GEO-POSITION TECHNOLOGIES IN CITY USE RESEARCH: ACCURACY EVALUATION IN THE CONTEXT OF UNIVERSITY STUDENTS MOBILITY

Bianca Chaves-Custodio
Architect, Urban and Architectural Management and Valuation PhD student
disetectura@gmail.com
+34 615 94 11 39

Mireia Ballús Martínez
Architect, Master in Urban and Architectural Management and Valuation
m_ballus@hotmail.com
+34 627 68 31 32

Fernando García Martínez
Architect, Master in Urban and Architectural Management and Valuation
fergarmar89@gmail.com
+34 660 74 78 22

Sandra Karina Meza Parra
Architect, Urban and Architectural Management and Valuation master student
s.mezap@gmail.com
+51 998 898 828

Liya Yang
Urban and Architectural Management and Valuation master student
liyayang@gmail.com
+34 688 50 64 16

Francesc Valls
Architect, PhD candidate, associate professor and researcher
francesc.valls@upc.edu
+34 93 401 19 33

Carlos Marmolejo Duarte
Architect, PhD. Associate professor
carlos.marmolejo@upc.edu
+34 93 401 63 96

Centre of Land Policy and Valuations (CPSV)
Architectural Technology Department (TA)
Technical University of Catalonia (UPC)
Av. Diagonal 649, 4ª planta.
08028 - Barcelona, Spain
cpsv.info@upc.edu
+34 93 401 63 96
+34 93 401 64 26

Key words: GPS tracking, GPS, mobility, smartphone.

Abstract

In the last years the broad potentiality and utility that geo tracking systems can offer have been explored in research fields not only related to geography, but medicine, leisure and tourism as well. Although this technology has been employed in mobility and transportation system analysis, there is still a lack of studies in the urbanism field.

This research seeks to evaluate the accuracy of geo-positioning technology tools in the analysis of peoples' movement and flows in the city. Therefore, we have performed an experiment using *Campus Mobility*, an open source application for Android smartphones developed by the Mobility, Transport and Territory Studies Group (GEMOTT) of the Autonomous University of Barcelona (UAB) based on *SpaceMapper* by John Palmer. While activated, the app tracks and records automatically spatiotemporal data from volunteers' smartphones every two minutes through the GPS. By the end of the experiment, a large dataset with more than 47.000 entries has been generated, including geographical position (latitude and longitude), date and time (timestamp) as well as an anonymous user ID. Additionally to the experiment, a survey has been applied to volunteers in order to contrast and complement results from automatically gathered data and users answers.

From the obtained dataset, we have investigated users' paths, movement and meeting points analytically and graphically, aiming to recognize patterns in volunteers' displacement and to detect possible anomalous data. For the graphic analyses we have created data visualizations in addition to dynamic maps that have been developed using ArcGIS and CartoDB tools. Both outcomes were combined in order to gain a deep understanding on the shortcomings and possibilities that geo-positioning technology tools offer to urban investigation field.

Finally we conclude that, despite minor errors, geo-position technology tools provide new great possibilities for city flows and mobility studies, being able to gather automatically a very large amount of detailed data that would be impossible to collect without an automated process. GPS tracking can be considered a powerful resource for urban studies, although those tools are not entirely accurate if applied to a very small scale analysis.

Introduction

Networks based on new information technologies provide the organizational basis for the transformation of productive relations of social and spatial base, where information flows construct a new flexible production system. Architects and planners have tried to analyze its function and the residents' impression about the city, in order to stimulate the diversity of large cities in detriment of the urban planning of the 1950s, where the automobile was the main actor. In this context, Jacobs (1961) studied the major American cities from the perception of the daily activities of neighbourhood, in order to assess the living situation and security in the streets of cities. On the other hand, Lynch (1960) analyzed the visual appearance of cities and the importance of understanding these urban environments through the construction of mental maps and surveys of participants.

This study aims to evaluate the accuracy of geo-positioning technologies equipped on mobile devices as an analytical tool in urban planning and mobility of citizens. Specifically, we studied the mobility of master and doctoral students within the metropolitan area of Barcelona. The central point is Barcelona School of Architecture (ETSAB), located in Campus Sud of Polytechnic University of Catalonia (UPC), the college town of Barcelona. In the experiment, participants installed *Campus Mobility* application on their smartphones. This application automatically tracked and recorded the geographical position of users each two-minutes for one week. These records generated an enormous dataset which was analyzed statistically and graphically. Furthermore, a survey about participants' activities and travel habits was made, which served as complementary information. This research proves that geo-positioning technology could be an effective tool to investigate various aspects of the city. And the patterns of behavior which were extracted from geo-positioning data could help decision makers to plan cities according to the habits of citizens.

State of Art

Studies related to application of tele-monitoring technology

Shoval et al. (2014) in their literature review regarding GPS, RFID, mobile and new technologies, mentioned that the share of the articles published in human geography journals is less than 13% of the total articles that made use of GPS and other tracking technologies. Health and transportation studies accounted for the major part of related publications. As for the field of mobility and transport, it is worth to mention the study conducted by Bohte and Maat (2009). Their study combines the techniques of tele-monitoring GPS, GIS tools and a web application in which participants interacted with each other.

Despite the significant technical advances, the uncertainties about the utility of urban remote sensing (Donnay, 1999) still exist. Shoval et al. (2014) are also concerned about the violation of privacy in research using tracking technologies, and as well as the shortage of funding to implement those researches. While Longley et al. (2001) emphasized the unreliability of remote sensing, in terms of defining the boundaries[1] of objects and clarifying the category of each zone. Besides, as Longley (2002) criticized, the infrequent collection of auxiliary information, such as the population census or registration of property.

Limitations and potentials of tele-monitoring techniques

The use of GPS has been proved by several researchers as a powerful tool for tele-monitoring, however, it must be combined with other traditional techniques and cannot replace those traditional methods (Spangenberg, 2014; Van der Spek et al, 2009; Zhang, 2013; Palmer et al, 2013; Nitsche et al, 2012); Van der Spek et al, (2009) used GPS technology to capture pedestrian paths in historic centers and show them on maps. These researchers believed that this new tool allowed them to compose the spatial and temporal data, spatial conditions, demographic and social information of participants, and the characteristics of movements. In spite of these advantages, there are some limitations of this technology, because the collected data are very specific, and difficult to interpret.

[1] The capability to outline the exact boundaries of the existing urban construction, roads and green areas, as well as different uses.

Spangenberg (2014) indicated the limitations on signal-loss and complexity of cleaning the data. This was the reason why many results have just been reduced to a simple display of routes. The study of Gutmann et al. (2008) refers to the rights of privacy, since in many cases, researchers might collect data that reveals other information about the respondent, or some so called "intruders" tried to get these information intentionally. Moreover, the reduced samples of participants in most investigations, makes difficult to deduce general patterns of behavior: 14, 20 and 55 participants in the studies held by Nitsche et al. (2012), Shoval (2010) and Spangenberg (2014) respectively. Nitsche et al. (2012) provided incentive or reward financially with vouchers or free transportation bonds for collaboration of volunteers, in order to encourage their participation in research. Another way to expand the volume of the samples is to utilize the Volunteered Geographic Information (VGI). Goodchild (2007) mentioned that it contains geographic information produced voluntarily by the individuals or public, such as web pages or geo-tag.

In order to reduce these limitations, sensors and wearable[2] devices are increasingly used to identify and locate the mobility on a map. However methodologies of using GPS or accelerometer (ACC[3]) separately face three major challenges (Zhang et al, 2013): low accuracy in identifying displacement, low capability in recognizing the details of mobility, and the complexity of generating data. Thus, incorporating accelerometer with GPS, allows to measure rotational and translational forces, when the GPS signal is very low or zero.

Methods for analysis and data representation

There are various methods for analyzing data which is generated by applications of tele-positioning technologies. Bohte and Maat (2009), after removing invalid data, classified series of points or track-points[4] into movement or stable situation, by measuring distance between points and the points' change of location after a certain period of time. In addition, to classify the movement in different modes of transport, they considered the maximum speeds and means of each movement, the proximity of those points starting positions and destinations of public transport stations. Palmer et al. (2013), in their experiment *The Human Mobility Project*, collected location data and mobility of different participants, while asked participants about their mood in association to different locations. From the obtained data, they have been able to obtain maps of the areas of activity per day and per hour, inferring which kind of place might be, such as the workplace and home.

Finally, as to the methods of representation, Ramakrishna et al. (2013) displayed a system of visualization which was based on spatiotemporal data combined with open source technologies, and web frameworks[5]. It created a powerful system of visualization online. The system was

---

[2] The term refers to the set wearable electronic devices that are attached to some part of the body, continuously interacting with the user and with other devices in order to perform a particular function, such as measuring vital a whining or register shifts.

[3] ACC is an instrument for measuring acceleration, typically that of an automobile, ship, aircraft, or spacecraft.

[4] *Trackpoint* is each point where information relating to x and y coordinates, time and travel speed are stored.

[5] *web frameworks* is a software framework that is designed to support the development of web applications including web services, web resources and web APIs.

used to view the history of emergency calls by Los Angeles Fire Department (LAFD) and identified previous patterns of incidents from the data. This case demonstrates the effectiveness of the system. In addition, this system observes several interesting inferences about LAFD operations, such as LAFD takes higher times to respond to localities that lie in the boundary of the city as opposed to ones that are in the center.

Objectives

This research seeks to evaluate geo-positioning tools' precision in the study of people's mobility, displacement and flows in urban environments. For that end an experiment based on *Campus Mobility*, a mobile application that monitors and stores spatial-temporal data from users through mobile phone's GPS, was carried out. Master and doctoral students from ETSAB have voluntarily engaged in the experiment. Additionally, a survey was applied to the participants.
From the dataset gathered during the experiment, users' paths, displacement and stationary points were studied analytically and visually, aiming to determine geo-positioning technologies' potentialities and weaknesses as a tool for urban studies.
Based on all the information and data generated by participants, we can draw conclusions regarding the value of geo-positioning technologies tools in the study of urban flows and mobility, as well as if they offer valuable elements to analyze the way we use the city.

Methodology

Data acquisition - Campus Mobility experiment

Participants, UPC master students and doctorates, installed *Campus Mobility* app on their smartphones. The application had to be activated during all the period that the study lasted, one week long. It automatically recorded the users' geographical position every two minutes if there was sufficient signal available. In addition, participants could indicate their last trip transport mode. An extensive dataset with more tan 47,000 records was obtained during the experiment week, it included information about geographical position (latitude and longitude), timestamp (date and time), and an anonymous ID code. With this information, we could calculate speed and acceleration.

Survey

A survey was applied to the same group of 21 participants of the GPS tracking experiment. The survey was divided in different sections: Mobility, where participants were asked about the kind of transportation used and times of travelling; activities, considering complementary activities realized during the week of the experiment around the ETSAB (within a radius of 15 minutes walking); demography and Android version used for the experiment.

Data Validation Methodology

From the obtained dataset, participants with a reduced number of samples and all data registered out of the experiment week were discarded, reducing the amount of registers to 34,402 records. Taking the latitude and longitude recorded by the *Campus Mobility* app, the

UTM_X and UTM_Y coordinates[6] were extracted. In order to better understand and identify possible errors in the data, we have establish two kinds of periods (*static* and *dynamic*), initially taking as reference periods where users were certainly *statics* (ex. nightime), as well as certainly *dynamic* periods (ex. time just before classes begin). Following we have plotted samples of both periods.

To detect errors analytically we have calculated the percentage difference between correlative points in UTM_X and UTM_Y coordinates. Analyzing the distribution of percentiles, we found a threshold of 0.00122 for UTM_X coordinates and 0.000222 for UTM_Y coordinates. This values were applied to differentiate *dynamic* (18,66% of all records) from *static* periods (81,39 %).

Afterwards we have analyzed *static* periods aiming to identify possible variations in the UTM_X and UTM_Y coordinates value. Finally we have analyzed *dynamic* periods, to find possible points that were uncorrelated and have progressive in values (positive or negative) in the UTM_X coordinates.

Visualizations Methodology

From the data collected during the experiment's week and after a long process of data cleaning, which consisted in cut out data out of the experiment week, as well as to eliminate analysis formulas and information regarding speed and time, we have performed graphic and dynamic visualizations using simultaneously two different platforms: CartoDB and ArcGIS.

From the cleaned dataset, we have generated a *.csv file, which included latitude and longitude, date, time and an user`s numeric ID. Finally we have produced dynamic visualizations in order to see participants paths over maps. At this stage maps were made using CartoDB, an online platform that allows the creation of geospatial data visualizations and dynamic visualizations. This platform uses *OpenStreetMap* maps as cartographic basis. Finally the cartography has been omitted to preserve participants' privacy.

For each research stage and after every advance in detecting erroneous points, we have generated new dynamic maps that have been analyzed in detail and which allowed us to identify patterns in the spatial distribution of participants' paths. The main goal of this task was to visualize movements and flows spatially aside from detect points which presented random behavior and could stand for some issue during register.

Before inserting the data on ArcGis, all records between 22:00 and 08:00 hours were also eliminated in order to preserves participants privacy and to avoid long periods of static visualization, since most participants were already at home at that time. After a *.shp file was created with this information in ArcGis. From this new file, we generated a map with XY coordinates, where X was the longitude and Y the latitude of the recorded points. Finally, all points were grouped according to the User ID code assigning them a number and a colour so each tracking could be visualized individually.

---

[6] UTM coordinate system: is a coordinate system which help to identify locations on the surface of the earth. It divides the earth into 60 zones. Unlike the geographic coordinate system, UTM adopts "meter" as its unit, instead of latitude-longitude pairs. This system is widely used in geo-location technologies, such as Google map and satellite image.

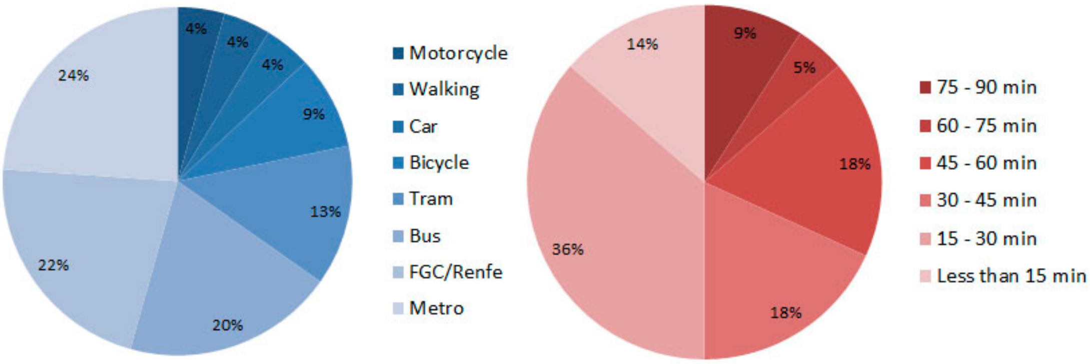
The cartographic base was only used to corroborate the veracity of the points. After that it was taken away so visualization cannot be read on a map preserving participants privacy. All original files and maps have been kept confidential.

Results

Survey Results

According to the survey, during the week of the experiment, public transport was the most used transportation to arrive at ETSAB (tram, bus, train and underground, in ascending order), as it can be seen in Figure 1. Users optimized their times by using public transport, since this guarantees an exact time of travel, contrary to cars. Also we could find that most of the participants took between 15-30 minutes to get from their house to ETSAB.

Figure 1. Transportation and time of travelling



Source: Own elaboration

We analyzed the average speed for each user (Table 1), where it was compared the actual movement speed, the average speed of all movements and the average speed for each point. The estimate of the real speed was obtained by dividing the distance between the central point of each of the participant's postal code and ETSAB, into the time taken for this trip according to the survey.

Table 1. Speed an transportation by user

ID	Distance PC – ETSAB (km)	Time taken accord. to survey (min)	Estimated speed (km/h)	Transportation	Speed by type of transport (km/h)	Average speed Points (km/h)	Average speed Interval (km/h)
1	0.962	15	3.85	Walking	4.5	4.66	4.84
2	21.777	80	16.33	Tram, FGC/Renfe	-	15.59	12.04
3	8.203	60	8.2	Bus, Metro	11.4	28.96	43.82
4	N/R	N/R	N/R	N/R	-	25.5	2.51
5	2.971	30	5.94	Tram	-	2.68	1.48
6	2.606	30	5.21	Car (not driver)	20.6	6.57	4.77
				Bus, Metro	11.4		
7	7.31	55	7.97	Bicycle	11.4	17.65	17.04
				FGC/Renfe, Metro	11.4		
9	4.509	15	18.03	Motorcycle (driver)	20.6	19.8	6.6
10	1.5	15	6	Walking	4.5	1.9	3.12
				Bus	-		
11	5.169	28	11.08	Bus, Tram	-	3.09	2.82
12	N/R	N/R	N/R	N/R	-	9.47	4.89
13	N/R	N/R	N/R	N/R	-	3.8	2.7
14	27.666	75	22.13	Metro	11.4	31.95	13.78
				Tram, FGC/Renfe	-		
16	29.264	60	29.26	Car (driver)	20.6	21.19	19.72
				Metro	11.4		
				Bus, FGC/Renfe	-		
17	0.962	25	2.31	Bicycle	11.4	2.46	3.23
				Bus, Metro	11.4		
18	4.659	40	6.99	Metro	11.4	13.55	5.87

Source: Own elaboration

The average speed per user shows certain relation between the type of transport used and speed obtained, nevertheless values tend to soften since all movements are considered.

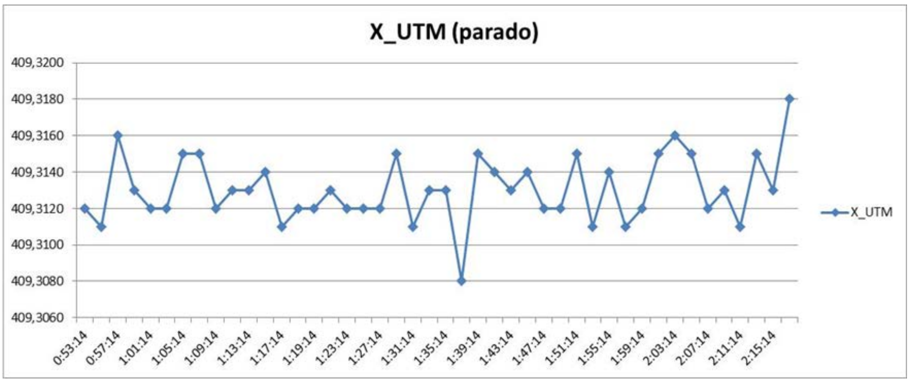
Regarding to improvements in accessibility infrastructure to ETSAB, most participants answered they would like a *Bicing*[7] station close to the faculty. Other comments included the existence of more frequency between buses; improvement to pedestrian's access; more parking space and finishing metro line L9.

Data Analysis Results

Different situations can be observed interpreting the UTM_X and UTM_Y plotts. In *static* periods, UTM_Y coordinate has the same value throughout all the term, while the UTM_X have a slight variation, repeating the same values as it's shown in Figure 2. It means that the UTM_X coordinate in *static* periods has a slight data distortion, since it should show the same value along the evaluated term. However, in *dynamic* periods, the plot show a succession of correlative and progressive points (positive or negative), in coordinates UTM_X and UTM_Y, displaying logical values.

[7] Bicycle sharing public transport system

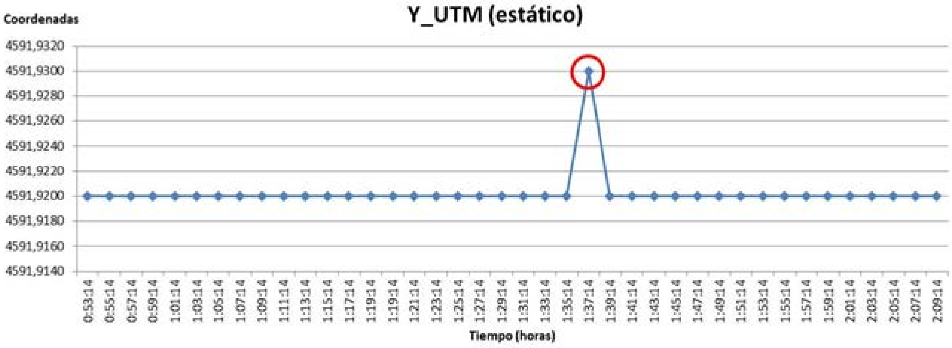
Figure 2. Static period UTM_X coordinate



Source: Own elaboration

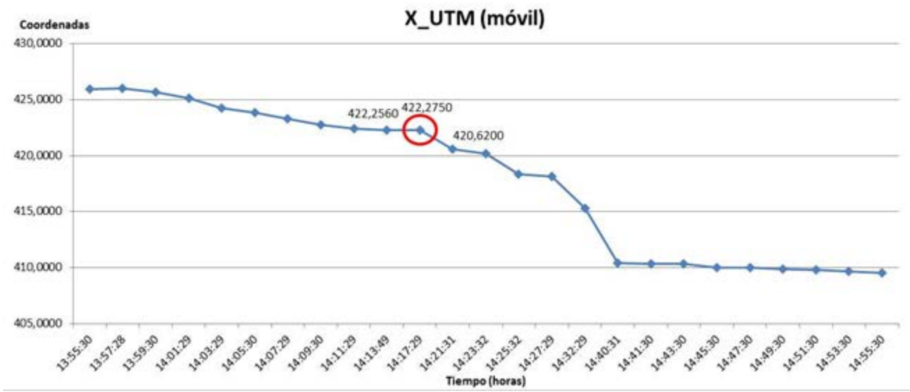
In *static* periods where UTM_Y coordinate remains constant, there has been found an error of 7.49% of all cases (ex. Figure 3). However in UTM_X coordinate, where there was a slight distortion, such disturbance increases to 55.63% of all cases, so it is considered as distorted values and not as errors.

Figure 3. UTM_Y coordinate error (static period)



Finally, in *dynamic* periods was obtained an error of 1.83% for the UTM_X coordinate (ex. Figure 4) and an error of only 0.94% in UTM_Y coordinate. It means that total errors in motion, are only 2.47% of all cases.

Figure 4. UTM_X coordinate error (dynamic period)



Source: Own elaboration

Data in Table 2 show that it's been detected a higher percentage of errors during *static* periods, due to two main reasons: Firstly there are a greater number of records belonging to *static* periods and secondly, UTM_X coordinate has a slight disturbance on its values in those periods. Moreover the study carried out has not been able to obtain the same amount of samples of all the participants, but not for that reason users with fewer records have obtained greater error rates.

Table 2. Total errors by user

USER	Puntos	Error Y_UTM parado		Distorsión X_UTM parado		Error X_UTM movimiento		Error Y_UTM movimiento	
		ABS	%	ABS	%	ABS	%	ABS	%
1	3058	287	9,39	2020	66,06	13	0,43	10	0,33
2	3517	325	9,24	2225	63,26	14	0,40	6	0,17
3	3031	275	9,07	1808	59,65	56	1,85	33	1,09
4	452	32	7,08	185	40,93	39	8,63	20	4,42
5	1294	84	6,49	523	40,42	106	8,19	60	4,64
6	2170	111	5,12	1314	60,55	37	1,71	12	0,55
7	1640	90	5,49	726	44,27	23	1,40	13	0,79
9	2580	107	4,15	1667	64,61	4	0,16	1	0,04
10	2706	286	10,57	1558	57,58	59	2,18	24	0,89
11	1663	55	3,31	699	42,03	46	2,77	36	2,16
12	1784	105	5,89	924	51,79	10	0,56	5	0,28
13	1327	83	6,25	611	46,04	48	3,62	31	2,34
14	1492	168	11,26	913	61,19	31	2,08	8	0,54
15	944	111	11,76	602	63,77	6	0,64	1	0,11
16	2328	141	6,06	1071	46,01	51	2,19	21	0,90
17	1544	143	9,26	931	60,30	19	1,23	9	0,58
18	872	25	2,87	249	28,56	31	3,56	15	1,72
Total	32402	2428	7,49	18026	55,63	593	1,83	305	0,94

Source: Own elaboration

Visualizations Results

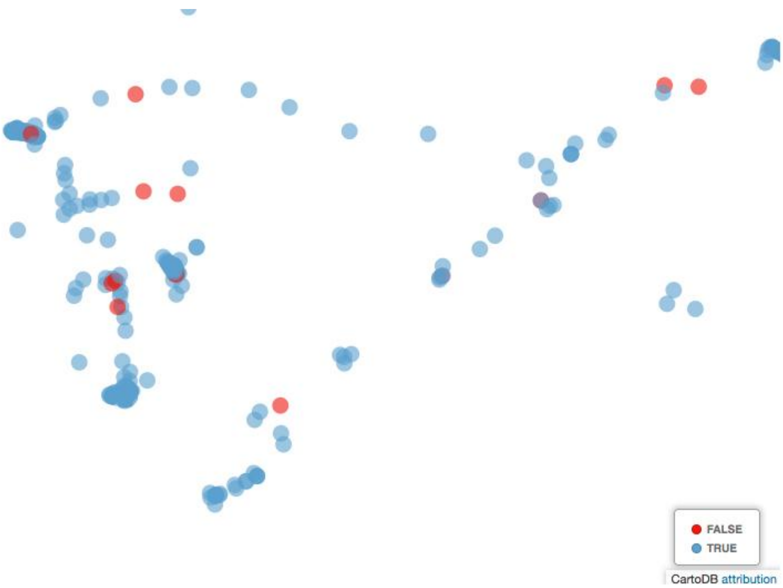
Regarding the results' visualizations, we have generated dynamic maps based on geographic and temporal information from the dataset, which allowed us to visualize users' routes along the experiment week (Figure 5). As in ArcGis, a different colour was assigned to each user, so that paths could be easily identified.

Figure 5. Users' routes dynamic visualization in three moments with timeline - CartoDB

Source: Own elaboration

Based on the data analysis results we have created a new dataset and subsequently new dynamic maps. This time assigning different colours, blue to the points considered "correct" (true) and red to the ones considered "wrong" (false), as it can be seeing in Figure 6, to check whether points identified as "false" had some sort of exceptional spatial behavior.

Figure 6 "correct" and "wrong" points visualization - CartoDB



Source: Own elaboration

In the case of ArcGis, when observing all points put on the map, some were visibly further from the zone where the experiment took place (Figure 7). To corroborate the validity of these points, we looked back to the Excel sheet and confirmed that the location before and after these points where into the study zone and that the period of time between them wasn't long enough as to perform a trip that long.

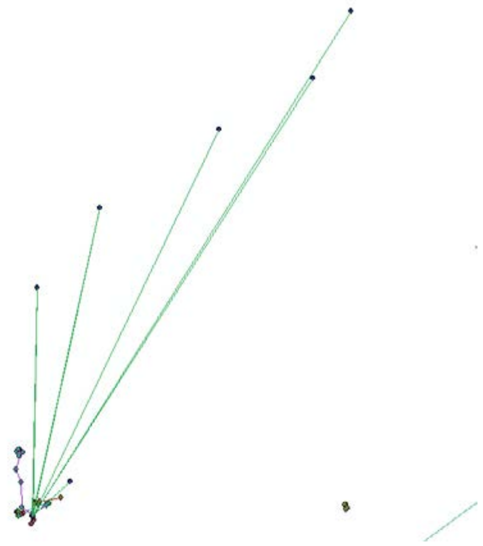
Figure 7. Tracked point out of study zone

Source: Own elaboration - Printscreen from ArcGis program

As a potentiality, the program permits to generate tracks and visualize them as videos, it also permits to configure the speed in which it can be shown. The option to mark tracks with lines and by colours according to the user, helps a better association of the movement. Also, being able to configure the visualization so it showed the tracks just during a certain period of time, helped to have a cleaner and better lecture of the data.

As a difficulty, special attention must be taken when inserting information about date and time to generate the tracks. It is very important keep always the same date and time format in order to avoid generating illogical graphic visualizations, such as in Figure 8, where registered points were placed randomly.

Figure 8. Recorded points randomly placed, forming a star shape tracking



Source: Own elaboration - Printscreen from ArcGis program

Conclusions

This research sought to assess the accuracy of geo-positioning technology tools in the analysis of peoples' movement and flows in the city. Therefore, an experiment using the mobile app *Campus Mobility* has been performed in conjunction with a survey. To that end ETSAB master and PhD' students have voluntary taken part.

From the gathered data analysis we can conclude that *Campus Mobility* app bear minor drawbacks when tracking and recording users' location. First, if the device has not been able to locate the user in a particular lapse of time, some points have not been recorded until the connection had been restored. Confirming previous studies (Spangenberg, 2014), we have observed that some unrecorded data corresponded to underground path segments, due to that not all users obtained the same amount of registered points (coordinates). In some cases the lapse of time between recorded points was critical.

Second, we have observed that even when the device remains static, there is a distortion in the location, generating an inaccurate recorded position. This distortion is more pronounced along the UTM_X axis and usually does not exceed ten meters. In some cases, we have detected points that do not correspond logically to users' paths, presenting exceptional spatial behavior, summing up 9.96% in total.

Regarding data visualization, we concluded that CartoDB generates better graphic representations when compared to ArcGis, apart from being simpler to use. The main constraint when using ArcGis is that it is too demanding in terms of RAM, resulting in very slow dynamic visualizations. Moreover, it is necessary to be very careful when introducing data to avoid the generation of mistaken representations.

Finally we conclude that geo-position technology tools, such as *Campus Mobility* app, provide great new possibilities for city flows and mobility studies, being able to gather automatically a very large amount of detailed data that would be impossible to collect without an automated process. GPS tracking can be considered a powerful resource for urban studies, although those tools are not entirely accurate if applied to a very small scale analysis.

Acknowledgments

The authors want to thank the group headed by Prof. Carme Miralles for their invaluable support, also to John Palmer and Frederic Batumeus for developing the Android App *Campus Mobility* for this conjoint project.

References

Bohte W. & **Maat** K. *Deriving and Validating Trip Destinations and Modes for Multi-day GPS-Based Travel Surveys: A large-Scale Application in The Netherlands*. Transportation Research 2009, Part C 17, p. 285-297.

Donnay, J.P. *Use of remote sensing information in planning.* Geographical Information and planning, 1999, p. 242-260.

Goodchild, M.F. *Citizens as sensors: the world of volunteered geography.* Geojurnal, 2007, no. *69*, pp. 211-221

Gutmann M.P., **Witkowski**, K., **Colyer**, C., **McFarland**, J. & **McNally**, J. *Providing Spatial Data for Secondary Analysis: Issuesand Current Practices Relating to Confidentiality.* Popul Res Policy Rev, 2007, DOI *10.1007/s 11113-008-9095-4.*

Longley P.A., **Goodchild**, M., **Maguire**, D.J. & **Rhind,** D.W. *Geographical Information Systems and science.* John Wiley & Sons, Chichester, 2001, 3th edition, UK.

Longley P.A. *Geographical Information Systems: will developments in urban remote sensing and GIS lead to "better" urban geography?* Progress in Human Geography, 2002, vol 26, no. 2, p. 231-239.

Jacobs J. *The Death and Life of Great American Cities*, 1961, New York: Random House

Lynch K. *The Image of the City*, 1960, Cambridge MA: MIT Press. OL 5795447M

Nitsche P. **Widhalm**, P., **Breuss**, S. & **Maurer**, P. (2012). *A Strategy on how to utilize smartphones for automatically reconstructing trips in travel surveys?.* Procedia - Social and Behavioral Sciences, 2012, no. 48, p. 1033-1046.

Palmer, J.R., **Espenshade**, T.J., **Bartumeus**, F., **Chung**, C.Y., **Ozgencil**, N.E. & **Li**, K., (2013). *New approaches to Human Mobility: Using Mobile Phones for Demographic Research*. Demography, 2013, vol 3, no. 5, p. 1105-28.

Ramakrishna, A., **Chang**, Y. & **Maheswaran**, R., (2013). *An Interactive Web Based Spatio-Temporal Visualization System.* Advances in Visual Computing, 2013, 9th International Symposium, ISVC, p.673-680.

Shoval, N., **Auslander**, G., **Cohen-Shalom**, K., **Isaacson**, M., **Landau**, R. & **Heinik**, J. *What can we learn about the mobility of the elderly in the GPS era?. Journal of Transport Geography, 2010, no. 18, p. 603-612.*

Shoval N., **Kwan**, M., **Reinau**, K.H. & **Harder**, H. *The shoemaker's son always goes barefoot: Implementation of GPS and others tracking technologies for geographic research.* Elsevier, Geoforum, 2014, no. 51, p. 1-5.

Spangenberg, T. *Development of a mobile toolkit to support research on human mobility behavior using GPS trajectories.* Inf Technol Tourism 2014, no. 14, p. 317-346.

Van der Spek, S., **Van Schaick**, J., **de Bois**, P. & **de Haan**, R. *Sensing Human Activity: GPS Tracking.* Sensors, 2009, no. 9, p.3033-3055.

Zhang, Z. & **Poslad**, S. *Design and test of a hybrid foot force sensing and GPS system for richer user mobility activity recognitio*. Sensors, 2013, no. 13, p. 14918-14953.