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An Automated System for Quality Control of Compaction Operations : Receiver Tests & Algorithms

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Abstract: When other conditions such as roller frequency, wheel load, and compactor speed are the same, the density of asphalt pavement is dependent on the number of coverages of the compactor. If the mat is compacted with less than the determined number of passes, there may be a large volume of air voids leading to a low density. On the other hand, if the mat is overly compacted, the aggregates will be crushed further and the attributes of the mix will be changed leading to a reduction in density. For this reason, monitoring the exact number of coverages over the entire surface of the pavement mat is desired.

This paper reports on research that started three years ago to develop an automated system for mapping compaction equipment using global positioning system technology (GPS). This paper describes the system along with tests devised to evaluate GPS performance under various conditions.

Keywords: Quality Control, Pavements, Asphalt, GPS, Receivers.

WORK TO DATE

There have been many efforts to develop the automated methods for the quality control of pavement compaction. Previous research include Compaction Documentation System (CDS, GEODYN, 1985), MACC (Froumentin et al, 1996) using a laser positioning system, and the Compactor Tracking System (CTS, Li, 1995).

The CDS system was a system of monitoring the compaction process where data such as lane change, direction change, number of passes, layer number, start and stop of the compactor are entered manually by the operator during the process. Since there is no sensor to identify the orientation and position of moving compactor, the operator must follow the moving path, which is decided previously. The MACC is a prototype operator aiding system for compactors that displays a real-time two-dimensional colored map of the compaction pattern. It has a similar concept to the CTS, but uses a different position determining method. The position is determined by Computer Aided Positioning System (CAPSY, Spectra Physics), a laser system, while the position data for the CTS is given by the GPS. Also, the two systems use different methods for calculating the number of coverages. The MACC uses a raster based system whereas CTS uses a vector based algorithm.

ASPHALT COMPACTION & QUALITY CONTROL

The life of an asphalt concrete pavement is increased when the air voids are reduced during the compaction process. A low percentage of voids contributes to flexibility. A high percentage contributes to raveling and instability. If the compaction process achieves the desirable range of air voids, there should be no densification of the pavement after it is opened to traffic.

Compaction of hot-mix asphalt concrete is usually accomplished in three steps: breakdown, intermediate, and finish rolling. Breakdown rolling takes place just behind the paver and intermediate rolling follows. Then, finish-rolling smoothes out any rutting or deformation on the surface caused by previous rolling steps (Hot-Mix Asphalt Fundamentals, 1996).

The best way to determine the most efficient number of passes required to achieve the designed density for a job is to roll a test strip and monitor the results with a nuclear gauge (see Figure 2.5) or other density test measures.

According to a study (Kilpatrick and McQuate, 1967), the joint and edge of pavement tend to receive less compaction while the center of the pavement receives more compaction. Inadequate compaction causes low shear strength and stability, poor resistance to deformation and skid, and moisture damage.

For this reason, in order to achieve the best quality of asphalt pavement, uniform density over the entire pavement mat is desired. When other conditions are the same, density of the pavement depends on the number roller passes, therefore, monitoring the number of compactor coverages is very important for quality control of pavement.

THE GLOBAL POSITIONING SYSTEM (GPS)

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 satellites transmit two carrier signals, L1 and L2. The L1 frequency carries the P-Code (Precise Code), C/A (Coarse Acquisition) Code, and navigation message. The L2 frequency carries a P-Code and navigation message and is used to measure the ionospheric delay by PPS equipped receivers.

GPS receivers can be categorized broadly into three types based on accuracy: C/A code, carrier phase and dual frequency receivers. Each of the three types offers different levels of accuracy, and the price of the receiver is dependent on its accuracy.

C/A code receivers typically provide 1 ~ 5 meter accuracy with differential correction, with an occupation time of 1 second. Longer occupation time (up to 3 minutes) will provide accuracy consistently within 1 ~ 3 meter and can be reduced to 30 centimeter. Carrier phase receivers typically provide 10 ~ 30 cm accuracy with differential correction.

Dual-frequency receivers are capable of providing sub-centimeter accuracy with differential correction. Dual-frequency receivers receive signals from the satellites on two frequencies simultaneously. In order to acquire and use both frequencies, the reacquisition time is longer than other receivers.

Differential Correction of GPS Positions

Differential GPS (DGPS) is a means of correcting for some system errors by using the errors observed at a known location to correct the readings of another receiver (rover). A reference receiver, or base station, computes corrections for each satellite signal. Most of the errors caused by the sources discussed earlier are eliminated by differential correction. Differential corrections may be used in real time or post-processed (Dana, 1996).

The most important consideration in DGPS is that the base station and rover have to be tracking the same satellites and taking data at the same time. For this reason and for high accuracy positioning applications, the base station and rover should be within 15 km. The quality of the corrections is a function of the distance between the base station and the rover.

GPS Equipment Testing

Determining the appropriate accuracy range for this research is very important because the price of a GPS receiver is determined by its accuracy. If the accuracy of a GPS unit exceeds the accuracy needed for this application, the cost would be higher for unnecessary accuracy and the application may not be economically practical. On the other hand, if the accuracy is lower than needed, the application would be satisfied at a lower cost but the utility of the quality control would be questionable.

In this research, four GPS testing plans were developed, based on the nature of the compaction operation, and on the environment a compaction operation would experience on a typical construction site. The next section discusses selection of GPS receivers, then describes the four tests and their procedures.

GPS Receiver Selection

Based on the characteristics of GPS receiver discussed earlier, four GPS receivers were selected for testing. These receivers represent the categories of accuracy (centimeter, decimeter, and meter), frequency (single, dual, and GPS/GLONASS), DGPS type (post-processing and real-time).

GPS Receiver Testing

Four test plans simulating typical work environments of a compactor were proposed and performed to evaluate the performance and accuracy of the GPS receivers. The GPS receivers were tested under the same test environment and configuration setup for each test.

Test 1. Stationary Test

Objective of this test is to test the accuracy of stationary GPS unit and compare it with the accuracy that the manufacturer claims. The procedure of this test is following.

1. Base unit antenna was located on a point, A, whose position is known.
2. The antenna of the roving unit was located on a point B.
3. The position data was collected for one hour.

Test 2. Kinematic Test

The kinematic test involves testing the accuracy when the GPS receiver is in motion. In this test, the GPS receiver was moving back and forth, at a typical compactor operation speed (3 to 4 mph), along a 400-foot straight line on a running track. The length of 400 feet was estimated based on a typical compaction mat length (50 feet of cooling zone and 350 feet of compaction zone). The procedure for this test is following.

1. 400 feet of a straight line on a running track was measured and marked.
2. A GPS receiver antenna was mounted on a golf cart. The data was collected as the cart was moving along the line five times, back and forth

Test 3. Reacquisition Time Test

Because of the work environment of compaction operations, the antenna can be temporarily obscured with obstacles such as trees and overhead bridges. This test was performed to measure the reacquisition time of the GPS units and examine the difference between dual frequency units and single frequency units. Procedure of this test is following.

1. Base unit antenna was located on a point, A, whose position is known.
2. The antenna of the roving unit was located on a point B.
3. The data collection was started.
4. Waited until the number of satellites that the unit was detecting reached at least four satellites or an RTK-Fix signal then the antenna was covered completely with a metal plate for 30 seconds and then uncovered.
5. Waited until the number of satellites reaches at least 4 again consistently for next test duration.
6. Steps 5 and 6 were repeated three times for to check the consistency of measurement.
7. Steps 5 through 6 were repeated with duration of 1 and 2 minutes.

Test 4. Electrical Interference Test

The objective of this test is to measure effect on the accuracy when other radio signals from communication devices such as walkie-talkies transmit around the GPS antenna. In this test, a set of Maxon UHF radios (CP-0521) whose transmission frequency is 450 MHz was used. The following is the procedure of this test.

1. Base unit antenna was located on a point, A, whose position is known.
2. The antenna of the roving unit was located on a point B.
3. The data was collected for 20 minutes, and while the data was being collected, a set of walkie-talkie was located above the antenna within a distance about 20 centimeters.

ALGORITHMS

Software was developed that uses the positioning input to develop a graphical depiction of the number of passes executed over the length of the roadway. With a known compactor rolling pattern, parameters for drum width, wheel base, and compactor, the compacted area for each pass is determined. By means of continuously connecting the front edge of the compactor, a closed polygon depicts the compacted area during this elapsed time.

Using an algorithm created during the early phases of development of the CTS system, these polygonal footprints of the compactor are terminated and stored. At this stage, the system has a number of overlapping polygons. To find the exact number of passes in each point in the roadway, we need to process these polygons to find the number of passes over each point (see Figure 2).

There are two methods that can be used. The first is based on image processing technology where images of polygons are "rasterized" and cell values at each location on the roadway are accumulated to develop the total number of coverages. The second method for processing these polygons uses vector and polygon topology to achieve this result. In this case, intersection polygons are calculated.

Benefits of the Raster Method:

1. Simple to implement.
2. Requires no data smoothing.

Benefits of the Vector Topology Method:

1. Small amount of data needs to be transmitted.
2. Small polygons can be eliminated from the data set further reducing data size.
3. Potentially faster with multiple compactors.
4. Simple processing required on compactor eliminating need for expensive on-board computational devices.

For this research, the investigators used a vector-based polygon topology method

Problems with the current system:

1. Performance is too slow. This is primarily due to inefficient program implementation, and inefficient processing of polygonal data.
2. Data smoothing of position points has not been implemented.
3. System cannot handle data from multiple compactors.

CONCLUSIONS

The following are the important conclusions drawn from this research:

1. Average range of stationary and kinematic test results of three receivers satisfied the accuracy claimed by their manufacturers. However, accuracies of stationary and kinematic test cannot be compared because of the human errors in the kinematic test. Theoretically, accuracy of the kinematic test is higher than that of stationary test due to the impact of multipath.
2. Test results showed that dual frequency receivers are more accurate than single frequency units in the stationary and kinematic tests. However, the reacquisition time of the dual frequency receivers is much longer than that of the single frequency receivers.
3. When GPS signals are interrupted by other radio signals, impact to the accuracy is severe.
4. Among the three receivers from each accuracy group, decimeter accuracy receivers were expected to be acceptable for this application.
5. More work is needed to realize the benefits of a vector-based approach to the development of the number-of-passes.

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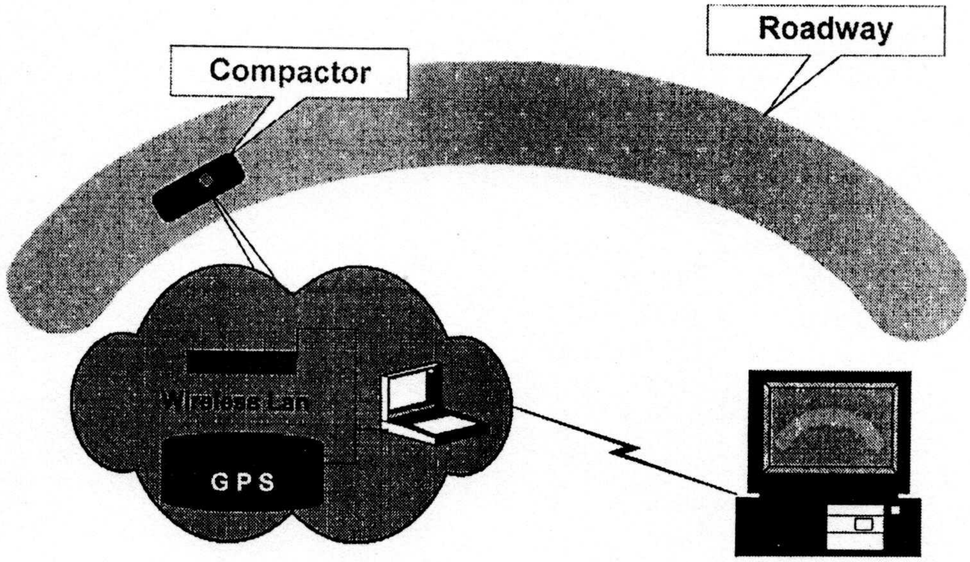
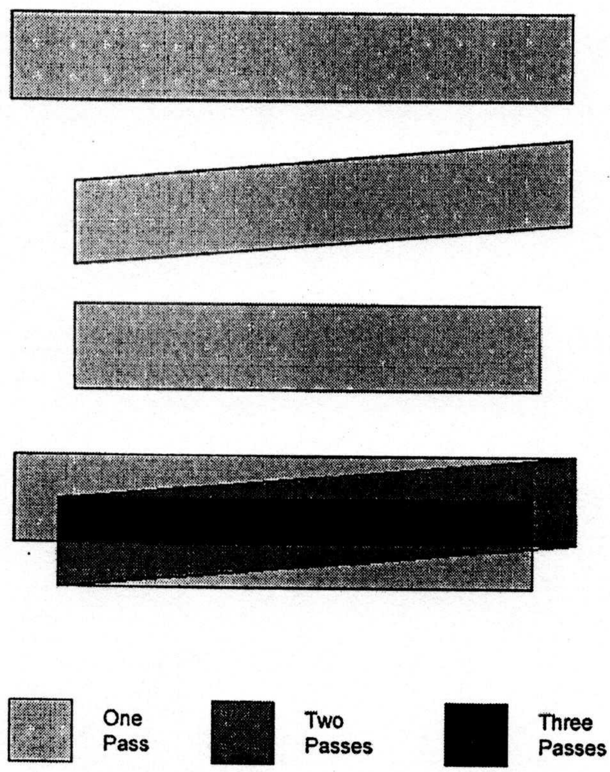

Roadway
Compactor
Wireless Lan
GPS

Figures 1 & 2


One Pass
Two Passes
Three Passes