NPL

Measurement At Home

Report on
‘Where on Earth am I?’

1. Overview

The challenge examines how buildings absorbing and reflecting radio signals from satellites affect locations reported by the Global Positioning System (GPS). Results received in a few days after issuing the challenge are used. **Thank you: AndrewH, Oliver & Elizabeth, Peter, Sas and Rachael.** Our key finding is that in most cases GPS works better outdoors than indoors by factors between 2:1 to 10:1.

2. Spans of measured locations for ‘Indoor’ and ‘outdoor’

Conditions (phones in order of ‘age’, oldest model first)			Span /m		Ratio
Phone model	indoor	outdoor	**indoor**	**outdoor**	**In:Out**
iPhone 6S	ground floor of 3 floor. Night. Raining	garden (day). Dry	15.6	6.78	2:1
iPhone 6S	ground floor of 3 floor. Night. Raining	park (night). Dry	15.6	1.27	12:1
iPhone 7	ground floor of 2 floor house	middle of field. Cloudy day	14.96	1.32	11:1
iPhone 8	ground floor of 2 floor house	middle field. Cloudy day	38.6	16.5	2:1
iPhone Xr	ground floor of house	park 50 from trees. Cloudy day	1.0	7.0	**0.14:1**
iPhone Xr	carpark – concrete + steel above	20 m from building. Sun/rain	159	4.0	40:1
iPhone Xr	Costco shop under steel roof	20 m from building. Sun/rain	42.9	4.0	11:1
iPhone	2 walls,	15 m from anything. Cloudy	15	5.5	3:1

The table here (above), shows values people submitted. ‘Span’ describes the largest difference between 5 measurements of latitude (north-south) in metres. The ratio in the final column compares measurements made indoors and outdoors. All results - except one, underlined in bold - show GPS works more precisely outdoors.

3. What is meant by accuracy, resolution, precision, repeatability and uncertainty?

Specific meaning of words in science helps understanding. In metrology (the science of measurement):

Accuracy is the closeness of agreement between the measurement result and the true value of the thing being measured. **Errors** (and there are usually many involved) are what cause the difference. A GPS example is a location result indicating that you that you are in a hedge when you know you are inside a house. In this case (and this is unusual in measurement science) you know your true value, so you can evaluate accuracy.

Resolution is the smallest difference that can be meaningfully distinguished. This task uses latitude readings to 6 decimal places. 0.000001 in latitude is about 11 cm.

Precision is a term used in measurement, calculation and specification, though metrologists do not like its use. It means ‘fineness of discrimination’ but often misused to mean ‘accuracy’ or ‘uncertainty’. In this task, typically, the last two of the six decimal digits keep changing, so precision here is about four decimal places.

Repeatability is a word metrologists use to describe the span of results for identical measurement conditions. This is what our GPS task investigates and is what we examine using the ‘span’ of results.

Uncertainty has a formal statistical definition that describes how confident you are with your measurement result.

4. What affects GPS accuracy?

This task does not investigate **accuracy** as we did not ask participants to compare GPS locations with true locations, but **repeatability** which indicates how well the system is working. Location apps use **repeatability** to estimate **uncertainty** which is displayed as a circle around the position inferring that the true location is somewhere inside the circle. A larger diameter circle indicates a higher **uncertainty**.

GPS satellites broadcast time-stamped radio signals that are received by devices like mobile phones, separate to the service provider's phone signal. Phones contain a 'GPS chip' that performs calculations using the satellite signals it receives. The calculations evaluate the time it takes signals to travel from each satellite to the receiver, and by knowing the satellite location, and signal speed, distance can be calculated. Typically, signal travel time is about 1/15th of a second, with 0.000000003 s indicating 1 metre distance. Good accuracy relies on knowing satellite locations, accurate (atomic) clocks on board satellites and radio signals travelling in straight lines at known speeds. Errors in any of these aspects will cause inaccuracy in the quoted position.

The table (right) shows the greatest errors come when atmospheric fluctuations (in ionosphere and troposphere) alter signal speed. A clever way to reduce this and other errors is to use *differential GPS* where a device receives a signal from a second GPS device (reasonably close by) with a precisely known location. Both receivers suffer the first four error sources listed similarly, though as the second device's location is known, these errors can be corrected. This reduces the first four factors in the third column. This solution requires an extra radio receiver in the GPS chip and an additional subscription to land-based system or a chip that can use separate satellite broadcast localised "Augmentation" signals.

Error source	**Standard GPS**	**Differential GPS**
Orbit error	2.5	0
Satellite clock	1.5	0
Ionosphere (>85 km above sea level) changes	5.0	0.4
Troposphere (<12 km above sea level) changes	0.5	0.2
Multipath	0.6	0.6
Receiver noise	0.3	0.3

5. Our results are not the last word on GPS device precision!

This experiment investigates the effects of multipath errors and receiver noise introduced by buildings which (according to the chart above) account for about a metre, though the results indicate the error can be much greater – by a factor of about ten. Nevertheless, apps can report locations of devices inside houses to a couple of metres, so something, perhaps averaging over long times, enables this better **accuracy**.

Results were not obtained for identical conditions as each measurement pair (indoor and outdoor) were done in different places at different times. Perhaps this experiment could have been designed better – perhaps alternating between results taken indoor and outdoor would have helped by obtaining result pairs closer in time.

An observation shared while creating this challenge was that a GPS tracker clocked up a considerable distance while apparently randomly moving around inside a café, while the owner was mostly seated. It was not the tracker moving, but fluctuating errors that lead to this chaotic motion.

And finally…

100% of participants reported results of iPhones which account for just 50% of UK mobile phones. Perhaps this is evidence budding scientists prefer iPhones. Experiments often throw up odd facts!

#MeasurementAtHome

npl.co.uk/measurement-at-home