Integration of Positioning and Computer-Aided Drafting and Design Technologies for Transportation Facilities

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The advent of improved computers has brought about unique potential for improved control of construction projects. One area of control is in the integration of computer-aided drafting and design (CADD) and positioning of data to provide real-time data to equipment and personnel on the site. The components required for real-time data about positions within a site include CADD and animation software as well as specialized hardware. Some current research has taken place at Virginia Polytechnic Institute in the area of the interface between CADD and positioning. Three areas of current research in the area of positioning are of interest. Potential applications and benefits of the interface between CADD and positioning range from surveying to controlling autonomous vehicles.

The power of computing is continuously changing perceptions of what is and is not possible. Raw processing speeds and graphic acceleration seem to be growing at an ever-increasing rate. This growth is enabling computing applications that were impossible a few years ago.

Some applications that have become possible because of this increased speed are in the areas of computer-aided drafting and design (CADD) technology and near real-time positioning technology. The CADD technology to be discussed is based on hardware and software in the Civil Engineering Department of Virginia Polytechnic Institute (VPI). The hardware and software to be discussed include CADD and CADD model animation capabilities. The positioning technology to be discussed is limited to current research at VPI. These areas of research include positioning with radio waves, lasers, and charge-coupled device (CCD) cameras. The potential applications of the interface between CADD and positioning will be limited to the area of construction improvements in transportation facilities.

HARDWARE AND SOFTWARE DESCRIPTION

Real-time positioning of moving objects or equipment requires fast graphics processing with state-of-the-art animation capabilities. The following subsections describe the components being used at VPI.

Software

The software includes three basic systems. These systems include a CADD package called Microstation, a CADD library and overlay called 3DM™, and an animation and visualization package called WALKTHRU™.

Microstation is a CADD product designed to run on Intergraph equipment as well as 386-based personal computers (PCs). Microstation offers excellent flexibility and ease of use for generating models. Because Microstation can be transferred from a PC to an upper-end Intergraph workstation, less complex work can be done on low-end workstations and moved to other workstations for more complex activities. Microstation is currently running on several platforms, including Intergraph Models 120 and 360, and several 386 PCs.

The 3DM™ product, made by Bechtel Software, runs concurrently as an overlay to the Microstation software. The 3DM™ product runs on all the platforms that run Microstation. Its system is primarily designed to facilitate rapid model generations and to extend the functionality of the Microstation software. The 3DM™ system runs at several different utility levels, depending on the machine on which it is being operated. The bulk of the 3DM™ program and library is resident on a Microvax. From the Microvax, the required components are accessed and down-loaded to each workstation via an Ethernet connection.

The WALKTHRU™ product, also by Bechtel Software, is an animation and visualization package that can rapidly manipulate CADD models given graphic acceleration capabilities. This program is designed to allow the user to graphically walk through a CADD-generated model. This walk-through allows for improved constructability review, as well as improved understanding of the overall model. The WALKTHRU™ animator retains dimensioning and coding details from the CADD-generated model. The dimensioning and coding details are required to interact with the positioning system.

Hardware

The hardware being used at VPI includes Intergraph and 386 PC workstations, a SUN 4/Raster Technology minicomputer, and a Microvax. All the hardware is linked via an Ethernet connection. The linkage allows for rapid file transfer from any system to any other system.

The Intergraph equipment includes several Model 120 and one Model 360 workstations. The primary use for this equipment is the generation of CADD models. Several 386 PC workstations can also generate CADD models.

The Sun 4/Raster Technology equipment is the platform used for graphics manipulation. The Raster Technology

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equipment is a graphics accelerator that allows for real-time viewing and manipulation of complex images.

The Microvax is used as a file server and storage device. Larger models can be stored and accessed through the Ethernet connection. The access and retrieval of data and models are transparent to the user.

POSITIONING DATA

The last pieces of data required for the integration of CADD and positioning technology are the positioning data. This positioning data must by *x*, *y*, and *z* coordinates of multiple identifiable objects. The data must be acquired and interfaced in real time, which is more easily said than done.

Several positioning systems being studied have the potential to provide real-time positioning data. These systems include scanning lasers, global positioning satellites, and laser bar codes. These three systems offer various advantages for differing applications.

The three positioning systems being studied at VPI are the automated positioning and control system (APAC), the automated laser positioning system (ALPS), and CCD cameras. The three systems are described in the following paragraphs.

APAC

The APAC system is a result of a National Science Foundation construction automation grant. The system consists of components shown in Figure 1. The APAC project has tested a series of prototypes and should provide accuracies in the 12-in. range given a marketed product development. The work has demonstrated the feasibility of the system and provided confidence in the system. The project is expected to be completed about March 30, 1990 (*1,2*).

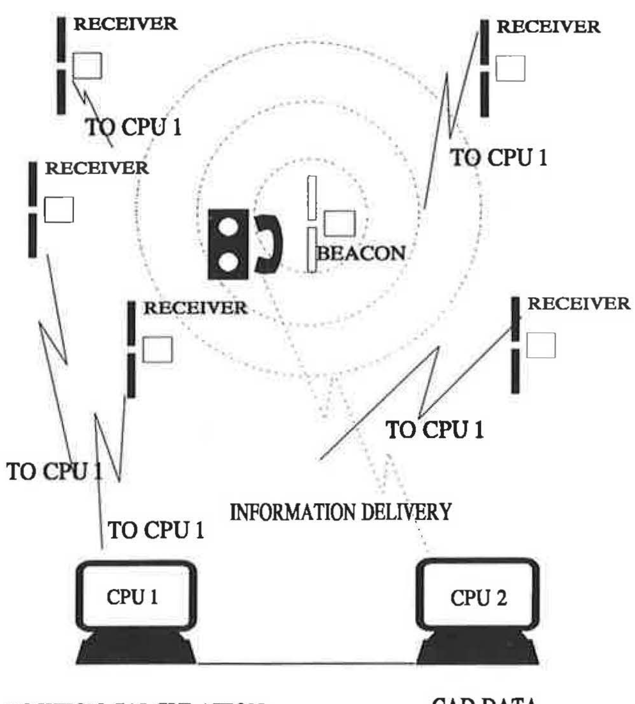

FIGURE 1 APAC system components.

The envisioned APAC system will provide for a frequency-hopping transmission of radio waves at a point within the site. A series of prelocated receivers with known *x*, *y*, and *z* coordinates will be around the site. The relative phase differences between each pair of receivers will be determined. CPU 1 will calculate the position of the beacon. The position data will be sent to the CADD data base in CPU 2. The CADD data base can be used to inform the individual or machine at the beacon of its current location or task. The positioning data integration with CADD data will be accomplished via the WALKTHRU™ animation system (*3*).

The APAC project has tested a 500- by 325-ft site. The site is in rolling terrain with a maximum of 35 ft in elevation change. Two receivers are at each corner of the site. One is 5 ft above the ground, and the other is 22 ft above the ground.

A test in early December 1989 demonstrated an accuracy of ±1.5 ft in the *x* and *y* coordinates and ±3.5 ft in the *z* coordinates. This test also confirmed some unresolved signal drift. This drift problem should be resolved shortly, and a more robust test of the system will be performed.

ALPS

ALPS is a method of determining the *x*, *y*, and *z* coordinates of objects using lasers. Accurate positioning is possible using a system with a rotating laser and laser detectors. By providing continuous position information on the *x*, *y*, and *z* coordinates, the system is ideal for point positioning and tracking moving objects, such as construction equipment. The currently envisioned ALPS will use a laser mounted on a vehicle; however, refinement to the system indicates that a system with lasers at the perimeter and detectors on the vehicle can be used.

The laser used in ALPS produces a narrow beam of light that is rotated perpendicularly about the vertical axis at a constant angular velocity. The laser beam strikes laser detectors in known locations. On being struck, the laser detectors become excited, allowing electrical pulses to flow through momentary circuits. Figure 2 shows the basis of ALPS in the horizontal plane, and Figure 3 shows the *z* coordinate.

Each laser detector is excited and creates an electrical pulse. Measuring the time difference between the electrical pulses provides the information of calculating the angle between the photodetectors from the rotating laser source. Using these angles, the *x* and *y* coordinates are determined by trigonometry. The *z* coordinate is determined by resolving the position at which the laser beam strikes the detector's vertical axis. This process is shown in Figure 3. The laser is mounted on a servo-stabilized platform, which allows for a level or nearly level plane. The platform is similar to those used by movie crews to film high-speed car chases. The platform is in a vehicle and can provide a completely smooth ride for the camera crew as the scene is filmed. The microprocessor converts the time and electrical impulse data into coordinate information. This system is expected to provide accuracies of less than ¼ in. in the *x* and *y* coordinates and ⅛ in. in the *z* coordinate.

ALPS seems to be an ideal method to get extremely accurate data on a real-time or nearly real-time basis. Given a 1-

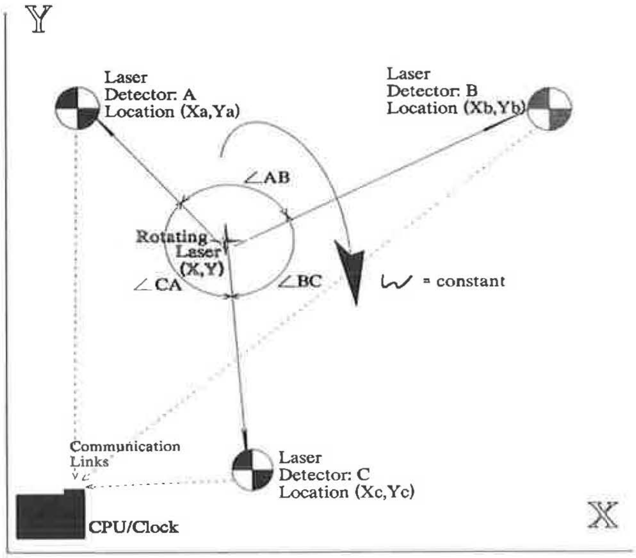

FIGURE 2 Determination of *x* and *y*.

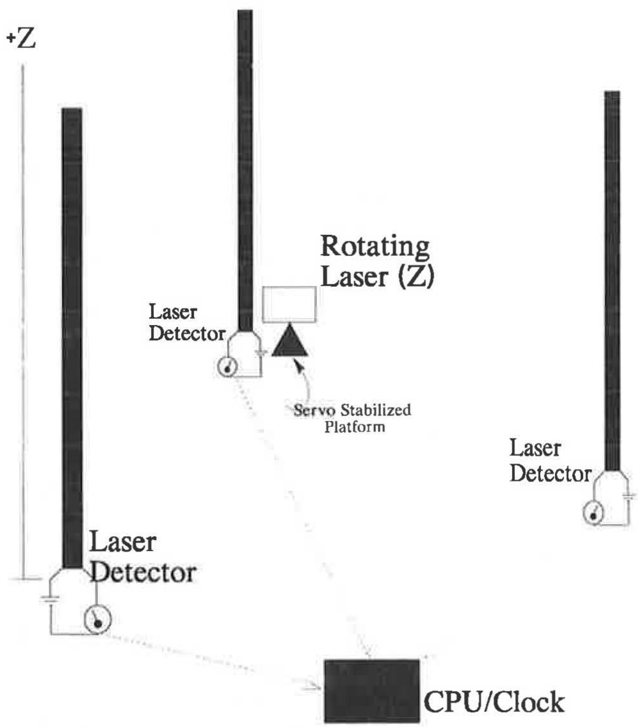

FIGURE 3 - Determination of *z*.

km² site, accuracies in the 1-cm range are expected to be possible. Accuracy would improve as the size of the site is reduced.

Several tests have been performed to determine the physical limitations of existing lasers and detectors. These tests were documented by Lundberg (*4*). The tests and a review of the existing technology verify accuracies in the ±¼-in. range on a 1,600- by 1,600-ft site. Additional work is being done, and a prototype system is being envisioned.

CCD Cameras

CCD cameras are currently being used on satellites to analyze existing surface features and variations from past surface feature analysis. A CCD camera uses photosensitive cells that are activated by light. Momentary circuits provide the capability of measuring light intensity and color. The 6,000-cell linear array cameras are in an orbit 500 mi above the earth. This system can provide 35-ft accuracy in *x*, *y*, and *z* coordinates given stereoscopic views of similar areas. A 4,000-cell linear-array CCD camera is currently available from Kodak at a price of about $12,000. This camera would provide theoretical accuracies of ¼ in. if cameras were positioned 1,000 yards from the objects of interest.

The Kodak CCD camera takes 1.5 min to sweep a 4,000- by 5,200-cell array. This length of time would preclude using the camera for real-time information gathering; however, this type of CCD camera would be ideal for as-built data analysis, which does not require real-time information.

Several 2,000- by 2,000-cell CCD cameras are available and can provide four updates per second. These CCD cameras would provide accuracies in a ⅛-in. range from 100 yards away.

The amount of processing required to analyze a number of 2,000- by 2,000-cell digital data components would be extremely large. Parallel processing or reduction in the area of study would be required to increase the system's performance to allow for real-time processing.

The interest in positioning using CCD cameras is mitigated by the cost of developing such a system and the speed of existing processors. The speed of the existing processors would have to increase a hundredfold to adequately attempt the solution without parallel processing. With parallel processing, the system could be accomplished today but at significant cost. The ever-increasing speed in processing capabilities may make real-time processing using CCD cameras possible in the near future.

The current approach at VPI is to work in peripheral areas of CCD technology. Specifically, these technologies are in the areas of stereoscopic image analysis and CADD interface. The envisioned system would be reversed engineering of existing facilities.

POTENTIAL USES OF THE CADD AND POSITIONING INTERFACE

A CADD and positioning interface is possible with today's technology. How the positioning data are obtained is subject to the system chosen. Each system described in the preceding section should provide varying degrees of accuracy. The potential usefulness of the interface is limited by the system's accuracy and update time.

The positioning systems were assumed to provide real-time positioning data with accuracies in the ¼-in. range. This accuracy is given as a target for several positioning systems. Such systems have several potential uses in the construction of transportation facilities. These uses are listed in order of accuracy demands, from the least to the most complex.

Cross-Sectional Analysis of Site

The simplest application of the CADD and positioning link would be to use it for quick and accurate topographic analysis. This analysis would be accomplished by driving a measurement vehicle with a beacon mounted on it. The beacon would continuously provide a method of recording *x*, *y*, and *z* data about the terrain. Although initial surveys would probably have been done already, this method could easily determine the actual site terrain at any point in time.

Current work at VPI includes the development of a graphics output module. The graphics module will directly output a terrain model from random *x*, *y*, and *z* position data. The model will be a three-dimensional representation and can be updated and recorded as the project is constructed.

Quantity Survey for Work

The next extension of the CADD and positioning link would be to provide a survey of the amount of work accomplished. This survey would use a measurement vehicle and beacon, like the cross-sectional analysis, but before starting the movement of the vehicle, a specific item would be identified and the survey would respond to that item. For example, the extent of subbase accomplished to date could be measured. The driver of the vehicle would first access the CADD data and enter the work item "subbase." All subsequent position data would be in reference to the subbase. All other work items of interest would be recorded in a similar fashion.

Laydown Yard Control

On larger projects, especially projects with multiple structures, the location and management of individual components can become extremely difficult. The current practice is to provide laydown yards around the site for these materials. Components can be temporarily or permanently lost, causing production and planning delays.

A laydown yard control system using positioning technology and bar-code reading technology is a viable alternative, especially if the entire site has been equipped with a positioning system. Figure 4 shows such an inventory control system (*5*).

The radio frequency (RF) portable terminal in Figure 4 would be a communication device as well as a beacon transmitter for positioning. In addition to the RF portable terminal, a laser bar-code scanner would read and record the identifying bar-code. The data display would include a map of the pertinent laydown areas with *x* and *y* coordinates for the specified component.

The laydown yard control system would be able to provide position coordinates for any item in the laydown yard. When a component is delivered to the laydown yard, a bar-code would be affixed to identify its specific characteristics and

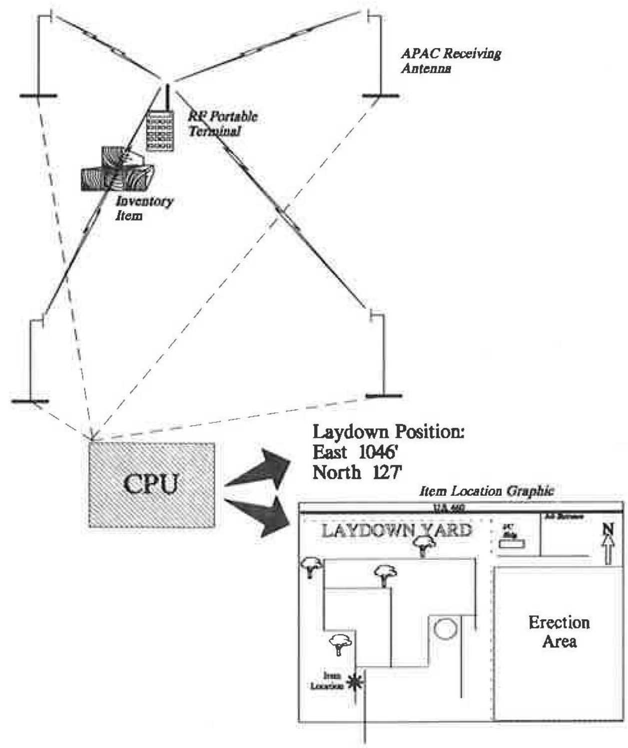

FIGURE 4 APAC system location of inventory.

object identification. After the component is placed in the laydown yard, a beacon would be activated, along with a readout of the bar-code. The object identification and its position coordinates would be stored for future retrieval. When the object is needed, the object identification would be accessed and the position coordinates would be obtained. A view of the laydown yard with roads and other pertinent terrain would be provided, with a point locating the position coordinates. A hand-held beacon would be able to direct the individual looking for the item to the required position.

A small-scale, 20- by 20-ft site has been tested. The position system used was the APAC system. A bar-code and inventory system from Omni Computer service of Piney Flats, Tennessee, was linked to the positioning system, and a two-dimensional output screen provided a visual representation of an automated vehicle. This test is further described by Lundberg and Beliveau (*5*).

Equipment Tracking

The positioning system will be able to track and monitor equipment movement through the construction site. Cycle times, queue lengths, and other delays can be immediately observed and researched. Traffic congestion and bottlenecks can easily be viewed.

The position for each piece of equipment will be recorded throughout a work day. Knowledge-based systems could be devised to study patterns and cycles. The output produced would be information on optimal equipment mix and rerouting schemes.

Grading Control

Grading control can be provided to equipment on a real-time basis as excavation work is done. The update rates for the position could be as high as 45 times per second. This update rate is significantly greater than the needs of most equipment; however, the rate would provide sufficient accuracy for all normal construction activities.

The system would work as follows:

1. The equipment operator would identify the grade activity of work being done. For example, a bulldozer is doing fine gradings for a roadbed.
2. As the equipment moves around, its current x, y, and z coordinates, including its slope and orientation, can be calculated and continually updated.
3. Sensing components would determine the elevation and orientation of the blade in reference to the positioning hardware on a piece of equipment. (These types of sensing components are currently available.)
4. The CADD data would constantly be polled in reference to the position and orientation of the blade with continuous readout of actual blade elevation as opposed to desired subgrade elevation.

Such grading control could provide a significant increase in productivity and work quality over present-day construction methods. The extension into partially automated or fully autonomous vehicles could further increase productivity and quality.

SUMMARY AND CONCLUSION

Research at VPI in the area of the CADD and positioning interface is proceeding. Information on the hardware and software required for real-time data availability to site personnel was presented, and some potential applications were provided. The status of the research on various systems was also provided.

CADD is currently approaching some maturity in the area of design. However, its use in the areas of planning and construction is in its infancy. A CADD and positioning link that offers real-time data will significantly change the productivity and quality of the construction process.

Positioning systems are the primary missing link to accomplish this construction improvement. Significant efforts using a number of different methods are underway. Researchers at VPI are studying the APAC system, ALPS, and CCD cameras for positioning. Several other positioning systems have been demonstrated to provide x, y, and z position data. Most notable of these are globally positioning satellites and scanning lasers. The systems being researched at VPI are other methods to obtain positioning data. However, the applications will work with any positioning system. As these positioning systems evolve, their accuracy will increase and cost will decrease. Consequently, methods of equipment control and surveying will be in for a potential revolution.

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