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Research paper

Semi-automatic methodology for augmented panorama development in industrial outdoor environments

Daniel Lima Gomes Jr.[a,b,*], Paulo Roberto Jansen dos Reis[b], Anselmo Cardoso de Paiva[b], Aristófanes Corrêa Silva[b], Geraldo Braz Jr.[b], Antônio Sérgio de Araújo[c], Marcelo Gattass[d]

[a] *Federal Institute of Maranhão, Computing Department, São Luís (MA), Brazil*
[b] *Federal University of Maranhão, Applied Computing Center, São Luís (MA), Brazil*
[c] *Hydroeletric Company of São Francisco, Recife (PE), Brazil*
[d] *Pontifical Catholic University of Rio de Janeiro, Rio de Janeiro (RJ), Brazil*

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ABSTRACT

The use of virtual reality (VR) environments based on augmented panoramas enables the creation of visualization scenarios in different application areas. These panorama-based environments significantly reduce the cost and the timeframe of developing VR applications. The use of this visualization modality in industrial environments is appropriate because in these scenarios there is little or no change of the viewable physical environment during long periods of operation. The combined use of VR concepts and augmented reality (AR) enables the creation of applications that use object detection based on image characteristics and the inclusion of information through an augmented environment. With this in mind, this paper presents a methodology for creating VR environments based on augmented panoramas that uses semi-automatic object detection using Haar-like features and real images of the operating environment. The methodology was used to create an augmented environment based on an electric power substation as a case study. This environment is used for visualizing power substation equipment variables, and it shows the possibilities of using several panorama formats for the visualization.

1. Introduction

Augmented reality (AR) is a technology that consists in adding virtual elements to the real world in real time, thus enriching the perception and interaction with the real world [25].

Especially in the last decade, applications that use AR have been developed in the medical, military, educational, tourism, geospatial, design, and industrial fields, among others [1,4,26,29]. The broadening of its use shows its great potential for application in various tasks in industrial activities.

One of the main reasons for the potential applications of AR is that the use of AR annotations is one of the most efficient and intuitive ways of providing contextualized information associated with a real-world view. This is because these annotations become context-aware information that appears associated with the scene at the same place as the object to which it is related [45,47].

According to Billinghurst et al. [2], the potential of AR is only beginning to be harnessed and there are many opportunities for applications to be explored. The ability to provide an immersive experience to the user enhances the results, obtaining improvement in training, for example, even while learning new tasks [18].

Basically, AR is based on the combination of real-world perception with virtual elements. This can be achieved through devices that enable the user to see both the real world directly through a viewfinder and the virtual elements that are projected [1].

Adding virtual elements enables the user to obtain information that is not available directly in the real world. Thus, these AR annotations provide great support for performing tasks in the industrial field, especially for monitoring of equipment and systems. The annotation itself provides information that is associated with an object. This approach enables the use of contextual data about an equipment using different pieces of information associated with that equipment.

According to Côté et al. [6], despite the existing potential and demand for AR applications in industrial environments, its use is still difficult mainly because of the complexity involved in achieving the precise tracking of position and orientation of handheld devices.

* Corresponding author.
E-mail addresses: daniellima@ifma.edu.br (D.L. Gomes Jr.), jansen@nca.ufma.br (P.R.J. dos Reis), paiva@deinf.ufma.br (A.C. de Paiva), ari@dee.ufma.br (A.C. Silva), geraldo@deinf.ufma.br (G. Braz Jr.), asergio@chesf.gov.br (A.S. de Araújo), mgattass@tecgraf.puc-rio.br (M. Gattass).

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The registration (alignment of virtual objects) and tracking are considered the critical issues in AR applications [30]. The tracking issue is considered as the main issue for outdoor AR applications, and it has become a more difficult challenge for AR applications owing to the real-time restriction. In applications that require real-time processing, this complexity translates to a longer processing delay, which ultimately makes the use of AR unfeasible.

One of the ways to make the detection faster and more efficient is to use fiducial markers. Usually, these markers are standardized bi-dimensional objects of a known location that can be detected through image processing algorithms [27].

However, in industrial environments, most of the equipment is powered all the time, restricting the movement of people to a minimum distance for safety. This hinders not only the process of installing markers in the scenario, but also its maintenance. Even with the use of fiducial markers that are more resistant to wear and tear caused by numerous factors (heat, inclement weather, or other conditions), these markers have the disadvantage of visibility. They have to be visible to be detected and calculated by an AR device, which, however, limits their applicability in industrial environments prone to occlusion by pipes and other equipment, or even the situation of viewing an equipment side that does not contain a fiducial marker.

In this way, the most effective way to detect objects of interest would be to use natural markers exclusively. In other words, the applications have to process the acquired image to identify the characteristics of the objects viewed in the scene, which makes it possible to distinguish them from others objects [19]. There are still unpredictable conditions like the dust - common in industrial plants - which can preclude the detection both in fiducial and natural markers

As an alternative to the difficulties encountered in the use of an application that uses pure AR, virtual reality (VR) approaches that use static panoramic images have been widely developed for industrial areas.

Panoramic digital images, or simply panoramas, are defined as an image, or a set of images, representing a particular space with a wide viewing angle, usually larger than the human field of view (FOV). Panoramas enable a continuous view of the region surrounding the observer or the point of the image acquisition [12].

A panorama enables the creation of a very realistic and detailed representation of the environment with everything that is visible from the point of image capture. This provides an enhancement of human visual system capabilities. Panoramas have been traditionally used in the construction of travel applications and virtual tours in museums, hotels, and tourist routes. In addition, they have been applied in the areas of education, engineering, and construction [6–8,12].

Augmented static panoramas are VR environments where real images are used as the background for the presentation of augmented information [7]. These panoramas can be processed offline, disregarding the markers and allowing the manual annotation of the objects in the image or the use of more accurate methods of pattern recognition than those used in real time. As a consequence of this, more reliable results are achieved. On the other hand, this approach has some disadvantages such as the inability of an application to incorporate dynamic elements and the fact that the captured images become outdated from the real environment [6].

In certain industrial environments these disadvantages can be minimized or disregarded owing to the arrangement of the objects in the environment, having little or no variation. An example of an environment with these characteristics is the substations of electrical systems, for which the use of applications with augmented panoramas is feasible.

A good solution to the problem presented in these areas is to provide the user of the system with information that is associated with its contextual data, without making the information confusing with various graphical interface elements. It must have minimal delays or blockages in the equipment processing and must also allow dynamic event monitoring.

On the other hand, in the industrial area, as in the power systems area, there are various information visualization standards created with the goal of making these systems understandable through visual annotations that are universally used. These standards present equipment information that allows a broad view of the system. The search for alternatives and new forms of visualizing information for this class of industrial systems has been proposed [31], such as energy flow, data grouping, 3D visualization, and, more recently, approaches using VR an AR.

It is important to emphasize that the use of AR or VR can be useful to the industry, but the cost of development is an important factor to be considered. According to Fite-Georgel [10], AR technology needs to be cost beneficial, scalable, and reproducible. This statement can also be applied to VR applications. In fact, what this means is that the method of annotating the physical or virtual world should be automated as much as possible because annotating a whole plant is labor intensive and costly.

This work presents a software architecture developed for the construction of augmented static panoramas with semi-automatic annotation of the equipment for the use in an industrial environment, with the possibility of integrating it into automation and control systems to allow the augmented visualization of an equipment with information from these systems. A reference implementation is also presented as proof of concept for the architecture proposed for the power systems substations environment. This reference implementation covers the construction, visualization, and interaction with representations of panoramas of industrial environments. It allows the interaction with the elements in the environment and the visualization of equipment attributes and their connection with automation and control systems.

Among the characteristics of the presented work, we highlight the following: the presentation of an authoring tool that facilitates the creation of applications by end users intuitively and without the need to use programming languages; the automatic recognition of the equipment present in the panorama for its annotation; the possibility of using different types of panoramas, ensuring the flexibility in creating applications based on this architecture; and the possibility of visualizing panoramas in stereo inside immersive environments using state-of-the-art technologies.

The rest of the paper is organized as follows. Section 2 presents the concepts related to the proposed methodology. Section 3 discusses the related works. Section 4 presents the architecture for creating and viewing augmented panoramas. Section 5 addresses the results obtained with the system case study. Finally, Section 6 provides the conclusion and discussion about the obtained results.

2. Material and methods

2.1. Panoramas

A panorama is defined as a broad view of a particular scenario. Most of the panorama-related works [3,9] focus on research on matching strategies in order to use planar images for the panorama assemblage. There are several panorama types, and each one has a specific way of interaction and visualization.

There are several methods for assembling images for creating panoramas, which are mainly classified into two groups: optical methods and mosaic-based imaging methods. The optical methods use dioptric or catadioptric systems for the image acquisition. The dioptric system consists in using *fisheye* lens (wide FOV), whereas