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USE OF GPS AND GIS TO INCORPORATE GRADE AND VEHICLE LOCATION INTO TRANSPORTATION AIR QUALITY MODELING

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This paper discusses the application of using a specialized GPS unit to conduct high speed surveys of roadway grade and crown characteristics. The system uses a single GPS receiver that has 24 channels capable of monitoring four separate antennas (6 channels each). Accurate grades, superelevation, and crown measurements are possible without differentially correcting the GPS data. However, to gather precise positional data that correspond to the roadway measurements, differential correction is required. This paper addresses the design and use of this attitude GPS unit. Accuracy specifications are provided along with techniques to maximize this accuracy.

The paper also discusses the use of dynamic segmentation to manage the roadway data collected with the attitude GPS unit in a GIS environment. Once in the GIS, roadway grades can be incorporated into engine load modal emissions estimation. Validation of this approach was done by comparing data collected with the attitude GPS unit with route surveyed data.

Keywords: GPS, Attitude GPS, GIS, Roadway Grade, Emissions Modeling

Use of GPS and GIS to Incorporate Grade and Vehicle Location Into Transportation Air Quality Modeling

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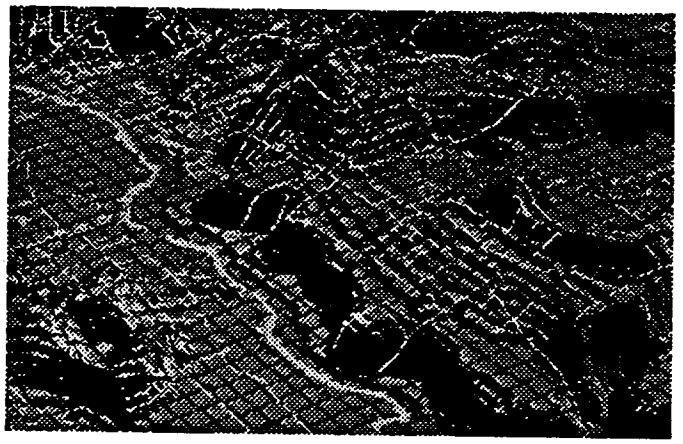
Introduction

Roadway grade increases engine load, which can lead to power enrichment and elevated emissions

Project Goal:

Develop accurate representations of roadway grades for use in modal emissions modeling



USGS Digital Elevation Model

Simple methods involve draping roads over a digital elevation model (DEM). Accuracy is a problem, especially on primary roads, due to cut and fill of terrain when roads are constructed.

Methods For Collecting Roadway Grades

"As-Built" Roadway Plans

USGS Digital Elevation Models

Conventional Survey Techniques

- Levels & Rods, Electronic Data Collectors, Survey Equipped Vehicles

Inertial Systems (Gyroscope & Accelerometer Based)

- PosNav System (Michigan DOT)
- Attitude Heading Reference System (Georgia DOT)

Vehicle Mounted Camera Cluster

- VIASAT Mobile Highway Survey System

GPS Techniques

- Survey-Quality static GPS
- Carrier Phase Kinematic GPS
- Attitude GPS

"As Built" methods take grades from road design plans. Accurate grades are provided, as long as plans were adjusted based on the finished road survey. It is very time consuming to locate and code plan grades.

Conventional methods are highly accurate but labor intensive. Roads must be closed or traffic diverted. Serious safety issues arise.

Survey equipped vehicles can collect up to six 50-foot sections of paved surface per setup. Extremely accurate, but entire system is expensive (can exceed $500,000.00).

Gyroscopic systems can collect both grade and bank information. Grade data are accurate to 0.1%, but system is costly (~ $70,000.00 for Michigan system in 1992)

Vehicle mounted camera: VIASAT developed at University of Calgary uses multiple cameras. Can collect data in kinematic mode, but grades are not very accurate and there is presumably a high maintenance cost.

Survey-Quality Static GPS

- **Requires a GPS base station and a GPS rover**
- **Millimeter accuracy in X, Y, Z**
- **Only requires one field person**
- **System requires carrier phase GPS, antenna, tripod, and data logger in the field**
- **2-5 minutes per point**

Advantages:

Survey-quality static GPS systems are highly accurate. Can give X, Y, Z positions within a millimeter through post-processing or radio-based differential correction. Only one field person is needed to collect data.

Disadvantages:

The initial system cost is high (total system can exceed $60,000.00) and data collection is extremely time consuming (must survey at close intervals to produce accurate grades on parabolic vertical curves). Safety is also an issue.

Carrier Phase Kinematic GPS (High Accuracy)

- **Data can be collected at high speed without degrading accuracy**
- **1 centimeter horizontal and 1.5 centimeter vertical accuracy is achievable with extensive post processing**
- **Accuracy is degraded with distance from base station (~1mm/kilometer)**
- **Cost is about $60,000.00 for complete setup**

UC Riverside is successfully collecting grades with a 2 Hz carrier phase GPS. High accuracy is achieved through extensive post-processing. Validation studies are forthcoming, but grade accuracy should be about 0.3% within a few kilometers of base station.

Advantages:

Grades can be collected at high speed Accurate to within 0.3% within 1 kilometer of base station. Can provide positional information without any other device.

Disadvantages:

Grades are degraded as you move father from base station (1 mm/kilometer). Cost > 60 k (an educational discount is available). Overpasses/obstacles will block signals from satellites.

Attitude GPS

- **Tracks vehicle position, heading, grade, and bank**
- **Multiple antennas connected to a multi-channel GPS**
- **Computer/data logger**

The attitude GPS has its origin in the aerospace industry. The unit we are using at Georgia Tech is designed for airplanes! Attitude GPS is capable of collecting position, grade, bank, and direction kinematically within a single unit. Each passive antenna (i.e. does not carry current) can simultaneously monitor 6 satellites. Differential correction is not required to get accurate grade (but is needed to achieve 1-2 meter positional accuracy). A notebook computer is used to store data and to check status of unit (to ensure that system is working properly). Photogrammetry option allows the user to "tag" data during collection (useful when passing over control points.

Advantages:

Grades can be collected at high speed Grade is accurate to within 0.2% within 200 kilometers of base station. Low cost.

Disadvantages:

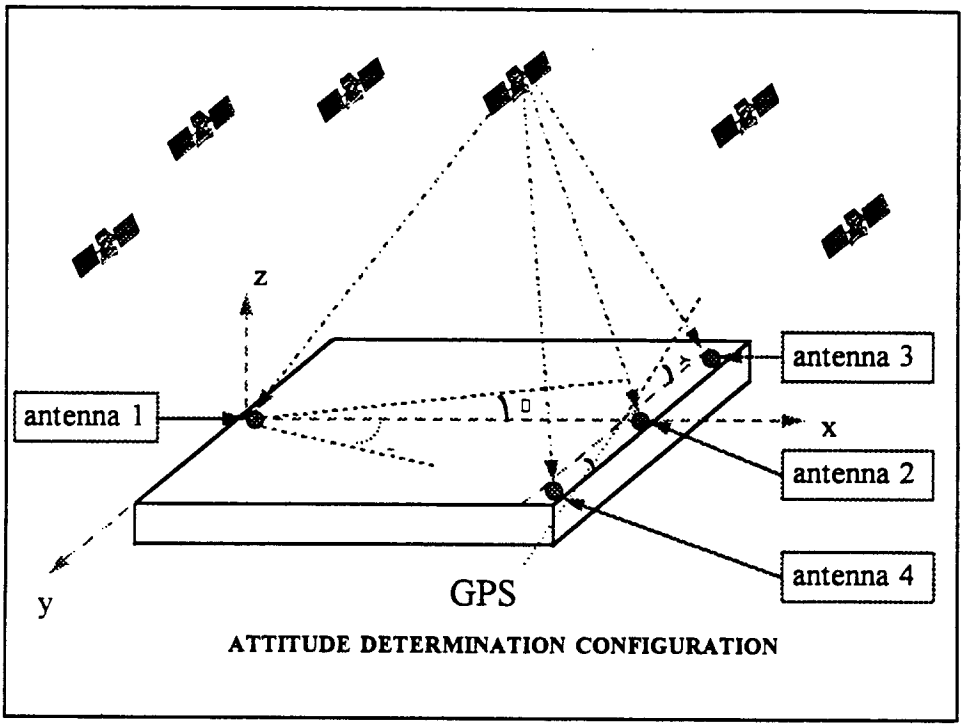
Spatial location of data are accurate to within 1 meter. Overpasses/obstacles will block signals from satellites.

Georgia Tech's Attitude GPS

- **Ashtech 3DF Attitude Determination Unit (ADU)**
- **Retail cost: $18,000**
- **4 Antennas**
- **Single receiver**
- **Published accuracy (2.5 meter baseline)**
  - Grade: 0.2%
  - Heading: 0.057°
- **Includes photogrammetry option**
  - $3,500.00 additional cost

The ADU Platform

- Four antenna system
- ADU Platform (T-structure) maximizes length of baseline vectors



ATTITUDE DETERMINATION CONFIGURATION

Maximum antenna separation is about 2.5m.

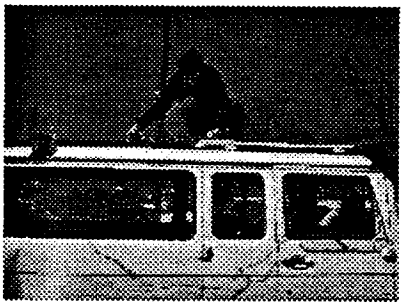
Antenna 1 collects position information.

Antennas 1 and 2 are used to compute grade (pitch angle). Antennas 1 and 2 are also used to compute the heading (azimuth or direction).

Antennas 1, 3 and 4 are used in the computation of cross slope, or the amount of superelevation/bank (roll) of the road on turns.

The whole computation process uses an Euler 3x3 rotation matrix.

Systematic Error Detection



- Compare GPS grade with both ground and roof grade (correct for systematic errors)

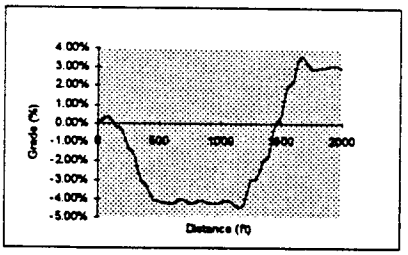
Kinematic Data Collection

A typical data collection session. Grade is unaffected by the speed of the vehicle. Buildings, tree cover, and overpasses can present problems. Thus, pre trip planning is recommended to ensure best results.

Grade by Conventional Survey

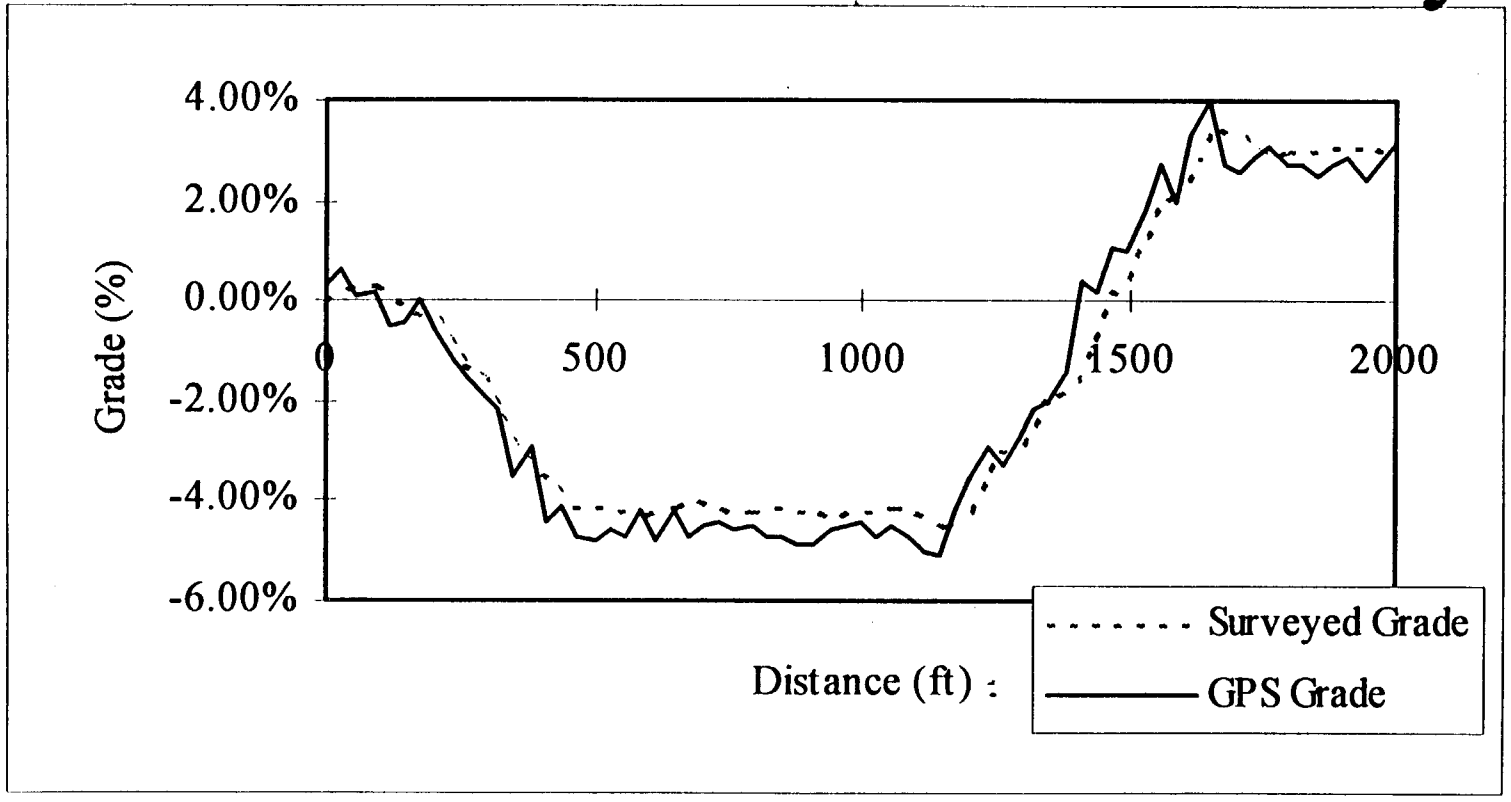
- To validate the grade computed by the GPS system, a 2000' roadway segment was carefully surveyed by differential leveling.
- Leveling results were then compared with the GPS results.

Surveyed Grade Data



- Grade varied from +4% to -5%

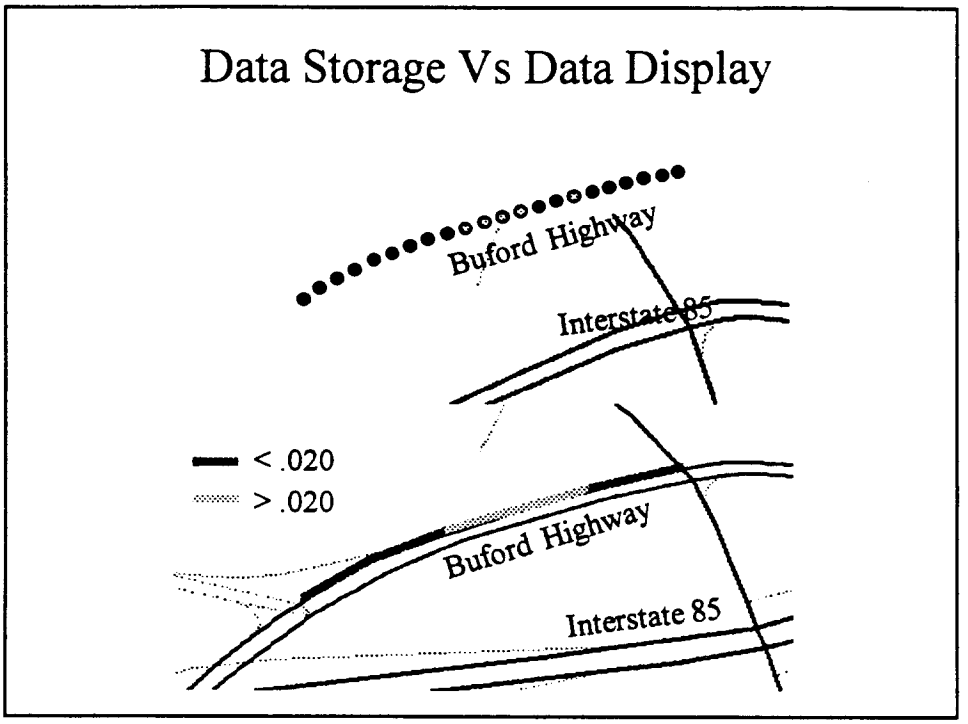
Grade Validation
2000' Section of Tech Parkway



No smoothing has been applied.

Some chassis deflection apparent on steep grades.

The maximum residual was 0.3% for this section of road.



Overall procedure for collecting, processing, and storing grades:

1. Data are collected kinematically in the field.

2. Post process differential correction improves position accuracy to within 1-3 meters.

3. Grade information is smoothed using a spline algorithm.

4. Discrete point grades (e.g. every meter) are derived from splined grade curves and are imported into the geographic information system (GIS) for analysis, storage, and display. Once in the GIS, the grades can be linked to modal emissions modules.

The upper figure shows grades as they are stored (discrete points).

The lower figure shows how a continuous thematic map can be created through interpolation between the discrete points within the GIS.

Advantages of Attitude GPS Unit

- Kinematic collection of grades (drive the roads)
- Accurate - Standard deviation < 0.1%
  Comparable to a kinematic carrier phase GPS
  Grade accuracy unaffected by distance from base station
- Differential correction required only for position
- Moderate cost compared to other methods
  (<$18,000.00)
- Supports geometric roadway design studies

Disadvantages of Attitude GPS Unit

- A recovery period (usually a few seconds)
  is associated with data drop, when overpasses/
  tree canopy/obstacles block satellite signals.
- Antenna arrangement is obtrusive.
- System is not very portable.
- System must be rigidly mounted
  to minimize wind effects.

Conclusions

Attitude GPS provides an accurate kinematic source of roadway grade and geometry data for use in GIS-based modal emissions models.

The attitude GPS system is cost effective.

A single base station can be used for an entire urban area.