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A STATE-OF-THE-ART REVIEW OF AUGMENTED REALITY IN ENGINEERING ANALYSIS AND SIMULATION

[1]MR M SURESH, [2]DR ARVIND KUMAR RAI

[1]Assistant Professor, Dept of Computer science and engineering, Pullareddy Institute of Technology.

[2]Professor, Dept of Computer science and engineering, University of Allahabad

Abstract: Augmented reality (AR) has recently become a worldwide research topic. AR technology renders intuitive computer-generated contents on users' physical surroundings. To improve process efficiency and productivity, researchers and developers have paid increasing attention to AR applications in engineering analysis and simulation. The integration of AR with numerical simulation, such as the finite element method, provides a cognitive and scientific way for users to analyze practical problems. By incorporating scientific visualization technologies, an AR-based system super imposes engineering analysis and simulation results directly on real-world objects. Engineering analysis and simulation involving diverse types of data are normally processed using specific computer software. Correct and effective visualization of these data using an AR platform can reduce them is interpretation in spatial and logical aspects. Moreover, tracking performance of the AR platformsinengineeringanalysisandsimulationiscrucialasitinfluencestheoveralluserexperience. The operating environment of the AR platforms requires robust tracking performance to deliver stable and accurate information to the users.

Keywords: augmented reality; numerical simulation; scientific visualization

1. Introduction

Engineering problems are generally mathematical models of physical phenomena [1]. There are various types of typical engineering problems, such as solid mechanics, heat transfer, fluid flow, electrical, magnetism, etc. Almost all physical phenomena, whether mechanical, biological, aerospace, or chemical can be described using mathematical models [2]. Mathematical models use assumptions and appropriate axioms to express the features of a physical system. The solution of a physical problem can be approximated by using engineering analysis and simulation techniques, such as numerical simulation. With the help of advanced computer technology, the computer can process fast and accurate calculation of substantial amounts of data, and enable intuitive result visualization. Scientific visualization can illustrate numerical simulation results graphically to enable engineers to understand and glean insight from their data. There exists a number of numerical simulation software, many of which are based on a WIMP-style (windows, icons, menus, pointers) environment. In the last several decades, the trend of using innovative and intuitive systems to solve engineering problems has become increasingly evident.

2. Overview of Computer Aided Technologies in Engineering Analysis and Simulation

This section is divided into three subsections. The first subsection summarizes traditional computer-aided engineering analysis and simulation technologies and their limitations. The second subsection introduces the basic architecture of AR-based systems. The last subsection provides a statistical survey on the trend of using AR in engineering analysis and simulation.

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2.1. Traditional Computer-Aided Engineering Analysis and Simulation Technologies

Numerical methods can be applied to obtain approximate solutions to a variety of problems in engineering. The use of mathematical methods can be traced back to early 20th century. With the development of computer technologies, developers have released several analysis and simulation software, such as ANSYS, Abaqus, COMSOL, etc. Traditional engineering analysis software including multiple windows incorporating graphical user interfaces, menus, dialog boxes, and tool bars. These software provide powerful solutions to engineering problems; however, these software often require users to spend time learning these the user interfaces of these software packages. Researchers have been working on improving computational efficiency, such as implementing neural networks [7]. Real-time systems enable engineers to observe simulation results as they are calculated [8]. This is a prospering research field considering it could be a very powerful learning tool [9]. In addition to computational performance, interactive simulation approach allows effective learning of behavior of materials [10] and could be used to accelerate the development cycle of a product [11].

2.2. Basic Architecture in AR based System

The limitation of current software and VR systems comes from the main concern in a user's daily life, which is towards the surrounding physical world instead of a virtual world. AR technology overcomes those limitations mentioned in Section 2.1 and provides a simple and immediate user interface to an electronically enhanced physical world [26]. AR visualization of numerical simulation results in the physical world can enhance perception and understanding of the dataset [27]. Near real-time update of results in the physical world enables a user to assess the influence of environmental parameters and analyze the problem efficiently. Therefore, AR has become one of the most promising approaches for engineering analysis and simulation. A typical AR-based engineering analysis and simulation system is illustrated in Figure 1.

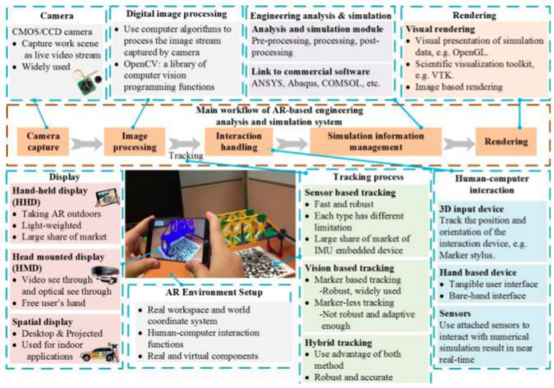

Figure 1. Workflow of AR-based engineering analysis and simulation system.

2.3. The Trend of Using AR in Engineering Analysis and Simulation

In this review, the articles were searched from the following online publisher databases, namely, Engineering Village, ScienceDirect, IEEE Xplore, Springer Link, ACM Digital Library, Web of Science, and Google scholar. All selected papers are ranging from 2004 to 2017 and related to AR-based engineering analysis and simulation. Among these selected articles, 48 of them will be discussed in Section 3. Figure 2 shows the research trend of engineering related analysis and simulation in AR. An upward trend can be observed from Figure 2. Four keyword combinations are used to filter relevant articles in ScienceDirect database. The column represents the occurrences of the AR related engineering analysis and simulation articles in the database.

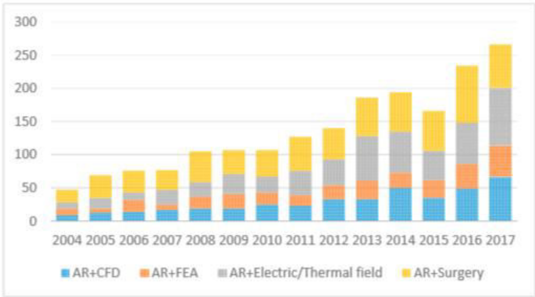

Figure 2. Trends of AR papers published with different keywords in ScienceDirect.

3. Techniques Used for AR Applications in Engineering Analysis and simulation

Different from common AR applications in other fields, AR applications in engineering analysis and simulation require robust tracking and visualization performance. The characteristics of engineering scenarios (e.g., lighting variation, poorly textured objects, marker incompatibility, etc.) have posed difficulties to most of the AR techniques available [78]. This section aims to provide a discussion on the techniques used for AR applications in engineering analysis and simulation.

3.1. Tracking

Tracking in AR technology refers to dynamic sensing and measuring of the spatial properties. Most reported researches used the marker-based tracking method. Marker-based tracking has been widely used ever since ARToolKit was available [30]. The advantage of marker-based tracking is computationally inexpensive and it can deliver relatively stable results with a low-resolution camera. In the research reported by Weidlich et al. [70], the FEA result is superimposed on a black-and-white fiducial marker that is pasted on the machine. Huang et al. [41,42] implemented a tracking system based on multiple markers. The multi-marker setup enhances the stability of the tracking performance by providing a wider range of detection. However, marker-based tracking intrudes the environment with markers and for engineering applications, visual cluttering introduced by artificial markers should be avoided.

3.2. Result Visualization

Visualization for AR-based engineering analysis and simulation is different from conventional AR visualization primarily due to the special data types involved. Volume rendering of simulation data in an AR environment can be realized using two methods, namely, (1) convert data into readable format, and (2) integrate visualization tools. One of the common visualization methods used in surgery and biomedical engineering is image overlay. As mentioned by many researchers[59,61,62,77], data is rendered with a viewport-aligned slicing image. A 2D textured representation is generated based on a user's viewport and superimposed on the real scene. Helfrich-Schkarbanenko et al. [93] described an image-based method, in which numerical simulation results can be transferred to a remote mobile device for visualization. Similarly, the method proposed by Moser et al. [94] allows low-resolution rendering and basic interaction function using an image-based method on mobile devices. Anzt et al. developed a finite element package called Hiflow3 [95]. With the support of this package, the simulation results of urban wind flow can be visualized on mobile devices using the image-based method. Instead of using 2D representation, the data format can be converted using data conversion software to be visualized in the AR environment. Figure 4 illustrates the data conversion procedure for analysis and simulation data in AR. Simulation results are transferred to a data conversion software, such as Blender and Paraview, and converted into the vectored graphic format.

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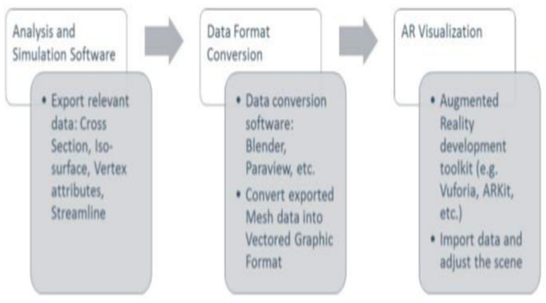

Figure 3. Simulation data conversion procedure

Visualization Toolkit (VTK) [96] is an open-source library with various supporting visualization algorithms and interaction methods. These visualization algorithms and interaction methods have been widely implemented into visualization tools, such as ParaView, Mayavi, VolView, etc. Bruno et al. [97] presented a system named VTK4AR. This system integrates basic VTK functions into an AR environment. The CAD model and CFD streamlines can be augmented on real models. VTK4AR offers enormous convenience to related research on scientific visualization of numerical simulation results. Huang et al. [27,41,42] used VTK in an AR-based structural analysis system. The interaction functions provided by VTK were utilized in this system to support volume slicing and clipping. De Pascalis [98] presented a remote rendering method for mobile devices. The simulation results are generated in the polygon file format (PLY), also known as standard triangle format. The PLY format file can be rendered remotely via VTK. However, the scalability of the system is restricted as only pre-defined PLY files can be visualized. Scientific visualization of volumetric data on mobile devices is still an untapped research area as compared with desktop-based visualization. Figure 5 illustrates the approach of integrating the VTK with AR in current studies [41]. The visualization pipeline consists of several parts, namely, vtkMappers, vtkActors, vtkRenderer, vtkCamera, and vtkRenderWindow. The images grabbed by a camera is rendered as virtual objects by using the vtkRenderWindow and vtkRenderer. The vtkActors represents the physical representation of the data in the rendering window. In order to register vtkActors in the world coordinate system, the fundamental AR camera information

4. Conclusions and Potential Future Directions

Today's engineering analysis and simulation software aims to provide an easy-to-use interface for the users. Augmented reality applications are becoming increasingly common in many different fields. One of the major advantages of using AR instead of VR is that AR allows users to interact with real objects in addition to virtual contents in the augmented scene, and can amplify human perception and cognition of the real world. This paper has presented a state-of-the-art review of research studies on AR application in engineering analysis and simulation. Even though there are many researchers working on AR-based engineering analysis, there is no report to provide a comprehensive review on those systems. The aim of this paper is to provide an overview of the recent developments in this field to facilitate further investigation. Numerical simulation methods are powerful tools for engineers who can perform on-site engineering problem solving with the integration of AR and numerical analysis and simulation tools.

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