Abstract

The setting out is the first step of construction of any building. This complex task used to be performed by means of specialized and expensive surveying equipment in order to minimize the deviation of the constructed areas from the information provided by design plans. This paper presents a new low-cost system oriented to the management of setting out in construction sites based on Augmented Reality technology. In this context, Augmented Reality allows surveying technicians to enhance the user's view of the real-world with visual information provided by virtual objects. The proposed system consists of an Augmented Reality application connected to a hardware platform based on commercial off-the-shelf (COTS) components. The results of the proposed experiments show that the presented approach can be considered an efficient quality/cost trade-off for setting out purposes in actual construction sites.

Keywords: setting out, layout, augmented reality, construction sites.

1   Introduction

The setting out of a building site, denoted also as layout process, is the procedure that ensures that each element of the works (e.g. building corners, wall lines or boundaries) is constructed in the right position and to the correct level from location information provided by design plans [1]. This marking out process is a very accurate procedure subject to all sorts of problems, which are checked by surveyors in existing permanent control points. The purpose of these control points is to avoid gross errors and to maintain the current setting out accuracy of the construction below a predefined acceptance criterion. Although the range of instrumentation available to the current engineers or surveyors is very wide, the new surveying equipment based on total stations, lasers levels or GPS tools have not totally been

removed from the market traditional theodolites, levels and steel tapes, because technical and cost considerations.

In this paper, we present a low-cost system, based on Augmented Reality technologies, focused on providing support to surveying technicians for the management of setting out in construction sites. The term Augmented Reality (AR) is often used to define some computer graphic procedures where the real-world view is superimposed by computer-generated objects in real-time [2]. Unlike the Virtual Reality, where the user is provided with a completely natural experience in realistic simulated worlds, the goal of the Augmented Reality is to realistically enhance the user's view of the real-world with visual information provided by virtual objects. Following this general approach, the proposed setting out system consists of a hardware platform based on commercial off-the-shelf (COTS) components and an Augmented Reality application. As in the case of Virtual Reality, the Augmented Reality offers interesting and wide spread possibilities to develop a large number of high-end applications in different areas of science and technology [2,3,4,5,9]. In this sense, several contributions have been presented in the fields of construction and architecture. In these fields, the technicians work with graphical descriptions such as 2D designs. Therefore, the introduction of innovative graphical interfaces, such as based on AR technologies, fits naturally into current work practices. These contributions exploit the use of Augmented Reality for exterior construction applications [4,5,7], present software frameworks for the development of AR applications, or even, propose AR systems based on mobile [7,8,11] or wearable computing [9] for the construction sector. However, although the setting out process has been recently emphasized as potential applications of Augmented Reality in the field of construction technologies [10], no actual contribution has been yet presented in this AR application context.

The hardware device of the proposed systems equips a high performance PTZ network camera, a reliable 3G-WiFi router and an AC voltage stabilizer in a 15-inch watertight box. This box is made of fiberglass and is located at the top of the main crane obtaining a high resolution top view of the overall construction site. Since this custom hardware device contains a standard web server (which is acceded through a reliable 3G network), the AR application establishes a connection to this server and obtains top-view images of the construction site in real time. In this sense, the software application of the proposed system acts as a remote monitoring device and augmentates the received images with the information included in the design plans. Once the application is initialized and a simple calibration establishes the equivalence between real-world images and computer-generated graphics, the system allows users to visualize the final location of the element of the works taking into account the information provided within the design plans. Moreover, the system provides an estimation of the final current setting out accuracy as well as superimposing the computer-generated graphics from design plans on the real-world images captured by the network camera included.

In order to evaluate the system performance, accuracy and usability, several experiments have been conducted comparing the proposed approach to not only traditional, but also to high-end, surveying equipment. The results of this performance evaluation show that the presented approach can be considered an

efficient quality/cost trade-off for setting out purposes in actual construction sites. In this sense, the proposed approach obtains a setting out accuracy of approximately 0.5-2 centimeters, in most of the tested construction sites, by means of low-cost equipment. Moreover, the application can be executed remotely avoiding the need to send personnel to the construction site for this kind of purposes.

The rest of the paper is organized as follows: Section 2 describes the background and purpose of technologies based on Augmented Reality as well as the main contributions of AR developments for exterior construction applications. Section 3 gives an overview and the main design considerations of the presented system. Next, Section 4 presents some experiments and results comparing the proposed system with different surveying devices. Finally, Section 5 presents some concluding remarks and future work to be done.

2   Background

The term Augmented Reality (AR) is often used to define some computer graphic procedures where the real-world view is superimposed by computer-generated objects in real-time [2]. Unlike the Virtual Reality, where the user is provided with a completely natural experience in realistic simulated worlds, the goal of the Augmented Reality is to realistically enhance the user's view of the real-world with visual information provided by virtual objects. AR systems are currently used in numerous applications such as medical, maintenance, scientific visualization, maintenance, cultural heritage and military applications [3].

Besides these contexts, exterior construction is considered as a suitable application area for AR developments [4,5,6,7,8,9,10,11]. In fact, the development of a construction project includes a significative number of three-dimensional activities. Professional traits and work behavior are all oriented towards the design, understanding, visualization and developments of 3D procedures. Workers are used to graphical descriptions such as 2D/3D maps or designs. Moreover, most of this information is already represented and communicated in graphical form. Therefore, new graphical user interfaces like Augmented Reality could be introduced very naturally into current work practices.

Most of AR applications specifically developed for the construction industry are oriented to outdoor construction processes [4,5,7]. Initially, the aim of these AR systems was to provide the users with a sense of space and realism about the size and dimensions of construction tasks developed in outdoor environments [4]. Moreover, new approaches based on augmented video sequences, and live video streams, of large outdoor sceneries with detailed models of prestigious new architectures (such as TV towers and bridges) were presented [5]. Currently, the last developments of AR applications oriented to construction processes not only avoid the use of external markers within the real scene, but also integrate sensors such as GPS devices, rate gyros, compasses and tilt orientation elements of the viewer's location [7].

Although the market offer several toolkits for the development of AR applications, some of them have been specially oriented towards the requirements of applications in the construction sector [4,6]. In this sense, the design on TINMITH2

[6] is based on a highly modular architecture where the software system is broken up into various modules that communicate with each other using the connection oriented TCP/IP protocol. Otherwise, the architecture proposed in a similar approach [6] is optimised to develop mobile AR and other interactive 3D applications on portable platforms with limited resources. This architecture is implemented in C++ with an object-oriented data flow design and manages an object store based on the Unix file system model.

Mobile computing could offer a suitable hardware platform for the development of AR applications to be executed in construction sites [6,7,8,11]. These contributions address a number of problems affecting mobile AR and similar environments related to performance and portability constraints of the equipments [6]. In this sense, an AR mobile application developed for architectural purposes [7] includes a feature tracking for estimating camera motion as the user turns the mobile device and examines the augmented scene. Another approach integrates an RFID reader, a headset and a wristband to be used by workers in order to improve their safety at work place in construction sites [8]. A recent work presents an AR system which places the models in geo coordinates, as well as managing data intensive building information models (BIM) on thin mobile clients [11].

Along with the developments of mobile computing, the technologies based on Augmented Reality exploit a promising field for wearable computers oriented to construction sector [6,9]. Since the main idea behind wearable computing is the augmentation of human capabilities by wearing devices, these technologies allow construction workers to facilitate critical tasks such as determine the proper excavation for buildings [10], visualising conceptual designs in-situ [6], making modifications on site, and representing construction and engineering data on real-time [9]. In addition to these purposes oriented to the construction sector, the setting out process has been denoted as a challenge when AR technologies are applied to the construction sector [10]. This process guarantees the components belonging to the building constructed in the right position and to the correct level from location information provided by design plans. Although these technologies could (with a proper visualization device) be used by construction technicians to identify the positions of reference points easily and mark them on the site by simply observing the rendered virtual reference points, from our knowledge all the current approaches are under development and not in commercial use at the present time.

3 Analysis

The proposed setting out system for construction sites consists of a hardware platform components and an Augmented Reality application. Since one of the main goals of the system is the development of a more affordable alternative than conventional equipment for surveying purposes in construction sites, the hardware platform has been developed using commercial off-the-shelf (COTS) components. This type of developments is oriented to reduce expenses and shorter development time, while maintaining the quality of the final product. Moreover, the AR application has been designed following a component-based model to enable continuous increase of functionality and portability.

3.1   Hardware Description

The hardware device of the proposed systems includes a high performance PTZ network camera, a reliable 3G-WiFi router and an AC voltage stabilizer in a 15-inch watertight box. This box is made of fiberglass and is located at the top of the main crane obtaining a high resolution top view of the overall construction site. Figure 1 shows an image of the final aspect of development as well as the final location of the hardware device when the experiment tests, described in Section 4, were completed.

   In order to fulfill the requirements for the high performance PTZ network camera included within the hardware device, Figure 1 show that the selected camera corresponds to a Toshiba IKWB-21A model. This IP camera includes a 1280x960 resolution CCD camera with a 22x optical zoom lens. Moreover, this camera operates as a stand-alone unit with a built-in web server where the AR application connects and obtains top-view images of the construction site in real time.

Figure 1: A detailed images of the 3G wireless image acquisition device adapted to be installed on a crane.

3.2   Software Description

The design of the software application for the proposed system has a software architecture following an "event-driven object-oriented" model. These software designs describe synchronous event-driven architectures composed of a set of components (modules), which are based on a classic object-oriented approach. The modules exchange custom messages which model internal actions or external events captured in real-time. In the case of the proposed application, the software system is composed of five independent and interrelated subcomponents, which work concurrently in a real-time manner.

   Figure 2 shows the diagram view of the architecture in relies on a centralized approach around an AR engine. This kernel, denoted as Sicura Engine, is

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responsible for launching the application, controlling the remote user interface and receiving the input data from the camera module. The development of the AR engine has been performed using the standard OpenGL ES (OpenGL for Embedded Systems). The tracking module implements our building recognition method based on the detection of the skyline from the image flow captured by the camera module. However, the main objective of the AR engine consists in merging the real-world images and the computer-generated graphics, which are visualized by the user by means of the display module. Finally, the data module loads the configuration of the design plan of the building from a DXF file. This neutral format (in this case, ASCII-based) is used by a wide variety of GIS and CAD systems such as Autocad, Intellicad or MicroStation as an exchange standard mechanism to store graphical information following a layer approach.
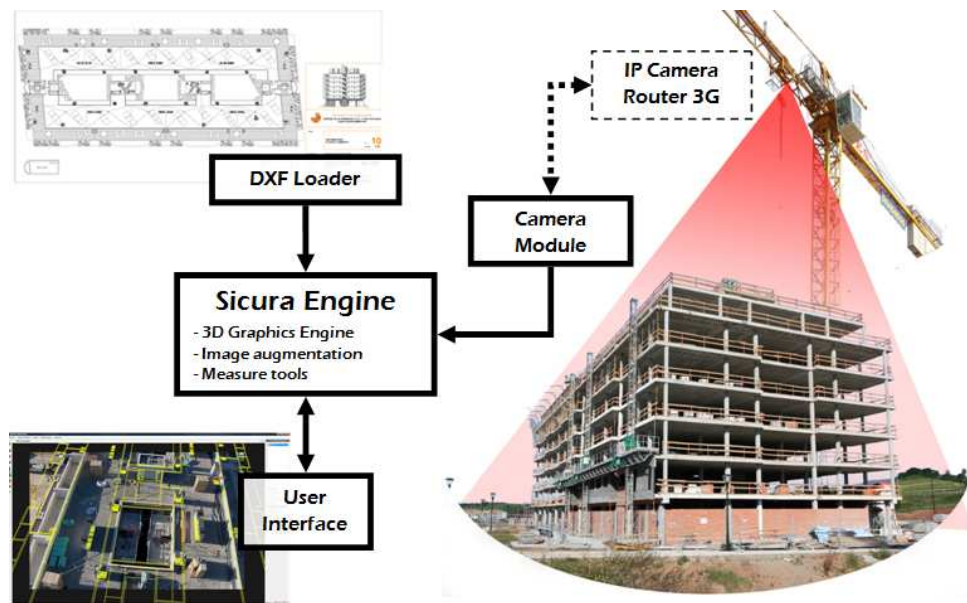

Figure 2: A modular view of the software architecture for the AR system.

Once the hardware device located at the top of the crane detects and available 3G connection, the AR application establishes a connection to the router containing the images from the IP camera in real time. In order to establish a relation between the camera images and the coordinate systems of the objects located at the actual scene, the AR application requires a quick and simple calibration process. Since the application shows the user both a window including the original designs plans of the building and another window with the images captured from the camera, this procedure consists of selecting the same four initial points, which dimensions are know, in both windows. As an example, elevator or square drain shafts are elements which can be used for these calibration purposes.

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4   Experiments and results

In order to evaluate the performance of the proposed approach to the management of the setting out problem in the building construction based on AR technologies, we have compared our system with conventional surveying equipment. In this sense, we have selected a total station over a combination of tripod and tribrach composing forced centering equipment. Because of availability constraints for the conventional surveying equipment, the total station corresponds to a "Leica TCR1205" model oriented to reproduce 3D digital surveys of outdoor environments in real time.

The systems were evaluated by a set of 12 experienced surveying technicians, 4 females and 8 males in a three-hour test session performed in a building construction site located at the town of Rivas (Madrid, Spain). This building construction site, owned by the Dragados construction company, included a 2000-inches tower crane to complete 74 apartments in two buildings. Since the under construction building was starting the slab stage, all participants completed a verification process consisting of 24 check point. Each check point required to compare the current status of the excavation corners to the original design plans of the building using both the conventional surveying equipment and our system. In this sense, the participant attended to a training session involving the purpose of the experiment and the operation of the AR system for layout purposes. Figure 4 shows an image of an actual view of the construction site including the location of the different verification points included within the experiments. Moreover, this figure show the use of our AR system at the same under construction zone where the computer-generated images obtained from the design plans are superimposed over the real images obtained from the custom 3G wireless camera.
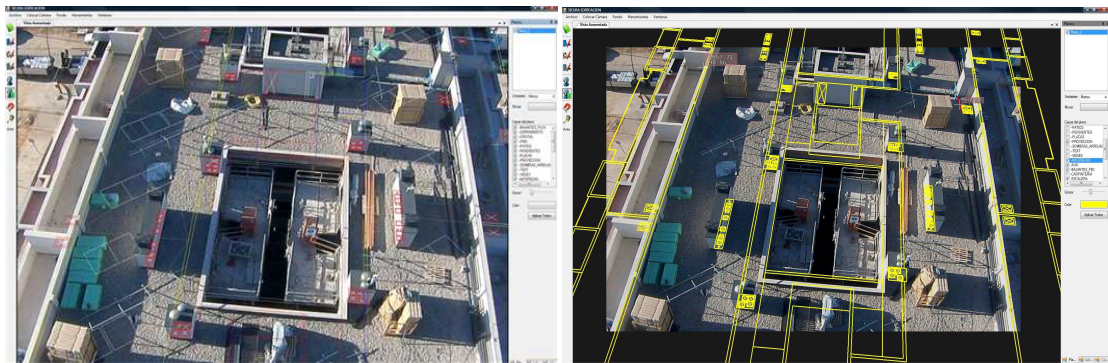

Figure 4: Images of the construction site obtained from the camera installed at the top of the main crane of the building. Verification points are represented in red color.

After finishing the experiment, the participants were invited to complete a questionnaire including ten evaluation parameters to compare the performance of both systems for the layout problem in construction sites. The categories evaluated by participants were:

- Usability and facility for use
- Overall ability to identify check point in actual environments
- Efficiency in operation
- General accuracy
- Compatibility with common CAD/BIM formats
- Visibility
- Manuel Handling
- Resistance (water and flame)
- Training Requirements
- Stowage

Each evaluation parameter was scored on a five-point scale (1=Poor, 2= Below Average, 3=Satisfactory, 3=Good and 4=Excellent) by the participants. Table 1 shows in each row the results of the experiment (expressing the average and standard deviations of the obtained data for each parameter) for both the conventional surveying equipment and the proposed approach, denoted as CSE and S-AR respectively.

Evaluation Parameter	CSE:Average Score	CSE:Standard Deviation	S-AR:Average Score	S-AR:Standard Deviation
Usability and facility for use	2.80	0.36	3.22	0.84
Overall ability to identify check points	2.74	0.25	3.30	0.98
Efficiency in operation	3.12	0.34	3.13	0.52
General accuracy	3.40	0.36	3.21	0.41
Compatibility with CAD formats	2.11	0.21	3.60	0.35
Visibility	3.33	0.34	2.70	1.31
Manual Handling	2.80	0.64	2.96	0.58
Resistance (water and flame)	3.90	0.12	2.52	0.26
Training Requirements	2.53	0.81	2.44	1.12
Stowage	3.01	0.52	2.80	0.92

Table 1: Results of the measured parameters for CSE and S-AR in the experiment.

Table 1 shows that the average values obtained by the CSE and the S-AR equipment reach similar values. Although the obtained results indicate that the conventional surveying equipment provides better accuracy that the proposed system based on AR technologies, the final precision achieved by both systems (about 0.5-2 centimeters) is reduced enough to complete setting out stages in construction sites. Moreover, the results shows that the conventional surveying equipment offers better visibility, manual handling and resistance that the proposed system. These expected results are a consequence of comparing a commercial product (with several years of introduction in the market) with the result of a research project, which has to be improved in terms of final quality before being commercialized. Therefore, the results show that the proposed system can be considered an efficient, inexpensive and portable alternative for setting out purposes in actual construction sites.

5   Conclusions

In this paper, we have proposed a new system based on Augmented Reality technologies oriented to offer facilities when solving the layout problem in construction sites. The proposed system allows surveying technicians to enhance the user's view of the real-world with 2D/3D visual information provided information from the initial design plans of the building.

Since the main aim of this approach is order to offer a more affordable layout solution than conventional surveying equipment, the proposed setting-out system consists of a hardware platform based on commercial off-the-shelf (COTS) components and an Augmented Reality application. This application has been designed following a component-based model to enable continuous increase of functionality and portability.

In order to evaluate the proposed approach, some experiments have been conducted comparing our layout system to traditional surveying equipment in an actual construction site. A set of surveying technicians was selected as participants for these experiments. The results of this evaluation indicate that the presented approach can be considered an efficient quality/cost trade-off for setting out purposes in actual construction sites.

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