Research Record

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Development of an Instrumented Vehicle to Measure Roadway Curve and Grade

Phase I of the Vehicle Development Process

What started out as an effort to save Michigan over $7 million in federal funding has turned into a seven-year long project that is still providing rewards for the Michigan Department of Transportation (MDOT). The project involved the development of an instrumented vehicle to accurately measure roadway curves and grades while traveling at highway speeds.

Before the project began, Robert Miller, data systems analyst with the Construction and Technology Division of MDOT, mentioned once in jest that they should survey the state with a cruise missile, because they are so fast. This comment was made in reference to the department's need for accurate, high-speed data collection for mapping to support other ongoing department activities. This long-remembered joke surfaced again as discussions began regarding the collection of the required data for the federal project. Although a missile guidance system wasn't used in this project, his idea wasn't far off and the comment helped to shape the course of the vehicle development process.

The project was initiated in response to the Federal Highway Administration's (FHWA) request for roadway data for the Highway Performance Monitoring System (HPMS) in 1989. The data needed for the HPMS included roadway capacity and serviceability of selected highway test sections and the road curvature and percent grade of each section. The curve and grade data for each section were to be classified into as many as 13 different groups. Each group classified curves by degree of curvature and grades by degree of slope. The test sections varied in length from a few hundred meters to over 32 km. All in all, there were approximately 6,774 km of total roadway among 960 sites to be evaluated. These sites were scattered throughout roughly 19,000 km of state trunkline.

Background

After receiving the request from the FHWA, MDOT starting collecting the required data. However, they discovered many obstacles in the collection of the curve and grade data. Initially, the department explored the possibility of using as-built plans for the test sections and extracting the required information out of them. This procedure didn't work out, as the process was slow and labor intensive. In addition, it was almost impossible to determine which sections of roadway had been updated and which set of drawings to use. The department also considered other alternatives for collecting the required data, including surveying and extracting the data off of aerial photographs. It was determined that surveying the test sections would be too costly and would provide more accuracy than was necessary for this project. The use of aerial photographs was also ruled out, as it would have been very labor intensive and costly.

In December of 1990, MDOT received another letter from the FHWA stating that the HPMS data must be submitted. Failure to submit the data would have jeopardized federal funding of the department's $7.1 million State Planning and Research (SPR) program. After receiving the letter, MDOT began exploring alternative methods of gathering the data; most notably, collecting the data using electronic methods.

The department submitted a cost estimate of $101,000 for development of the vehicle to the FHWA in June 1991. This estimate included the cost to purchase necessary equipment, and labor to equip the vehicle and to collect the data. In September of 1991, MDOT received approval from the FHWA. Once MDOT received the approval, they moved swiftly to outfit the vehicle, develop the necessary software, test the system, and collect the data.

In May 1992 the instrumentation was installed in the vehicle and by July 1992 the initial testing and calibration were completed. In October 1992, all of the data were collected and processed according to the FHWA requirements. Upon completion, the project was within budget.

Instrument Selection

In order to provide the accuracy needed to satisfy the FHWA curve and grade data requirements, the instrumentation had to meet the following criteria:

1. The system must measure and record its position relative to an initial position.
2. The device must be stable, with respect to its position determination, for a sufficient length of time to measure the longest test section. The device must also provide repeatable measurements.
3. The system must provide sufficient accuracy to "close a loop." In other words, after completing a test section, the coordinates at the beginning of the section should essentially be the same as at the end of the section.
4. The instrument must be able to detect a change in heading of 0.10 degree and a change in pitch of less than 0.01 degree.
5. For safety reasons, the system must operate at highway speeds. This specification was added by MDOT, as most of the testing was to be completed on highways. Failure to record the required data while traveling in the flow of traffic could pose a safety concern to MDOT personnel and other drivers.
6. The device must return data samples based upon roughly uniform time intervals. The control software will then re-sample the data at uniform 4 ft. intervals. The signal processing steps used in reducing raw data rely upon careful control of sampling intervals throughout data collection.
7. The system must collect latitude, longitude, pitch, heading, and distance traveled, or it must collect enough data so that the required items could be computed.

MDOT reviewed the specifications from twelve manufacturers of navigational equipment, based on the above criteria. Smiths Industries of Grand Rapids, Michigan, produced a navigational system for the Abrams M1A2 tank that, with modifications, met the criteria for the curve and grade project. The inertial guidance system is commonly referred to as a Positional Navigation (PosNav) unit.

System Description

The entire system, although complex in its operation, is fairly straightforward in appearance. The system consists of the PosNav unit, a power supply, a 486-based microcomputer, an electronic odometer, and an electronic compass. The PosNav unit and the computer communicate via a standard RS-422 serial cable at 9600 baud. The PosNav unit also receives auxiliary input from the electronic odometer. The system is mounted in a department-owned van.

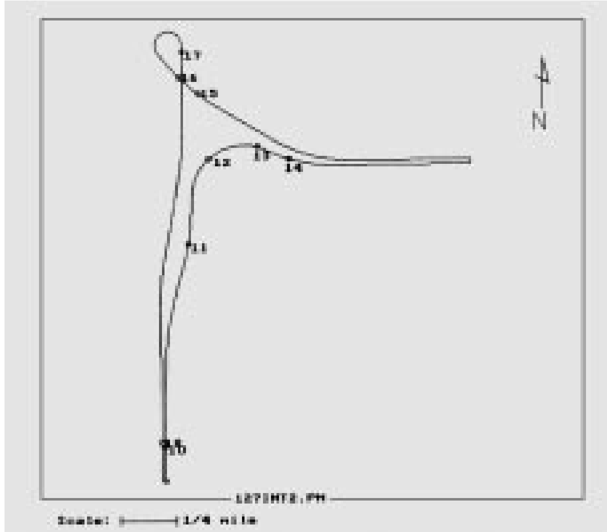

Figure I: Example of roadway map generated by post processing software

The PosNav unit is self-contained and has dimensions of roughly 7 in. x 10 in. x 6 in. The unit operates on 28 volts DC. The system is mounted to the floor of the vehicle on an adjustable aluminum plate to facilitate alignment with the vehicle's line of travel. This also allows for easy removal and quick reinstallation. The vehicle was initially equipped with a gasoline-powered, 110 volt generator. This has since been replaced with a power supply that consists of a set of batteries which are charged by the vehicle's alternator (refer to figure 2). The power supply is connected to a power inverter that provides power to the computer and PosNav unit.

The computer is equipped with a monitor and keyboard and is shock-mounted on a custom-built stand. The stand not only helps to isolate the computer from vehicle vibrations, but also has a large desktop and an adjustable keyboard stand that swivels out of the way when not in use. The stand also provides a convenient mounting location for the power inverter.

The electronic odometer sends a pulse to the PosNav unit approximately every 0.6 in. of vehicle travel. These pulses are used to synchronize the vehicle's position with the PosNav unit's calculated coordinates. The electronic compass is used to accurately determine the vehicle's heading at the start of each test section.

Software Development

In order for the system to function and to provide the data required by the FHWA, three computer programs had to be written. This included a program for calibration and testing, data collection, and data reduction.

The data collection program enables the computer to communicate with the PosNav unit. It handles input from both the operator and the PosNav unit and reconstructs positional information from the data received. The program receives data at 20 samples per second and linearly interpolates the data to record 4 ft. spatial samples, regardless of vehicle speed. This program also provides information about the status of the data collection process to the operator. This enables the operator to monitor the system for possible problems. Even though the computer is shock-mounted, vehicle vibrations or rough roads could cause the hard drive to fail. To safeguard against data loss, the data collection program stores information to a buffer, either memory or floppy disk, before writing to the hard drive. Additionally, a floppy disk backup of the program was prepared, just in case.

The calibration and testing program was developed to provide extended commands to the PosNav unit. Because this program has special privileges and could be used to alter the system's scaling and calibration, it was removed from the system once calibration was completed.

The data reduction program reads the raw data files and draws maps of the route on the computer screen. Refer to Figure 1 for an example of a roadway map generated by the software. Each section is identified and that portion of the data is processed and filtered to remove the effects of wind on the vehicle, driver steering variances, road roughness, and vehicle bounce. From this smoothed data, the required road features are extracted and classified. For each test section, a summary report of curves by degree of curvature and grades by percent grade is produced (see Figure 3).

System Calibration and Operation

The preliminary testing and calibration were completed in July 1992. This involved driving a number of test routes and entering data. The test runs served a number of purposes: they provided valuable input in the development of the first-of-a-kind software and enabled Miller to work out potential problems; they enabled the operators to practice and work out the best procedures for collecting data; they also provided validation of the system and permitted verification of positional accuracy based on known, surveyed locations. The testing also revealed the need for the PosNav unit to be positioned and oriented in the vehicle with extreme care. An early test showed some cross-track errors, resulting in a skewed map. The effect was traced to the fact the PosNav unit was reading distance data via the electronic odometer, which was initially located on the driver's-side front wheel. The PosNav was located behind the driver and the unit was sensitive enough to detect the difference in its travel path from that of the front wheel. The problem was solved when the PosNav unit was moved directly over the differential and the electronic odometer input was taken from the transmission. This permitted the PosNav unit and the electronic odometer to follow exactly the same path along the ground.

The system is sensitive enough that when viewing a map that it has generated, it is possible to detect where the vehicle has driven along the same route, but in different lanes. Also, at the end of a run, the PosNav is able to determine if it is parked in a different space than where it began.

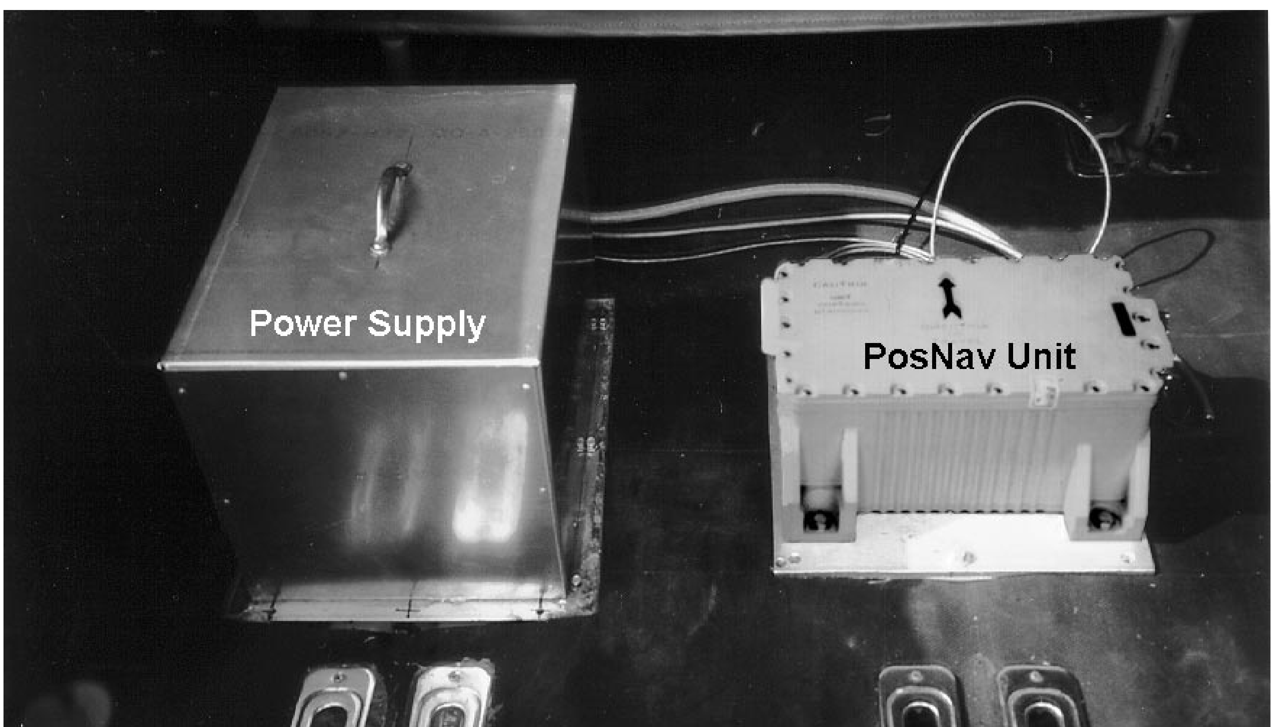

Figure 2: Positional Navigation Unit and power supply mounted in the back of the MDOT van

HPMS Curve and Grade Processing Log

File: D6629A.PN
HPMS Id: 1760230395110
6900 records processed.

Curves by Degree of Curvature

Class	Number	Miles
0.0 to 0.4	34	4.905
0.5 to 1.4	33	1.307
1.5 to 2.4	0	0.000
2.5 to 3.4	0	0.000
3.5 to 4.4	0	0.000
4.5 to 5.4	0	0.000
5.5 to 6.9	0	0.000
7.0 to 8.4	0	0.000
8.5 to 10.9	0	0.000
11.0 to 13.9	0	0.000
14.0 to 19.4	0	0.000
19.5 to 27.9	0	0.000
28.0 greater	0	0.000
Total length		6.212

Grades by Percent Grade

Class	Number	Miles
0.0 to 0.4	6	4.943
0.5 to 2.4	6	1.269
1.5 to 4.4	0	0.000
2.5 to 6.4	0	0.000
3.5 to 8.4	0	0.000
8.5 greater	0	0.000

Figure 3: Example grade processing log for one Highway Performance Monitoring System section

Two operators are required for data collection. One drives the vehicle while the other operates the computer and keeps track of the data collection. Both operators work together to identify measurement sites. They start the day with a printed listing of the route, which includes a description of the beginning of each test section relative to a visible feature, such as a county line, roadway feature, or mile marker. At the beginning of each test section the computer operator presses a function key to place a marker record in the data file. The driver watches an independent electronic odometer and warns the computer operator when they are approaching the end of the test section. Other function keys suspend and resume data recording while the vehicle is being driven between test sections. This avoids re-initializing the system. Typically, about a dozen test sections are recorded in a single file. At the end of each day, the data is copied to floppy disks, and at the end of each week, the floppies are returned to the office for cataloging, archival storage, and data reduction processing. Throughout the early stages of the project, the data was processed as quickly as possible to identify any potential problems.

The system worked very well during the data collection. Only 20 of the 960 test sections had to be re-measured. Of those sections, most were due to either misidentification, or the fact that during the first test run, the section was not accessible due to construction or maintenance. The team was able to collect, process, and submit the required data to the FHWA in approximately four months. This is much quicker than would have been possible using any other method of data collection.

Considering the FHWA funding that was at stake, the cost of building the vehicle and collecting and processing the data was a relatively small investment. In addition, the vehicle is still in use by the department on other high-speed mapping projects.

The vehicle has undergone a number of changes since the original curve and grade project. The next *Research Record* will discuss Phase II of the vehicle development, including the addition of a Global Positioning System (GPS) unit, and integration of the data collected into the ongoing Geographical Information System (GIS) which is being developed by MDOT.

Reference Material

Development of an Instrumented Vehicle to Measure Roadway Curve and Grade
Research Project: 92 G-280
Research Report No. R-1323
Leo DeFrain, Robert Miller, John Darlington
Michigan Department of Transportation, 1997.

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