Virtual and Augmented Reality Applications Development Methodology using natural markers in industrial scenarios

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***Abstract*—In this Ph.D. research[1], we have proposed a methodology for development of Virtual Reality (VR) and Augmented Reality (AR) applications, using natural markers for industrial scenarios. The proposed methodology uses the object annotation concept and visualization proposals are presented both for development of VR as for AR environments. In VR environments, the methodology is applied for object detection step of the semi-automatic authoring tool. On the other hand, in AR environments, is presented the concept of georeferenced natural markers, which use the georeferenced data integrated with object detection process using image processing techniques. The energy substations scenarios were used as case study for both approaches. This work proposes using Haar-like feature based natural markers integrated with homomorphic filtering for object training and detection process. The results enable the equipment detection at different points of view, within the operating scenario. Besides that, in AR, it enables the pose estimation in real-time using ORB features, while in VR it enables the semi-automatic object detection, which are used as information points for inclusion of virtual information. Several industrial scenarios, and especially the energy sector, has a high degree of complexity in the information processing and visualization. In this sense, beyond the 3D natural markers methodology, this work presents visualization applications for industrial scenario visualization in VR and AR approaches.**

***Keywords*—** Virtual Reality, Augmented Reality, Natural Markers, Haar-like features

I. Introduction

Industry 4.0, according to [1], is a digital transformation of the industry, that modified the way of product manufacturing and the economic environment itself in several markets.

In this context, several changes are happening in different areas due to the use of technologies such as IoT, Artificial Intelligence, Augmented Reality, among others.

The Augmented Reality (AR) technology is an approach that enables the user to visualize the real world overlapping or combining virtual objects [2]. This technology use the registration of information or computer-generated images from a view of the user in the real world (physical world). It intends to increase the user's viewing experience, adding information associated with the user's context. This enhances the user's understanding of the environment in which they are located.

[1]Ph.D. thesis conducted between March 2013 and August 2017

Especially in the last decade, applications that use AR have been developed for several areas, such as medical, military, educational, tourism, geospatial, design, among others [3]–[9].

One of the factors that hinder the use of AR is related to the need for real-time processing. In addition, there are factors related to the complexity of the information involved in each area and the process of detecting objects present in these scenarios. In our proposal, we used the concepts of natural markers to detect objects from the scene.

Natural markers are detectable objects, generally in AR environments, which means unprepared or non-pre-instrumented scenes. The detection of these objects requires the extraction of image characteristics and matching procedures with previously registered patterns. The use of AR also provides, based on interactivity, that the user select the type of information desired in relation to a particular object.

Despite the benefits, the use of natural markers in AR is still not a widely adopted practice in applications, especially in industry. It can be said that the main cause of this is the difficulty of carrying out all the necessary operations of this type of marker (detection, tracking, pose estimation, loading of information) in real time. In this area, various prototypes and techniques have been presented over the years, but the implementation cost and the benefits of using AR are usually considered in real applications such as industrial scenarios.

In computer vision, the detection of objects in images is one of the fundamental problems. The problem of detection associated with pose estimation has been one of the challenging research problems in the area.

Therefore, there is a demand for using virtual reality and augmented reality technologies in industrial environments. It also emerges that a robust solution for real-time object detection and identification remains an open and challenging problem. Several reasons may explain this challenge, such as lighting, sudden change of perspective that modifies the focus of the camera and makes it difficult to obtain the characteristics of the image, occlusion of part of the object, among others.

The main objective of this Ph.D. thesis [10] is to propose a methodology for the development of AR environments without using fiducial markers and the development of VR environments using natural markers in scenes of industrial environments. It is noteworthy that, although it has been applied to the scenario of electric power substations, it can be easily adapted to other application areas or other environments.

The rest of this paper is organized as follows. Section 2 presents related works, showing the VR and AR proposals related to our work. In Section 3, we present the results and contributions of our work. Finally, Section 4 concludes the paper.

II. Related Work

This section presents related works focusing on VR visualization in the industrial scenario and the challenges involved at the development of AR applications.

In Brazil several VR research projects and application of this technology to companies can be perceived over the years, as in [11], [12], [13], among other applied works in the industry.

The VR and AR technologies, as well as artificial intelligence, for many years, have inducted a big expectation in users and professionals in the software development field. It is true that many devices and systems of these categories have been created, but there is a large potential development of VR and AR concepts for industrial applications in several areas.

A. Virtual reality visualization in industrial environments

In the context of industrial environments, VR systems have been widely used, such as in [14], which uses the VR system for training operators from the energy substation, allowing visualization of any substation within the network and using visualization and interaction devices such as HMDs and 3D mouse. This way it is possible to navigate through the virtual world and interact with elements of the system, in a similar way to our approach. The operating situations can be simulated and this type of system allows the operator to visualize problems and the behavior of the system in certain operating situations.

Many works use VR for simulating and visualization of electrical systems, mostly used for training purposes. In the field of electrical systems, there is a large gap between the theoretical study related to the equipment and the functions and operation of the equipment in the real scenario [15]. Although the work addresses the area of simulation, improving students learning through visualization of the equipment in real images of the operating environment allows a better understanding of the operation situation.

In [16] is presented the concept of augmented panoramas using static images (offline), which are VR environments that enable the use of pattern recognition techniques. The images are processed in offline format and do not have the real-time processing limitation. It is noteworthy that this approach, from the moment of the capture of the images, works with outdated images of the real environment. On the other hand, it is a reasonable solution in environments where the scenario is not frequently modified, as well as making it possible to use this visualization for remote management. It is possible to add panoramic cameras to the augmented panoramas, enabling real-time viewing environments.

A panorama-based view is presented in [17] within the scenario of electrical systems. In the proposal, cylindrical panoramas are used to include information about equipment, allowing interaction with the user. The application is a proposal for visualization that helps the operators in the decision-making process, however, it has a low degree of immersivity, functioning mainly in the browser of a computer. In relation to the panoramas used in our thesis, both cylindrical as spherical panoramas are used in order to guarantee the user a greater degree of immersivity.

In [18] it is proposed the use of VR in electrical systems using the simulation of the state of the system, allowing the interaction with the equipment operation variables. The system shows the integration of the data acquisition system (SCADA) and an overview of the substation through the addition of information from SCADA system in the virtual environment, using a similar data communication to the data used in this thesis for VR and AR.

B. Visualization with augmented reality: applications and challenges

According to [19], the technological demands for building AR environment are much higher than for VR environment. Display devices, tracking techniques, hardware, and software are a key part of the success of this application category. Another problem is that the processing techniques has the real-time restriction, after all the addition of virtual elements to the scene is performed in real-time.

In [20] it is stated that object detection is a fundamental task in outdoor environments. Detection results can be used for object recognition, tracking, and mapping of the environment. The work applies the detection using security robots of the substation and algorithms of object detection processed in the cloud. Another interesting strategy presented is reducing the comparison area with costly algorithms like SURF and SIFT in order to optimize the processing.

The use of image-based visualizations for creating AR environments has not been widely used. In [21] a solution is proposed for the organization of the information including labels in the scene. This information, even when the image detection is performed, overlaps the scene objects and thus increase the understanding of users in AR systems. In this way, the inclusion of information through the processing of images and natural markers has several levels of complexity to be solved for application in real systems, even with the correct identification of the objects in the scene.

As observed in several works, the search for new visualization techniques is still necessary. In the AR field, notable advances in hardware and mobile devices in recent years have increased the potential for using the technology in real applications. In addition, the new technologies for improving the work of control center operators, for example, may improve the equipment operation tasks and enable remote monitoring of operating environments.

III. Results and Scientific Contributions

The proposed methodology in this Ph.D. Thesis using natural markers is used for development of both VR and AR applications Thus, the methodology is applied to georeferenced natural markers for creation of AR environments, and natural markers associated with the VR authoring process in a semiautomatic solution for object annotation of the virtual scene.

In general, the proposed methodology consists of the steps presented in Figure 1.

A. Georeferenced Natural Markers in AR environments

The object detection uses a Haar-feature based cascade classifier. The cascade classifier is constructed using the concept of several classifiers (Equation 1), that enables the correct detection of a type of object in the scene. Since the detected object has different characteristics depending on the viewed face, it is necessary to use as many images as possible of the faces of the object in the training step. In this way, this work creates a natural marker based on Haar-like features with all the points of view of the object used in the training.

$$H(x) = \alpha_1 h_1(x) + \alpha_2 h_2(x) + \alpha_3 h_3(x) + ... + \alpha_n h_n(x) \quad (1)$$

Using the approach of multiple faces of the object, we create a natural 3D marker. Each group of images corresponds to a particular face of the equipment as depicted in Figure 2. The visualization result using georeferenced natural marker can be seen in Figure 3.

Besides that, the images used both in training as in real detection are modified using the homomorphic filter. The homomorphic filter is a technique used to solve lighting and reflectance problems in image processing. According to [22], the filter analyzes the illumination and reflectance information, obtaining an image with a highlight of the high frequencies and attenuation of the low frequencies. The reflectance $r(x, y)$ is the amount of light reflected by the objects in the image, and the illumination $i(x, y)$ is the amount of light in the image (Equation 2).

$$f(x, y) = \log(1 + f(x, y)) \quad (2)$$

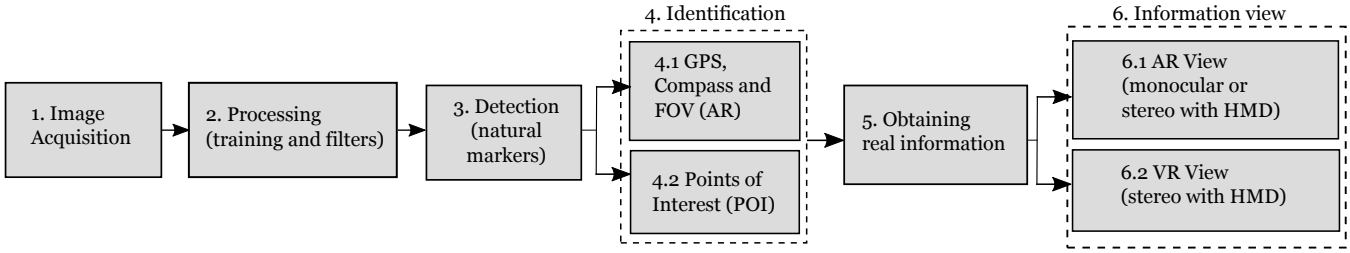


Fig. 1. General steps of the proposed methodology for annotation using natural markers in RV and RA environments.

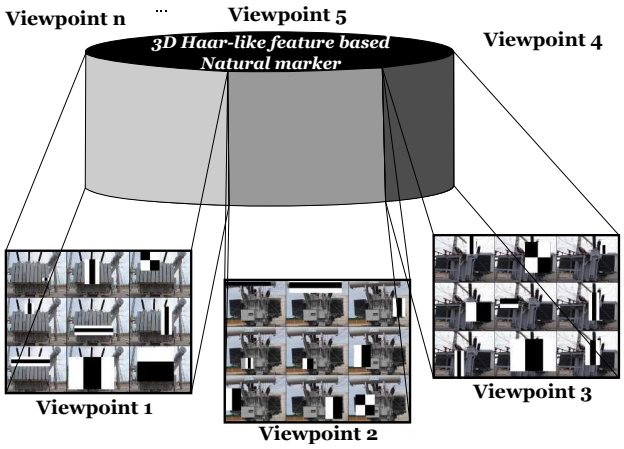


Fig. 2. Conceptual illustration of natural 3D marker based on Haar-like features

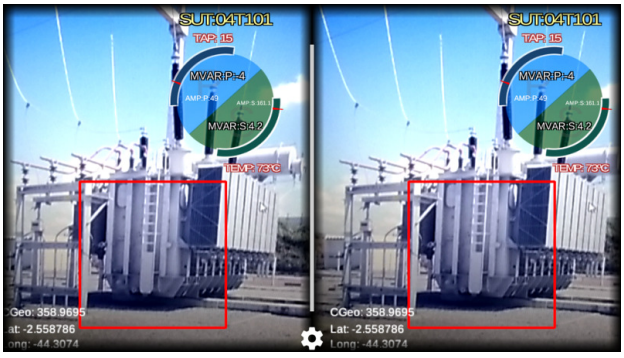


Fig. 3. Object detection using georeferenced natural markers in stereo AR environment

During the equipment detection in the image (used as case study in our work), three main variables are considered: the user location at the time of image acquisition, the georeferenced location of the equipment present in the substation and the orientation for the Field Of View (FOV) calculation of this observer. The FOV is calculated based on the camera's intrinsic parameters, described in Equation 3.

$$\alpha = \arctan \frac{s}{2f} \qquad \begin{array}{l} s = \text{ Sensor dimension} \\ f = \text{ Focal length} \end{array} \tag{3}$$

In the AR approach, the pose estimation process is performed after the object detection. At this step, we use ORB features to detect keypoints and extraction of image characteristics. The motivation for using ORB features is also related to the time in the feature-matching process, which is fundamental to solve the problem of real-time pose estimation for AR applications.

B. Virtual reality environments using semiautomatic detection of objects

Mobile devices such as smartphones and tablets were used to capture images in different formats. The image formats used in the acquisition step were: JPEG/raster, cylindrical panoramas 180^{o} and spherical panoramas.

The proposed authoring tool uses the generated natural marker detector, but without using georeferenced data. The Table 1 shows the comparison between this thesis proposal and other works in the VR area with augmented panoramas. Our work intentionally does not use 3D models for generating VR environment in a faster development approach depending only on image acquisition.

TABLE 1
COMPARISON BETWEEN THE VR PROPOSED ARCHITECTURE AND OTHER WORKS

Work	Augmented	Authoring	3D models	Immersive	Object Detection
[16]	-	-	X	X	-
[23]	X	-	X	X	-
[24]	X	-	X	X	-
[17]	-	-	-	-	-
[25]	X	X	-	X	-
[26]	X	X	-	X	-
[27]	-	-	-	-	X
[28]	X	-	-	X	X
[29]	X	-	-	X	-
[30]	-	-	-	-	-
Our approach	X	X	-	X	X

For the tool validation, we used the Post-Study System Usability Questionnaire (PSSUQ). According to [31], this questionnaire evaluates the system usability. The PSSUQ was applied to 71 academic users (among undergraduate, master and doctoral students, as well as researchers in the area of electrical engineering) and 6 CHESF operators. The Figure 4 shows the visualization application created using the panoramas-based authoring tool for development of VR environment.

The Figure 5 shows the PSSUQ results, according to the level of acceptance of the users. The levels are defined in the questionnaire and ranges from 1 (fully agree) to 7 (I strongly disagree).

We can infer that the operators had greater ease using the VR application in relation to the academic public. We can suppose that this result is caused by the familiarity of the operators with the operation scenario. On the other hand, it is possible to infer that this type of visualization allows the academic public, especially

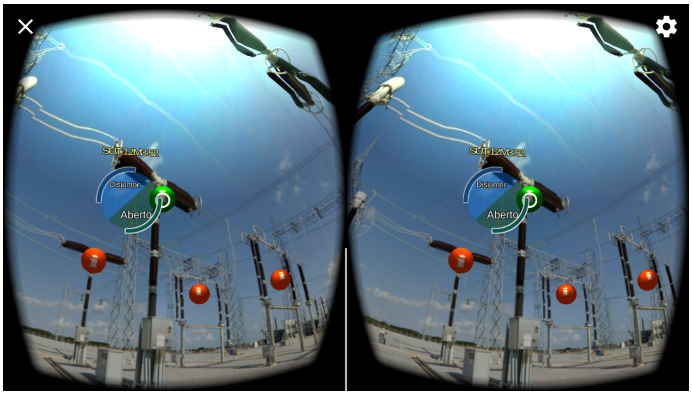
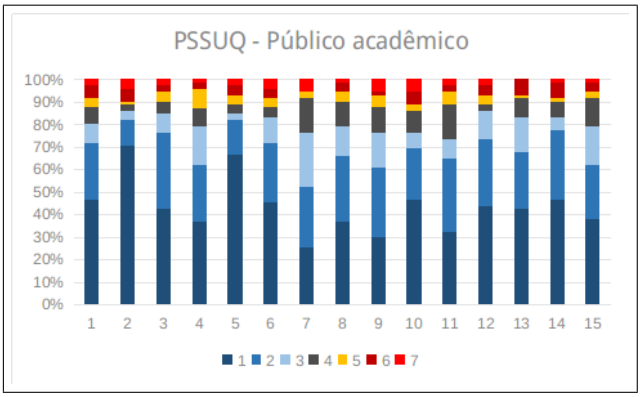
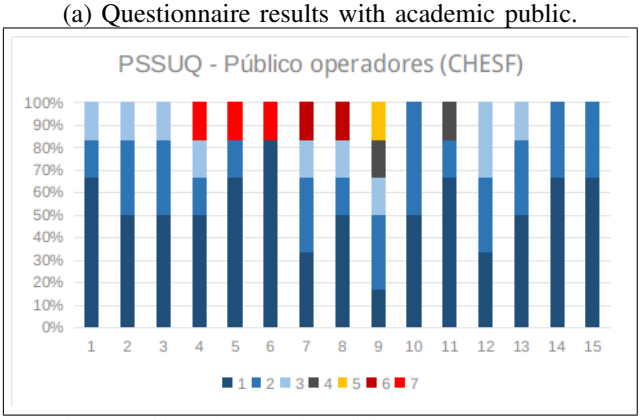


Fig. 4. Spherical panorama view with user interaction and equipment information



(a) Questionnaire results with academic public.



(b) Questionnaire results with CHESF operators.

Fig. 5. Results of PSSUQ application

undergraduate students, a way of visualizing the real scenario of operation in the electrical engineering area. The solution can be adapted for different situations and also used for teaching purposes.

IV. Conclusion

This thesis presented a methodology for using natural markers for annotating objects in VR and AR environments. Image processing techniques are used in object detection problem for annotating equipment in industrial scenarios. Despite applying the methodology to the energy substations scenario, this contribution has applicability in other outdoor scenarios.

Besides that, architectural proposals related to the methodology for the creation of these visualization environments were proposed in the thesis. These architectures were used for development of the VR and AR case studies. Thus, the thesis has proposed applications within the scope of industry 4.0 to enable visualization within the operating environment of the electric power substations.

In the specific AR approach, the concept of georeferenced natural markers was also presented. This proposal focuses only on AR environments using information from sensors on mobile devices, providing the identification of objects detected in outdoor environments.

In the specific VR approach using offline images, the proposal has the disadvantage of generating an outdated visualization if changes occurred in the environment. However, it is worth noting that, in industrial scenarios (as is the case with energy substations), it is not common to occur changes in the operating environment. Thus, after performing the training of the desired objects, it is probable that there is no need to re-train the classifier again in the short/medium term.

Beyond that, the visualization proposals present innovation possibilities in different aspects. It can be used in training situations in which the electrical system operator can view data from the SCADA / EMS system and perform maintenance actions, or see if a particular equipment is switched off or not in operation area. It is also possible to use, in the case of virtual reality, as a solution for remote visualization of a substation or to configure simulations and operator training scenarios.

A. Publications

As a result of this Ph.D. thesis, a book chapter, three journals and two articles in conferences were published. In addition, two software registries related to RV and RA applications, respectively, were made at INPI [32]. The publications with direct relation to this research are listed below:

- Journals:
  - Gomes, Daniel Lima; Paiva, Anselmo Cardoso de; Silva, Aristófanes Corrêa; Braz, Geraldo; Almeida, João Dallyson Sousa de; Araújo, Antônio Sérgio de; Gattass, Marcelo. Augmented visualization using homomorphic filtering and Haar-based natural markers for power systems substations. *Computers in Industry*, v. 97, p. 67-75, 2018. (**Qualis A2, Impact Factor: 2.850**)
  - Gomes Jr, Daniel Lima; Reis, Paulo Roberto Jansen dos; Paiva, Anselmo Cardoso de; Silva, Aristófanes Corrêa; Braz Jr, Geraldo; Gattass, Marcelo; Araújo, Antônio Sergio de. An Approach for Construction of Augmented Reality Systems using Natural Markers and Mobile Sensors in Industrial Fields. *International Journal of Computers Communications & Control*, v. 12, p. 507-518, 2017. (**Qualis B1, Impact Factor: 1.29**)
  - Gomes Jr, D. L.; Reis, P. R. J. ; Paiva, A. C. ; SILVA, A. C. ; Braz Junior, G. ; Araujo, A. S. ; Gattass, M. Semi-automatic methodology for augmented panorama development in industrial outdoor environments. *Advances in Engineering Software*, v. 114, p. 282-294, 2017. (**Qualis A2, Impact Factor: 3.198**)
- Conference/Symposium:
  - Gomes Jr, D. L.; Reis, P. R. J. ; Paiva, A. C. ; Silva, A. C. ; Araujo, A. S. Detecção de transformadores em imagens de Subestações Elétricas com SURF e KNN. In: *V Simpósio Brasileiro de Sistemas Elétricos - SBSE2014*, 2014, Foz do Iguaçu - PR. V Simpósio Brasileiro de Sistemas Elétricos - SBSE2014, 2014.
- Software Registry:
  - Ferramenta para visualização de dados com detecção automática de objetos em ambientes de realidade aumentada através de marcadores naturais georreferenciados (Registro de Software INPI BR 51 2018 001193-4)

  - Ferramenta de autoria de ambientes de Realidade Virtual e visualização com panoramas esféricos (Registro de Software INPI BR 51 2018 001191-8)

In addition, the following works were published as related research during the course of this doctorate:

- Book Chapter:
  - dos Reis, Paulo Roberto Jansen; Junior, Daniel Lima Gomes; de Araújo, Antônio Sérgio; Júnior, Geraldo Braz; Silva, Aristófanes Correa; de Paiva, Anselmo Cardoso. Visualization of Power Systems Based on Panoramic Augmented Environments. *Lecture Notes in Computer Science*. 1ed.: Springer International Publishing, 2014, p. 175-184. ISBN: 978-3-319-13969-2.
- Conference/Symposium:
  - Pessoa, A. C. P.; Gomes Jr., D. L.; Reis, P. R. J.; Paiva, A. C.; Silva, A. C.; Braz Junior, G.; Araujo, A. S. Uma Ferramenta de Autoria para Construção de Ambientes de Realidade Virtual para Subestações de Energia Baseada em Panoramas Aumentados. In: *Workshop of Industry Applications (WIA) in the 30th Conference on Graphics, Patterns and Images (SIBGRAPI'17)*, 2017, Niterói, RJ, Brazil. Workshop of Industry Applications, 2017.

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