Interactive Augmented Reality Visualization for Improved Damage Prevention and Maintenance of Underground Infrastructure

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Abstract:

During a typical excavation operation, there is a high risk of inadvertently damaging the existing subsurface utilities. Such incidents cause significant financial loss to the project and can delay or abruptly halt ongoing construction. In many cases, they also pose a life threat and often result in accidental deaths. As a result, constructors are required to protect utility systems during excavation operations. In this paper, the applicability of advanced visualization and tracking technologies to improve work safety during urban construction projects by enhancing the visual perception of construction equipment operators is discussed. The integration of Augmented Reality (AR) visualization and the Global Positioning System (GPS) is explored to create real time views of an excavation site in which CAD models of the underground utilities can be accurately superimposed over live video streams of the real world with the resulting views being displayed to the equipment operator in real time.

INTRODUCTION

Underground utilities and installations (e.g. gas, data, sewer, fuel, electric, water) are vital components of urban infrastructure that are constantly exposed to inadvertent damage during construction or excavation operations. An accident causing damage to subsurface infrastructure can lead to significant loss of project financial resources and delay or abruptly halt ongoing construction. In addition, such incidents may pose a threat to human lives and often result in accidental deaths. Due to the high risks involved and in order to protect public and private utility systems and installations, excavation contractors are encouraged and in most cases required to continuously follow federal and state regulations and practice adequate Subsurface Utility Engineering (SUE) methods during the actual excavation process. SUE is a process used to accurately identify and map underground utilities through the use of surface geophysics, surveying, data management and non-destructive excavation techniques. SUE has been recognized as the best available method to map underground infrastructure and is endorsed by a variety of organizations such as US Department of Transportation, National Transportation Safety Board, US Department of Energy, American Society of Civil Engineers, Associated General Contractors of America, and many universities and utility companies (ASCE 2003). The results of a study conducted by Purdue University for the Federal Highway Administration (FHWA) also indicated that for every $1 spent on SUE at least $4.62 was saved on the overall project (Purdue University 1999).

Existing regulations in many states require excavation and drilling contractors to contact local utility companies and request manual location marking of existing subsurface installations on the ground before they start excavating. As shown in Figure 1, a typical manual marking requires submitting written requests to local utility companies several days in advance of the actual excavation job.

Figure 1 – Process of Manually Marking the Underground Utility Lines

Once it is determined that markings are required, the request is assigned to a field locator, who will locate and mark the excavation site with paint, stakes and/or flags. The contractor can start the actual operations only after the locations of important underground utility lines are color marked on the ground (MISS DIG System 2007). However, manual marking of underground utility lines can be a time consuming and costly task. In addition, if sufficient care is not exercised, or if the congestion of underground cables and pipes is high, a utility line may be overlooked or incorrectly marked in the marking process causing a potential catastrophic accident during the excavation process.

In this paper, research that explores the applicability of advanced visualization and tracking technologies to improve work safety in urban construction projects is discussed. The research objective is being pursued by exploring techniques of enhancing the knowledge and visual perception of construction equipment operators and other site personnel. This is achieved using Augmented Reality (AR) visualization and the Global Positioning System (GPS) to create real time views of an excavation or drilling site in which CAD models of the underground utility lines are accurately superimposed over live video streams of the jobsite. CAD data that represent existing subsurface infrastructure has to be integrated into the AR application. This data can be obtained from different sources including local utility companies. Real time views of the jobsite are captured using a video camera mounted on the construction equipment or a mobile user, whose position is continuously obtained from GPS and updated in the system. The final AR visualization can be displayed to the equipment operator through a display installed inside the cabin, or to site personnel using head-mounted or other display devices. Knowing the geometry of a construction or drilling equipment and its current configuration, forward kinematics can be used to continuously calculate the exact position of its digging implement. If this position is too close to an area occupied by existing underground utility lines, the operator can be visually and audibly warned to take the necessary precautions and prevent potential impact or damage.

The designed AR system can be integrated into all types of construction equipment (e.g. excavators, loaders, dozers, graders) to enhance subsurface infrastructure damage prevention during a typical excavation, drilling, road construction, or maintenance projects. What makes the application of the AR system highly appealing to contractors and local utility companies is that it can be easy to install and operate, requires less manual work, and at the same time, the required implementation cost is significantly lower than the potential savings in project time and financial resources that result from preventing accidents.

SYSTEM COMPONENTS AND DESIGN

As shown in Figure 2, two important sources of information are used in order to create and display the final augmented view of the excavation site to the equipment operator: Local utility company data, and tracking and video data. Local utility companies typically keep digital records of the location of subsurface utility lines. In order for such data to be used inside the visualization system, they have to be first converted to CAD models. This can be done through the geometric modeling step. The level of accuracy of the resulting CAD models is an important factor when determining how accurate and reliable the final augmented output of the visualization system is. Real world data is another important component of the system. It consists of live video streams of the excavation site and position of the excavation equipment. A video camera installed on top of the equipment can be used to capture real time views of the surrounding environment while a GPS device mounted on the equipment collects and sends positional data (in form of longitude, latitude, and altitude) to the visualization system. The system can use this positional data to determine the portion of the excavation site currently accessible to the equipment. Appropriate CAD models of the existing utility lines within this portion of the site can then be loaded and superimposed on top of the real time views of the scene.

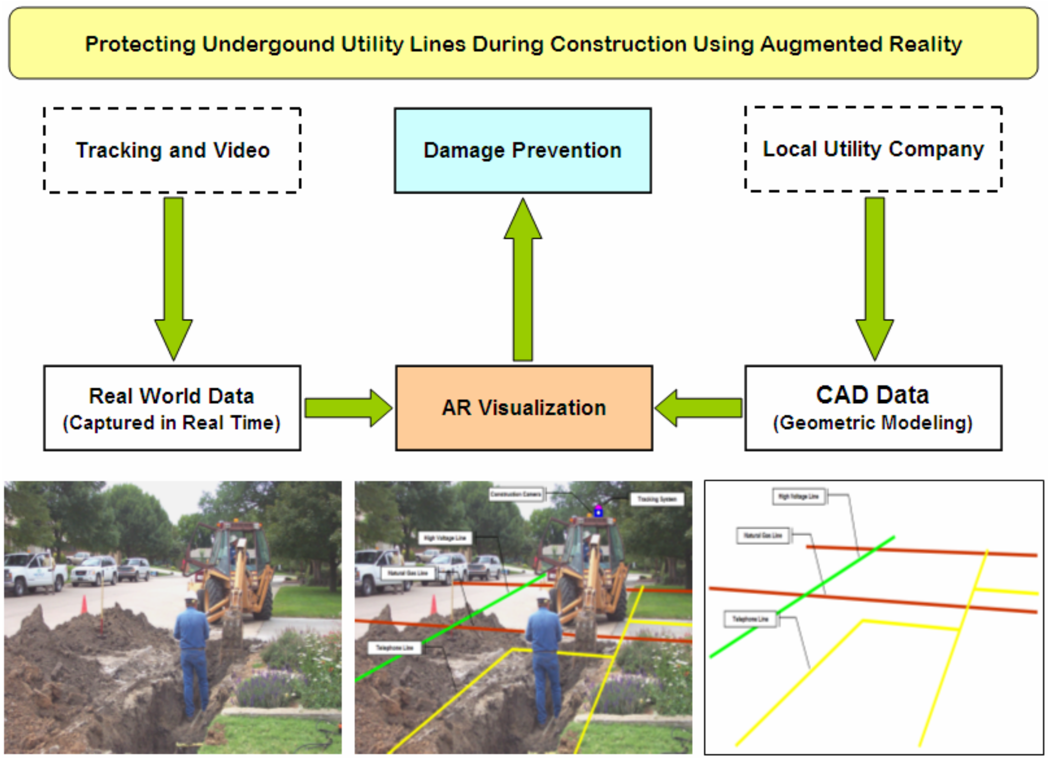

Figure 2 – Data Flow Diagram of the Designed System

As shown in Figure 3, the output of the visualization system consists of a mixed view of virtual utility lines and real excavation site which can be shown to the equipment operator in real time through an in-cabin mounted display. Figure 3 also shows another scenario in which a member of the site crew is looking at the same augmented scene though a Head Mounted Display (HMD). Having a non-operator person looking at the resulting views can significantly decrease the risk of hitting an actual utility line due to the equipment operator inadvertently ignoring a subsurface line being shown through the in-cabin display. The site person can be an excavation inspector who is equipped with a wearable computing platform. Inside this mobile apparatus, a laptop computer and a GPS receiver device can be installed and secured. A head orientation tracking device can also be installed inside the hardhat which sends three important pieces of data (yaw, pitch, and roll angles) to the system to determine the inspector's direction of look (i.e. line of sight). Together with positional data coming through the GPS device, head orientation data can be used to calculate the inspector's spatial context in the form of a viewing frustum and augment appropriate CAD models. The final augmented view can then be displayed to the inspector through the HMD which is firmly installed in front of the hard hat.

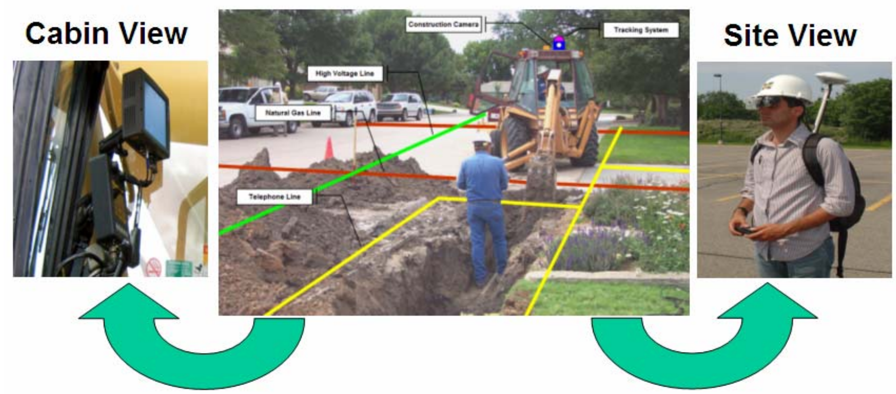

Figure 3 – Displaying the Final Augmented View to the Operator and Site Personnel

It is important to note that the accuracy level of the GPS device is also an important parameter when determining the position of the superimposed CAD models relative to the equipment. However, for the purpose of this research, GPS data with an accuracy of 50 centimeters or better can provide reliable results. The main reason is that according to excavation rules set by many states and counties, contractors are not allowed to use machine excavation in areas as close as 60 centimeters to existing utility lines (Buckeye Partners 2007). Depending on the field conditions at the project site, nature of the subsurface utility line, and the potential threat it may cause to the site personnel and neighborhoods, the clearance requirement can even increase to 1.5 meters.

In order to achieve higher accuracy levels, other GPS data communication techniques such as Real Time Kinematics (RTK) can be used. When used appropriately and in the absence of ambient radio signals, RTK improves the GPS accuracy level to a few centimeters (Ehsani et al. 2004). Figure 4 shows how an RTK-based GPS data communication can be integrated into the designed visualization system in this research. As shown in this Figure, a RTK base antenna and radio signal transmitter are first mounted on a remote spot with known global position. An RTK rover antenna together with a radio signal receiver, both mounted on top of the excavation equipment, continuously communicate with the base station. Knowing the speed of the radio signal and using the time of flight concept, the exact position of the RTK rover antenna (i.e. the equipment) can then be calculated and used inside the visualization system.

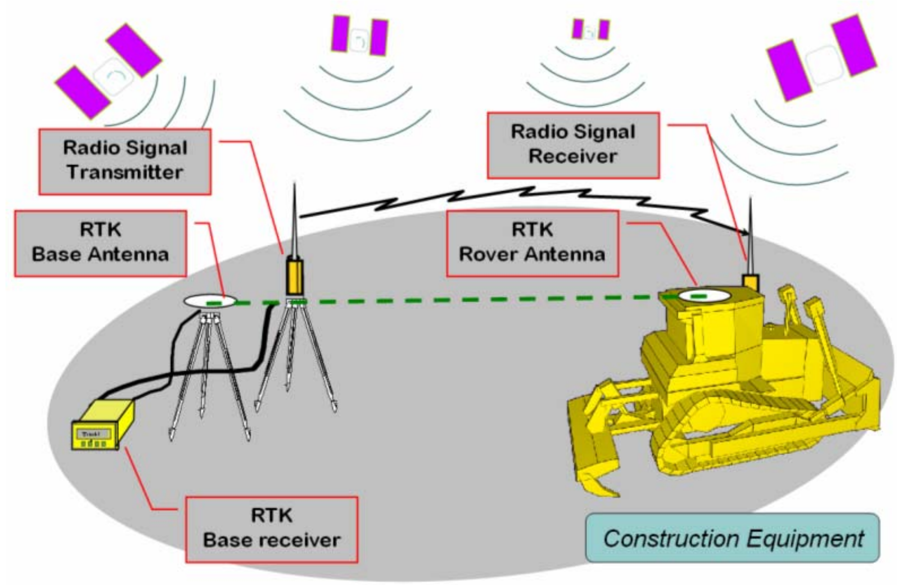

Figure 4 – Using RTK Communication to Improve GPS Data Accuracy

DESIGN OF AN AUTOMATED ALERT SYSTEM

Visual and/or audio alert systems are convenient means to enhance operator's perception of the excavation site. In the absence of such systems, the operator will have to constantly look at the display mounted inside the equipment cabin and interpret the augmented scene based on the contents of the AR visualization. Sometimes, the operator may overlook a certain CAD model or miscalculate the distance between the equipment implement and the subsurface lines. In order to avoid such cases, the visualization system must be accompanied by an automated alert system. The system should constantly calculate the distance between the equipment endpoint (e.g. shovel, blade, and scoop) and CAD models of the utility lines being visualized. If the calculated distance is less than a threshold value initially specified to the system, an alert message can be sounded for the operator.

The automated alert system introduced in this research, works on the basis of forward kinematics (Crane and Duffy 2008, Kamat and Martinez 2005). As shown in Figure 5, at each instant of time, the position of the equipment's implement can be calculated based on the global position of the GPS device (mounted on top of the equipment) and current equipment configuration. For the excavator shown in this Figure, knowing the geometrical properties of the equipment such as the boom, stick, and bucket lengths as well as their angular configuration, real time forward kinematics algorithms can be used to calculate the exact position of the bucket's teeth. When compared to the global position of the underground utility lines (known to the system from the geometric modeling step), the bucket's teeth position can determine if the equipment is too close to a utility line. Appropriate warning messages can then be sounded for the operator.

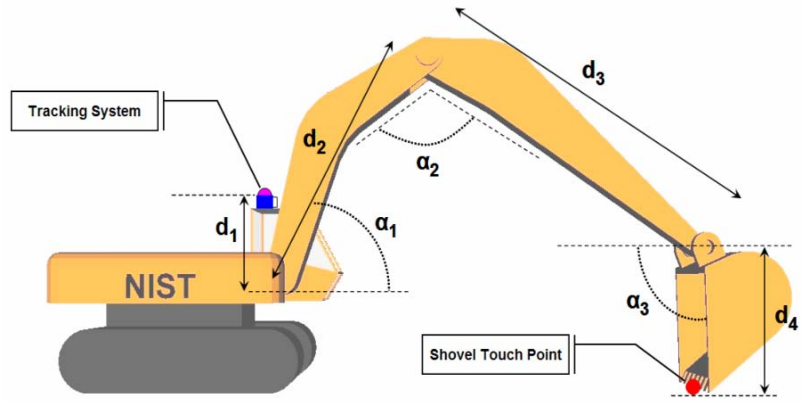

Figure 5 – Using Forward Kinematics to Calculate the Implement Position

A significant advantage of this alert system is that the output can be used inside a mechanical feedback loop which can override the operator and potentially stop the equipment in case of a real life threatening emergency.

VALIDATION RESULTS

The presented work is part of a larger ongoing research project that explores the use of AR visualization in supporting the planning and design of construction operations. The authors have successfully developed and tested the mobile apparatus illustrated in Figure 3 which enables a site engineer to “look” at underground utility lines in locations where actual excavation operations take place (Behzadan et al. 2008, Behzadan and Kamat 2007). The design of this AR visualization system is generic and it can be used to visualize any type of operations and display the results to a freely moving user in real time. Several proof-of-concept experiments using different operational scenarios have been conducted to validate the functionality of the designed visualization system (Behzadan 2008).

Figure 6 shows an AR visualization scene of a steel erection operation created by the mobile AR visualization system. The virtual elements of the visualized scene depicted in this Figure are CAD models of columns and beams, as well as a tower crane. The user of the system is equipped with the designed mobile AR apparatus and is able to navigate inside the visualization and look at the superimposed graphics from different perspectives and positions. While this Figure illustrates how the designed system can be used to visualize an operation above the ground level, the same setup can be effectively used with CAD models of subsurface utility lines to visualize an underground environment such as a trench excavation.

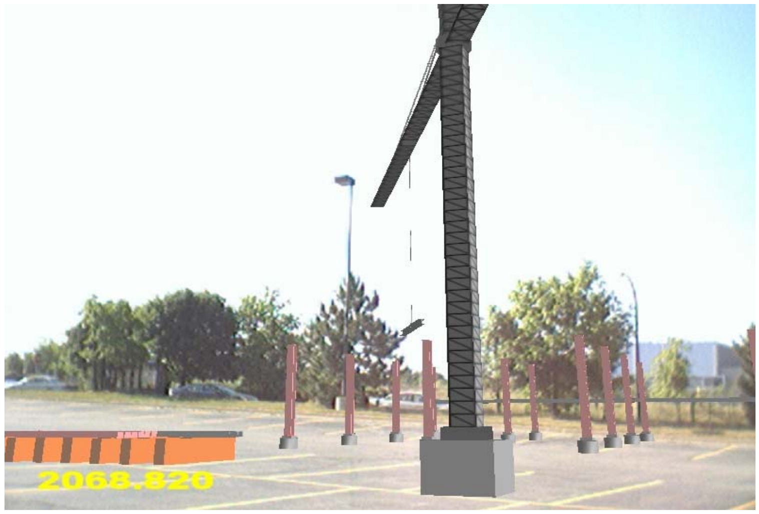

Figure 6 – An Augmented Reality Animation of a Steel Erection Operation

CONCLUSION AND FUTURE WORK

In this paper, the critical need of protecting underground facilities during a typical excavation process was highlighted. Design and implementation of an AR visualization system which enables equipment operators as well as other site personnel to look at virtual models of subsurface utility lines at the excavation site was also discussed in detail. Experiments with the designed hardware and software system prove the feasibility of the idea of creating real time visualizations of computer models on top of live video backgrounds. Such visual information support can significantly reduce the risk of damaging hidden utilities by enhancing the operator's perception of the environment in which the actual operation takes place.

The authors are currently working on the design of a safe and secure method of mounting tracking and video devices on typical construction equipment. The design must enable continuous data transmission between the construction machinery and the visualization system without limiting the equipment's motion and exposure to the elements of the excavation site. In addition, work is in progress to develop robust forward kinematics algorithms to calculate the exact position of the equipment implement based on the incoming data of the GPS device. This also requires installing motion sensors and orientation trackers in different locations on the construction equipment to provide the system with real time configuration and angular motion data.

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