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A Long Walk Off a Short Pier

A Case Study of GPS Position Dither in Motion

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Peter H. Dana Spring 2007

Introduction

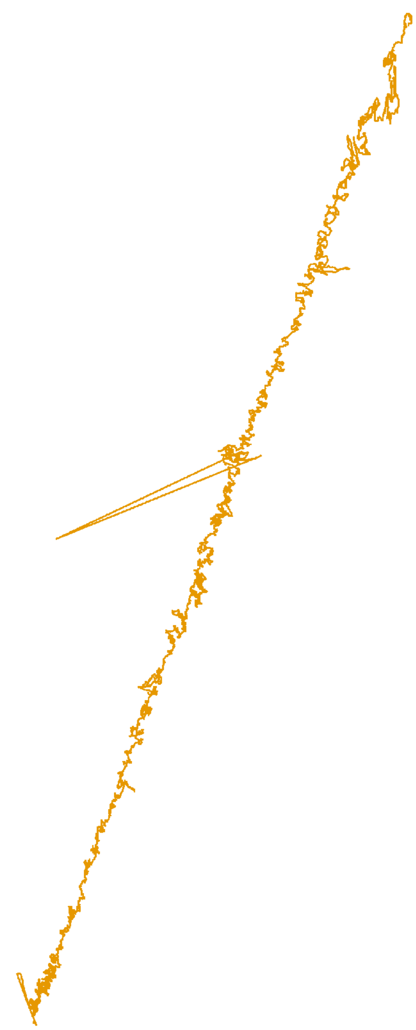
WHILE it is generally accepted that stationary GPS location fixes will, over time, produce a point cloud averaging down to the estimated location of the receiver, there is a pervasive misconception that GPS is somehow “more accurate” when in motion.

“I had that problem with my car. If I parked, my position would jump around by up to, like, ten feet. When I was moving it was pretty accurate, though,” remarked an acquaintance in regards to this case study.

This case study involved an traversing a known, public, linear path, over varying amounts of time, in a repeatable fashion, in an effort to demonstrate the potential inaccuracies of GPS readings even when in motion.

We will take a look at the collected data, the location it was captured at and the methodology with which it was captured and analyzed.

A Long Walk

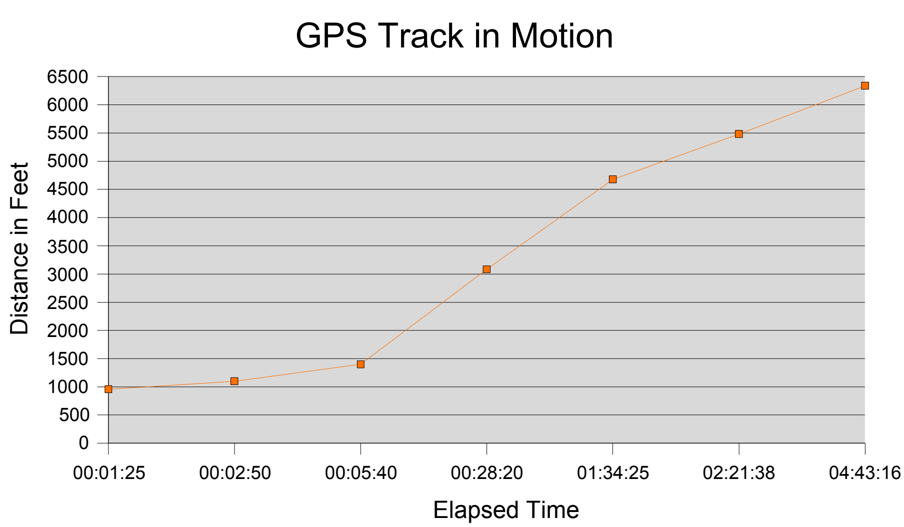


Rendering of the total “long walk”

GIVEN a GPS track of fixed length measured in an exorbitant length of time – specifically, approximately 950 feet measured in four hours, forty-three minutes and sixteen seconds – one can visualize excessive perturbations in the recorded line. As with multiple stationary measurements, the effect is something akin to a point cloud. However, as the receiver is indeed moving, the line connecting these points loops back onto itself, adding substantial length and detail.

We can take this path, its constituent points and its length, and sample data from it at regular intervals to change the time scale while preserving the overall character of the data. The following graphs demonstrate the original time scale, the time scale reduced by half (sampling every other point), reduced to a third (sampling every third point), to a tenth (sampling every tenth point), to a fiftieth, to a hundredth and to one two-hundredth of its original time for capture.

The crudest measure is length. GPS tracks measure length by measuring the distance between points. These points were captured in WGS84 and projected to the Texas State Plane Central NAD 83 survey feet coordinate system for length measurements. The original measurement captured NMEA sentences every two seconds, for a total of 8342 points. Connecting these points offered a length of 6337 feet. Compare to the sampled measure of 1/50 (five minutes, forty seconds, a fast walk), a much more accurate 1398 feet.



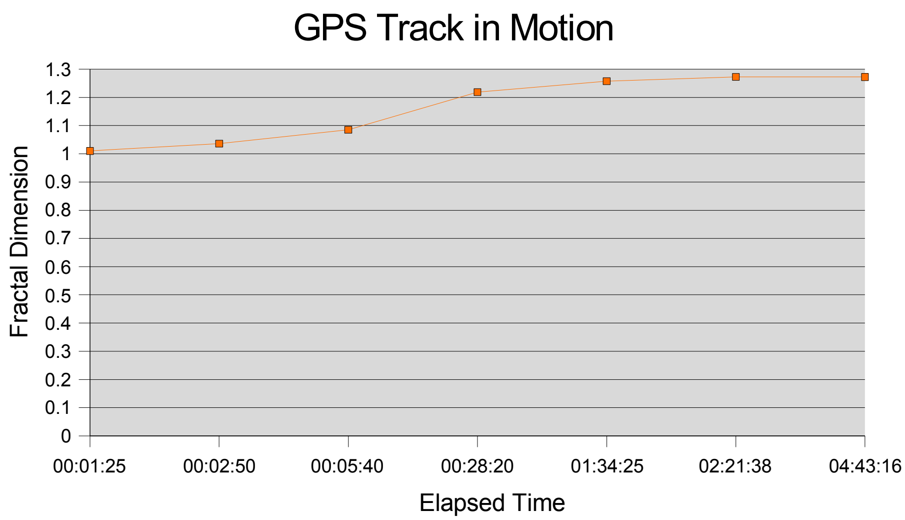
It has been said that GPS position errors in motion have fractal dimensions. Fractal dimension is a complexity measure: a measure of the tortuousness (the opposite of straightness) of a line at various scales – in our case, time. Fractal line measurements range from 1.0 (perfectly straight) to 2.0 (no longer a line, but a two-dimensional plane). An increase in fractal dimension is an order of magnitude increase in complexity. We see a fractal dimension of 1.27 at the highest time scale, and this is preserved even when halving it. Even a reduction to one-tenth of the time scale only reduces us to a fractal dimension of 1.22. Only with dramatic reductions in sampled time do we see values approaching 1.0, beginning at 1.09 for 00:05:40.

"GPS position dither is very similar to a complex path with fractal dimensions at some walking rate." Peter H. Dana, March 2, 2007

"For each line, the fractal dimension (*D*) is calculated as follows:

$D = \log(n) / (\log(n) + \log(d/L))$

whereby *n* is the number of line segments that make up the line, *d* is the distance between the start and end points of the line, and *L* is the total length of the line, i.e. the cumulative length of all line segments." Hawthorne Beyer

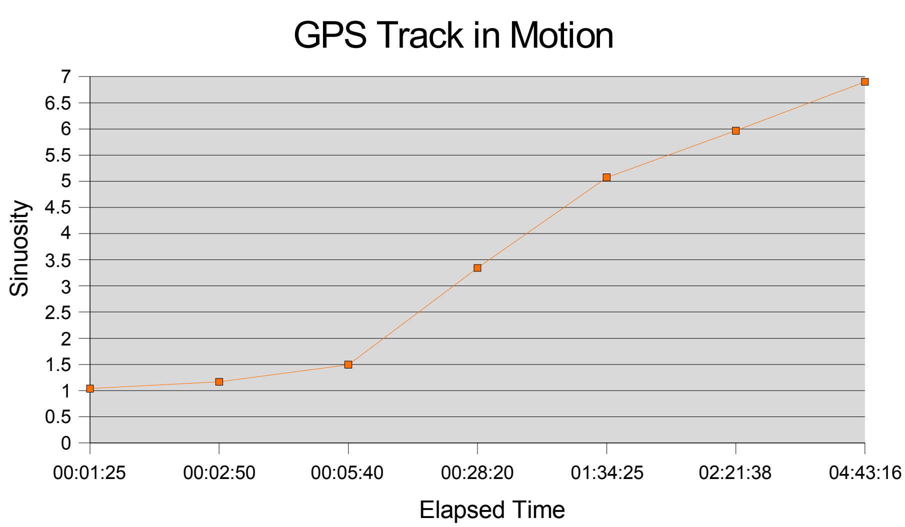


A more graceful indicator of perturbations within a line is sinuosity. Sinuosity is the measure of back-and-forth variation in a line, such as to add to its length in comparison to a straight line from beginning to end. A straight line has a sinuosity of 1.0. Here, too, we see dramatic increases in sinuosity as the measurement time increases (6.9), just as with the raw length value. We only see values approaching 1.0 with the more natural speeds, e.g. 1.5 at 00:05:40.

"For each line, sinuosity (*S*) is calculated as follows:

$S = Lt / Lsf$

whereby *Lt* is the total length of the line, i.e. the cumulative length of all line segments, and *Lsf* is the distance between the start and finish locations." Hawthorne Beyer



It is readily apparently that slow traversal speeds can adversely affect measurement quality, adding substantial noise to the system. This comes at a substantial risk to accuracy: the length of the bridge increased over seven times in our longest sample rate. So much error is injected into the data stream at that point that even reducing the data to ten percent of its original content is not enough to give a reasonably straight, accurate line.

This is where drawing a statistical line becomes difficult. While it is apparent from the graphs and figures that 10% is terribly inaccurate, but 2% is fairly reasonable, this is difficult to translate into minimum recommended traversal times, because the data corruption due to the slow initial collection is pervasive:

Remeasuring the 950' path at a normal walking rate of approximately eight minutes (and some two hundred points) yielded an accurate length, a fractal dimension of 1.000969 and a sinuosity of 1.005184, all essentially straight.

Given an average human walking speed of three miles per hour, 950' should be able to be traversed in under four minutes. Six minutes gives a reasonable winnowing of inaccurate data. Eight minutes of fresh data provides us a fairly accurate traversal, giving us a third greater leeway over the poorer data. Thirty minutes of poor data is far too long, plus 33% is forty minutes to provide an upper bound on a maximum “too slow” measurement. It might not be unreasonable, then, to suggest that taking 10x over an average walking pace to record data would risk severe adulteration of a position stream, and that no more than 5x an average pace should be taken.

Data points:

Time	Points	Fractal	Sinuosity	Length (Feet)
04:43:16	8342	1.27	6.9	6336.82
02:21:38	4171	1.27	5.96	5482.11
01:34:25	2781	1.26	5.07	4678.87
00:28:20	835	1.22	3.34	3083.71
00:05:40	167	1.09	1.5	1398.4
00:02:50	84	1.04	1.17	1100.03
00:01:25	42	1.01	1.04	957.99

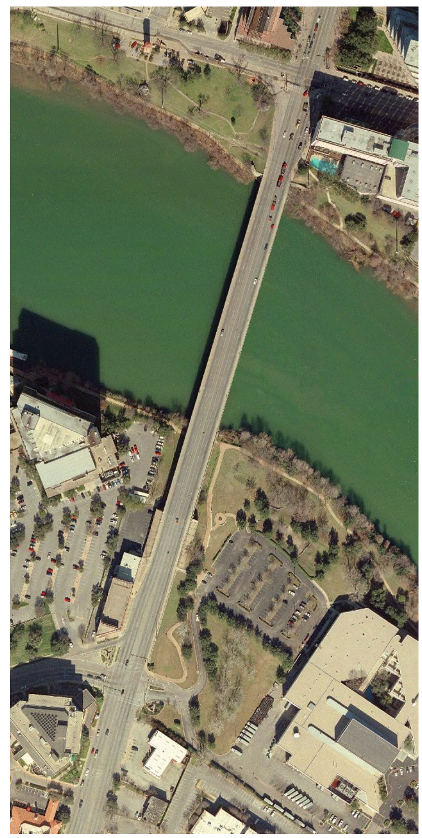
A Short Pier

THE Congress Avenue Bridge in downtown Austin, TX was built in 1910. It spans Town Lake (the Colorado River) between 1st Street East (Cesar Chavez Street East) and Barton Springs Road. It comprises three lanes of traffic in each direction with no bike lanes, shoulders or median. Pedestrian sidewalks are available on each side of the bridge (only the curb separates them from traffic), and a three foot high metal railing bounds the pedestrian walkways from the edge and the water.

A spray-painted utility service marker at the south end of the bridge reads “1000' fence.” This is in line with the approximately 950' length of the supported portion of the bridge as measured during the study.

The bridge was selected because of its safe, 24/7 availability (it is a public thoroughfare and street lights illuminate it overnight); its straight and linear path; and its substantially clear view of the sky (including an essentially unencumbered view to the horizon to the northwest and southeast from the middle of the bridge). These attributes provide a practically best-case scenario for GPS measurements.

The suspended portion of the bridge has definitive beginning and ending markers by way of the seams in the concrete on either side. These markers were used to begin and end all measurements.



Six-inch true-color aerial photography tile from the City of Austin, showing the Congress Avenue Bridge spanning Town Lake (2003)

Methodology

Scouting the location was fairly straight-forward given modern tools such as online aerial and satellite photography. Google Maps was used to quickly locate open areas within a short drive from the University of Texas at Austin campus.

Paths needed to be at least 150 meters in length, so an appropriate zoom level was set in Google Maps to make easy visual comparisons against the stepped scale line. 150 meters was the minimum to provide enough data even if GPS' estimated 15 meter unaided accuracy was obtained (of course, finer resolution was hoped for).

Parks, cemeteries, walking trails, bike paths and other similar edifices were considered and rejected for various reasons: no defined straight paths, overhanging foliage, potential for awkward social interactions, etc. At under 290 meters, the aforementioned Congress Avenue Bridge was additionally ideal from both availability and repeatability perspectives.

Garmin eTrex Legend GPS receivers are made available to students of the Department of Geography and the Environment in the College of Liberal Arts at the University of Texas at Austin. These blue, left-handed units are in Garmin's "Mapping Handheld" product line, a notch above their "Basic Handheld" series. These handhelds have been noted by ESRI for their use with participatory and low-cost mapping projects. With a suggested retail price of around US$160 and an online price of around US$125, it probably represents the expected functionality of any amateur or financially restricted collection effort.

"A Cost-Effective Approach to GPS/GIS Integration for Archaeological Surveying." ArcNews Fall 2006 Issue. ESRI. Retrieved May 2, 2007. <http://www.esri.com/news/arcnews/fall06articles/a-cost-effective.html>

"Mapping Handhelds." Garmin | Products. Garmin, Ltd. Retrieved May 2, 2007. <https://buy.garmin.com/shop/shop.do?cID=145>

"Garmin eTrex Legend GPS Navigator." Amazon.com: Electronics. Amazon.com, Inc. Retrieved May 2, 2007. <http://www.amazon.com/dp/B000058BCQ>

The Garmin eTrex Legend 12-channel receiver is waterproof to one meter for thirty minutes, supports real-time differential correction through WAAS and via an external beacon receiver, updates its position every second, can output NMEA sentences over an RS-232 serial line, and runs for well over six hours on two alkaline AA batteries.

The onboard data collection facility on the eTrex is limited to waypoints, tracks and routes. Collecting waypoints requires at least two button presses and you cannot see any other information (direction, odometer, satellite configuration, etc.) while you are collecting them. Once you have initiated a waypoint collection, the waypoint location is not updated between the time of your initial press and the time you press “OK” to save the location, even if your location substantially changes.

Garmin, Ltd. eTrexLegend personal navigator owner's manual and reference guide. Taiwan, 2002.

The eTrex can store up to ten tracks plus one “Active” track, which is the track currently being collected. Tracks can have up to 9999 points, which can be collected as frequently as once a second (making for approximately two hours and fifteen minutes of collection time at this highest rate). Once the active track is stored, the track is simplified, causing dramatic data loss. A track of over 5600 points was reduced to approximately sixty points according to the receiver's on-screen display and to two points – a beginning and an end – when downloaded to a PC. Two different PC-based applications, DNR Garmin and GPS TrackMaker reported the same (lack of) data. Even downloading from the active track is problematic, as the receiver seems to occasionally drop points during the transfer. At least ten points went missing in each active track download, but no indication was provided of which ones or when; only that the total count reported by the receiver was different from the total count received by the software.

It should be noted that for any recreational use, smoothing these essentially straight tracks to start and end points is likely precisely what would be desired.

DNR Garmin <http://www.dnr.state.mn.us/mis/gis/tools/arcview/extensions/DNRGarmin/DNRGarmin.html>

GPS TrackMaker <http://www.gpstm.com/>

Routes are limited to fifty points and so were not experimented with for this study.

To avoid these issues, WGS84 NMEA sentences were chosen to be collected for this long walk. However, this had its own pair of concerns: the proprietary RS-232 serial cable (ultimately provided by UT) and a serial data collection device that would survive the desired length of collection: over six hours.

Global Positioning System satellites (NAVSTAR GPS) orbit the Earth twice every sidereal day. Given the rotation of the Earth, they rise and set over any particular location on the ground in a maximum of six hours. This means to achieve the greatest amount of potential irregularities (including experiencing the densest atmosphere at each horizon), any distance measured would ideally be measured over a precisely or greater than six hour span.

It would have been particularly nifty to model the estimated satellite positions in the sky, perhaps using software like SaVi and Geomview, and use that to pick particular times or even locations for measurement.

Few modern laptops enjoy even a five hour battery life, let alone at least six during active data collection. Popular models, such as the Apple MacBook and MacBook Pro (each advertising at least five hours “depending on configuration and use”), do not feature serial ports, requiring additional serial-to-USB adapters, which would consume additional power. Taking six hours to drive along a major thoroughfare with a machine plugged into a cigarette lighter would have likely quickly incited the ire of a traffic officer. Laptops supporting multiple batteries would still have required awkward swaps in the middle of data collection, risking damage or lost data. Bare serial data loggers start at US$60 (requiring assembly) and work their way up from there.

“Technical Specifications.” MacBook and MacBook Pro. Apple, Inc. Retrieved May 2, 2007. <http://www.apple.com/macbook/specs.html> and <http://www.apple.com/macbookpro/specs.html>

“Logomatic Serial SD Datalogger.” SFE Widgets. Spark Fun Electronics. Retrieved May 2, 2007. <http://www.sparkfun.com/commerce/product_info.php?products_id=752>

Instead, a Palm IIIxe PDA was obtained, second-hand, for US$5. This handheld, originally released in 2000, was an 8MB upgrade to the venerable Palm III line of PDAs. Battery life using standard, replaceable, alkaline AAA batteries, was traditionally measured in weeks of daily use or even months of casual use. 8MB of RAM would ensure plenty of storage for NMEA sentences. The Palm IIIxe docks and synchronizes over a serial port using a cradle, which was cannibalized to produce just the internal cable for ease of use and transportation. Software availability was practically assured due to the popularity of the Palm III line.

For those readers unfamiliar with the hardware, Dale DePriest, author of A GPS User Manual: Working with Garmin Receivers, has lots of great links and information on using older Palm devices for GPS at his "Navigation and the Palm OS" site. <http://www.gpsinformation.org/dale/Palm/pilotgps.htm>

A 9-pin male-to-male null-modem adapter was required to couple the two female serial cables together (as they were intended to connect to PCs, not to other serial devices); one was assembled from off-the-shelf adapters from a major electronics chain for US$10.

Several Palm III-compatible GPS logging applications are available, including a few free applications, out of which NMEA Monitor was selected. NMEA Monitor can record a single NMEA sentence type, or all sentences, to Memos, which end up as plain text files after synchronizing to a PC. As total storage capacity was untested (individual memos are limited to four kilobytes each and while NMEA Monitor creates new memos every 4K, it is unknown if there is a limit to the total number of possible memo files), only $GPGGA sentences were logged. These were captured at a rate of one every two seconds.

NMEA Monitor <http://www.cru.fr/perso/cc/nmea_mon/>

$GPGGA sentences are Global Positioning System Fix Data messages, providing time, latitude, longitude, quality of the reading (invalid, GPS or DGPS), number of satellites in view, relative horizontal accuracy (HDOP) and other data less relevant to this study.

LONG walk data was collected over the course of four hours and forty-three minutes at a relatively constant, awkward shuffle. The intent was to move no more than half an inch a second (which would have made the under-300 meter trip over six hours in length), but without external monitoring of distance traversed, this proved to be difficult.

As the eTrex receiver is intended for left-handed use, it was placed on the western (south-bound traffic) railing of the pedestrian sidewalk at the south end of the bridge and, with a stiff arm, slowly slid forward as the operator shuffled north.

Short walk data was collected over the course of eight minutes in the same manner, at a relaxed walking pace, after the long walk.

DATA was synchronized to a desktop PC running Palm Desktop 4.1.4 per the requirements of the Palm IIIxe. NMEA data was manually copied and pasted from the multiple Memo files into a single text file, one for each walk.

All NMEA sentences reported a DGPS fix due to real-time WAAS correction.

Nearly half the points in the long walk reported ten or eleven satellites in view and 99% had at least seven. More than half the points had an HDOP of 1.0 or less, with 96% at 1.4 or under.

All of the points in the short walk reported at least eight satellites in view, with more than half reporting at 10. More than half recorded an HDOP of 1.1 or below.

The NMEA sentence files were converted into GPX format using GPS Babel, one file for each walk containing both waypoints and tracks. The date was supplied as $GPGGA sentences have none.

The GPX files were converted into ESRI shapefiles using gpx2shp. This created both a point shapefile and a line shapefile, sparing the need to connect-the-dots (over eight thousand of them) within ArcMap.

GPSBabel
<http://www.gpsbabel.org/>

```
gpsbabel.exe -p "" -w -i nmea,date=20070429 -f "nmealongwalk.txt" -x transform,wpt=trk,del=n -o gpx -F "longwalk.gpx"
```

gpx2shp
<http://gpx2shp.sourceforge.jp/>

```
gpx2shp.exe longwalk.gpx
```