GPS-BASED WIRELESS COLLISION DETECTION OF CONSTRUCTION EQUIPMENT

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Abstract: This paper reports on research related to avoiding collisions in construction sites using differential GPS technology. In this project, the researchers developed and implemented a system where GPS technology was used in tracking a single vehicle and relaying its information to a central server. Using another simulated vehicle, the server evaluated collision scenarios and sent cautionary messages to the roving vehicle if a collision is impending. The paper concludes with a summary of the application, along with a discussion of the limitations of GPS technology and the required augmentation by other technologies.

Keywords: GPS, collision detection, construction, robotics, automation

INTRODUCTION

Construction sites with regular and robotic equipment suffer from the potential of collisions between the various types of equipment. Such collisions are extremely costly in terms of their potential injury and other related costs and wasted time. The situation is further aggravated in sites with a large number of robotic equipment that is remotely operated from relatively long distances with the aid of cameras. In this situation, construction robotic equipment operators are often limited in their viewing fields due to insufficient cameras or bandwidth and other transmission challenges. The aim of this project is to detect and prevent impending collisions through the application of the Global Positing System (GPS) and wireless communications.

COLLISION DETECTION TECHNOLOGY

Several technologies exist for collision detection and avoidance. They differ in their cost, size, response time, reliability, and effective operational range. Ultrasonic technologies rely on high frequency devices. They have a low implementation cost, small size, and have a fast response time. They are not reliable under some conditions, and their range is only a few feet. Infrared technologies have been used for a while. They have a very small implementation cost and are small in size. However, they exhibit a high response time, are not very reliable, and their range is also very short. Radar technologies are perhaps the most effective for collision detection. Improvements have led to size reductions and high reliability. However, their cost is relatively high. Vision technologies have also been used for collision detection. However, their cost is extremely high due to heavy computational requirements. They also suffer from low reliability in some lighting conditions.

GPS technologies offer a multitude of benefits and their costs have been continuously decreasing. The major benefits of using GPS are that these technologies are not dependent on line-of-sight issues (to other vehicles), which is one of the major limitations of all the technologies listed above.

GLOBAL POSITIONING SYSTEM

Global Positioning System (GPS) is a satellite based radio-navigation system. There are 24 GPS satellites orbiting the Earth and transmitting radio signals. Based on measurements of the amount of time that the radio signals travel from a satellite to a receiver, GPS receivers calculate the distance and determine the locations in terms of longitude, latitude, and altitude, with great accuracy. GPS was created, and is controlled by the U.S. Department of Defense (DOD) for military purpose, but is available to civilian users worldwide free of charge.

GPS can be used in various areas such as air, land, and sea navigation, mapping, surveying and other applications where precise positioning is required. The system inherently has no limitation in speed or altitude, but U.S. DOD requires that commercial receivers be limited to operate below about 900 knots and 60,000 feet (18,000 meters).

Accuracy of GPS is the degree of conformance between the estimated or measured position, time, and/or velocity of a GPS receiver and its true time, position, and/or velocity as compared with a constant standard. Radio navigation system accuracy is usually presented as a statistical measure of system error and is characterized as predicable, repeatable, and relative accuracy (*Fundamentals of GPS*, 1996).

Figure 1 : Mount Fugen Volcano Site

The accuracy of GPS receiver is affected by errors caused by natural phenomena, mechanical failure of elements in the system, or intentional disturbance.

For the purpose of collision detection, real-time high position accuracies (sub-meter) are required.

TELE-EARTHWORK SYSTEM

In 1994, Mount Fugen volcano, situated in southern Japan, erupted (see Figure 1). Lava flows from the volcano flowed downhill threatening the town of Shimabara. A project was developed to construct two canals to channel away future flows into the Sea of Japan.

Since work of this nature is carried under the constant threat of lava flows, it was desirable to use in construction, an automated tele-earthwork system, remotely controlled from a safe distance (See Figure 2).

The Fujita Corporation, a large Japanese Construction conglomerate, developed and implemented a Tele-earthwork system. This system consists of dozers, backhoes, trucks, and other ancillary vehicles and equipment. The system is designed to be remotely operated and has been used in several projects as shown in Figure 3.

and large number of equipment, have proven

Figure 2: Fujita Tele-Earthwork System in Operation

1994: 1st trial at Mt. Fugen
(Excavating and transporting earth and sand) 6,500m3
1994: 2nd trial at Mt. Fugen
(Excavating and transporting earth and sand) 16,000m3
1994-1995: 3rd trial at Mt. Fugen
(Excavating and transporting earth and sand) 100,000m3
1997: Recovery from disaster of a slope collapse at Kumamoto
1997: Recovery from disaster of a slope collapse at Nagano
1997: 1st trial of unmanned constructing dam at Mt. Fugen
1998: Recovery from disaster of a slope collapse at Akita
1998: 2nd trial of unmanned constructing dam at Mt. Fugen
1999: 2nd trial of unmanned constructing dam at Mt. Fugen

Figure 3: Fujita Tele-Earthwork System Application

to be impractical.

COLLISION-RELATED ISSUES

In automated construction applications, especially in the case of remote operation, the lack of true visual and depth perception increases the likelihood of collisions between equipment involved in the operation.

And while the literature is full of work related to optimum path selection for robotic and automated equipment, the implementation of these algorithms, especially in earthmoving sites with their constantly changing topology

The mostly widely used technology for collision detection is radar-based. And while this technology is excellent for avoiding outright collisions, it is ill-suited for applications that involve work in dirty environments, with large objects or terrain obscuring other vehicles that are not detected by radar. Here GPS technology comes to the rescue.

Because the technology does not rely on line of sight to other monitored vehicles, the researchers developed an architecture for sensing and warning vehicles of impending collisions as shown in Figure 4.

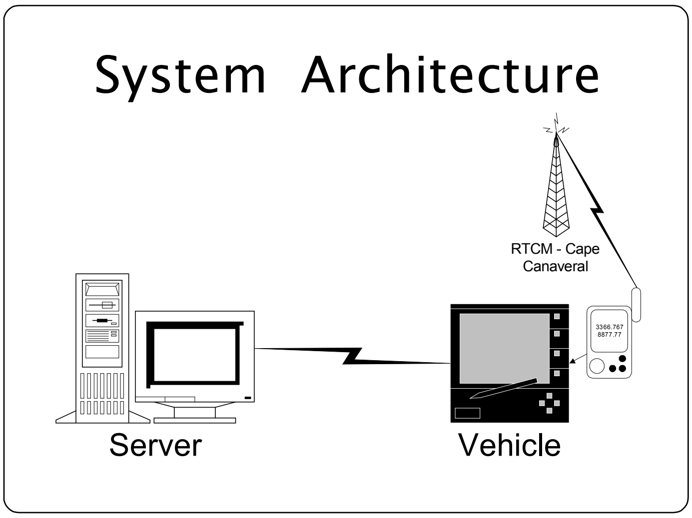

Figure 4: System Architecture

Figure 5 shows the schematic of an advanced technology construction system developed by Fujita Corp. All of the construction equipment at the site operates without on-board drivers. The vibrating roller moves autonomously, aided by GPS. Another backhoe, bulldozer, and two dump trucks are remotely controlled, each by a different operator.

While operating the equipment, each remote operator had to be watching several screens showing images from a camera on the vehicle, and another remotely controlled camera at the site. This denies operators the improved capability of controlling equipment in reference to "true" 3D perspectives. To avoid collisions, this architecture required increased vigilance by operators, and frequent verbal warnings among operators.

In this project, the proposed collision detection system would have substantially improved construction efficiency, and reduced operator overload.

HARDWARE ARCHITECTURE

The hardware is comprised of two subsystems, a server subsystem, and a mobile (rover) subsystem. The server subsystem consists of a PC-based server connected to a radio. The rover (equipment side) consists of a differential GPS system receiver, GPS, a laptop, and a radio.

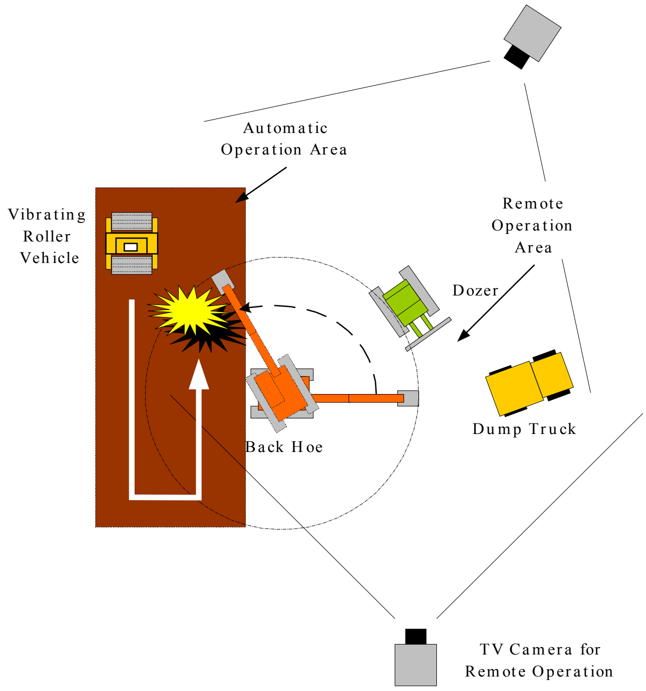

Figure 5: Arrangement of equipment in site

SOFTWARE ARCHITECTURE

The software architecture is shown in Figure 6.

The software consists of:

1) Vehicle Software
This software receives the DGPS message and then sends it to the server. The position is formatted according to the RMC sentence.

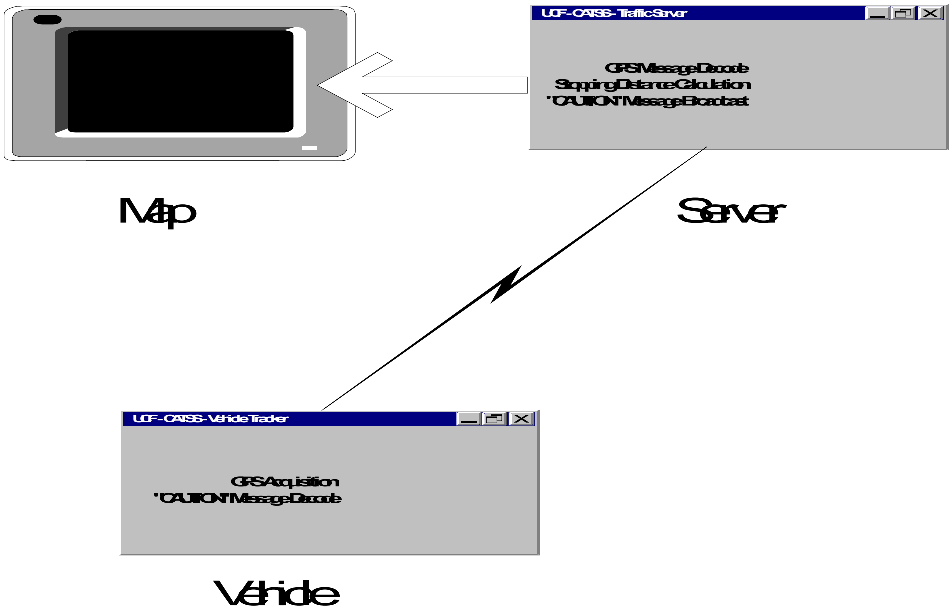

Figure 6: Software Architecture

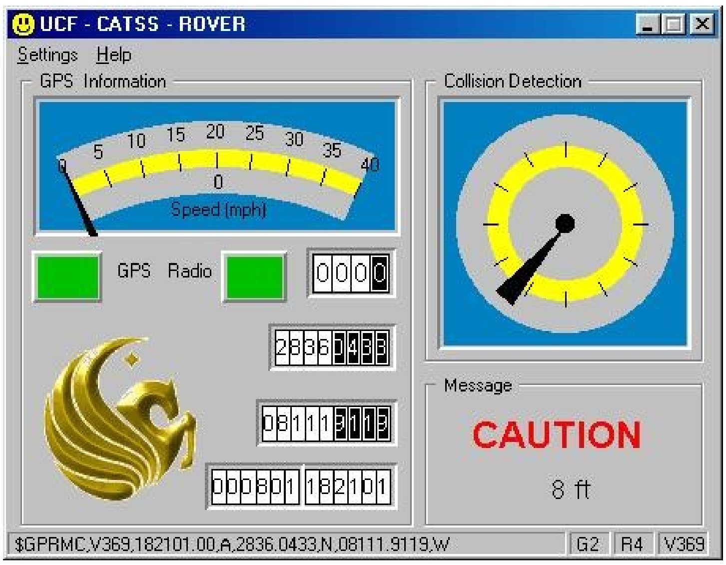

Figure 7: Equipment Operator Display

2) Server Software

This software receives position information from the construction equipment, and calculates potential collision scenarios with the simulated vehicle. If a potential collision is detected, the equipment operator is alerted with the speed and direction of the simulated vehicle (see Figure 7). The operator can also view construction equipment position, and track on a an aerial view of the construction site, as shown in Figure 8.

Figure 8: Impending Collision

COLLISION DETECTION ALGORITHM

The collision detection algorithm works by calculating the intersection point of the two vectors representing two moving vehicles. Each vector is defined by a point And a direction. In this case, The GPS position of the vehicle (i.e. vehicle location), and the vehicle bearing (also from GPS input) define each vector.

After the intersection point is computed, and knowing the vehicles' speeds from GPS, the program calculates the distance from the potential collision point to each vehicle location. The program also calculates the braking distance required for each vehicle in its operational scenario. If the braking distance required approaches the distances above (within a specified tolerance value), the server then issues potential collision alerts to the vehicles in question transmitting an alert message, along with the direction and distance of the vehicle in question.

CONCLUSION

This paper presents research aimed at utilizing GPS technology and wireless communications for collision detection on construction websites. The technology can be applied in both automated as well as traditional construction sites.

The technology presented here seems to have a lot of promise, however, several areas such as optimum system architecture, signal reliability, GPS accuracy, and potential differential signal latency and communications issues have to be evaluated.

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