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GPS Forensics and Data Analysis

GPS Data Acquisition

Automatic Vehicle Location (AVL) systems that also include a GPS component record vehicular location via an onboard GPS receiver. Modern receivers are actually extremely accurate and report locations, speeds and distances in a very reliable manner. GPS devices also allow for error-correction and an allowance for predictability, so that travel through a tunnel or other obstruction does not result in a product failure.

Latitude, Longitude and Altitude are recorded by the GPS as a result of a triangulation-like process, based on the reception of signals from a constellation of satellites. From this data, speed and direction are calculated from the time differential between each recorded location point.

That is, the GPS system is primarily based on time. Location is derived from the time differences between satellite signals that reach the receiver, and speed/direction are derived from the time differences between recorded location points. Thus, there is a constant interrelationship between time, location, speed, heading (direction traveled) and distance traveled. While errors may affect the entire system, only the most severe (and rare) internal circuitry failures can result in a segregated failure, for example, where the recorded time, speed and direction is correct but the recorded location is erroneous.

Once the GPS acquires and records the satellite signal, the receiver either stores the information through internal memory (chip, memory card, etc.) for later retrieval (via downloading or removal of the card), or the data is *retransmitted* through another system to a control/monitoring station.

- For Police and Public Safety systems, the vehicle's Police Radio System typically hosts the retransmission of GPS data on a single, dedicated radio frequency or a dedicated radio channel of a multi-frequency (trunked) radio system.

- For private systems, such as those used by trucking companies, data is typically transmitted via the cellular telephone system whereby the vehicle is a non-voice "subscriber" to the cell system, and the GPS "calls" the base station to report locations on a regular basis.

- Long-haul trucking firms actually utilize another satellite system instead of the cell system for retransmissions. The GPS data is not sent by the cellular network to the base station, but instead *uplinked* to a subscription-based commercial satellite system which

allows communication in areas well outside of cellular coverage zones. Data is passed through the satellite and *downlinked* to the base station.

At the base station or dispatch console, the data stream is reconstructed into a latitude/longitude format and overlaid onto a street map, resulting in a "moving map" display of all GPS receivers (vehicles) in the fleet.

GPS Data Formats

Each GPS receiver and/or GPS retransmission system may be programmed to sample the location information on fixed basis, such once per second or once per minute. A Police system may designate a high sampling rate, such as each second (60 samples per minute, 3600 samples per hour) while a long-haul trucking company may only provide a sample every 15 minutes or even every hour.

As mentioned, the time plus latitude and longitude are recorded and all other parameters... speed, heading, etc. ... are derived from this data. A data printout for an AVL system will typically contain lat/lon, time of day, speed and direction. Many systems also "geocode" the lat/lon and provide the nearest known street address, roadway intersection or roadway milepost to the lat/lon point.

Analysis and Validation; i.e., "Accuracy"

With only a printout or (better still) an electronic file of recorded time and lat/lon points, the sampling rate, speed, heading and distance can be calculated. For analysis purposes, each of these parameters may be used for either data validation or error identification, examples of which follow:

- A tabulation of calculated speeds should not exceed the range of speeds expected for a specific vehicle or a specific route. A Police vehicle should probably not have a sustained maximum recorded speed of 100 MPH in a congested, lunchtime downtown area where we know such speeds are unlikely, while a commercial tractor-trailer should probably not have a sustained minimum speed of 5 MPH on a rural Interstate highway. Both examples may lead to a conclusion of erroneous data.

- A tabulation of locations should not have any points "off in left field" when compared to the remainder of points. A vehicle traversing a particular route should maintain progression along that route, not unexpectedly "jump" to some other location.

- A tabulation of sampling times should illustrate a consistent sampling rate... once per second or other setting... and not provide instances of "missing" time or inconsistent sampling.

These parameters are usually tabulated, charted and mapped independent of the original printout or software/mapping package in an effort to highlight data consistencies, reveal inconsistencies and uncover potential errors. Findings which result from such an exercise are compared (at least) to manufacturer-published error rates for the particular GPS/AVL system. Empirical comparisons may also be employed to test the correlation of previously-recorded data with new data along a known and controlled route.

The analysis will conclude that a system is...

1) Performing as advertised, within the acceptable error rate, and providing time/location/speed/distance/heading data within a reasonable degree of accuracy; or...

2) Performing in a quantifiably substandard manner, exhibiting an unacceptable error rate, and providing erroneous data; or...

3) Performing in a suspicious manner, potentially exposing mechanical/electrical tampering, data manipulation, or other nefarious circumstance whereby data appears to be accurate for the majority of the recording period, except for one or more circumstances of data failure or inaccuracy.

For properly-operating and modern AVL systems, one may expect a high level of accuracy. This will be illustrated through consistent times, locations, speeds and other parameters for the entire recording period.

Potential Defense Strategies

GPS errors, in fact, do occur. While these errors may be exploited as a defense strategy, both the quantity of errors and severity of errors are important elements. From simple to complex, explanations of several claimed errors and true error scenarios follow:

- **A GPS system has a data "dropout" and records no information while going through the Kinney Tunnel on Federal Highway in Fort Lauderdale.**

  This is a known and predictable circumstance as opposed to an anomaly. For all but the most sensitive GPS receivers, a data dropout may be expected soon after a vehicle enters a tunnel, parking garage or similar structure, with re-acquisition occurring as a vehicle emerges from the structure. This scenario is not a GPS error and has no effect on the remainder of any recorded data.

- **A GPS system operates as expected for the majority of a driver's 10-hour shift, but has a data "dropout" for *n* minutes just before shift-change, then once again operates normally.**

  This scenario raises curiosity about mechanical or electrical tampering with the GPS hardware in the vehicle, either by disconnecting a communications antenna cable, or power cable, or both. Operators have been caught tampering with hardware when a vehicle is being used in an unauthorized manner, at an unauthorized location, or for traveling at an unauthorized speed. A cable is simply disconnected for the duration of the clandestine act, then reconnected as if nothing anomalous had occurred.

  - Some systems, however, include backup circuitry, anti-tampering alarms and even (hidden) backup GPS devices for fail-safe operation.

- **A GPS system appears to be operating properly, but the driver is reporting a location, route or speed different from what is being seen by a dispatcher or monitoring station.**

  This scenario is plausible due to the fact that GPS data is *retransmitted* to the base station by means of a completely separate radio system from that of the GPS receiver

itself. That separate radio system may be affected by radio transmission delays, radio interference or problems at the base station including a slow "refresh" rate of the dispatcher's map display. For example, if a GPS is reporting a position every 5 seconds but the map is refreshing with a 5-second delay, the map will always have to "catch up" to the vehicle's actual position.

This scenario will likely still produce an accurate data printout regardless of any errors on the "real time" map display. If the dispatch system's delayed timestamp is recorded in lieu of the original GPS timestamp, the printout will indicate a constant timestamp error but all other parameters will be intact. That is, the locations and speeds will be accurate on the printout, except they will have really occurred 5 seconds prior to the timestamp for each data point in this example.

- **Using the previous scenario, except that a driver's reported location and the vehicle's (map) displayed location are different only on a random, brief and/or intermittent basis.**

  This may be indicative of a faulty GPS antenna cable or similar maintenance issue, or perhaps a case of severe radio interference to the GPS signal.

  A cable may be loose or a vehicle-mounted GPS antenna may have been damaged, causing an intermittent connection problem. This will usually result in a data dropout for the duration of the maintenance problem, but all other recorded points will be accurate.

  Alternately, locations with high electro-magnetic radiation may interfere with the 1500-MHz range GPS signal and produce erroneous results. Buildings, multi-level expressway interchanges, parking garages, dense tree canopies and mountainous areas may also block/reflect GPS signals and cause anomalous recordings.

- **The GPS system is reporting all or a large number of data points inaccurately.**

  A driver may claim that a GPS/AVL system is just wrong: The driver states the vehicle was never at the recorded location but was instead a mile (or many miles) away. Or, the driver claims the vehicle was in fact on the recorded route, but never driven at the high rate of speed logged by the system.

As stated, there is a continuous interrelationship between time, location, speed, heading and distance. A system failure can render all parameters to be erroneous, but having just *one* parameter be "wrong," such as only the reported speed or only the reported location, is highly improbable if not impossible.

A complete system failure may certainly report all points and parameters incorrectly, and these failures can be based in any combination of damaged hardware, corrupted software or improperly programmed software. Erroneous data will be exposed once the recorded points are tabulated and mapped separately from the original host system, typically showing an impossible progression of points "jumping around" on the map plus inconsistent speeds and headings.

Another source of error is geocoding software mentioned previously. Geocoding systems attempt to supplement lat/lon nomenclature with simple street addresses, making the vehicle's location easier to visualize and track. Thus, a recorded point such as 26.27656 Degrees North, 80.26635 Degrees West is instead identified as 3626 Coral Springs Drive, Coral Springs, Florida.

Problems arise when the geocoding index cannot truly find a *nearby* address and instead substitutes the *nearest known* address from its linked Postal database. The "nearest known" address may be many feet, yards or sometimes miles away from the actual recorded GPS coordinates.

- As an example, a vacant lot with no structures and no mail delivery may not have an assigned street address. The lot exists in the local Property Appraiser's database as a specific parcel with a legal land description and identifying portfolio number, but postal addresses will not be assigned until a Site Plan is approved and the structure or structures are built.

- A truck parked overnight in the vacant lot will be accurately recorded by the GPS, but the geocoding software may supersede this information with an erroneously-identified local street address for the truck's overnight stay.

Robust geocoding software falls back to listing the nearest roadway intersection (such as "Coral Springs Drive and West Sample Road") or the nearest roadway segment (such as "Coral Springs Drive 0.1 mi. north of West Sample Road") instead of assigning a street address which is beyond a pre-programmed radius to the actual recorded coordinate point.

This circumstance can be uncovered through empirical testing of the GPS/AVL equipment and/or the re-mapping of GPS data when all reported coordinates and reported street addresses are provided in the printout.

In conclusion, modern GPS/AVL systems are not foolproof but almost so. Beyond the circumstances of tampering, claimed errors can usually be traced to equipment faults, temporary signal interference (from identified sources), signal retransmission delays or error-prone geocoding software.

Analytical tasks are best performed on raw GPS data points, freshly downloaded from the GPS device if possible, and require the use of lat/lon coordinates in addition to any street addresses. Furthermore, the ability to perform equipment testing and conduct sample runs along the same route (or sample segments thereof) will aid in determining the true "accuracy" of a system.

Wyman Enterprises, Inc. is available for consultations, data acquisition and data analysis for most GPS-related cases. When multiple Experts/Consultants are retained to provide independent opinions, Wyman Enterprises, Inc. can serve as the Analytical Project Manager and/or data aggregator for the efficient presentation of all findings.

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