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The U.S. Army Corps of Engineers (USACE) Topographic Engineer Center (TEC) and Caterpillar Inc. are cooperating in the joint research and development of a system to position, track, and maneuver construction and other equipment during their normal construction activities. The positioning system will be based on software developed by TEC that uses the Global Positioning System (GPS). This software will be integrated with Caterpillar developed software tools that serve to automate the construction activities and increase productivity and safety.

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CATERPILLAR AND TEC JOINT RESEARCH PROJECT: CONSTRUCTION VEHICLE NAVIGATION AND AUTOMATION

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BIOGRAPHICAL SKETCH

Mr. Walker holds a MS in the field of Surveying Engineering from Purdue University (West Lafayette,IN) and a BS in the field of Computer Science from Old Dominion University (Norfolk, VA). In 1988, Mr. Walker accepted a position with the U.S. Army Topographic Engineering Center. There he is responsible for maintaining and developing new software packages that will directly support the surveying and mapping function of the Corps of Engineers District and Division Offices.

Mr. Gudat holds a BS in Electrical Engineering from the University of Illnois with additional graduate studies at University of Calfornia Los Angeles. During his thirteen years at Hughes Aircraft Co., Mr. Gudat was responsible for the design of electronic controls and ECM signal processing systems for military aircraft, space vehicles and ground support systems. For the last fifteen years, Mr. Gudat has been a staff engineer at Caterpillar, Inc in Systems and Controls Research where is responsible for system design, integration and test of autonomous earthmoving vehicles. Mr. Gudat has received many patents and is a Registered Professional Engineer in the states of California and Illnois.

ABSTRACT

The U.S. Army Corps of Engineers (USACE) Topographic Engineer Center (TEC) and Caterpillar Inc. are cooperating in the joint research and development of a system to position, track, and maneuver construction and other equipment during their normal construction activities. The positioning system will be based on software developed by TEC that uses the Global Positioning System (GPS). This software will be integrated with Caterpillar developed software tools that serve to automate the construction activities and increase productivity and safety. This project will produce an idealized autonomous construction vehicle navigation and automation system that will be modified (adapted) to various construction vehicle platforms, platforms that include

an off-highway truck, a dozer blade, or a motor grader blade. Computer Aided Drafting and Design (CADD) tools based on the envisioned vehicle navigation system will be integrated -- offering the user highly accurate responsive production, planning and monitoring tools not currently available. This paper will summarize recent and future activities to complete the successful transfer of this technology from the government to the private sector.

INTRODUCTION

The majority of construction activities require some form of earth movement, whether it be grading, clearing, cutting and/or filling. Before, during, and after these construction activities, site surveys and stakeouts are constantly being performed to verify that the project area is consistent with the engineering design. In years past, these designs were drafted by hand and interpreted by surveyors in the field as to whether the proper quantities of soil are being excavated and/or deposited. With the aide of CADD and other automated surveying means, we are able to accurately and efficiently design and construct in the virtual world of computers. Until now that automation stopped when moved from the computer to the project site. In other words, earth moving equipment operators still rely on experience and wooden stakes accurately placed by surveyors to communicate the proper design surface.

In April 1993, the Topographic Engineering Center (TEC) and Caterpillar Inc. signed a three year Construction Productivity Advancement Research Program Cooperative Research and Development Agreement (CPAR-CRDA) to develop a GPS based construction vehicle positioning and navigation system that will be adapted to various construction equipment platforms. The envisioned system will combine the latest technology in GPS positioning along with a suite of CADD tools. This offers the equipment user computer-generated views to display and continuously update the topography during normal construction activities. The system will also produce as-built drawings of the construction site that can be electronically transferred back to the design engineer for verification of the proper design surface. The ultimate goal of this project is to eliminate the need for the traditional stakeouts in construction and earth moving projects.

In order for the CPAR-CRDA to be a success, there are two main components of the system which must operate without failure and be economically feasible in a construction environment. Before any automated earth moving activities can begin, the position of the equipment in the real world must be known. This information must also be graphically relayed to the equipment operator. Therefore, the positioning system and CADD interface (dynamic construction site data base) are the fundamental building blocks of this CPAR.

POSITIONING SYSTEM

The CPAR project will provide the equipment operator with GPS positioning information which is used to automate construction activities. A significant restriction to this activity is the ability to position in real time. In fact, until recently, the ability to position a moving platform with GPS (to a few centimeters) required very strict operational constraints and procedures which were unfeasible in a construction environment. In 1988, under funding from the Dredging Research Program (DRP), TEC began developing a real time GPS-based positioning system capable of delivering 3-D positions accurate to less than a decimeter over a range of approximately 20 kilometers. This real time system is based on algorithms developed by Dr. Benjamin Remondi of the National Geodetic Survey (NGS). Prototype development of the real-time system, termed On-The-Fly (OTF), was performed by the Special Projects Division of John E. Chance and Associations (JECA) Inc.

Currently the OTF real-time system requires dual frequency (L1/L2) geodetic receivers capable of receiving full wavelength carrier phase measurements during Anti-Spoofing (AS). A base/reference receiver is placed over a known control monument and its raw measurements are broadcast over a telemetry link via computer to the rover receiver. The rover setup requires a telemetry link (to receive reference station measurements), a computer, and a GPS receiver. The raw measurements from both the reference and rover receivers combined with the OTF algorithms are used to compute the rover's position in real time. The OTF system offers the opportunity to reduce the costs of construction and earth moving projects for the USACE and the private sector.

Real-time tests of the GPS based OTF positioning system aboard a hydrographic survey vessel were conducted in Norfolk, VA during August 1993. The results from these tests showed that sub-decimeter accuracy is achievable in a real-time dynamic environment. Following these tests, JECA/TEC completed the development of the prototype GPS based positioning system and performed a public demonstration of the system in Wilmington, NC and Astoria, OR in October and November 1993.

CADD INTERFACE

Today, the majority of engineering design work is being performed in a CADD environment. However, some of the benefits of CADD design work are lost when drawings are plotted and taken to the field as 2-D sheets. Extending the electronic automation (CADD) to the field will allow the equipment operator to view and update the design/terrain information during normal construction activities. Caterpillar has developed and demonstrated in-house, an on-the-machine dynamic construction site data base. This system is capable of updating the terrain in real time using a commercial GPS package. During initial tests, a dozer operator was able to cut a simulated highway out of a hillside while observing an on-the-machine display of the changing work site.

TESTING

There have been two experiments which test the effectiveness and feasibility of the positioning system and CADD interface.

First, the TEC hardware and positioning software were successfully combined with Caterpillar's Dynamic Site Data Base on a Track-type Tractor (dozer) at the Peoria Proving Grounds in December 1993. The machine operator was able to prepare a section of a highway construction site without grade stakes or a survey crew, relying on the geographical display on the machine only. Simultaneously, the dynamic construction site data was broadcast to a remote location (Reference Station/Base) and updated in real time to provide a current, topographic model of the site. This experiment proved to be a big success, i.e., the interface between the two software packages and the operator performed without failure. During the test, two possible locations for the GPS antenna were investigated, on the cab and on the blade. At this time, the cab appears to be the optimal location for the antenna, until a process can be developed to prevent modification of the as-built (terrain model) caused by raising the blade and moving to different sites.

Next, two repeatability tests were performed at Caterpillar's Technical Center in March 1994 to test the repeatability of the OTF positioning software over known baselines. These tests were conducted on a known test course to determine the precision of the OTF position results. The first test was conducted in the afternoon and the second the following morning, thus using different GPS satellite constellations. Several points were repeatedly observed during each test. The results between the tests verified that the OTF system can consistently measure in the sub-decimeter range.

FUTURE ACTIVITIES

Future activities of this CPAR-CRDA include: 1) Support for the development of robotic construction equipment and integration of spatial coordinates into a real-time CADD package. Preliminary discussions between TEC and Caterpillar have explored possible means of interfacing with CADD graphics packages and a further evaluation of protocols and standards will continue; 2) Currently the minimum requirement to successfully transmit the appropriate raw GPS data to both the reference and rover sites is a radio modem operating at 4800 baud (9600 baud recommended). A comparison of available radio links has so far not identified the "best" means of transmitting/transferring both the GPS data and construction site data base information; 3) At this point, only high cost geodetic receivers are capable of being used with the OTF positioning system. Further investigation into alternative procedures and use of lower cost receivers will be addressed.

In conclusion, combining OTF positioning and CADD demonstrates the viability of bringing this construction navigation and positioning system to a truly production level system.

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