Expert Systems With Applications 55 (2016) 48–58

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

A 3D GIS-based interactive registration mechanism for outdoor augmented reality system

Wei Huang[a], Min Sun[b,*], Songnian Li[a]

[a] Department of Civil Engineering, Ryerson University, Toronto, Canada
[b] Institute of RS & GIS, Peking University, Beijing, China

ARTICLE INFO

Keywords:
Augmented reality
3D GIS
ARGIS
Registration

ABSTRACT

Registering virtual objects with reference to their corresponding real-world objects plays a key role in augmented reality (AR) system. Although there have been a lot of work on using vision-based method to perform registration for indoor AR system, it is very difficult to apply such registration method for outdoor AR system due to the inability to modify the objects in outdoor environment and the huge range of working area. 3D Geographic Information System (GIS) is capable of providing an outdoor virtual geographic environment where users are located at, which may provide users with a corresponding virtual object for the one in the physical world. In this study, a 3D GIS-based registration mechanism is proposed for outdoor AR system. Specifically, an easy-use interactive method for precise registration was developed to improve the performance of the registration. To implement the registration mechanism, an outdoor AR system built upon 3D GIS was developed, named Augmented Reality Geographical Information System (ARGIS). ARGIS has the capability of performing precise registration in outdoor environment without using traditional vision tracking method, which thus enables users to arbitrarily manipulate the system. A prototype was developed to conduct experiment on the campus of Peking University, Beijing, China to test the proposed registration mechanism. The experiment shows that the developed registration mechanism is feasible and efficient in the outdoor environment. The ARGIS is expected to enrich the applications of outdoor AR system, including but not limited to underground facility mapping, emergency rescue and urban planning.

1. Introduction

Augmented Reality (AR) combines and aligns real-world and virtual objects in a physical environment to serve a wide array of applications, including medical procedures, manufacturing, entertainment, construction and education (Azuma et al., 2001, 1997; Lee, Huang, Huang, Hsieh, & Lee, 2012b; Seo & Lee, 2013). In accordance to the tracking method used, AR system can be classified into indoor AR system and outdoor AR system (Azuma, Hoff, Neely III, & Sarfaty, 1999). An indoor environment is being treated as a finite space that can be registered with specific fixed artificial references (e.g., fiducial markers). Thus, common vision tracking methods can be directly applied to aid in virtual object registration within indoor environment. On the other hand, an outdoor AR system requires Global Positioning System (GPS) and Inertial Measurement Unit (IMU) sensors to aid in the registration process due to the inability to modify the objects in outdoor environment and the huge range of working environment (Behringer, Park, & Sundareswaran, 2002; Feiner, MacIntyre, Höllerer, & Webster, 1997; Piekarski & Thomas, 2002; Thomas et al., 2000). Despite that, the performance of real-time registration can hardly satisfy the demand of object tracking by using GPS and IMU only in outdoor environment because of the systematic error produced by the equipment. Therefore, it is necessary to develop a new method to fill this gap, which enables the outdoor AR registration to be accomplished efficiently and precisely.

Conceptually, the augmented objects in any AR system should have their corresponding objects to be associated in the real world. Thus, 3D Geographic Information System (3D GIS) is able to provide a good digital version of any outdoor environment where users are located at. Traditional 3D GIS emphasizes high quality photorealistic 3D objects (static objects are mainly considered), while such a requirement is not necessary in AR system because users are already situated at the outdoor scene. Generation of 3D GIS models and their corresponding data management process are thereby simplified dramatically. Outdoor AR system only requires

* Corresponding author. Tel.: +86 1062764484.
E-mail addresses: wei1.huang@ryerson.ca (W. Huang), sunmin@pku.edu.cn (M. Sun), snli@ryerson.ca (S. Li).

http://dx.doi.org/10.1016/j.eswa.2016.01.037
0957-4174/

the 3D wireframe models of augmented objects, and the system should place more emphasis on invisible information of physical environment, such as objects size, attribute information (e.g., building names and street names), directions, and geometric characteristics (e.g., distance, area and volume).

In this study, 3D GIS is introduced to AR system to improve the efficiency and accuracy of registration in outdoor environment. The combined system is named as ARGIS. First, a coarse registration process can be achieved by using virtual 3D GIS objects and positioning data collected by GPS and IMU sensors. Then, with the aid of a handheld interactive device, users can perform precise 3D registration of outdoor scenes based on the principle of 3D coordinate transformation. Such a human–computer interaction can facilitate the refinement of registration from passive mode into active operation, resulting in a better flexibility and higher registration accuracy. Moreover, the interactive device also provides a tool which enables users to communicate with each other (e.g., input certain simple commands to request the augmented views of other users).

The paper is organized as follows. Related work is presented in Section 2. Section 3 introduces the architecture of ARGIS. A new interactive method for precise registration is explained in Section 4. The experiment is discussed in Section 5. Conclusion and future work are presented at the end of the paper.

2. Related work

Existing studies, such as Zlatanova and van den Heuvel (2002), Ghadirian and Bishop (2002), Liarokapis et al. (2005) and Uchiyama, Saito, Servières, and Moreau (2009), used 3D GIS to provide auxiliary information of outdoor scenes (e.g., building attributes, road maps and environmental-related information) to the AR system. Another stream of research focuses on the development of registration methods based on the information provided by 3D GIS. These studies, including Thomas et al. (2000), Behringer et al. (2002), King, Piekarski, and Thomas (2005), and Schall et al. (2009a), attempted to track apparent references or objects provided by 3D GIS, and subsequently registered these objects into video streams. Due to the complex nature of urban morphology, it is hard to locate the reference objects and this kind of registration methods may not be practical in outdoor environment.

On the other hand, Jiang, Neumann, and You (2004) and Satoh, Anabuki, Yamamoto, and Tamura (2001) proposed to combine the use of GPS and IMU sensors together with vision tracking, leading to a viable solution for outdoor AR registration. However, the registration does not work well under rapid viewpoint displacement and rotation (Yuan, Ong, & Nee, 2006). Fong, Ong, and Nee (2009) developed a hybrid tracking method that used data collected by GPS and IMU to locate users' position, and subsequently performed registration by tracking pre-defined references. Recently, there have been several attempts using virtual 3D models to improve registration accuracy (Behzadan & Kamat, 2007; Schall et al., 2009b), or GPS and gyroscope signals to stabilize registration process (Azuma, Neely, Daily, & Leonard, 2006; Piekarski & Smith, 2006; Reitmayr, Eade, & Drummond, 2005). However, these methods still require the use of vision tracking, which has several drawbacks: (1) objects with complex geometry (e.g., trees), or situated under non-uniform illumination (i.e., under/over-exposure) are hard to be recognized; (2) vision tracking can only handle static scenes without significant fluctuation, and thus the operation is sensitive to the user's stability; and (3) vision tracking demands powerful computing capability that imposes significant hardware burden for outdoor AR.

Actually, some interactive operations were used to tackle these problems involved in vision tracking. Piekarski and Smith (2006) proposed an interactive method for an outdoor AR system that registered 3D objects in outdoor environment using special robust gloves. However, the proposed system was developed based on tracking the gloves to add 3D objects without any geographic information provided. Azuma et al. (2006) introduced mobile beacons to act as a reference for tracking, and combined the positioning data collected by GPS to register virtual 3D objects. The study only included a simulation experiment without any performance testing in outdoor environment. Moreover, most of the recent researches on mobile AR system (Carmigniani et al., 2011; Vincent, Nigay, & Kurata, 2013) are heavily dependent on the use of predefined artificial signs/targets, which cannot satisfy the registration process in complex outdoor environments.

Recently, some vision tracking independent outdoor AR applications have been developed. For instance, Lee, Dunser, Nassani, Billinghurst (2013); Lee, Dunser, Kim, and Billinghurst (2012a) developed a mobile outdoor AR application for city visualization and a virtual tour to Antarctica AR application. However, most of these applications mainly focus on the variety of related information provided to overlay, without reporting on registration performance. Moreover, they placed efforts on adding some related information around a location or about a building just into the interface of the applications rather than precisely registering them into the corresponding objects in the real world (Li, Weng, Zhou, Hao, & Zhao, 2013; Yovcheva, Buhalis, & Gatzidis, 2012).

In summary, the aforementioned researches either still need to use vision tracking and rely on certain predefined artificial signs/targets to accomplish the registration process or do not perform precise registration. To tackle these issues for outdoor AR, this work aims to develop an outdoor system (i.e., ARGIS) to demonstrate a new registration mechanism without using vision tracking which enables precision registration to be accomplished efficiently in outdoor environments.

3. An overview of ARGIS system architecture

The system architecture of the proposed ARGIS follows a typical 3-tier client/server architecture, which consists of multiple mobile clients, a centralized server and a 3D GIS database, as illustrated in Fig. 1. Each mobile terminal (client) requests data from the server to augment the scene of outdoor environment through wireless network. The server at the back-end searches and fetches data from the 3D GIS database according to the client's location and orientation measured by GPS and IMU and pushes the requested data to the client. The 3D GIS database stores 3D objects (e.g., wireframe model of buildings) so that they can be streamed to the client for precise registration. Furthermore, ARGIS allows each client to share the current augmented images with other clients and the server, and thus, for example, rescuers who work as a team could conduct more accurate rescue operations if they know certain details about other teammates' working scene.

Fig. 2 illustrates how the ARGIS interactive registration works. First, the mobile client system utilizes real time GPS and IMU data to approximately match the virtual objects to the corresponding real-world objects in the physical environment. Then, users can fine-tune the position and/or orientation through the handheld interactive device, which improves the matching accuracy between the wireframe models and the corresponding real-world objects. This process is considered as the precise registration between virtual environment and physical environment. With the introduction of 3D GIS, such precise registration process can be performed by interactively matching the objects in the physical environment (e.g., a house) to the corresponding objects in 3D GIS (e.g., the 3D wireframe model of a house). Comparing with the visual tracking method, this method avoids the video streaming process and thus dramatically reduces the computational consumption of the system and breaks the limitation of work space.