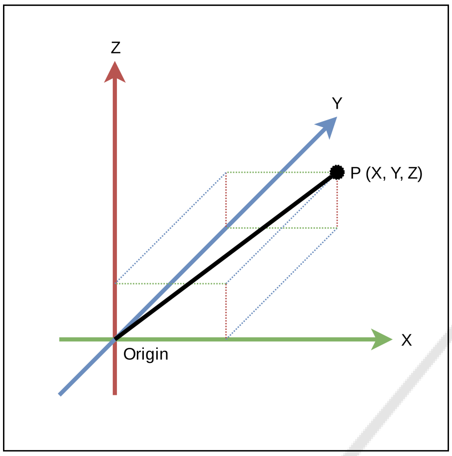


Figure 6: Cartesian coordinate system.

Since F2S2 performs the acquisition process in a semi-spherical format, the position of a given photo can be defined using a spherical coordinate system. This coordinate system is also based on three dimensions to define a position in space: $P = (r,\Theta,\varphi)$ (Figure 7), where:

r: distance from point P to the origin of the system;

Θ: angular variation between the projection of point P in the plane formed by the axes XY;

φ: angle formed by the line connecting P to the origin and the Z axis.

F2S2, in turn, has a four-axis system (H, V, C and B) for scanning objects (see Figure 8), where:

H: displacement of the camera on the horizontal axis;

V: displacement of the camera on the vertical axis;

C: inclination of the camera in relation to the horizontal axis;

B: rotation of the object on its own axis.

In the F2S2 coordinate system, the position of a point (Frame) is given by $F = (H,V,B)$.

The value of the C-axis does not have to be informed to define the position of a Frame F, since, for a certain position of H and V, there is only one inclination C that links F to the origin of the system. $C = arctangent(H,V)$ calculates the value of C.

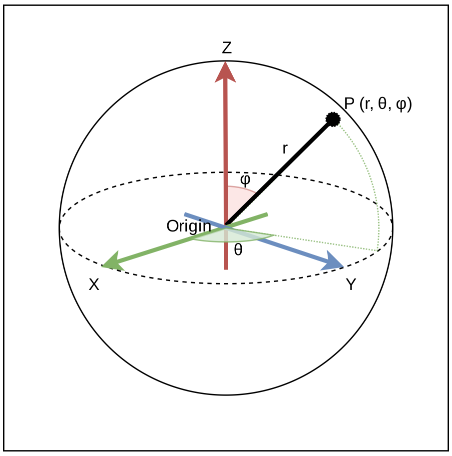


Figure 7: Spherical coordinate system.

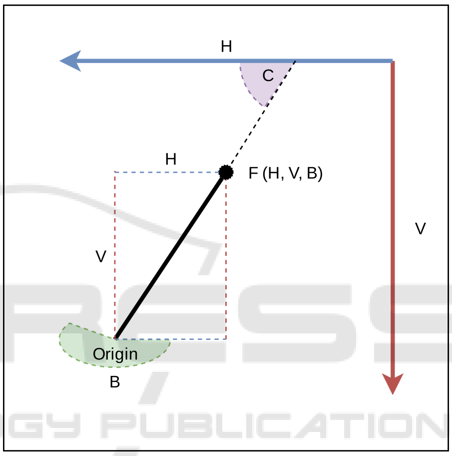


Figure 8: The F2S2 coordinate system.

Since there are three coordinate systems involved in the process of digitizing objects until their exhibition, one should establish a conversion system from one to the other.

Considering the spherical coordinate system, which represents the position of a Frame in relation to the Object, this system can be converted to the Cartesian and F2S2 systems by Equations 1 and 2, respectively.

$$\begin{cases} X = r \times sine(\Theta) \times cosine(\varphi) \\ Y = r \times sine(\Theta) \times sine(\varphi) \\ Z = r \times cosine(\Theta) \end{cases} \tag{1}$$

$$\begin{cases} H = r \times cosine(\Theta) \\ V = r \times sine(\Theta) \\ B = \varphi \\ C = \Theta \end{cases} \tag{2}$$

To convert the Cartesian coordinate system used in graphical computing environments to the spherical and F2S2 coordinate systems, Equations 3 and 4 are used, respectively.

$$\begin{cases} r = \sqrt{X^2+Y^2+Z^2} \\ \Theta = arccosine(Z \div r) \\ \varphi = arctangent(Y,X) \end{cases} \tag{3}$$

$$\begin{cases} H = Z \\ V = \sqrt{X^2+Y^2} \\ B = arctangent(Y,X) \\ C = arccosine(Z \div r) \end{cases} \tag{4}$$

The F2S2 coordinate system used in the acquisition of the images can be converted to the spherical (Equation 5) and Cartesian coordinate systems (Equation 6).

$$\begin{cases} r = \sqrt{H^2+V^2} \\ \Theta = C \\ \varphi = B \end{cases} \tag{5}$$

$$\begin{cases} X = r \times sine(C) \times cossine(B) \\ Y = r \times sine(C) \times sine(B) \\ Z = V \end{cases} \tag{6}$$

Since the coordinates in the F2S2 coordinate system are known during the Frames acquisition process, it is possible to calculate the spherical coordinates of each Frame relative to the scanned object. Subsequently, to carry out the interactive visualization of the generated model, the coordinates of the observer are calculated in a graphical computer system (based on the Cartesian model). The frame corresponding to that display is found in the spherical model, and the image associated with that position is displayed.

Interactivity

Interactivity during the visualization of the generated model may occur in two ways: navigation and geometric transformations (rotation, translation, and scale). Therefore, it is possible to manipulate the images with the basic characteristics of a three-dimensional model. Navigation allows you to change the point of view to any angle of the object, that is, changing the view from one position to another. Figure 9 shows a sequence with a frontal position, right navigation, upward navigation, and, finally, navigation to a view from above.

Geometric transformations do not alter the point of view of the object but lie over a photograph. Translation is the capability to move the image on the screen, for instance, from the center to one of the corners. Rotating is changing the orientation of the image, for instance, allowing a photograph with the acquired object to be displayed in whatever inclination.

Scaling is the possibility of zooming the image in or out, making it larger or smaller. As the acquisition occurs in 4k or 8k, a non-pixelated view is obtained. Normally, when you enlarge an image, say, by 800%, it becomes blocky. But in an image with the pixel density achieved by the F2S2, this does not happen.

Figure 10 shows a digitized model and a sequence of changes delivered by these geometric transformations: 10(a) original image, 10(b) major scale, 10(c) translation, and 10(d) rotation.

The interactivity of the generated model also allows for the addition of hypermedia contents, buttons, and regions of interest in the images, allowing, for example, clicking on parts of the image to display information about it, as shown in Section 4 - Figure 14(c).

Stereoscopy

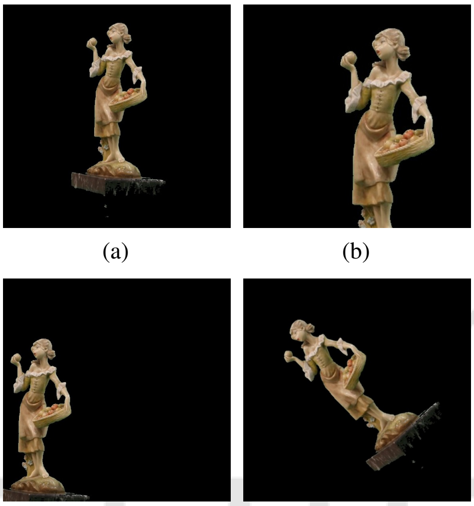
The information on depth and proportion can be generated using some artificial resource. An example is a single image captured by a common photo camera. Depending on the type of image to be captured, the notion of depth and proportionality is taken into account. (Murray, 1994) presents the definitions and discusses the issue of perception of depth. One can apply so-called passive effects, such as rotating by 90°, to a static image. These effects are inherent to the world as we see it and do not depend on the way in which they are captured. The characteristics of this type of effect are perspective, lighting, occlusion, shadow, and texture gradient.

Perspective gives us the sensation of objects being larger or smaller than others depending on their position. Illumination is an effect that contributes to giving shapes to objects; it also produces the effect of shadow, which is easy to visualize and understand, as for shadow to exist there must be light. Occlusion occurs when one object overlaps another, that is, it stands in front of another hiding parts of the one behind. In order to create a notion of depth, one can also use texture gradient, since its effect is a repetition of the pattern present in the virtual environment or object.

In short, all of these characteristics are related to the 3D effect on virtually created objects, since they are originally flat, and that does not change with the application of these effects. However, through their application, one has the feeling that the object has depth and proportion. You can see these effects in photographs, as shown in Figure 11, without the need for a software application.

(a) (b) (c) (d)

Figure 9: Interactivity: navigation.



(a) (b) (c) (d)

Figure 10: Interactivity: geometric transformation.

Figure 11: Passive effects.

Unlike the types of passive effect cited, stereoscopy in humans is of the active type. This means that two images are needed for the brain to form the notion of depth and proportion. The brain treats an image captured by a single eye as flat, mainly lacking the notion of depth. Stereoscopy comes from the fact that the human vision presents a difference between the images captured by the eyes due to their position since, in humans, they are facing forward and with an average separation of 6.5 cm. This difference, called binocular disparity, allows for two slightly different images, one for each eye, enabling the mentioned notions, and known as the stereoscopic view.

As for the stereoscopic view on devices such as TVs, monitors, cell phones or screen projectors, there is also a concept of distance. However, it is related to parallax. Parallax is understood to be the positioning changes of an object in relation to the different points of observation, or the apparent displacement of a reference from the movement of an observer. It allows you to have a feeling of depth. In other words, the stereoscopic view is obtained by means of the difference in the positioning of the eyes and the crossing point of the images of each eye.

Parallax and Disparity for the formation of stereoscopic images are similar. As seen, parallax is related to the projection plane of the images, so its measurement is carried out in this plane. The disparity is a retina-related measure, the distance between the eyes. The use of some apparatus to view stereoscopic images, such as glasses, causes parallax to become the so-called retinal disparity. Thus, parallax will produce retinal disparity and will be responsible for the production of the stereo vision.

Parallax can be given in terms of angular measure, thus relating it to disparity by taking the distance between an observer and the plane of projection into account. As mentioned, there is a mean difference (DM) between the eyes, given in centimeters; if you also have the distance in centimeters between the observer and the plane (d), you can calculate the angular measure (α), as seen in Equation 7.

$$\alpha = 2 \arctan \frac{DM}{2d} \tag{7}$$

Using the F2S2, you can create stereoscopy without the need for transformation, which is very common when you make a picture with two parallel or convergent cameras. In the latter case, the image must be adjusted so that the common points of both the right and left images are present; otherwise, you will have problems with stereoscopy, which may cause discomfort during visualization.

The F2S2 scanning process eliminates the need to apply mathematical transformations, since it acquires the images in different angles, as happens in the human view, where each eye perceives the object from a different position. Thus, the image scan enables stereoscopy by simply overlapping two scans.

The name of these two images is stereo pair. Based on the parameters of parallax and disparity, the selected images are 6° apart (angular variation Θ). Using a pair of images 2° or 4° apart generates less intense stereoscopy. Pairs of images in which the distance is more than 6° will cause discomfort.

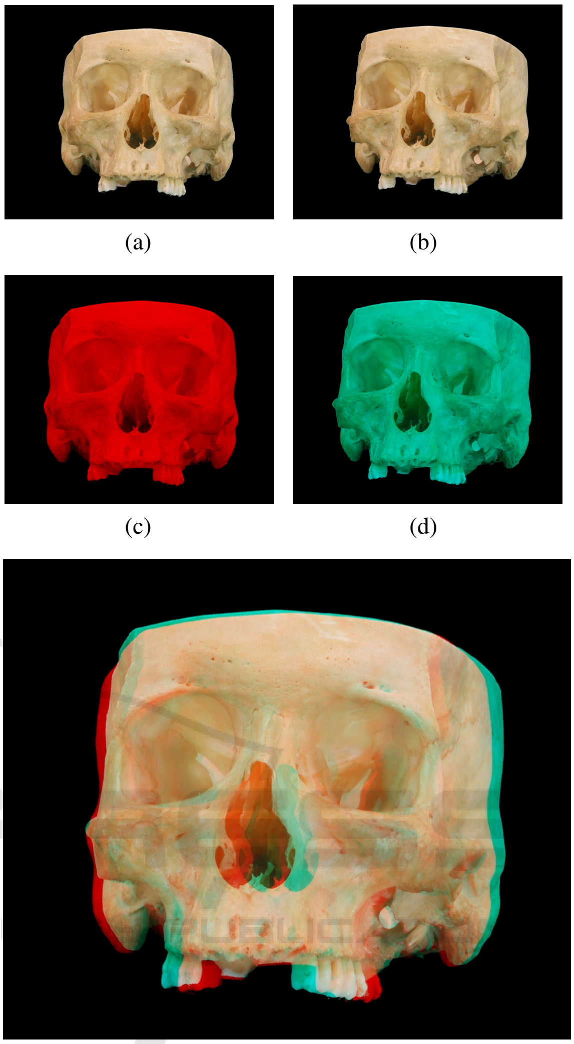
The anaglyph technique was used for the stereoscopic visualization as seen in Figure 12. In this technique, the color channels in the two images are changed, placing the image seen by the left eye in one color and the right one in another. Normally, the red channels are used for the left images and cyan (blue and green) images for the right ones, as was the case in the first few years of 3D cinema, although this depends more on the colors present in the lenses of the glasses. Despite the processing of the images, the stereoscopic visualization maintains the original color of the object.

Figure 12(b) was acquired with a 6° difference in relation to Figure 12(a) of which the green and blue channels were removed, leaving the red channel only. In Figure 12(b) the red channel was removed, leaving the cyan. This process is accomplished at runtime by means of Equation 8.

$$EA = 255 - \frac{(255-M)*(255-Ii)}{255} \quad (8)$$

AE (Anaglyph Stereoscopy) is the final image, M or Mask is the image of the upper level (Figure 12(a)) and Ii the image of the lower level (Figure 12(b)).

This is done with all the images acquired by F2S2, obeying the criterion of angular variation Θ. For example, the acquisition of a stream of 2 in 2 degrees, obtaining 180 images, allows stereoscopy between the 1^{st} and 4^{th} frames (0° and 6°, respectively), 2^{nd} and 5^{th} (2° and 8°), 3^{rd} and 6^{th} (4° and 10°), and so on, repeating the angular variation $\Theta = 6°$. Since the last are formed between the 177^{th} and 180^{th} (352° and 358°), 178^{th} and 1^{st} (354° and 0°), 179^{th} and 2^{nd} (356° and 2°), 180^{th} and 3^{rd} (358° and 4°), all possible visualizations of the object are covered.



(a) (b) (c) (d) (e)

Figure 12: Images: (a) Left, (b) Right, (c) Red, (d) Cyan and (e) Anagliph.

3 LEARNING OBJECTS

Diversity within the educational environment fosters discussion among all learners, both students and teachers, about how to present content as they all try to find new ways of supporting the teaching-learning process.

We understand that it is in this context that Learning Objects (LO) come in (Redmond et al., 2018) (Srivastava and Haider, 2017). A definition of LO, according to the Learning Technology Standards Committee (LTSC-IEEE), is “any digital or non-digital entities that can be used, reused or referenced during learning with technological support”[2].

Thus, we address here how to prepare the contents generated by F2S2 for use in several domains, especially in education. That is, all the objects scanned by F2S2 are considered “raw resources” ((Tarouco et al., 2014) pg.17) for the creation of LOs, and should be prepared for the devices of the visualization mentioned in section 2. In (Guterres and Silveira, 2017b)

[2]LTSC - http://sites.ieee.org/sagroups-ltsc/home/

is presented a framework that may help you develop LOs.

From the point of view of education as discussed by (Wiley, 2002), the application of LOs itself does not guarantee that pedagogical objectives are achieved. He questions the use of the $LEGO^{TM}$ blocks introduced by Hodigns (Hodgins, 2002) as an LO, claiming it to be a simplifying metaphor, which may neglect the challenges of creating educational experiences. Despite this, due to the diversity within the educational environment, every student's need must be taken into account. (Mendéz et al., 2016) address the concern of adequacy of each student to LOs.

A consensus is that LOs should contain reusable contents, that is, they should meet this criterion for their elaboration. Despite this definition, there are barriers to the adoption of this type of initiative, since institutions differ on what constitutes an LO. But there are also various development problems, as seen in (Guterres and Silveira, 2017a).

In an attempt to overcome these barriers, we seek to develop reusable LOs in different areas of knowledge that offer dynamic interaction, allowing participants to intervene freely to move an object to the desired position, for use in educational environments, for example, classrooms, or on their own devices such as notebooks or Virtual Reality.

To be accessible and reusable, LOs are stored in so-called repositories. An example is found in (d. Silva et al., 2017). (Rodes-Paragarino et al., 2016) address repositories adopted by teachers. Repositories make metadata available (LTSC, 2002) besides ontologies, which also facilitate searches (Araujo, 2017) (Carvalho et al., 2017) (Lima et al., 2017) (Sanches et al., 2017).

Repositories should provide LO metadata (MOA) with a high degree of semantic interoperability. The Open Archives Initiative Protocol for Metadata Harvesting (OAI-MPH)[3], which is in version 2.0, aims to collect metadata through an application-independent interoperability framework.

However, this paper does not aim to produce repositories nor metadata, but an LO with the objects scanned by F2S2. This LO may be made available in some repositories with metadata for access in the future. The idea of this paper was to create an LO and evaluate its feasibility through the participation of a group of teachers from different areas and levels. We describe the outcomes in section 4.

[3]http://www.openarchives.org/OAI/2.0/openarchivesprotocol.htm

4 LO ASSESSMENT

The objects scanned by F2S2 allow for the construction of an LO that offers interactivity and visual acuity. However, it needs to be scrutinized by those who might use it: students, teachers, and pedagogy professionals. Therefore, we held two meetings to test an LO with respect to acceptability.

In one meeting, we showed teachers and a professional in pedagogy an LO. In the other, a group of students attended a lesson. After these meetings, we handed out questionnaires with the objective of evaluating the LO and its acceptance by those involved.

We produced the LO from the digitization of a human skull and added interactivity and stereoscopy properties, as well as buttons identifying the bones. When you click on a button, the skull rotates to the selected bone, which appears on the screen and is highlighted. Figure 14 shows the LO screens used in the search. Figure 14(c) shows the maxillary bone was selected and evidenced.

Evaluation by the Teachers

The invited teachers work at different levels of education, ranging from medium to higher levels. They received manipulation instructions and used the tool as if they were teaching a lesson. They were then asked to comment on positive points or those that are flawed and should be improved.

We prepared the environment with a multimedia projector and two notebooks with the tool running on both. Thus the teachers could manipulate the tool on the notebook connected to the projector to become comfortable with the manipulation commands as well as to view the object also on a monitor/TV and not only projected on the wall/screen, for the projector was not of high resolution.

This procedure was adopted for them to have a visual experience of quality that a TV/monitor, even if only FullHD and not in 4k, could provide. Participants were able to discuss the use of the LO at the levels in which they operate. They started to suggest what would be interesting for a given level and what could contribute to the learning process.

A cross-sectional study was carried out on May 28 and 29, 2018. Aiming for greater variability in the sample, we invited 15 teachers working at the medium technical level (computer science and biotechnology), post-technical (oral and dental health), and higher level (biological sciences and systems analysis and development). The teachers were asked to analyze if the same LO could be interesting for the different courses. As the selection considered the courses

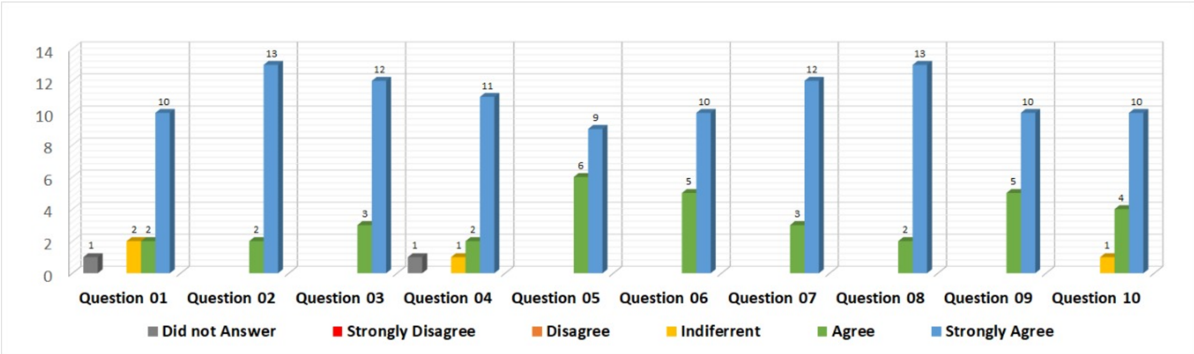
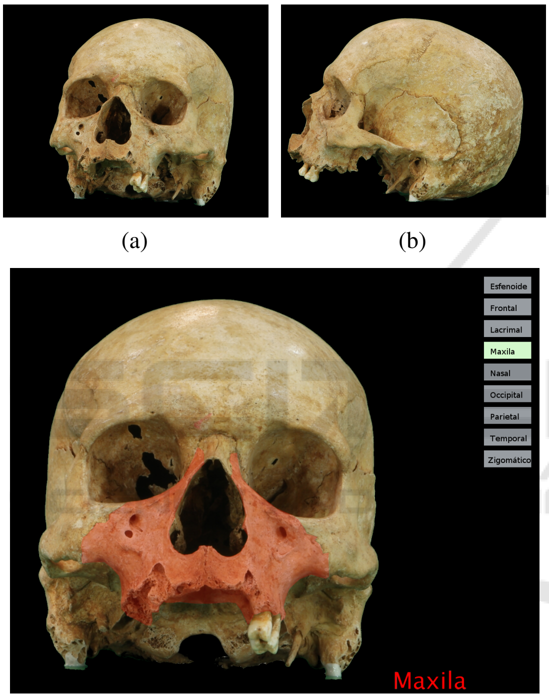


Figure 13: Teachers' answers.



(a) (b)

(c)

Figure 14: The Learning Object.

in which the participants work, the sample is non-probabilistic.

All teachers signed a free and informed consent form. After the presentation and effective use of the tool, they answered a questionnaire with ten closed questions, and a scale from Strongly Disagree to Strongly Agree. The questions were:

1. Were you comfortable using the environment to display the content to the students?
2. Do you think software like this can help you in the teaching-learning process?
3. Would you use this environment in your classes?
4. Do you believe that you can use the environment in a multidisciplinary and interdisciplinary way?
5. Do you believe that you can use the environment for problematization?
6. Do you believe that you can use the environment in active methodologies?
7. Do you think that this environment can be a way of attracting the attention of the students?
8. Do you think that the present object, giving the sensation of being an object similar to the real one by its color, texture, and shape, can motivate the students?
9. Can the manipulation of the object and visualization of all angles encourage interaction/discussion between the teacher and the students?
10. Can the manipulation of the object and the visualization of all angles encourage interaction/discussion among students?

We structured the questions in order to answer three hypotheses based on Ackerman's study, which argues that the lack of interactivity (three-dimensional visualization) and the imprecision of the models (visual acuity) hinder the learning process of anatomical structures. The hypotheses were:

1. The content, with its interactive visualization features and visual acuity, motivates the teacher in the teaching-learning process. Questions 1 to 6;
2. The content, with its interactive visualization features and visual acuity, motivates the student in the teaching-learning process. Questions 7 and 8;
3. The interactivity and visual acuity of the environment promote discussions between teacher and student, and among students. Questions 9 and 10.

Hypotheses 1 and 2 were based on the premise that the interactivity of the model can help understand three-dimensional biological structures, and this can motivate the teacher and the student. Hypothesis 3 is based on the possibility that, in contrast to materials such as a photo in a book, that directly exhibit a particular structure, the interactive model enables examining the structure and visualizing it by different angles. Interactivity was assessed in relation to promoting in-class discussions when compared to static materials. The answers obtained by the questionnaire can be seen in Figure 13.

Questions 1, 2, and 3 address comfort and reliability of the teachers' use of the tool; comfort can be determinant for its adoption in the classroom and can help in the teaching-learning process. In response to these questions, 93% of teachers indicated that they agree or fully agree that they felt comfortable, believe that the system can help to teach and that they would use LO in the classroom. Two teachers were indifferent, and one did not answer, because he did not use the tool but just watched the others.

Questions 4, 5, and 6 map the teachers' believes that this technology can be used in a multidisciplinary and interdisciplinary way, for problematization or in active methodologies. In response to these questions, 95% of the teachers said yes, one teacher did not respond, and another was indifferent. As to the totality of responses obtained on hypothesis 1, 94% of teachers agree that the tool is motivational in the teaching-learning process.

With regard to questions 7 and 8, linked to hypothesis 2, all teachers agreed or fully agreed that LO could be a motivating factor for students. Questions 9 and 10, related to hypothesis 3, outline if the interactivity of the tool can promote discussions in the classroom, since it encourages the student to search for the information and not wait, solely and exclusively, for the teacher's answer. To this hypothesis, 96% of the respondents agreed or fully agreed that the tool could encourage in-room discussions. One teacher was indifferent.

In addition to the questionnaires answered by the teachers, we invited a pedagogue to participate in the presentation and later interviewed her in an open interview, with predetermined questions and ample freedom of reply. The teacher questioned the computational resources needed to apply the technology: "High-resolution TVs and expensive computers are not a reality in most classrooms in Brazil". In this regard, in the coming years, these technologies tend to become cheaper and become standard, thus entering the classroom.

As for the present system, according to the pedagogue, the fact that the model is interactive and encourages the student to explore information makes understanding of the subject of the lesson "complete" and makes the tool a good option for active methodologies. Interactivity and the possibility of seeing all the angles of the object can encourage interaction in the class since it can make the student analyze the whole object and not only the displayed angle. "It can foster and engage curiosity".

Based on the analysis of the answers, the LO, according to the teachers, through its interactivity and visual acuity, allowed for the visualization of details that synthetic objects do not offer; nor do photos, compared to this LO, allow full visualization and manipulation of the object.

Evaluation by the Students

In a similar way to what we did with the teachers, on February 8, 2019, we taught a lesson to a group of 23 students of the technological course in Radiology, in which we used the same LO presented to the teachers. After the lesson, we gave the students a questionnaire with the following questions:

1. Were you interested in the content because it was in three dimensions?
2. Do you think software like this can help you in your learning process?
3. Do you feel that this interactive environment might draw more of your attention than static environments such as photos, books, and slideshows?
4. The fact that the skull can be rotated to view other sides can favor discussions about the topic of the lesson?
5. Zooming in on more detail can foster debates on the subject of the lesson?
6. Compared to drawings, photos, books, or slideshows, can three-dimensional content encourage class discussion?
7. Do you think that the object presented gives you the sensation it of being an object similar to the real one by its color, texture and form?
8. Describe the experience of using the environment and think of the possibilities it may offer to your learning process. (Open-ended question).

The purpose of these questions was to map two hypotheses:

1. The environment, with its three-dimensional visualization characteristics, interactivity, UHD and fidelity of form, color, and texture, motivates the student in his learning process. Questions 1, 2, 3, and 7.
2. The interactivity and fidelity of the environment promote discussions between teacher and students and among students. Questions 4, 5 and 6.

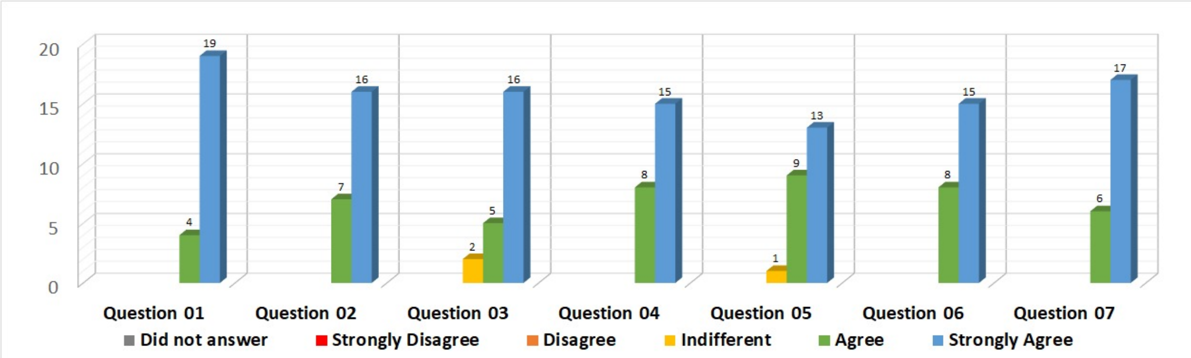


Figure 15: Students' answers.

Hypothesis 1 is based on the premise that the interactivity and visual acuity of the technology used can help in the understanding of three-dimensional structures, motivating the student in his learning process. Hypothesis 2 examines whether interactivity can promote classroom discussions as it offers the student the opportunity to search for the information instead of readily getting it, just as in a book that shows the ideal perspective for analysis of a given structure. Figure 15 shows the answers obtained by the questionnaires.

As for the answers, the perception of the students involved in the study is that the characteristics of interactivity, three-dimensionality, high resolution, and fidelity motivate the student in his learning process since to questions 1, 2, and 7, 100% of the students answered affirmatively. Regarding question 3, two students classified it as indifferent, and 91% responded affirmatively.

According to the students' response, the presented technologies are able to motivate discussions in the classroom since questions 4 and 6 received a 100% affirmative answers, and only one answer to question 5 was indifferent.

With regards to question 8, discursive, 15 of the 23 students answered the question. One reported: "... I have difficulty in concentrating on my learning, and these images helped me focus on the whole explanation ...". Other 08 students stated that the possibility of visualizing structures in high resolution, with visual acuity and three-dimensionality could help them in their learning process.

One of the students still wrote: "The presence of the object in 3D gives a real notion of the mass and shape of the object, which is a better way of understanding the function of the object". This answer confirms Ackerman's claim that interactivity and visual acuity are important for the understanding of three-dimensional structures.

5 CONCLUSION

This paper presented an evaluation of an LO produced from scans of the Full Frames Semi-spherical Scanner. As a contribution, the scanning method offers a feature for a new form of 3D visualization with visual acuity.

So, we created an LO by digitizing a human skull, adding interactivity to the 3D visualization. This object was manipulated by students and teachers, who answered a questionnaire about the use of the tool. The results show that interactive material is an alternative that can motivate teachers and students, as well as being able to promote debates between teacher and students and among the students.

Although the number of teachers who answered the questionnaire is not sufficient to generalize conclusions about the technology developed and the object generated, those who manipulated the tool considered that the visualization adequately represents the real object, and it can help in the teaching-learning process.

Our next steps will involve the preparation of learning objects to be used in class, and experiments to evaluate the effectiveness of the objects compared to other technologies without interactivity, visual acuity, and stereoscopy.

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