On Foot Navigation: When GPS alone is not enough

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Integrate GPS/INS navigation systems is a common topic for aeronautical and road applications. The use of these technologies for personal localisation requires, more than ergonomics and portable sensors, a total other approach for dead reckoning algorithms. This paper will focus on different human applications and reveal the particular problematic encountered.

Key Words: GPS, INS, Barometry, Navigation, Electronic Magnetic Compass

Introduction

Contrary to a widespread belief, satellite signal such as GPS and GLONASS are not continuously available everywhere on Earth, and in any weather conditions. Electronical waves may be interrupted or affected by multipath in urban canyons, or under dense vegetation. Also, optimal antenna positioning is not always possible in enabling a good reception.

In order to remedy these limitations, dead reckoning systems are necessary. Although inertial systems (INS) such as gyroscopes and accelerometers have been used frequently in aviation, and car navigation, the application of these technologies to the positioning of persons is still in its infancy.

At present, the integration of GPS measurements with data from other portable sensors, is one of the strongest research domains at the Geodetic Engineering Laboratory of the Swiss Federal Institute of Technology, in Lausanne (EPFL).

Coupling satellite data with differential barometry

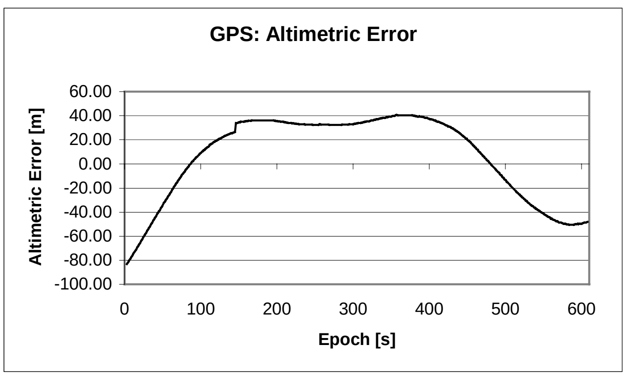
Direct consequence of the geometry of a satellite system, the altimetry is the weakest component of the 3-D position. In fact, the majority of the errors disturbing the GPS signal are in the vertical direction. With the aim of improving this component, the combination of GPS code with barometrical altitudes, measured by a high precision portable meteo station (HM30 Thommen), appears to be a good solution. Different studies (Sudau 1994, Perrin 1999) have shown that altitude values are strongly influenced by atmospherical conditions. The precision of the measurements provided by only one barometer presents an important drift, directly correlated with the displacement of the air masses through time. An initial precision of 1 m, deteriorates rapidly to reach 10 m after one hour.

By analogy with DGPS, the use of a barometrical base station situated at a known altitude improves the results considerably, as well as their temporal stability. A test conducted on the leveling network of the city of Lausanne, with more than 300 m height difference, showed a sub-metric precision of the computed relative altitudes. The relation between the mean error on the altitude, and the distance from the base station is: σ_H = 46 [cm] + 42 ppm

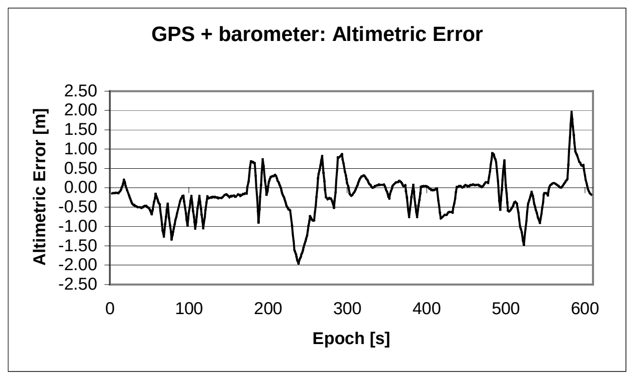
It has emerged from different tests that the precise modelisation of the temperature is an important phase of this method. Using the Laplace equation rather than the Jordan equation (Kahmen and Faig 1988) for a 300 meter difference in height, an uncertainty of 5°C induces an error of 5.5m in the altitude. Dynamic trials at more than 60 km/h with skiers and cars have brought to the fore perturbations linked with air displacement (high/low pressure).

Differential barometry improves the determination of the vertical component significantly, from ± 100 m for GPS only to ± 0.6m with differential barometry (Figures 1). Moreover, this additional data brings further advantages.

- Whereby a single fix requires the simultaneous availability of at least 4 satellites, 3 are sufficient when the vertical component is determined by means other than GPS.
- As compared with a GPS only solution, the added redundancy improves the capability to detect errors in the measurements.



a)



b)

Figure 1 a) Precision in altimetry using GPS only has an uncertainty of +/- 100 m.

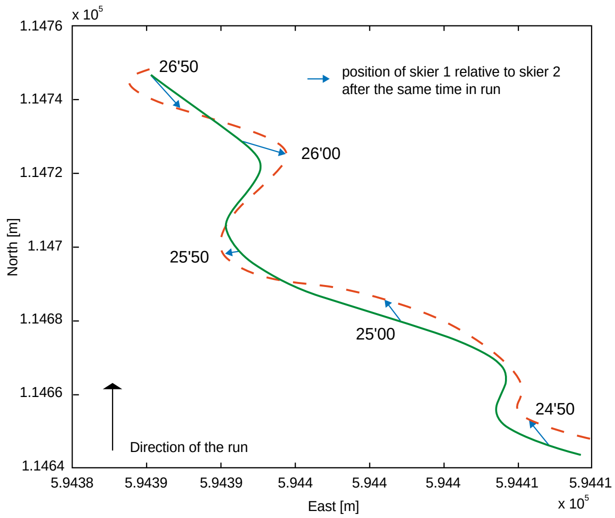
b) Integration of barometric measurements and GPS improves altimetric precision to 0.6 m

GPS and Accelerometry : an eventful love story

The high sampling frequency (5 Hz to 20 Hz) of new receivers has opened expectations for new applications.

In alpine skiing the analysis of speed and acceleration profiles permits the identification of parameters, able of improving the athletic performance.
The precise position of skiers is determined by DGPS, using smoothed code algorithms, while Doppler measurements provide accurate speed (Figure 2 and 4).

Accelerometry gives complementary information for a-posteriori analysis, such as the propulsion force at the start of the run, the aerial phase proportion (jumps) during the whole run and the centripetal acceleration in curves. Filtering lateral accelerations determines the individual signature of each gate passage (Figure 3). Coupling all this information with video shots, every movement of the skiers can be directly related to its effect.



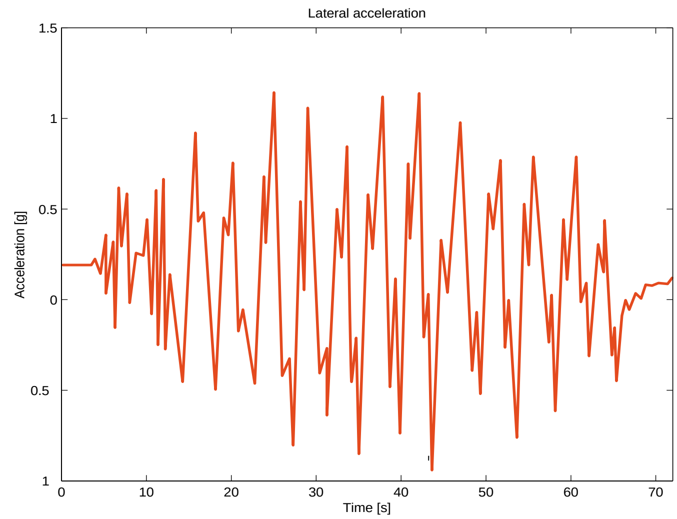


Figure 2: The superimposition of two runs shows where skier 1 made up time previously lost on skier 2. We can appreciate the tighter trajectory of skier 1 passing closer to the gates and so gaining time.

Figure 3: During a Super G skiing run, each gate passage can be clearly identified through the variations of the filtered lateral acceleration.

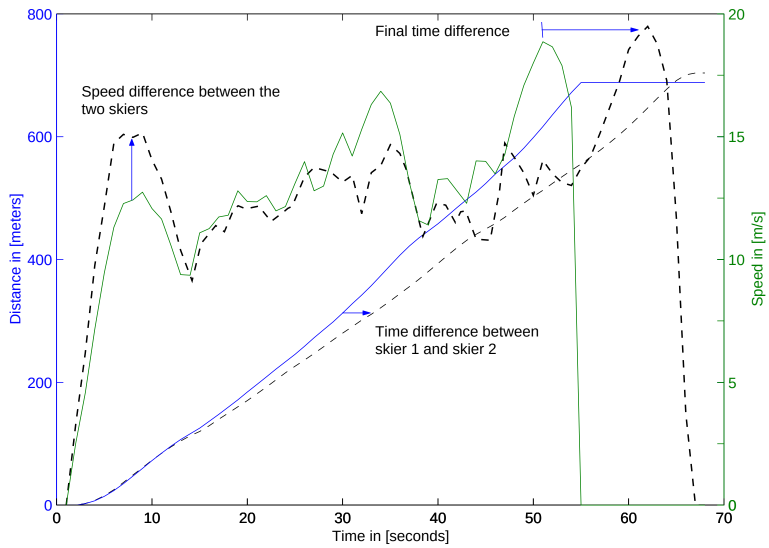


Figure 4: Speed and cumulated distance profiles for two skiers on the same run.

Replacing GPS

As satellite signals aren't always available (e.g. urban canyons, indoor activities, etc.), there is a major interest in finding sensors capable of replacing satellites during all blind periods. Again accelerometry as dead reckoning navigation seems to profile itself as a promising solution. Algorithms are presently developed within the scope of a project, in collaboration with the Institute of Physiology. The aim of this project is to relate the energetical expenditure of a person with his physical daily activity.

Previous studies demonstrated the great impact of incline on walking energy expenditure (Bobbert 1960, Minetti 1995), which is poorly estimated by accelerometry alone in uphill and downhill conditions (Melanson and Freedson 1995, Terrier, Aminian and Schutz 1999). In open areas, DGPS phase positioning presents the most suitable and accurate solution for defining the speed and travelled slope of a person. Several tests have shown that combining both antero-posterior accelerometry and differential barometry approximate the DGPS speed very well, the mean correlation coefficient value being around 0.9 (Figure 5).

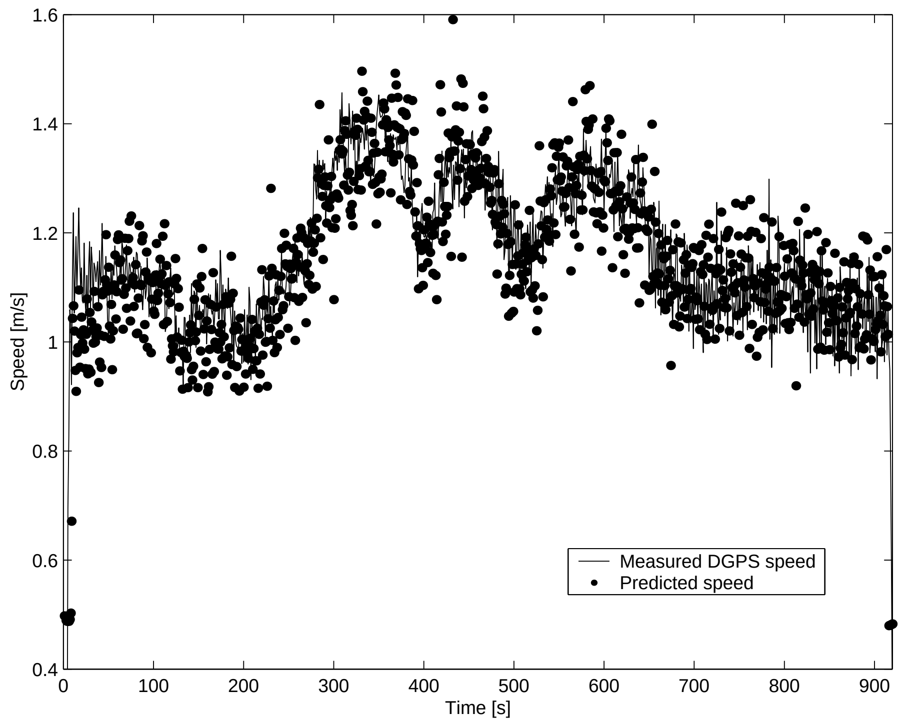


Figure 5: Speed prediction with coupled accelerometer and altimeter versus DGPS phase measurements taken as "ground truth". Correlation between measured and predicted speed is: r = 0.92.

However, what about dead reckoning for people localisation? The total loss of satellites has been almost completely solved for vehicles using odometer and map-matching, but owing to the complexity of the human walking pattern, the optimal solution for on foot navigation is still to be improved.

Dead reckoning for people is principally based on step count and azimuth of displacement. The number of steps is calculated by accelerometry and the azimuth is obtained through the means of an electronic compass (fluxgate). Two main difficulties appear very quickly. The **first** one comes from the length of strides that permanently varies with the slope and with the walking attitude of a person. The **second** one is the presence of biases in sensor data caused by magnetic perturbations such as high voltage lines or metallic objects.

Preliminary tests (Jud 1997, Anken 1999) were conducted using the commercial Dead Reckoning Module ^{TM} from Point Research Coorporation (USA). These tests brought to the fore the necessity of a periodical recalibration of the sensors. Again, DGPS, when available, presents a convenient use solution. Most of time, the shape of the route is preserved by original measurements, while absolute position mainly suffers from biases. If applications allow post-processing treatments, 1-2 meter precision results can be reached after an affine transformation (Figure 6). The main constraint of this method is that the person has to stop on points with known coordinates during the run. This aspect is far too constraining for common use but could be very interesting for surveying tasks.

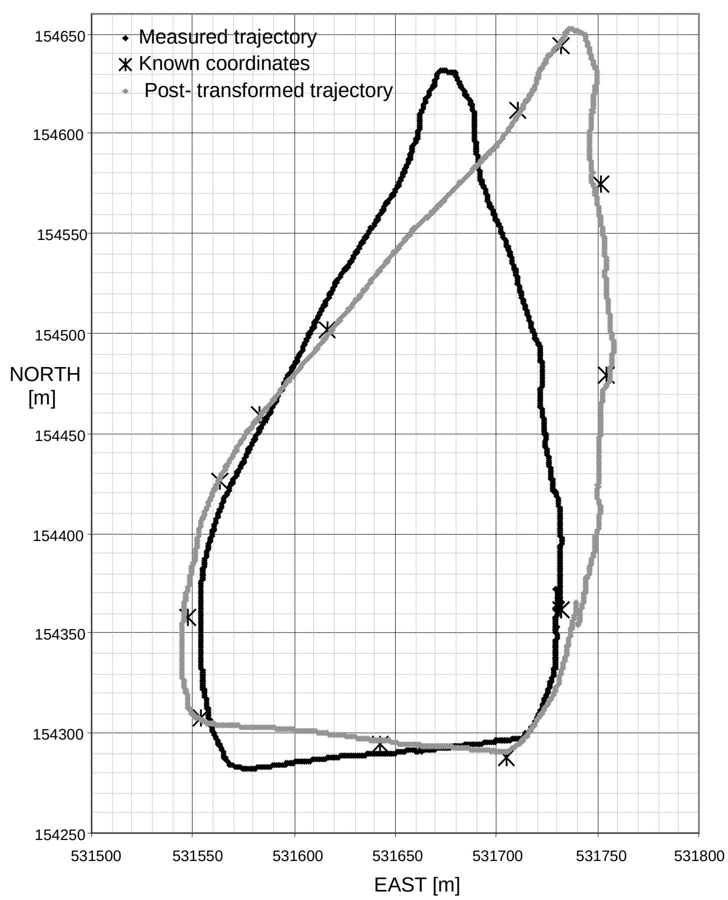


Figure 6: Measured and transformed trajectory after an affine 4 parameters transformation. The standard deviation on the known points is 1.25 m.

It must be stressed that simple or double integration of 3D accelerometry to deduce speed and position, is not possible because of the lack of orientation and precision of the sensors. This method is applicable in aeronautical navigation where a speed error of 1 m/s after a small period of integration, represents only 0.5% of the speed. This proportion totally changes for normal human walking speed at about 1.5 m/s.

Conclusion

Even if it appears that satellite positioning has revolutionised the worlds of both surveying and navigation, we have to beware of considering GPS as the global solution to all problems of localisation. Used alone, it doesn't cover all navigation needs, but reveals itself as an excellent component of a more complex system, in which each element improves the efficiency of the whole. As human walking parameters are strongly correlated with time, laboratory research is directed to the use of wavelet transformation analysis, together with Kalman filtering. Different methods to extract the occurrence and the frequency of steps are being developed. Dynamical calibration of the stride using GPS measurement is another main research topic. Whether with accelerometers, gyroscopes, barometers or inclinometers, the optimisation of data coming from space will depend strongly on its terrestrial homologue.

Adapting the famous military proverb about strategy, we can affirm that:

"In GPS sensor integration there is strength !"

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