A Video-Enabled Dynamic Site Planner

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ABSTRACT

Construction site layouts need to be planned for safety and efficiency before the site operations can begin. However, current planning methods rely heavily on the experience of planners. Inexperienced planners can easily neglect objects or misestimate object size and location during planning. This research aims to develop a video-enabled dynamic site planner that enables planners to model on-site objects from images from closed-circuit television (CCTV) and helps planners to simulate the site in real-time virtual construction. Two main methods are developed in this site planner. The first is the *rapid image planar modeling* method, which enables users to rapidly construct 3-D geometric models of the on-site objects from the video image. The second is the *video-based virtual construction planning* method, which provides a process for site layout planning in a simulated virtual construction environment. We have implemented this site planner by using a game engine. After an example case pertaining to layout planning, the results show that this system can help planners identify potential problems that will occur in the actual site layout process. The system can also serve as an information platform to reduce the gap between construction simulation and reality.

INTRODUCTION

Construction site layout planning is one of the most important preliminary tasks in a construction project. To accommodate limited space, plans must be made for the locations of facilities, the space for traffic, the accessibility of vehicles, etc. (Easa and Hossain 2008). In particular, the issues of site layout and vehicle access are two common problems encountered in construction projects. Enough space for material placement and vehicle accessibility are critical concerns at typical construction sites.

In the past, construction layout planning has relied heavily on the level of experience of the planners (Li *et al.* 2009; Yang *et al.* 2013). The safety and efficiency of construction activities were issues that were often hard to address simultaneously. Clearly, the lack of an effective tool to help planners simulate different on-site situations is a major problem.

Planners need to accommodate temporary facilities and equipment in limited space to ensure that all processes continue without conflict. Traditional methods such as site observation with 2-D maps easily neglect on-site situations and temporary facilities. Since the shape and size of temporary facilities are easily misestimated, the probability of conflicts arising between actual construction

processes leading to suspension of activities is high (Zouein *et al.* 2002). In other words, another significant problem is the reliable communication of on-site information during the layout planning process.

RESEARCH BACKGROUND

Virtual construction technology has become a useful method and significant improvement over traditional construction layout planning methods. This technology provides a simulated environment to help engineers visualize and explore 3-D spaces. Furthermore, acquisition of on-site data is essential for virtual reconstruction of the actual construction site.

Virtual construction is a management tool. It uses computational methods to model, simulate, and visualize construction scenarios on computers (Lai and Kang 2009), and can help planners identify potential problems that may occur in actual construction processes (Gu and Tsai 2010). The visual and interactive nature of virtual construction software has gained attention among educators. Nikolic *et al.* (2011) used a virtual construction environment to provide engineering students with a means to visualize 3-D information. This educational virtual construction environment was used to help students develop their decision-making skills. Zhang *et al.* (2012) indicated that physical objects, construction information, and process animation are essential elements in a practical 3-D virtual construction system designed to aid planners. As is clearly evident from these related research works, virtual construction has multiple applications in construction management. These works also discuss the various types of information that are essential to implementation of the virtual construction system.

Because of the dynamic outdoor environment of construction sites, helping planners to understand the on-site situation is a key point for site layout planning. For this purpose, a digital camera is a common method of collecting the real-time site information (Tang *et al.* 2010). A digital camera can be installed easily and has the potential to automatically capture object sizes and positions (Wu *et al.* 2010). Likewise, a camera connected to a closed-circuit television (CCTV) system can be an effective tool in construction site management (Ju *et al.* 2012), and Kim *et al.* (2013) have actually developed an on-site construction management system that employs a CCTV system. In this system, the CCTV cameras are the source of project data. Engineers can monitor the construction site from the acquired site images. Because CCTV cameras have their own Internet Protocol (IP) addresses, engineers can also see real-time site images from anywhere and at any time as long as they have an Internet connection. The findings and results of these related research works and applications suggest a CCTV camera is a good solution for communication of on-site situations to planners.

RESEARCH GOALS

In this work, we describe a site planner that employs a CCTV video camera. This site planning system can help planners to easily apprehend on-site objects from the video and directly model the reality of the site in a virtual construction environment. The planner can also simulate the real construction in the real-time virtual construction environment rather than relying on 2-D maps and experience. The site planner can facilitate the achievement of the following goals:

1. Planners can capture on-site objects rapidly based on video images from the CCTV. All objects will be modeled in virtual construction.
2. Virtual construction can provide a simulated environment for site planning. Planners can arrange objects and try the optimal layout in the virtual construction.

METHODOLOGY

In this work, the *rapid image planar modeling* method and the *video-based virtual construction planning* method have been developed.

Rapid image planar modeling method. This modeling method enables planners to reconstruct 3-D geometry models from a video image. In order to find the transformation between the planar image and a 3-D world, one must first select a basic plane like the ground from the real world. After taking a photo, all objects on this plane will be projected onto the image plane. A coordinate transformation that maps a location on one plane to the other plane can be computed. In other words, every real point (x_i, y_i) on the ground has a one-to-one image point (u_i, v_i) on the image plane. The image plane and the real plane are depicted in Figure 1.

Image Plane

(x_1, y_1) (x_2, y_2)
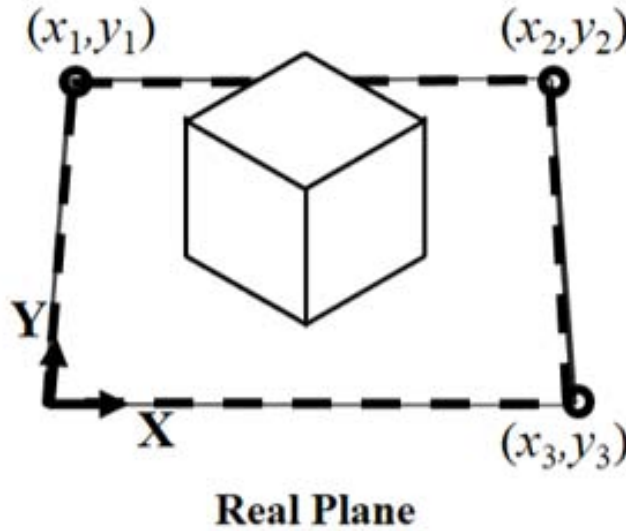
Y

X

(x_3, y_3)
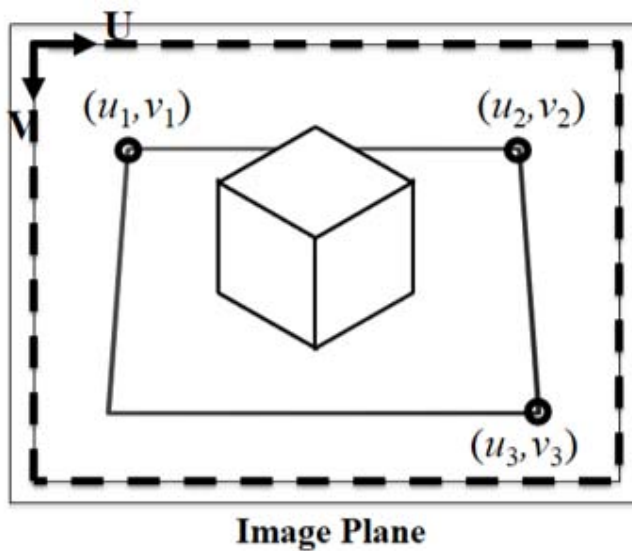
Real Plane

Figure 1. Image plane (the UV-system) and real plane (the XY-system).

In the homogeneous coordinate system, the transformation from the image coordinates to the real coordinates can be represented by:

$$\begin{bmatrix} u_i \\ v_i \\ 1 \end{bmatrix} = \mathbf{M} \begin{bmatrix} x_i \\ y_i \\ 1 \end{bmatrix} \tag{1}$$

In equation (1), $\mathbf{M}$ is a 3x3 transformation matrix, which may include the perspective matrix and transformation matrices such as translation, rotation, or shear. We can solve for the matrix $\mathbf{M}$ using the known point coordinates by using the Direct Linear Transformation (DLT) method (Hartley and Zisserman 2004). At least four control points with known coordinates are needed to solve to obtain the transformation matrix $\mathbf{M}$. We can survey the related positions of the four points on the site, and find the corresponding image coordinates on the screen. After solving for the matrix $\mathbf{M}$, we get the transformation between the image plane and the real plane (e.g. the ground). We can then us M to find the real position of any point from the image. We can also calculate the length between each two points and the area from at least three points as long as these points are coplanar.

Video-based virtual construction planning method. This planning method provides a process for site layout planning in virtual construction simulations. It consists of four steps (Figure 2):
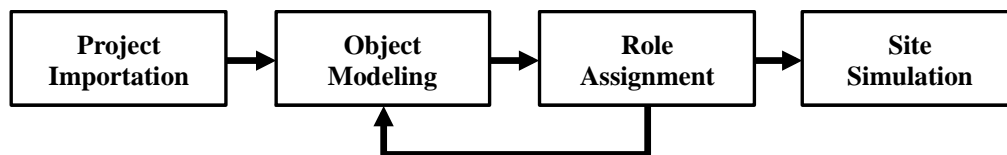

| **Project Importation** | **Object Modeling** | **Role Assignment** | **Site Simulation** |

Figure 2. The four steps of the *video-based virtual construction planning* method.

(1) Project importation

In order to use a virtual construction, planners need to first import the 3-D environment scene and construction information. We suggest this should include information about existing buildings, fences and terrain, which are fixed in the real environment. These features will help planners recognize what is modeled by the virtual construction simulation.

(2) Object modeling

By using the proposed *rapid image planar modeling* method, the planner can get the real object position as long as it is on the ground. Planners can sketch the bottom of an object on the image, and a real-size rectangle will be immediately rendered in the virtual construction environment. The transformation mapping points between the image and the real world allows all objects to be modeled with the correct sizes and in the correct positions. If planners manually set the height of the rectangle, it will be a 3-D geometric object such as a rectangular solid in the virtual construction environment.

(3) Role assignment

After the 3-D model is constructed in the virtual world, the planner can assign each object properties such as name, type, or action. This will help planners identify the objects in the simulation. Thus, planners can model all of the real objects in the virtual construction by repeating the steps of object modeling and role assignment.

(4) Site simulation

Finally, planners can start to simulate site operation in the virtual construction environment. Such simulations are reliable because they are modeled based on the on-site video images. Planners can optimize layouts by rearranging objects in the virtual environment rather than repeatedly moving the actual objects in the real world. The site layout planning will be faster and more precise. Furthermore, assigned objects can also be applied in an automatic simulation. For example, a path-finding simulation could be used after vehicles and obstacles are assigned.

IMPLEMENTATION

The proposed video-enabled dynamic site planner was implemented using Unity3D. Unity3D is a 3-D game development platform that provides real-time rendering, a scripting interface, artificial intelligence, and networking. To test the *rapid image planar modeling* method, an on-going construction project in Taiwan was used. At least four control points with known coordinates are needed to solve for the transformation matrix in equation (1), so four points on the image needed to have their corresponding real-world locations surveyed. In this case, the corners of fences and gates were selected as the control points. Existing building, fences, trees and terrain were also imported in the virtual scene. The image of the video and the virtual construction scene are shown in Figure 3.
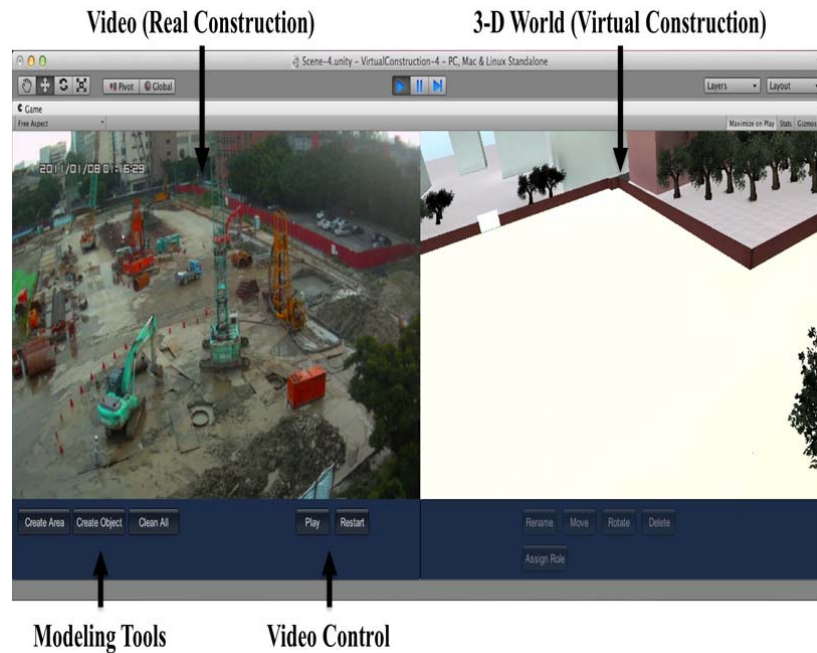
Video (Real Construction)   3-D World (Virtual Construction)

Modeling Tools   Video Control

Figure 3. Images of the video and of the virtual construction scene.

Planners can work with the real construction image and use the mouse to sketch a planar rectangle in the working area. They can also sketch the rectangles for the bottoms of on-site objects and then use the mouse to set the height manually. The site planner interface as it appears after all working areas and objects are modeled in the virtual construction environment is shown in Figure 4. Each plane and rectangular solid in the 3-D world (virtual construction) is a representation of a working area or on-site object in the real world.

Working Areas and On-site Objects   Real-size Rectangles and Rectangular Solids

Object Information   Edit Tools   Assigned Object (an excavator)

Figure 4. Planners can model working areas and on-site objects in the image as rectangles and rectangular solids in the virtual construction environment.

After constructing the virtual environment, planners can start to assign roles to the objects such as excavators, cranes and obstacles. They can also move or rotate the objects as necessary to optimize the site layout and run simulations such as path-finding in the virtual construction environment.

CONCLUSION

This research is an ongoing project for site planning based on CCTV video. The proposed video-enabled dynamic site planner can capture the object sizes and positions from the on-site video. A transformation between an image plane and a real basic plane has been applied for modeling on-site objects, so that planners can quickly model the on-site objects in a virtual construction environment. It is simpler, faster and more affordable than other data collection technologies such as laser scanning and GPS-based RFID. The proposed site planner also can provide a reliable virtual construction environment for planning and simulation. The virtual construction helps planners determine the space requirements of the various objects that will be on the construction site. They can find the optimum arrangement of objects in the virtual environment rather than having to move them in the real world.

The proposed site planner effectively reduces the gap between reality and construction simulation. In future works, the accuracy of the *rapid image planar modeling* method will be evaluated and the usability of the proposed video-enabled dynamic site planner will be validated.

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