Research Record

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Development of an Instrumented Vehicle to Measure Roadway Curve and Grade

Phase II - Integration of GPS

One of the hottest topics of conversation in the transportation industry is the use of Global Positioning Systems (GPS) and their integration into surveying and mapping operations. The Michigan Department of Transportation (MDOT) is no exception to these conversations, as MDOT has jumped feet-first into the fray with their ongoing GPS efforts. The Construction and Technology (C&T) Division of MDOT has been developing GPS technologies that will be used for a number of applications in future departmental operations.

A Step Back in Time

In the previous Research Record (please refer to *Research Record* #84), the development of an instrumented vehicle to measure roadway curve and grade data was discussed. This vehicle was developed by MDOT in response to the Federal Highway Administration's (FHWA) request for roadway data for the Highway Performance Monitoring System (HPMS) in 1989. The required data 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 more than 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. Failure to submit the data would have jeopardized federal funding of the department's $7.1 million State Planning and Research program.

A number of data-collection methods were explored and ruled out due to time and cost restraints. 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. 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 the project. The use of aerial photographs was also ruled out, as it would have been very labor intensive and costly.

It was at this point that MDOT decided to explore other electronic methods of collecting the required data within the time and budgetary constraints imposed by the FHWA. Using a specially equipped, department-owned van with an electronic odometer, an inertial guidance system (commonly referred to as a Positional Navigation (PosNav) unit), DOS-based microcomputer, specialized software written by MDOT personnel, and an electronic compass, MDOT personnel were able to equip the van, perform testing and calibration, and collect the required data in roughly a five month span. All of these operations were completed within budget and the collected data were processed and submitted on time.

The initial data collection system components were selected based on their ability to meet a number of criteria needed to gather the data in both a timely and accurate manner, and their ability to produce usable output. The PosNav unit is similar to those used in an Abrams M1A2 tank and is produced by Smiths Industries of Grand Rapids, Michigan. The PosNav unit and the computer communicate via a standard RS-422 serial cable at 9600 baud. The PosNav unit receives auxiliary input from the electronic odometer that sends a pulse 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 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 is equipped with a power supply that consists of a set of batteries that are charged by the vehicle's alternator. 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.

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

The calibration and testing program was developed to provide extended commands to the PosNav unit.

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, enabling the operator to monitor the system for possible problems.

The data reduction program reads the raw data files and draws maps of the route on the computer screen. 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.

Brief History of GPS

The GPS system is a satellite navigation system that is funded and controlled by the U.S. Department of Defense (DOD). GPS provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity, and time. GPS satellite signals are used by the receiver to compute positions in three dimensions and the time offset in the receiver clock. Even though the system was designed for, and is operated by, the U.S. Military, there are many civilian users of GPS world-wide. Common uses include marine and aircraft navigation, the use of hand-held GPS receivers for hunting, fishing, hiking, and other outdoor activities, and vehicle location systems such as moving-map displays in new cars. Police, fire and emergency medical service vehicles are being equipped with GPS receivers to determine the closest vehicle to an emergency, which will in turn provide the quickest response time. MDOT uses GPS systems in high-precision surveying, and in the tracking of maintenance trucks and snow plows.

Although the basic GPS is the most accurate radio-based navigation system developed, limitations in the standard GPS system prevent its use in civilian high-precision, real-time mapping and surveying operations.

A GPS receiver needs at least four satellites to determine position. Many receivers now monitor as many as a dozen channels and use as many satellites as possible. Satellite geometry (the distribution of "visible" satellites in space above the horizon at one particular moment) affects the positional accuracy of any receiver. Achievable positional accuracy of a single GPS receiver continually varies with this changing satellite geometry. Atmospheric effects distort the GPS signal paths and arrival times, add-

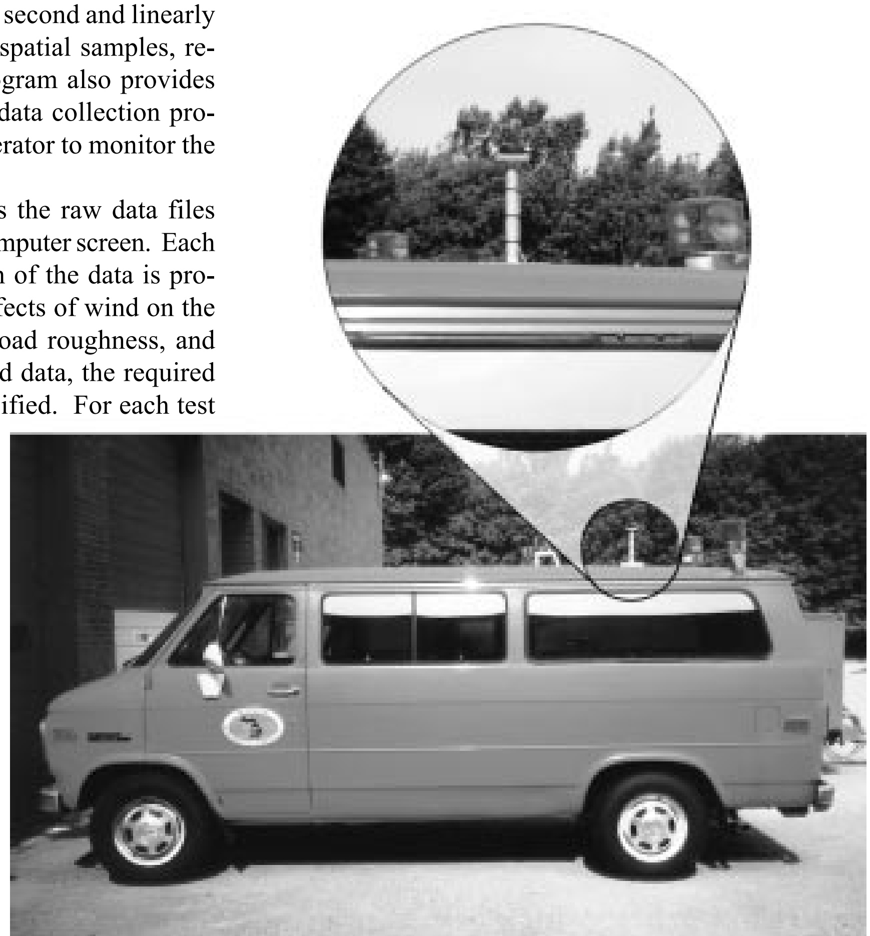

Figure 1: MDOT data collection van with blow-up of external antenna

ing to positional errors. Furthermore, the military purposely degrades GPS signals by disturbing the clock timing (called "clock dithering") and altering satellites' ephemerides (calculated position of each satellite). These two effects are called "selective availability" and are imposed to prevent highly accurate instantaneous position determination. This reduces the potential of unauthorized usage of GPS for military advantage. These combined factors hinder a receiver's ability to produce the accuracy needed for high-precision applications. At any one instant, a position may differ from a "true" position by as much as one hundred meters, but averaging positions over a time interval reduces this error considerably. Obviously, this is not practical in a moving vehicle.

Several techniques have been developed to overcome current GPS limitations. One technique is to capture raw GPS data and process it later. Accurate GPS satellite positions are published about two weeks later, when there is little or no military consequence of using that data. To make maps in real-time, another technique called Differential GPS (DGPS) can be used. DGPS uses a reference receiver at an accurately known position. This receiver compares a position measured from the satellites to its known position to determine this time-dependent error. It then transmits these differential corrections to the roaming receiver which applies corrections to its measurements. Using this technique, positions may be determined to within a few meters, or better.

Integration of GPS

As mentioned earlier, the previous system developed by MDOT was sufficient to provide the required curve and grade data for the FHWA HPMS project. However, upon the completion of that project, MDOT looked to the future and started to explore further uses for the vehicle. One of the biggest drawbacks of the previous system was that even though it was very accurate, the results were sometimes slightly skewed. The maps and data produced were very accurate, but this accuracy was relative to a given starting position.

An inertial system might compound any error in initial position and direction over a long survey run. At the end of a data collection run, the map created from these data might be slightly skewed or offset when compared to known positions. MDOT eventually implemented several techniques that can help identify and correct these effects.

In order to extend this system to apply to a wider range of important projects, MDOT added a portable Rockwell PLGR GPS receiver to the PosNav unit. Initially, GPS is used to provide more precise beginning coordinates to the inertial system to minimize one source of error. Given

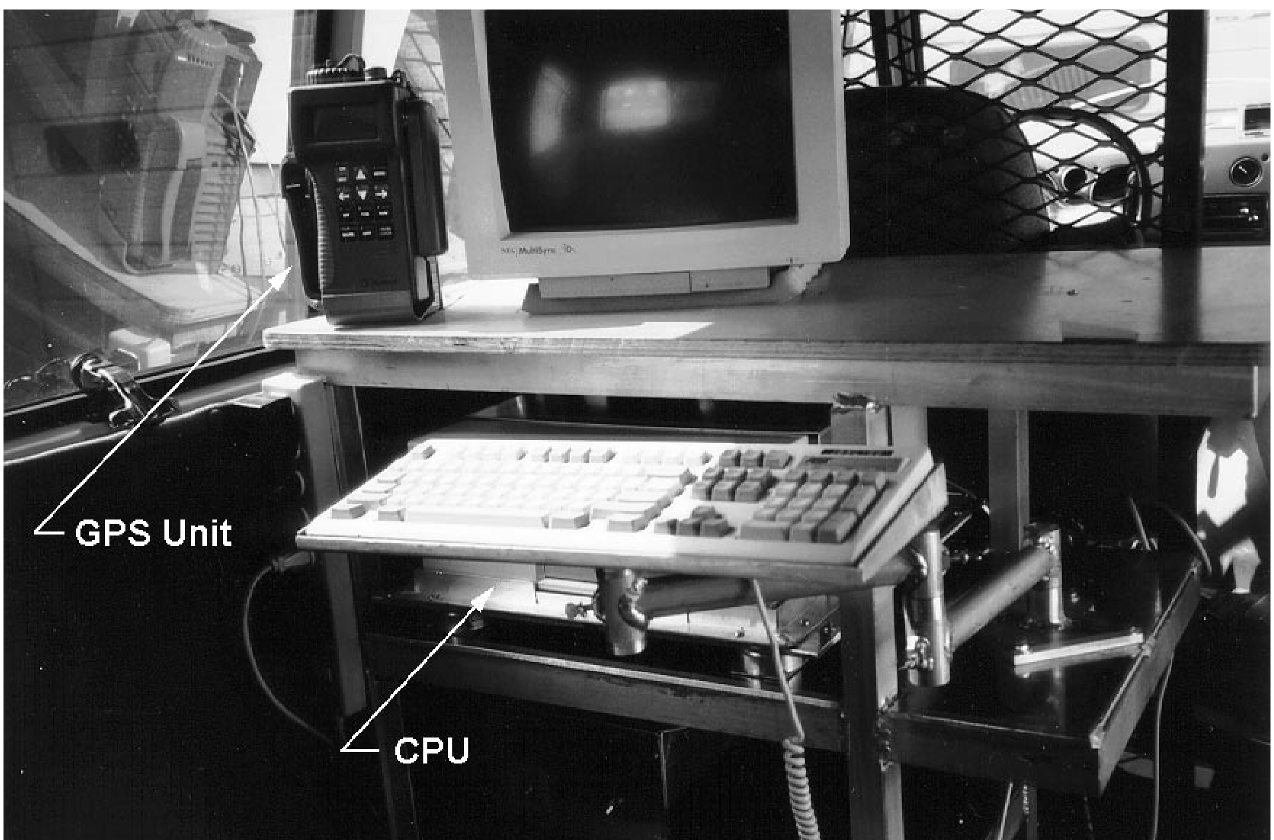

Figure 2: GPS Unit and computer mounted on custom-built stand in the back of the MDOT van

enough observation time and effort, GPS can provide ground positions with an error of only a few centimeters, but such techniques are nowhere near real-time. An inertial system can provide great short range accuracy. The trick was to use the best of both systems, while minimizing the inherent limitations of each.

Although the addition of GPS sounds simple, the process was much more involved than simply plugging a GPS receiver into the PosNav unit. Many subtle issues needed to be addressed, such as modifying PosNav to work with or without GPS, handling GPS interruptions such as when passing under a bridge, modifying the start up procedures, and filtering out such effects as wind on the vehicle, tire pressure, and vehicle loading.

Robert Miller, the data systems analyst with MDOT's C&T Division, worked closely with engineers from Smiths Industries, maker of the PosNav unit, to develop the required software and digital filters to enable the PosNav and GPS to function together optimally. This work involved a number of trips between Lansing and Grand Rapids in the van as different methods were being tested.

A technique of using Kalman filters, which is common in electrical engineering, was implemented. A variety of filter states and system error models were studied. Such processing filters require a great deal of arithmetic to implement, and one of the system limitations was to stay within the computational capacity of the inertial system, while providing necessary navigation update rates. A five-state filter was finally implemented to achieve the required long-range accuracy as well as to correctly reduce intermittent effects of GPS when its accuracy was less than ideal.

Relatively speaking, the PosNav unit is able to collect data in a very precise manner with very small movements and/or changes in vehicle position, and the GPS unit is very accurate over long distances. The system is designed such that both systems work in tandem to collect the data: if the GPS unit starts producing poor data, the PosNav unit will give increasingly more weight to its measurements than those from the GPS.

As additional geodetic monuments were added throughout the state, it became apparent that the use of DGPS would greatly improve the accuracy of the system. Geodetic monuments refer to precisely determined points that provide the common base of reference to correlate longitude, latitude, height, scale, and orientation.

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System Description

Basically, the addition of the GPS unit and the additional software that was created are the biggest changes to the system described earlier and in *Research Record* #84 (please refer to Figure 2). The GPS unit is mounted on the workbench next to the computer monitor. The GPS unit has an external antenna mounted on the top of the van, which greatly increases the range and reception of the unit (please refer to Figure 1).

Operation of the system is also very similar to that described previously. One operator drives the van while another sits at the workbench to input data and monitor the system. A test run begins with the computer operator first locating the exact starting location using the GPS receiver.

A Look to the Future

Future uses for the data collection system are endless. It is believed that data gathered using the system will eventually be integrated into MDOT's ongoing Geographical Information System (GIS) effort. This will be very important, as the data could be used to collect data for a spatial referencing system and a roadway features inventory. The spatial referencing system could include a digital Atlas of the state. The roadway features inventory could include the location of various roadway features, such as guardrails, signs by type, bridges, lights, traffic signals, etc. The system will also enable MDOT to collect and maintain other data that were previously very difficult, labor intensive, and costly, such as surveys and mapping projects.

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