Trimble

GPS / Dead Reckoning

Application Note

TRIMBLE PLACER GPS 455/DR

Preliminary Subject to Change without Notice

Trimble

Placer 455/DR Application Note

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1 Introduction

The Placer 455 DR combines information from several sensors: GPS, a gyroscope, and the vehicles odometer to provide continuous positioning information to the user.

Under normal operating conditions the system performs accurately however, there are extreme environments where the performance of the Placer may degrade. This application note examines:

- Types of errors for each sensor
- How these errors effect system performance
- Strategies for installation and operation to minimize errors and maximize performance

1.1 Product Design

The Placer 455 DR is designed to perform optimally in an environment where:

- GPS outages are under 300 seconds.
- When GPS is available, it is frequently available for continuous periods of at least 5 seconds of 3D fixes.
- The vehicle stops 5 or more times per hour for at least 5 seconds each time.
- The vehicle speed exceeds 22 mph (36 kph) about 6 times an hour during periods when GPS is available.

1.2 Scope and Audience

This document is not intended to replace the installation manual for the Placer 455/DR. It is intended as a guide to installers of the Placer 455/DR, giving them a better understanding of how the product operates. This document can also provide potential users of the Placer 455/DR with additional background information to help them determine if the product is suitable for their application.

1.3 GPS vs. DR for a mobile positioning sensor

Many of Trimble's customers are very familiar with the GPS system as well as Trimble's Mobile Positioning products. These GPS-only products require no initialization in order to provide position information. Usually connecting power, antenna and an interface cable are all that's needed. The GPS sensor operates based purely on information received from the satellites. As long as sufficient satellites are visible, the GPS-only sensor can provide current position information. If the satellites are blocked the GPS-only sensor will cease to output positions until the satellites are visible again. Under marginal conditions GPS accuracy may be degraded. With the exception of some filtering done on the positions reported, errors that occur in a current GPS position will have no effect on positions reported later on. Each GPS position is determined independent of past positions.

Dead Reckoning on the other hand requires installation, calibration and testing to verify that the system is configured correctly. While periodic calibration is unnecessary, the installation is more involved than with a GPS-only product. The Placer 455/DR uses additional sensor information to provide position updates when satellites are not visible, as well as helping to reduce errors in tough GPS environments. Since dead reckoning propagates position based on the last known position, errors tend to grow, the error increasing until the position is updated by an absolute position fix. For the Placer 455/DR, that update is performed when GPS is available.

2 Operating environment and it's affects on accuracy

2.1 GPS error sources

The most challenging problems for GPS occur in urban canyons. In this situation tall buildings obscure GPS satellites (SVs) often to the point where a position fix cannot be computed (with GPS alone). Table 1 shows the type of GPS position fix and velocity computed for varying numbers of visible SVs.

No. SVs	Position Type	Comments
0,1, or 2	none	
3	2 dimensional fix	A 4th "artificial" SV at the earth's center is added by the system firmware. This position assumes the user's height remains the same and correction for altitude changes is not possible
4	3 dimensional fix	Users latitude, longitude, and altitude are determined
5 or more	3 dimensional fix	Redundant SVs. In this situation some types of errors from a single SV can be detected and that SV then removed from the set used to calculate the position fix.
4 or more	2 dimensional fix	In cases where the satellites are not spread out enough (called a poor dilution of precision or DOP) the Placer firmware may compute only a 2 D position fix.

Table 1. Number of Usable GPS Satellites and Type of GPS Position

The urban canyon problem mentioned above is illlustrated in Figure 1. This shows the number of observable SVs during a test in San Francisco. The period between point 80 and point 400 occurs in the financial district where buildings are mostly 5 or more stories in height. When less than 4 satellites are visible, the is no opportunity for a 3D fix to update the dead reckoning position.

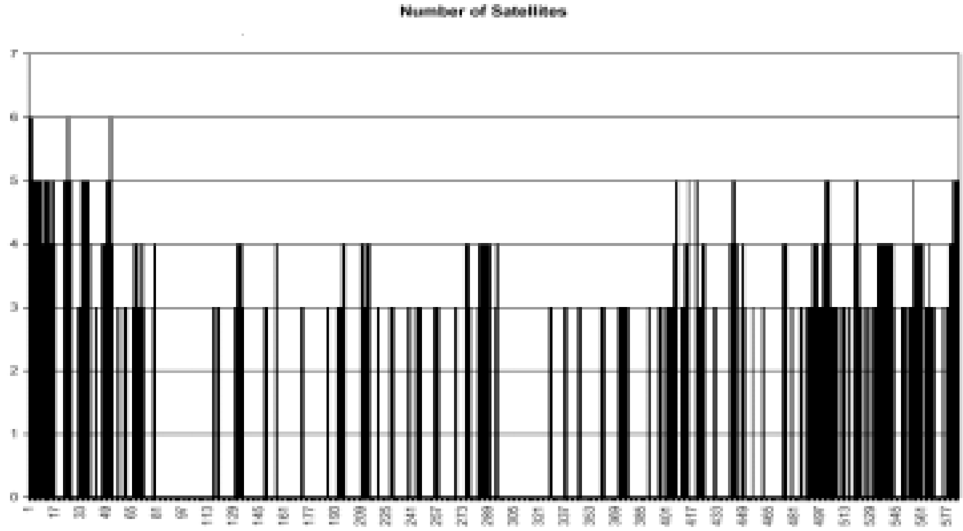


Figure 1: Satellite visiblity, San Francisco downtown area.

The most severe error source for GPS in an urban canyon is from reflected signals. This can either be in the form of multipath distortion where both the direct and (perhaps several) reflected signals are received at the antenna from one SV, or in some cases, only the reflected signal reaches the antenna (see Figure 2).

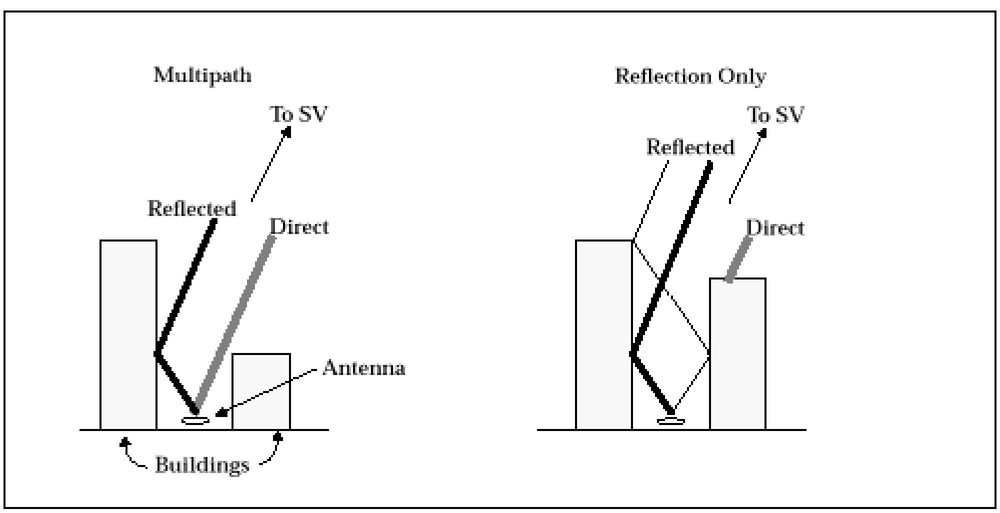


Figure 1 Multipath and Reflected Signals

Usually, reflected signals are received in urban canyon environments where there are no redundant SVs to use for testing and rejection of a bad SV measurement. The consequence is positions errors usually between 200 to 500 meters although errors up to 3km have been observed in Manhattan. The GPS velocity is also often erroneous in these cases.

Figure 3 shows an example of such a raw GPS position error and Figure 4 raw GPS heading errors, both from a San Francisco test.

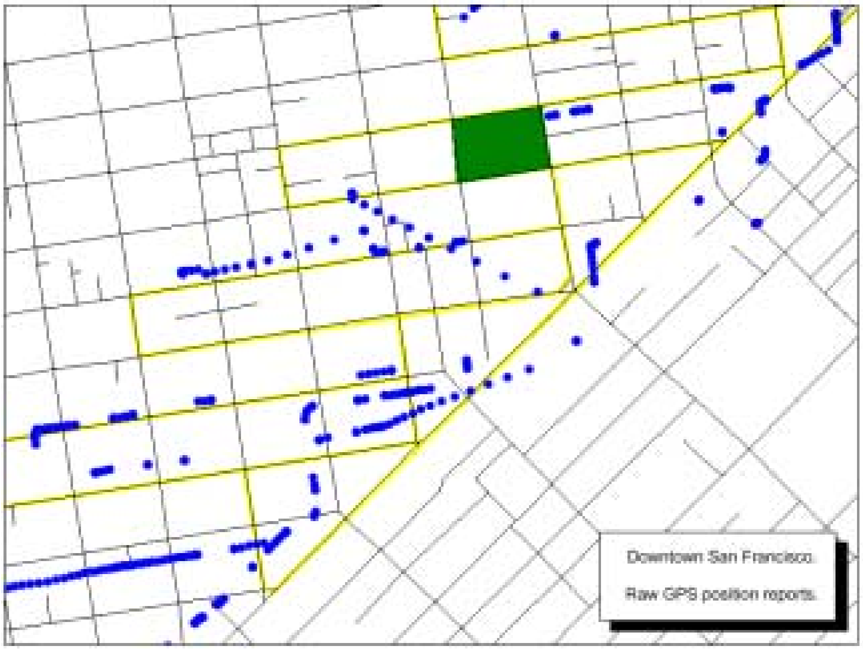


Figure 3: Raw GPS positions errors

All GPS position fixes should fall on the city street, but are displaced by multi-path distortion.

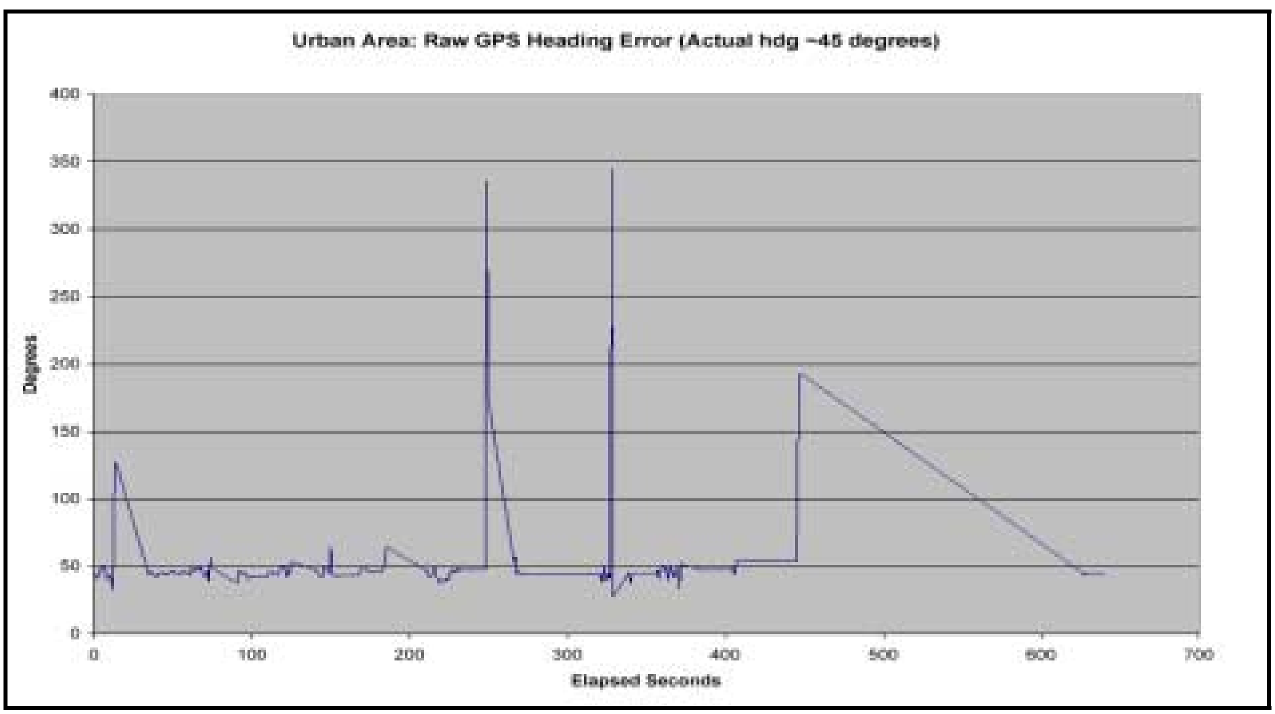


Figure 4: Raw GPS heading errors while driving a straight street in a dense urban environment.

Changes in elevation are another source of GPS errors. The example in Figure 5 shows the affect of an actual elevetion change while receiving only enough GPS signals to compute 2D position fixes. The elevation error is translated into a horizontal position error. During short periods of 3D position fixes the vehicle tracks move back toward the actual position of the vehicle on the street.

Figure 5: Position error due to change in elevation. Dotted lines are position tracks from 3 different tests on the same steep hill in San Francisco.

2.2 Dead Reckoning error sources

2.2.1 Gyroscope

The Placer 455/DR uses a rate gyroscope that measures the rate of change in heading. Because the gyro does not measure absolute heading, but rate of change in heading, an external source of absolute heading information is needed. In the Placer 455/DR GPS is used to provide this heading information.

Figure 5 shows how the accuracy of the heading derived from the GPS signals increases as velocity increases. Typically, for the same set of satellites used in the solution, the error ellipse remains about the same for any GPS derived velocity. Hence, the GPS heading error is inversely proportional to the vehicle speed.

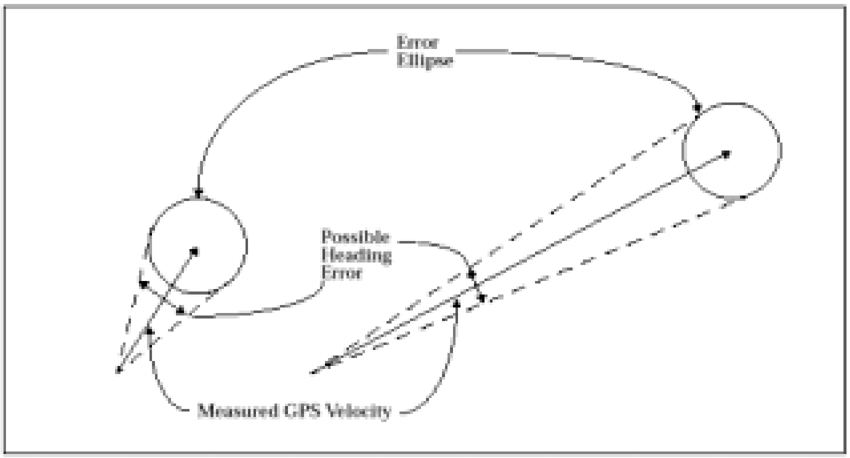


Figure 5: Effect of speed on heading error.

The Placer 455/DR uses a combination of a speed threshold and some indicators of the GPS velocity accuracy to decide if the GPS heading should be used to correct the system heading.

- GPS heading is NOT used under 5 m/s (11 mph., 18 kph.)
- Between 5 m/s and 10 m/s (11-22 mph, 18-36 kph) GPS is used if the quality is acceptable (lower speed requires higher quality)
- Over 10 m/s (22 mph / 36 kph) GPS heading is almost always used.
- A maximum correction of 10 degrees per second is allowed.
- The GPS heading is blended with the DR heading using a time constant that varies depending on many conditions. As a rule of thumb, the DR heading will adjust to match the GPS heading with about 5 seconds of GPS measurements that meet the above criteria.

2.2.2 Odometer

The largest single error source for the odometer system is caused by changes in tire diameter associated with temperature changes. In a fashion similar to the gyroscope, the GPS derived speed is used to automatically adjust the odometer scale factor. The threshold used to decide when to accept the GPS speed measurement is essentially the same as outlined for the gyroscope. However, the time constant for incorporating the GPS speed is about 900 seconds.

The maximum error usually occurs when a vehicle has been running during the day and then shut down and restarted the following morning. Even in this case the odometer error is usually under 1% during the first 15-minute period while the tires warm up and the scale factor is adjusted.

2.2.3 Environment

The DR system is a 2 dimensional system. The odometer and gyroscope in the vehicle can only measure the vehicle position in two horizontal dimensions since there are no DR sensors in the Placer 455/DR that measure altitude. As a result the vehicle altitude is assumed to remain constant when there is no GPS available.

When the vehicle travels up or down hills, the altitude change translates to position error in the horizontal plane. For example, travelling 100m up a 30 degree slope the vehicle should only move 100cos(30) m or about 86.5m horizontally and 100sin(30) or 50m vertically Instead the Placer reports travelling 100m horizontally. (San Francisco does have hills this steep).

A similar problem occurs when heading changes are made and the vehicle is not horizontal. Examples would be, turns on steep hills, or banked turns such as freeway interchanges. Figure 6 shows an example on a freeway cloverleaf.

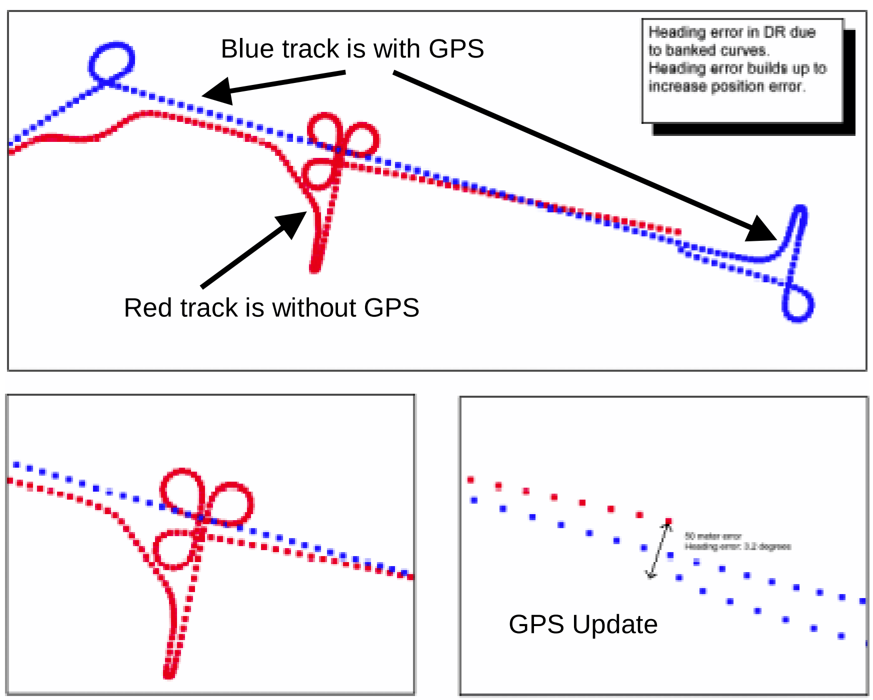


Figure 6: error due to banked curves.

In this example GPS was disabled for the part of the test entering the cloverleaf to the north and continuing through the cloverleaf and proceeding to the east. At the point GPS was enabled the vehicle position track moves south approximately 50 meters to the proper GPS computed position. The return track to the west (in blue) with GPS enabled illustrates the heading error in the original track to the east (red).

3 Installation Issues

3.1 Vehicle interface

Careful installation and calibration are crucial to getting the best performance from the Placer 455/DR. Unlike a GPS-only system, information from sensors in the vehicle is necessary to determine the vehicle's position when GPS satellites are not visible. In addition to these times with no satellite visibility, this information is also used to reduce errors that can occur in partially obstructed areas.

3.2 Speed Signal

The Placer 455/DR's connection to the vehicle, besides for power, is via the vehicle speed sensor. This is normally used in the vehicle for speedometer, odometer, cruise control or emissions control. In commercial vehicles this signal may be routed to a taximeter or tachograph. The Placer uses this speed signal to determine two different things. By counting the number of pulses received during a given time period, the Placer determines vehicle speed. This distance/speed information is combined with the turn rate information from the gyro to determine how the vehicle is moving.

The second, very important, item is detecting whether the vehicle is stopped or moving. Every time the vehicle is stopped, an internal calibration of the gyro's heading rate bias is calculated. The gyro used in the Placer 455/DR reports the rate of turn of the vehicle. When the vehicle is stopped, the rate of turn should be zero. The Placer reads the gyro information every time the vehicle is stopped, and if the gyro shows any turn rate it will record that rate, and will use that rate, or bias, as the "zero point" when determining how much the vehicle is turning when it is motion again.

This is where the stopped/moving distinction is important. If the odometer signal is incorrect and the vehicle is moving but the speed signal shows it is stationary, the Placer will attempt a bias calculation. If that "zero point" is incorrect, the subsequent vehicle's path will be incorrectly reported, tending to arc to the left or right of actual course when driving in a straight line. If the signal is incorrect and always shows the vehicle in motion, even when stopped, the Placer will not attempt any bias calculation. Since the gyro's bias changes slowly with time and temperature changes, this also can result in an incorrect bias value, resulting in incorrect heading being reported.

With an incorrect gyro rate bias calculation, plots of the Placer's path may show incorrect headings as the vehicle turns, or it may show curving paths where the vehicle has traveled in a straight line.

This is why the odometer signal is crucial to the Placer 455/DR performance. Problems with this signal can result in not just an error in distance traveled, but also in direction of travel. See Figure 8 for a sample plot from a Placer 455/DR with a bad odometer signals that resulted in a bad gyro bias calculation.

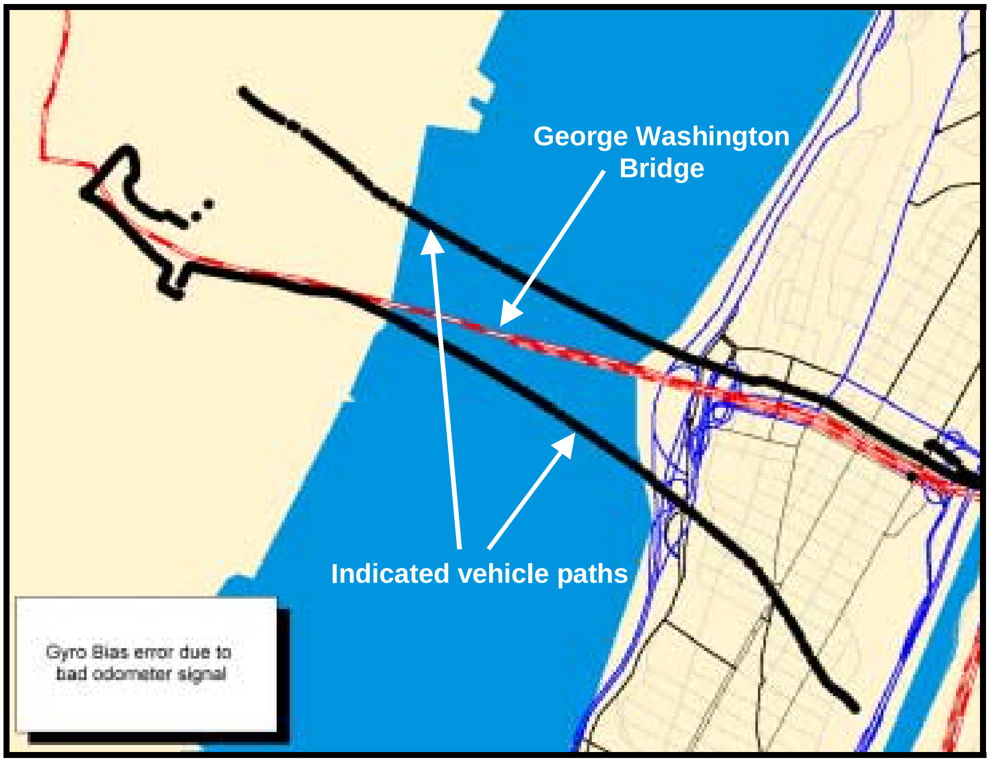


Fig 8: Incorrect Gyro bias causes plot to curve away from actual path on bridge.

3.2.1 Types of available speed signals

Speed signal types vary from vehicle to vehicle. Most current vehicles provide an electrical signal that is easily accessible for connection to the Placer 455/DR. Other vehicles, primarily older vehicles, use only a mechanical connection to the speedometer / odometer, and require a transducer to generate an electrical signal. The easiest source of transducers is a shop that installs and services taximeters. The signal used for the Placer 455/DR is the same signal used in just about every taxi to run its meter.

Existing signals in vehicles tend to be one of two types: analog or digital.

Analog signals are usually the output from some sort of small generator and looks like a sine wave if connected to an oscilloscope. These signals often change in voltage as the speed changes: as the speed increases, both the amplitude and the frequency of the signal increase.

The digital, or square wave signals are a little different. If viewed with an oscilloscope they are one of two alternating voltage levels with sharp transitions. These signals are usually generated by some sort of switch turning on and off as the vehicle moves. The distance between each transition is fixed. The switch could be a mechanical reed switch in an old vehicle, or a Hall effect transducer in a newer vehicle. The Hall effect transducer would switch the voltage on or off as a magnet in the vehicle's transmission passed by the transducer. This type of signal generator produces constant voltage levels, even at very low speeds.

The existing signal in some vehicles may not be usable for the Placer 455/DR. An analog generator type may produce such a small signal at very low speeds that the signal is indistinguishable from noise on the same wire. If this is the case, the Placer will have problems determining whether the vehicle is stopped or moving at very slow speeds. This will result in unacceptable performance as mentioned earlier. This same signal may be perfectly acceptable for the vehicle's use since most car speedometers do not read below 5 miles per hour, and cruise controls tend to not operate at low speed.

3.2.2 Marginal Speed Signals

As part of the calibration process, if the vehicle's signal voltage is low, the Placer 455/DR in combination with the calibration software will attempt to accept low voltage signals. However if it accepts too low a signal it may sometimes accept noise from other electrical components and interpret the noise as a speed signal. Some customers have reported a Placer working properly at driving speeds, but seeing speeds of 60 miles per hour when they stop. This is usually an indication of noise that is being interpreted as the speed signal. Once the speed signal dropped low enough, the noise was higher in amplitude than the true speed signal, and was interpreted by the Placer as the speed signal.

3.2.3 Additional equipment to improve the speed signal

Some customers have found that a signal conditioner helps the Placer 455/DR distinguish between low speed signals and noise. Some conditioners come with adjustments that can be used to tune the output, producing a clean digital square wave that allows an existing speed signal to be used with the Placer.

Some existing vehicle signals just cannot be used. In these cases it is necessary to add hardware to generate a speed signal. For some vehicles it may be possible to add a transducer to the vehicle transmission along with the existing one. For others magnets and a hall effect pickup could be added to one of the wheels. Again a taximeter shop is the best place to consult for advice on how to get a usable signal from a particular vehicle.

3.3 Calibration issues

3.3.1 Calibration procedures

The current software provided by Trimble for calibration of the Placer 455/DR is Pinit140.exe. This DOS application guides the user through the steps necessary to interface with the vehicle's speed signal and to calibrate the gyro scale factors. **It is crucial that all the steps in the application be followed, and done in order**. The odometer portion must be performed first since the gyro portion of the calibration is dependent on a correct speed signal. As mentioned above, the speed signal is important for gyro bias calculations, and must be working properly before the gyro calibration can begin.

3.3.2 Calibration in a test vehicle

For some vehicles it may be impractical to turn the circles required for the gyro calibration. This portion can be performed with the Placer 455/DR and gyro in any convenient vehicle where the proper odometer signal is available. After completing the entire calibration process the Placer 455/DR, with the same gyro, can be moved to the desired vehicle. The Placer / gyro pair must be moved as a set for the calibration to remain valid. After moving to the desired vehicle the odometer calibration must be performed. If the installation is in a fleet of identical vehicles is it possible for the odometer calibration to be performed one time, and the odometer calibration values manually entered into the remaining Placers for subsequent vehicle installations. The manual entry of calibration values may be done with the same Pinit140.exe software used for calibration.

3.3.3 Only one calibration needed

Calibration of the Placer 455/DR, done properly, need be done only one time. The Placer while in use does small, fine calibration automatically. It never requires re-calibration by the user after a proper installation and calibration. Replacement of the Placer or the gyro will require the unit be recalibrated. If the Placer / gyro pair is moved to another vehicle, only the odometer calibration need be updated.

4 Operation tips for improved performance

4.1 Choice of route

Route choice can have an effect on performance. An area like Manhattan Island, New York City has many, many tall buildings. But, the areas of extreme urban canyons only cover a small percentage of the entire island. A vehicle passing through one of these areas would be without GPS coverage, or in marginal coverage, for a short period of time and a short distance traveled. However, a vehicle traveling up and down one or two blocks entirely within this area might be able to travel several kilometers, or go several hours, with either no GPS coverage or only poor coverage. A vehicle passing through this area, driving along one street will likely show better performance than the vehicle that has been driving up and down that street for the past hour.

Some customers who use the Placer 455/DR need to drive up and down every street in a city. If those customers had to drive every street, but had flexibility in the order they drove the streets, they could get better performance from the Placer by driving routes that passed in and out of difficult areas, rather than a small route that was entirely inside the difficult area. The more time has passed, or the longer distance traveled without a GPS update, the greater the dead reckoning error growth may be.

4.2 Time of day

When driving in heavy traffic, speeds tend to be lower. As mentioned above, low speeds make it harder to get an accurate GPS heading update. At very low speeds heading updates may not be made at all. At moderately slow speeds the potential error in a heading update is greater than at high speeds. Base on speed alone, a route driven during traffic peak may result in lower performance from the Placer 455/DR than the same route driven at higher speeds during off peak times.

5 Testing and Troubleshooting

After calibration, the Placer 455/DR should be tested to verify proper installation. If the installation were done in an unfamiliar vehicle, or by a novice installer, problems might not be obvious until the Placer is used in its actual operating environment. Careful testing of the Placer and collection of the diagnostic messages output can help to reveal errors before the Placer is put into operational service. The information below should help installers to detect problems with the installation or to gather the information necessary to get additional support.

5.1 Tools for data collection / analysis

GPSSK is the DOS application provided by Trimble for use with TAIP (Trimble ASCII Interface Protocol) sensors like the Placer 455/DR. It can be very helpful in troubleshooting installation or calibration problems. It can decode TAIP messages on-screen, plot positions graphically, and log messages for later analysis.

For assistance from Trimble in troubleshooting a Placer 455/DR installation, the raw TAIP data is the best thing to send for analysis. While screenshots from maps or other applications are helpful for illustrating that a problem exists, more information is usually needed to identify the problem and make recommendations.

Generally the Trimble Technical Support department will ask a customer to collect LN, X1, and ST messages output from the Placer once per second. These messages, collected while the vehicle is moving in the environment where the problem occurred are usually enough to identify installation or calibration problems. These same messages should also point out potential equipment failures.

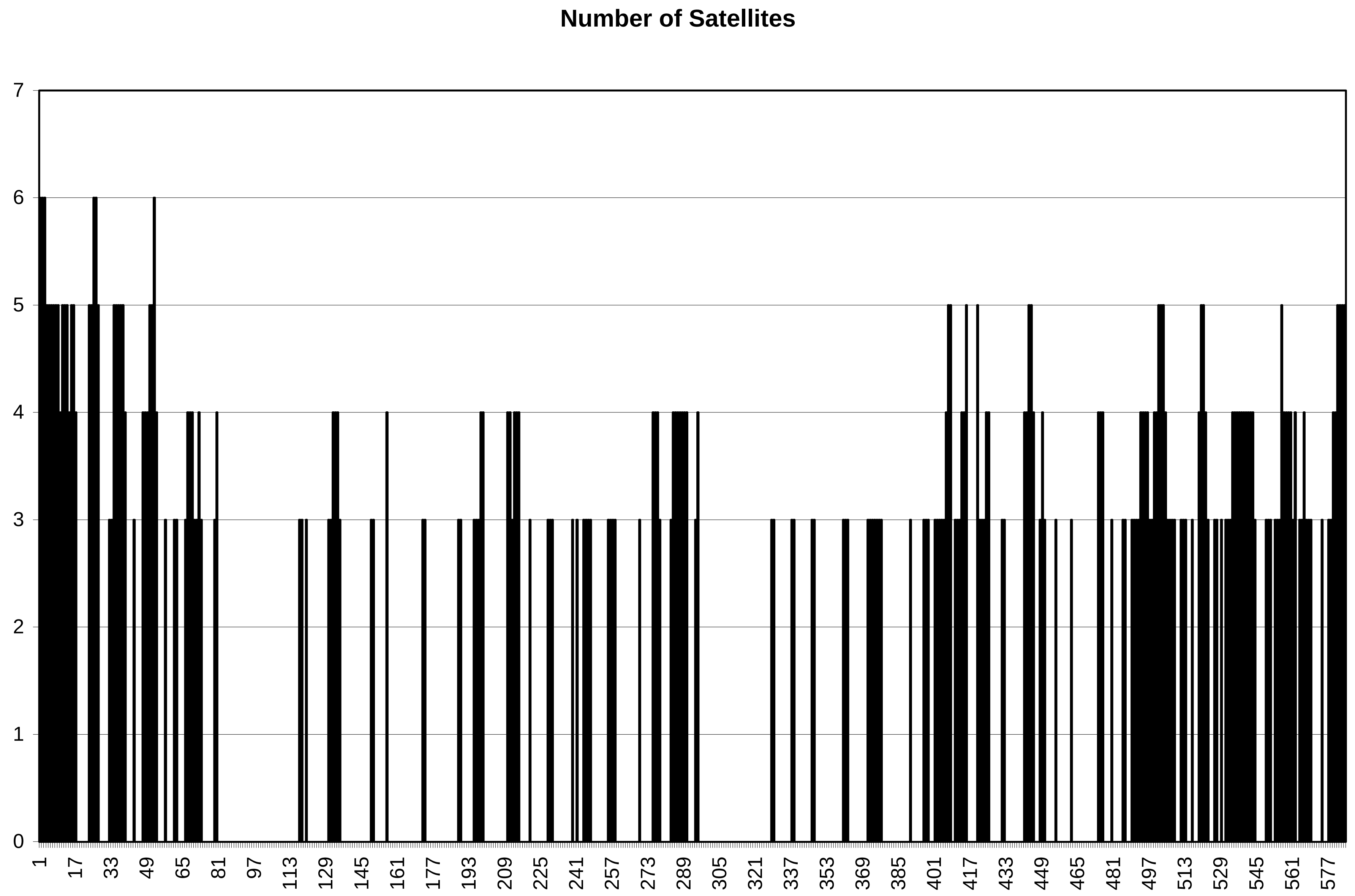
When Trimble receives these messages from a Placer 455/DR it is the X1 message that provides the information about the dead reckoning sensors: the gyro and the odometer signal. A complete description of this message is in the product manual, and when logged with GPSSK the various fields are decoded to the screen.

The odometer scale factor shows how many pulses per mile are being received from the vehicle's speed signal. The calibration performed at the time of installation provides an initial estimate of the scale factor, but over time the motion of the vehicle with GPS available will fine-tune this scale factor. Tire wear and inflation changes are slowly accounted for, resulting in this scale factor changing slightly over time.

The gyro rate bias is calculated when stopped and reported in degrees per second. When a vehicle is stopped this value may change by a small amount. However, when moving it rarely changes. The range of this value should be small, usually much less than a degree per second. If analysis of the data from a customer showed this number to jump while the vehicle is stopped, it may be an indication of no odometer pulses at low speed. If odometer pulses are not recognized by the Placer when the vehicle is moving, and the vehicle heading changes, the Placer will compute a false heading rate bias rather than recognizing the actual turn the vehicle has made. If the vehicle were to continue moving this could result in a continuing turn rate error that would last until the next time the vehicle stopped. A plot of these positions might show a long curved path, even with the vehicle traveling in a straight line.

If the bias *never* changed over a long period of time, that might be an indication of false odometer pulses when stopped. If stopped and receiving these pulses the Placer erroneously determines it is still moving and does not compute a new bias value. This also creates a heading error that grows as the vehicle moves.

The gyro left / right scale factor values do not change over time. These two values are determined when the gyro calibration is done by the installer while driving in circles as part of the calibration procedure. By default both of these numbers are 1.000. It safe to assume that they will never both be 1.000 after calibration, so if the X1 message shows both values to be 1.000, then this Placer 455/DR was not properly calibrated. Also, these two numbers should be both close to 1.000, if either is off by more than .10, there may be a problem with the calibration.


Number of Satellites
0
1
2
3
4
5
6
7
1
17
33
49
65
81
97
113
129
145
161
177
193
209
225
241
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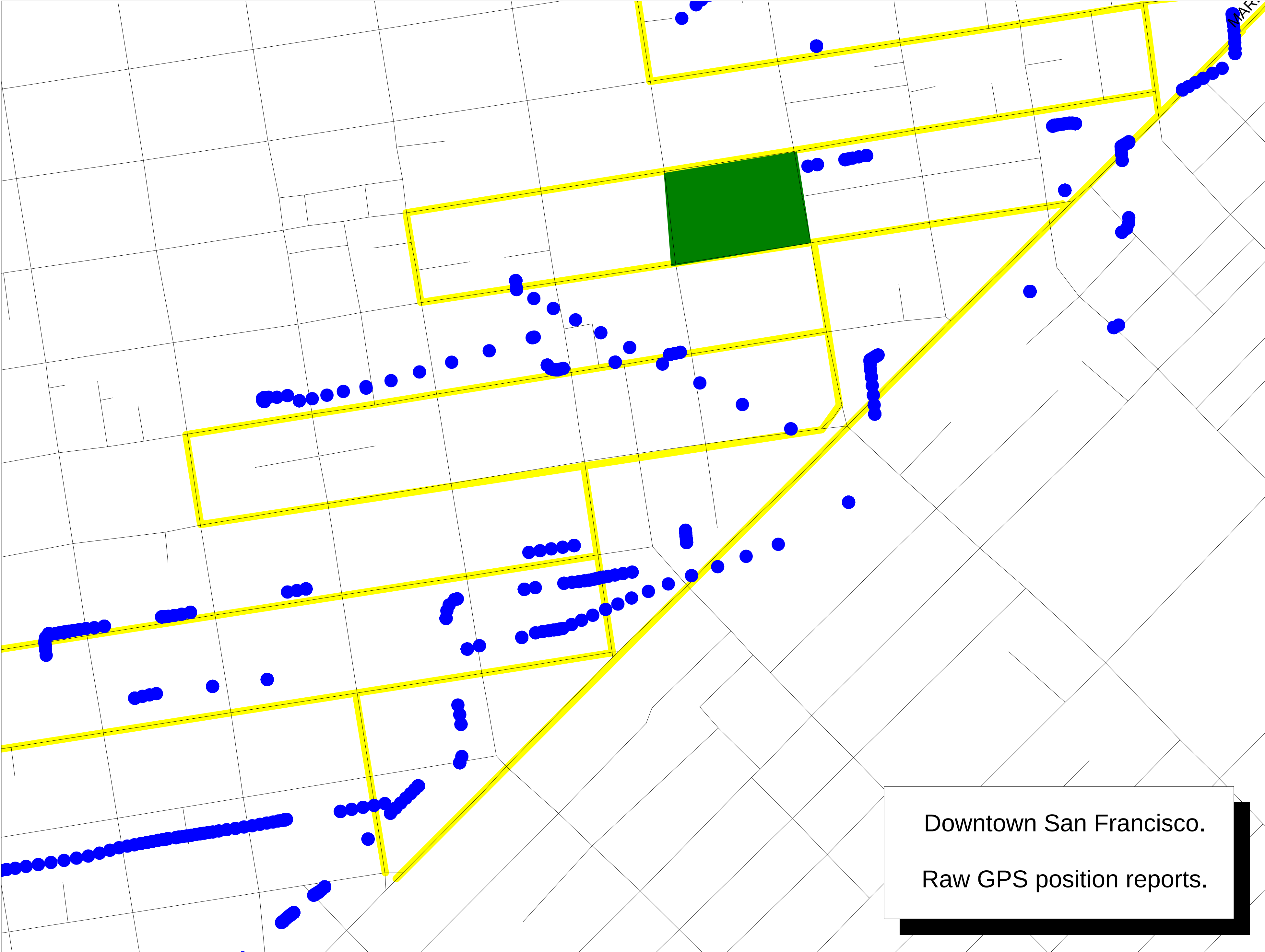
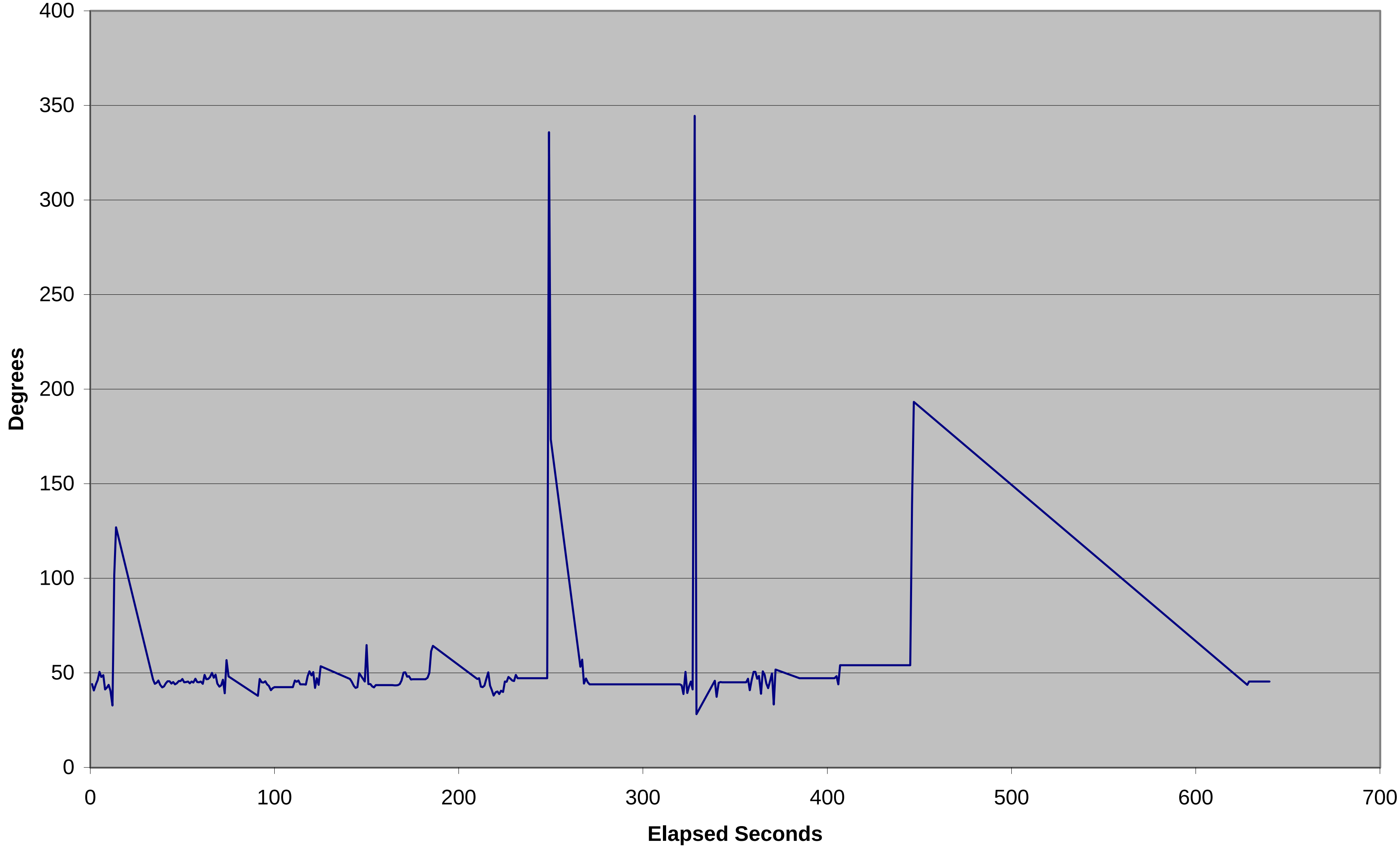


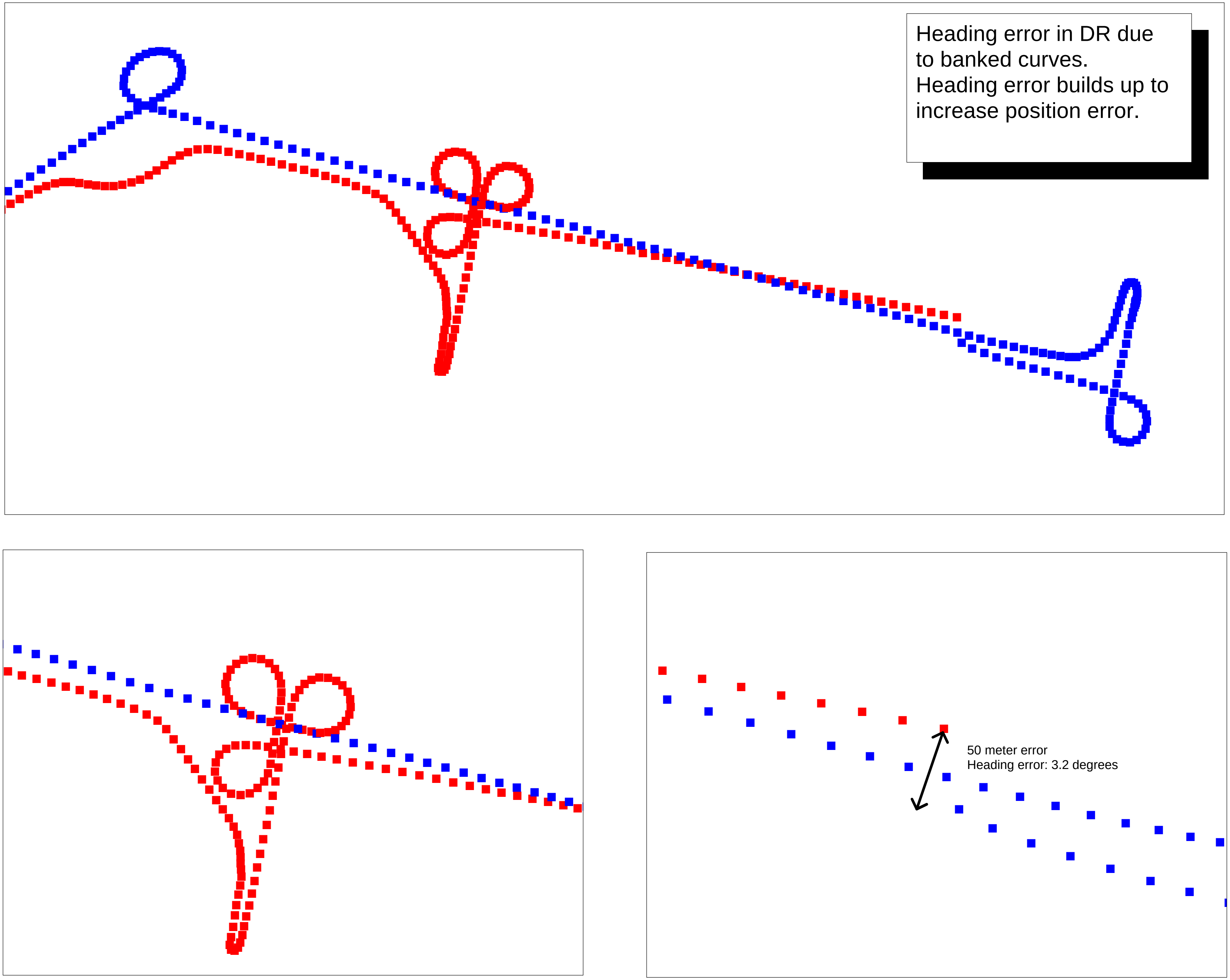
Downtown San Francisco.

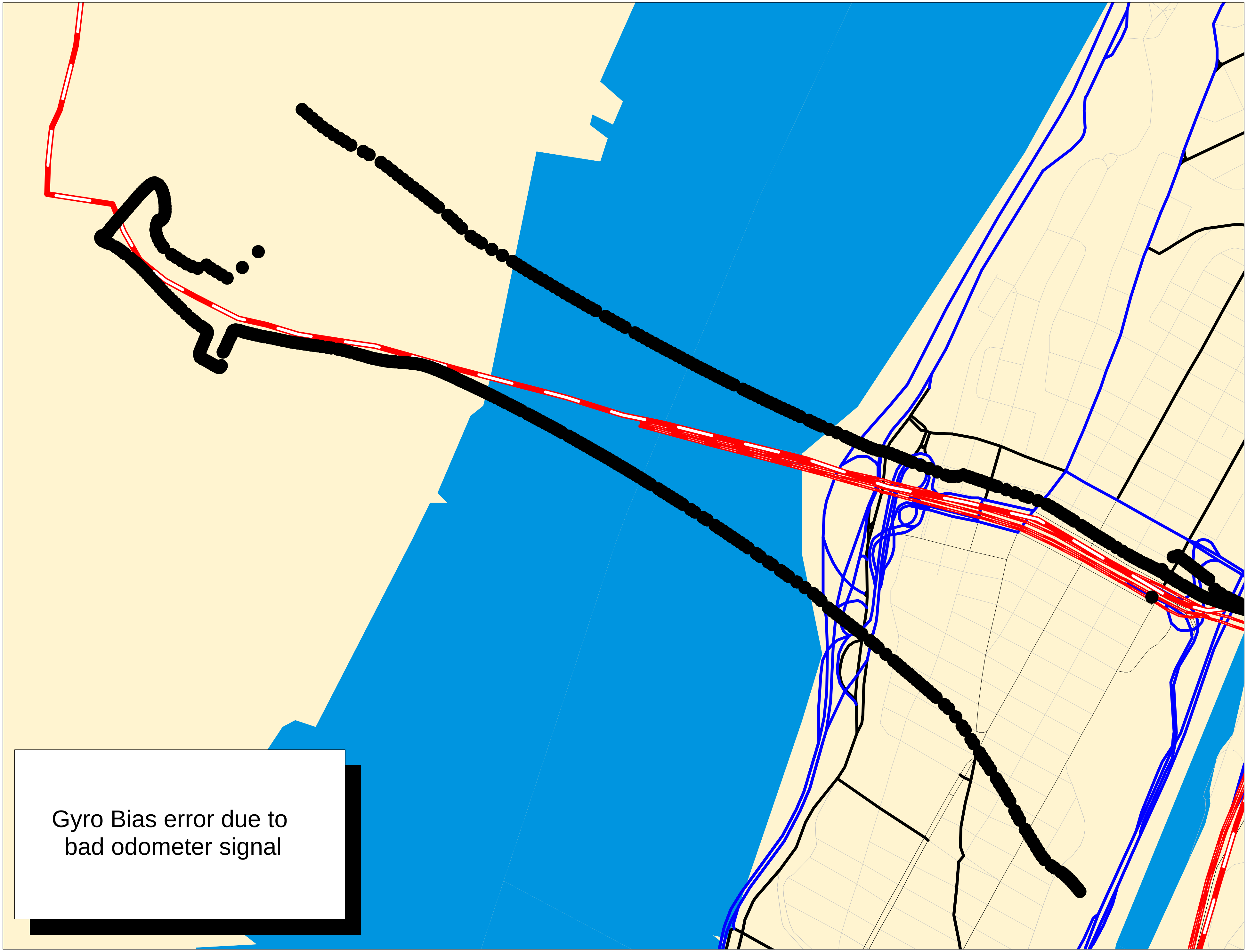
Raw GPS position reports.

Urban Area: Raw GPS Heading Error (Actual hdg ~45 degrees)



CALIFORNIA
PINE
2ND


Heading error in DR due to banked curves.
Heading error builds up to increase position error.
50 meter error
Heading error: 3.2 degrees



Gyro Bias error due to
bad odometer signal