Measuring distance through topographic models

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Abstract:

Accurate measurement of distances is of paramount importance to transportation infrastructure planning. Be it for estimating travel time, locating accidents and hazards through road markers, planning maintenance services, or setting prices for building contracts, distance is the primary metric upon which all aspects of the job are based, given that transportation infrastructure deals mostly with linear features. Yet, countries with older infrastructure often don't know for how long their networks run – especially so in case of developing countries. Brazil currently has over 2640000 km of roads, with construction documentation lacking for most of the network. The most used method for generating distance measurements, the car odometer from driving between two points, while apt for doing macro-regional planning, is unfit for large-scale engineering work, as this study shows below.

The industry standard for measuring distances uses a precision odometer connected to specialized tires, used either on their own or as a "fifth wheel" on a vehicle. Such method, however, is laborious and slow, and only generates a scalar between two points, with any new distance necessitating a new measurement, even if the two sets share a common space, or if one distance is a subset of the other. This paper proposes the usage of systematic mapping techniques to generate topographic linear features with measuring information, from which any distance can be calculated. To generate these features, first a linear path is constructed in GIS software over a route. The height information of each node in the path is then extracted from a source, and then the topographic distance is calculated from the vertical profile. Finally, an M coordinate is generated for each node.

For comparison between sources, a base path was used as ground truth. This path was constructed from a GNSS survey along the road, collected on cinematic mode at 10Hz (1.1 m gap between points), and post-processed with fixed-phase relative positioning tied to a base station. The mean positional quality achieved was 2.5 cm of planimetric, and 4.3 cm of altimetric precision. Two other sources of height information were used for comparison, one a flight DTM with 33 cm LE90 and 1 m of cell size, and the NASA 1 Arc-second SRTM with a nominal 9 m LE90 and 30 m cell size. Furthermore, a planimetric distance using a navigational GPS device (C/A code only) was also calculated. Two highways were selected for testing, and divided into 341 segments of 200 meters each, to account for the influence of slope in the calculations.
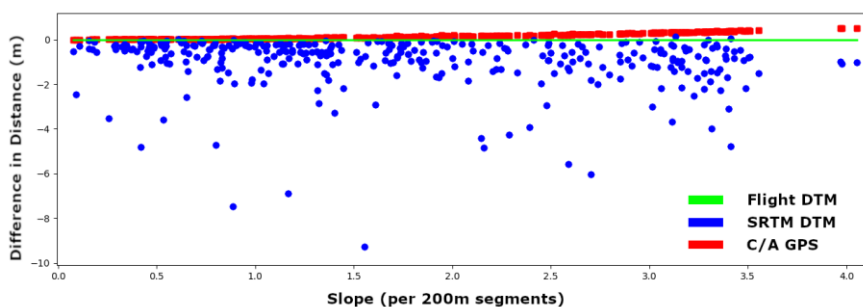
Figure 1. Distance measurement comparison between test sources and high-precision GNSS.

As expected, the flight DTM came the closest to the base model, deviating from it at an average of 31.95 ppm, with 2.8 ppm of standard error. It is, however, the most expensive and time-consuming method. The SRTM deviated an average of 5131.53 ppm and showed very high variation, with 8481.96 ppm of standard error. The navigation GPS deviated at an average of 685.18 ppm, with 633.11 ppm of standard error. Both the SRTM and GPS appear to deviate further from the base model as slope increases, but given that few segments with over 2.5° of slope were present in the sample, a correlation could not yet be established. For comparison, the average of the car odometer method was 16654.51 ppm, with a standard error of 22661.69 ppm.

Given its high deviation, the SRTM is unfit for precision work, but is a big improvement over using the car odometer for general indications. Further studies with mid-range DTMs should be done to provide a remote sensing alternative. The handheld GPS had better results than expected, given its nominal precision of 15 m. Despite a probable larger absolute positioning error, its relative error distribution remained steady enough to allow a good distance measurement.