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Classroom Study of GNSS Position Accuracy Using Smartphones

K. Izet-Ünsalan[1], **M. Ünsalan**[2]

1. "Ovidius" University, Faculty of Mechanical, Industiral and Maritime Engineering Blv. Mamaia 124, Constanta, 8700, Romania
2. "Politehnica University of Bucharest", Faculty of Electronics, Telecommunications and Information Technology, Blv. Iuliu Maniu 1-3, Bucharest, Romania
kunselizet@yahoo.com

Abstract. The data used in this paper were collected by the participants of the first MOOC (Massive Open Online Course) "GPS: An Introduction to Satellite Navigation, with an interactive Worldwide Laboratory using Smartphones", offered by Stanford University through Coursera, taught by professors Per Enge and Frank van Diggelen.
More than 1000 users worldwide determined their position in open and urban areas and submitted their results, which were compared with the claimed accuracy. Additionally, the authors of the MOOC have proposed the "Law of Urban Multipath" that predicts GNSS position accuracy based on heights of buildings in the proximity.
In this study, the aforementioned data was analysed to obtain practical results that can be used to improve the accuracy of simple smartphone and tablet based GNSS measurements.
In the undergraduate course taught by the first author, this methodology was used as a laboratory tool for the improvement of navigation and positioning skills of the students.
Keywords: GNSS, Position Accuracy, Smartphones

1. Introduction

Smartphones are one of the most widely used electronic devices worldwide, increasingly being a vital part of daily life. Their functions have developed from simple voice and text message transmission devices to various internet and wireless services, as well as photography and health-monitoring within the few decades since their introduction.

From the first GPS enabled phone in 1999, it is estimated that out of an estimated 5.8 billion devices that use the globally installed base of GNSS in 2017, 5.4 billion are smartphones, followed by automotive GPS systems that amount to 380 million devices. [1]

Besides global navigation satellite system (GNSS) chipset, smartphones include many sensors, such as inertial measurement units (IMU), odometers, altimeters, etc., that empower users to plan their activities. Collected data were used to study travel behaviour patterns, for planning efficient transport services. [2, 3, 4, 5] Most of these experiments were in localized areas, rather than global coverage, or with a limited number of participants, or data were automatically collected in passive mode by various installed applications.

First Massive Open Online Course (MOOC) "GPS: An Introduction to Satellite Navigation, with an interactive Worldwide Laboratory using Smartphones" was offered by Stanford University through the open distant education scheme "Coursera" in the last quarter of 2014 and was taught by professors Per Enge and Frank van Diggelen. [6]

In this MOOC, there were more than 31000 registrants from 192 countries, 3000 finished the course and 1700 from 100 countries participated at the 3 laboratories.

This was the first MOOC that used smartphones as laboratory tools. The organizers have claimed that is the first time that when data has been collected on this large scale.

2. Methodology and data processing

Laboratory A studied GPS accuracy. First, the participants were given the task of obtaining a GPS-fix in an open space. What was recommended was to go in a place with previously known coordinates, in order to be able to compare the obtained position with the previously known coordinates of the location and then estimate the error. For Android users, an application can confirm that the position is obtained from satellites and not from wi-fi or GSM cell-towers.

The second set of measurements were made near buildings with various heights.

Then, the data were introduced in a Google Form on the course's web site. Those data are: location coordinates (latitude – longitude), estimated error for open area, city or town name, location, estimated error and the heights of the buildings around location.

Estimated error ranges and building height ranges are presented in the following table:

Range	Errors	Building height
1	0 - 2 m	One floor
2	2 - 5 m	2 -3 floors
3	5 - 10 m	4 - 10 floors
4	10 - 20 m	11 - 20 floors
5	20 - 50 m	21 - 50 floors
6	50 - 100 m	> 50 floors
7	100 - 200 m	
8	> 200 m	

For this laboratory, 1087 students from 100 countries have collected measurements (fig. 1, 2). An Excel file of the said measurements was made available for all participants.

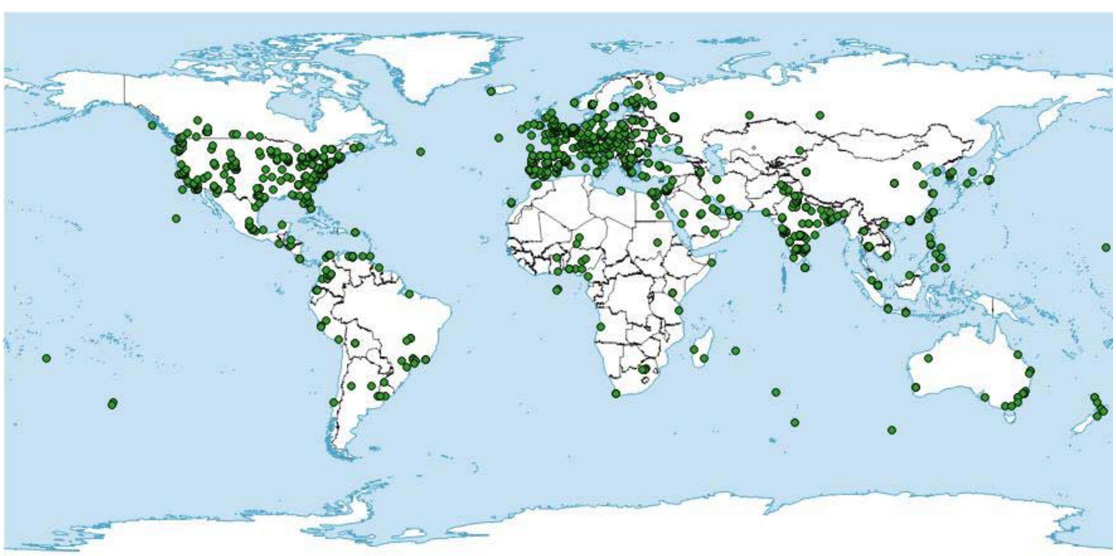

Fig. 1. Worldwide participants at the Laboratory A - observation points

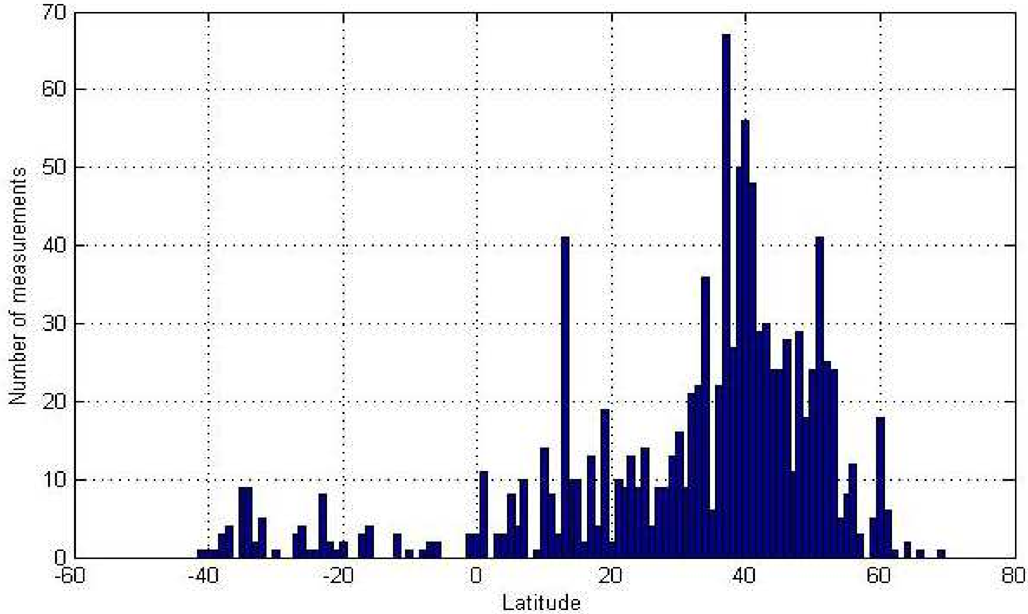

Fig. 2. Number of measurements versus latitude

The measured mean error in open areas is 4.88 meters, which is very close to the claimed accuracy of 5 meters. The standard deviation is 10.194.

For the second set of measurement, greater errors were recorded, as expected, due to multipath caused by the buildings. The measured mean error is 16.56, and the standard deviation is 22.596.

The distributions of errors are shown in fig. 3, 4, 5.

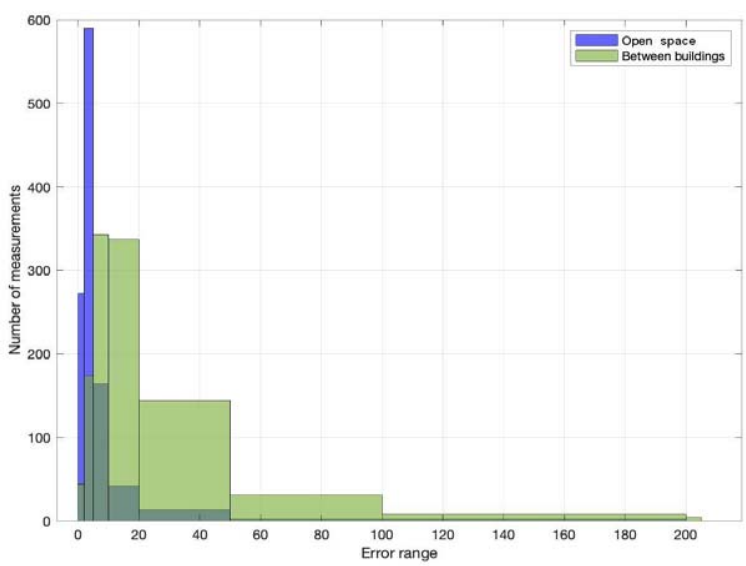

Fig. 3. Distribution of errors

Based on the collected data, the authors of the MOOC have proposed the "Law of Urban Multipath" that predicts GNSS position accuracy based on heights of buildings in the proximity [6]:

Mean Accuracy (m) = Building height (floors) + 5 m

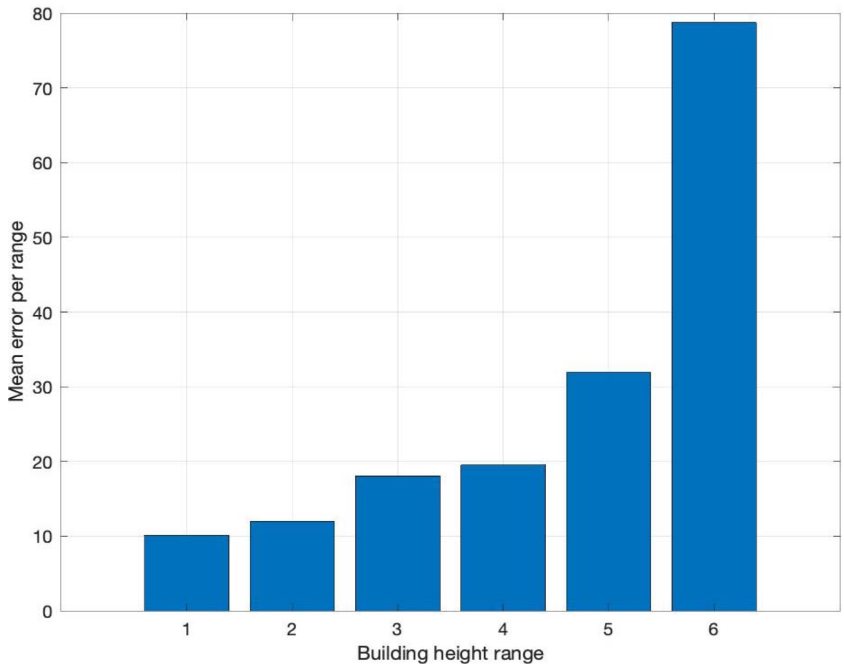

Fig. 4 Errors vs building height

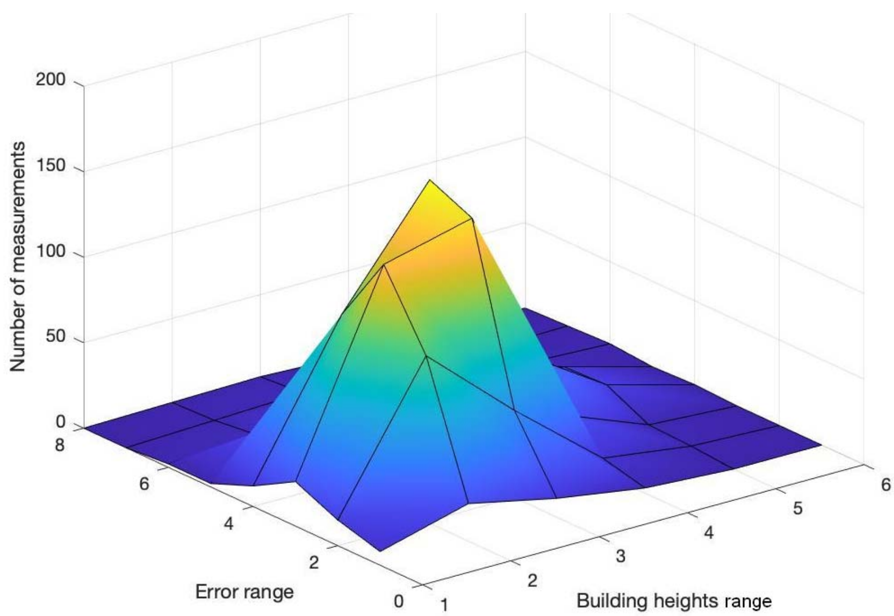

Fig. 5 Errors vs building height

- Urban myth 1: accuracy is dependent on latitude

Data were classed in 10 degree latitude zones from Equator to Northern Pole and Equator to Southern Pole, in order to compare the variation of precision with latitude. Number of measurements for each segment of latitude and the value of estimated error are presented in the following tables and in fig 4:

Latitude	40-50 S	30-40 S	20-30 S	10-20 S	0-10 S
Open space Total samples	1	35	21	12	11
Mean error (m)	3.5	3.7142	4.7142	4.1666	5.4545
Near buildings Total samples	1	34	21	14	11
Mean error (m)	35	17.3529	12.9523	15.6071	21

Latitude	0-10 N	10-20 N	20-30 N	30-40 N	40-50 N	50-60 N	60-70 N
Open space Total samples	44	122	96	285	292	148	18
Mean error (m)	4.0682	6.7951	6.4635	4.1736	4.1147	4.3885	3.8055
Near buildings Total samples	47	123	94	284	290	148	18
Mean error (m)	15.3936	18.9186	19.9946	14.7517	14.6120	18.1351	14.5555

Variation of accuracy is insignificant at different latitudes for open space measurements. For measurements near buildings, there is only one between 40-50°S with error in the range 20 - 50 m, therefore it is inconclusive.

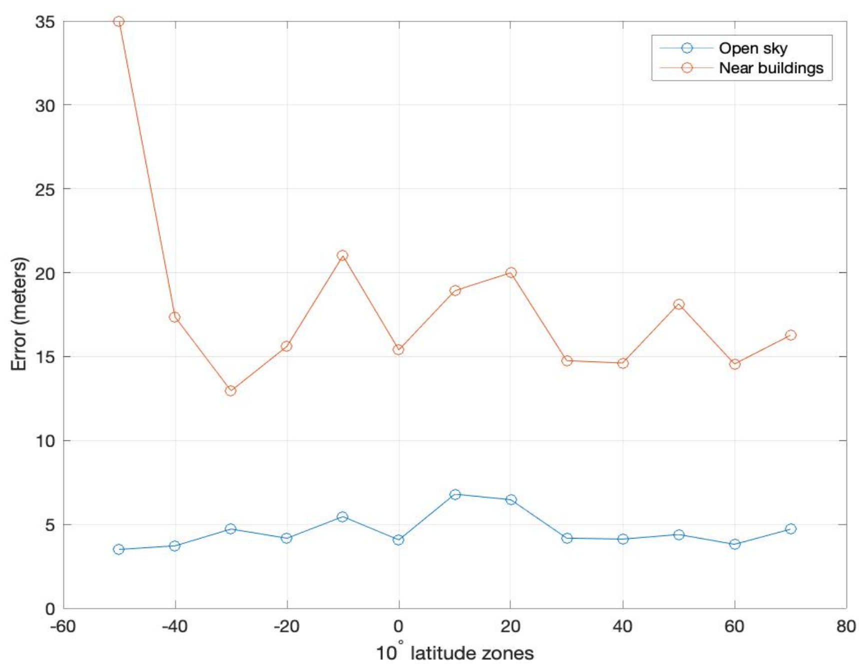

Fig. 6 Variation of mean error with latitude

3. Practical value and use for students

The methodology was used for one of laboratory sessions of "Integrated Navigation Equipment and Systems", taught to the students enrolled at "Marine Systems and Equipment" undergraduate program of The Faculty of Mechanical, Industrial and Maritime Engineering in "Ovidius" University of Constanta.

Most of the students had no previous knowledge and skills related to navigation or usage of maps or charts. The purpose of the laboratory is to empower basic skills for unexperienced people, with standard smartphones and not to transform them to navigation experts. Due to overreliance or wrong use of GNSS receiver or related smartphone applications, a significant number of cases of lost or disoriented persons have been recorded. Thus, the authors consider it useful to provide some supplementary information and to fight the two urban myths about GNSS services:

- Urban myth 2: GNSS is not functional if there is no cell network.
- Urban myth 3: A-GNSS improves the accuracy.

Data were collected in 2017-18 and 2018-19 academic years when the related course was offered.

For 2017-18, the results for 26 measurements in different places are:

	GNSS	A-GNSS
Open space Mean error (m)	5.8846	6.5
Near buildings Mean error (m)	7.4230	8.3846

Also, students were made to take measurements in 11 points on the route in fig. 7. The results for 18 measurements are:

	GNSS	A-GNSS
Mean error (m)	7.3955	7

In 2017-18 there are 30 measurements on the route in fig. 7, and the computed mean error was 6.78 m.

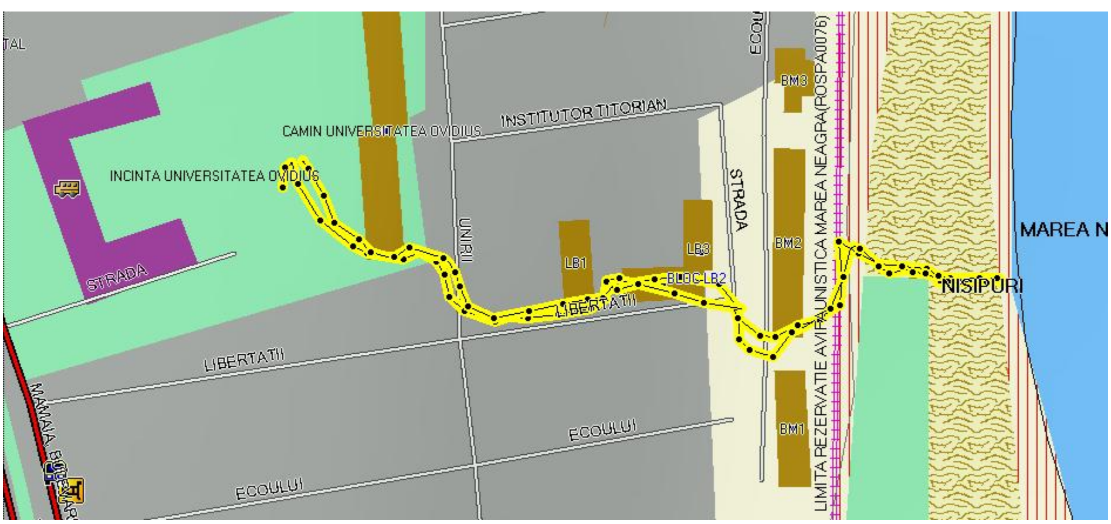

Fig 7: Track from MapSource

The errors were greater than those obtained for the MOOC, since the students had no posibility to know the actual error, comparing with the map in Google Maps and an exact location. They used the value of the error provided by the manufacturer of the application installed on the smartphones.

They could learn to configure the smartphones to use only the embedded receiver in zones without phone signal and that the use of A-GPS did not improve accuracy, but reduced the time to first-fix.

4. Conclusions

The MOOC provided a very good opportunity for collection of data. Since it covered a wide distribution of participants worldwide, it was possible to have a global assessment of the accuracy of the GNSS system.

Also, the students were able to use this application by the standard “smart” cellular phones, gaining knowledge and skills in that field that not only had professional outcomes, but also in everyday life.

5. Acknowledgments

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