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Leveraging the Ubiquitous GPS Sensor on the Smartphones for Accessible Land Surveying

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Abstract

The Global Positioning System (GPS) is an essential tool in land surveying. GPS has become an alternative method of surveying that requires less manpower and less time. However, GPS devices are still expensive to buy, especially for students. On the other hand, almost every student has a smartphone with a built-in GPS sensor, so this GPS is certainly accessible to everyone with a smartphone. This study used a smartphone's GPS to conduct land surveying at the campus of Bengkulu University. This smartphone's GPS was used to track various parameters such as coordinates, elevation, and distance between two or more points to calculate the area within the study area. The innovative method of using the built-in GPS sensor in smartphones will provide convenience for users and introduce simplified open-source software for the land measurement process. The measurement was calibrated using a conventional roll meter to verify the linear error by comparing the two measurements between the smartphone's GPS and roll meter. The smartphone's GPS reading was logged using GPS Waypoints and My Tracks, free Android applications on the Google Play store. This study's average error in measurements obtained using GPS on smartphones was 3.02%. This value is sufficient for the initial stage of low-cost land surveys and falls within ideal conditions for GPS measurements. Therefore, this article emphasizes the potential of smartphone GPS to optimize techniques in education and scientific investigations.

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Introduction

The surveying technique has developed significantly in many sciences regarding the instruments and methods [1]. Education also incorporates it as part of the curriculum and research. Equipment in various laboratories is equipped to meet the needs of surveying engineering. This illustrates that surveying engineering is essential in various fields of life. Specifically, at the University of Bengkulu, not all laboratories can provide surveying equipment services for every student due to the limited number of tools.

Researchers are continuously working to improve the quality of survey data collection. Survey data is portrayed graphically by the construction of maps, profiles, cross-sections, and diagrams [2]. The use of survey data through GPS tracking has been used for urban planning [3], to assess landslide-prone areas [4], to monitor changes in waste disposal areas [5], and for environmental and ecological conservation [6], [7], as well as for transportation safety and efficiency [8]. Many land surveying methods offer high accuracy, such as a direct measurement using an analog roll meter, a theodolite instrument, an unmanned aerial vehicle, or a terrestrial laser scanner [9]. However, the roll meter is only effective in a small area, while the theodolite requires more manpower, time [10] and limited to certain places.

A Global Positioning System (GPS) device is a standard tool for collecting survey data, like pedestrian route data, tomography, epidemiological investigation data, forensic data, and agricultural and forest data [11]–[16]. GPS surveying can be conducted day or night, and it provides direct acquisition of 3D coordinates [17]. The accuracy and precision of the measurement results are compared with each of the other methods and devices [18], [19]. The GPS provides an easier way to conduct a land survey, as the standard handheld GPS indicates about a 12% error compared to the results of the total station survey [20]. GPS is a standard tool for surveying but is often too expensive for students, and some institutions do not have enough equipment to meet their needs. Therefore, a more affordable and readily available method for land surveying is needed, one that avoids costly tools like total stations and laser scanners. Using smartphones as personal navigation tools for survey data can be a cost-effective and ubiquitous option. Popular smartphones use integrated global navigation satellite system (GNSS) receivers [21].

Furthermore, smartphones have been equipped with various sensors, including Global Positioning System (GPS) receiver, acceleration, magnetic, and gyroscope sensors. This equipment holds the promise of enabling the use of a smartphone for numerous applications [22]–[24]. The apparent advantages of a smartphone are that it is easy, cheap to obtain, and is owned by everyone, including students and omnipresent. [25]. S. Korpilo and A. Hardy have used smartphone GPS to track the movement of people in a specific area and over a certain period, yielding results that indicate this device can be developed for further analysis and tracking [26], [27]. Based on these findings, this paper aims to give further insight into the usability of the ubiquitous smartphones for survey data, to test the performance and accuracy of the smartphone's GPS, and to compare the survey results conducted by both the smartphone's GPS and the conventional roll meter. Although research using GPS on smartphones has been conducted by other researchers, such as K. Merry [28], that research did not compare the results with other surveys or measurements and used a different type of smartphone. This becomes the main distinction from the research presented in this paper.

Experimental Method

The usability of smartphones for surveying data was tested in the Bengkulu University (UNIB) area. It is situated at 3°45'27.39"S and 102°16'34.98"E near the west coast of Sumatra. Its elevation ranges from 11 to 17 meters above sea level, covering an area of 24.9 ha. The eastern part of the UNIB campus area is reviewed using Google Earth Pro.

Various software is used to process survey data on smartphones and personal computers. GPX Waypoints and My Tracks applications are installed on Android smartphones. These applications are freely available on the Google Play Store. The software installed on the personal computer is Google Earth Pro, TCX Converter, Google Sketch Up, and 3D Surfer.

Google Sketch Up and 3D Surfer are paid applications, but they also provide free versions. Google Earth Pro and TCX Converter are free applications.

The device used in this study is a standard low-end Android smartphone from Xiaomi, the Redmi Note 4. We chose this phone because it is a medium-priced smartphone commonly used by students. We calibrate the smartphone's GPS to determine the linear measurement error by comparing it to a 100-meter-long roll meter. The smartphone’s GPS is calibrated in the open field to avoid overhead obstacles. The roll meters were laid out with varying distances, starting from 30 m, 40 m, 50 m, and up to 100 m. For example, when the roll meter is stretched to 30 m, the smartphone's GPS is placed at the starting point, 0 m, and the position is recorded using the smartphone’s GPS. Then, at the endpoint of the roll meter, which is 30 m, the position is recorded again using the smartphone’s GPS. The distance measured by the smartphone's GPS is obtained based on the recorded starting and ending positions from the smartphone’s GPS. This process is repeated for the following distance ranges, which are 40 m, 50 m, and so on up to 100 m.

After the calibration, the research area collects as much waypoint data as possible. We use the previous satellite imagery of the eastern part of the UNIB campus to plan the locations of the waypoints to be collected. As with any land surveying activity, access to the area is a prerequisite. It had planned to track the campus’ exterior border area and collect waypoints at 5-meter intervals. However, the UNIB campus contains numerous inaccessible areas, including bushes, water bodies, and dense vegetation. To overcome this problem, additional GPS data, such as elevation, is only collected from Google Earth Pro in some of the inaccessible spots mentioned above.

We process the collected data using various techniques. First, the multiple GPX format files are imported into Google Earth Pro to visualize and verify the waypoints and track locations. Then, the multiple GPX files are exported into a single KML format file. After that, the KML format file is then converted into a CSV format file using a free software called TCX Converter. TCX Converter is the software that handles many incompatibilities between files for different outdoor GPS devices and mapping software [29]. The high-resolution satellite imagery of the area is copied as a JPEG format picture to compare with the measurement result obtained later.

This CSV format file is required to visualize the data into a contour line map using Golden Software's Surfer 3D application [30]. The contour map is then exported as a BMP file, and we used the Google Sketch Up application to create a 3D CAD surface and a 3D CAD map of the eastern part of the UNIB campus. The whole process is shown in Figure 1.

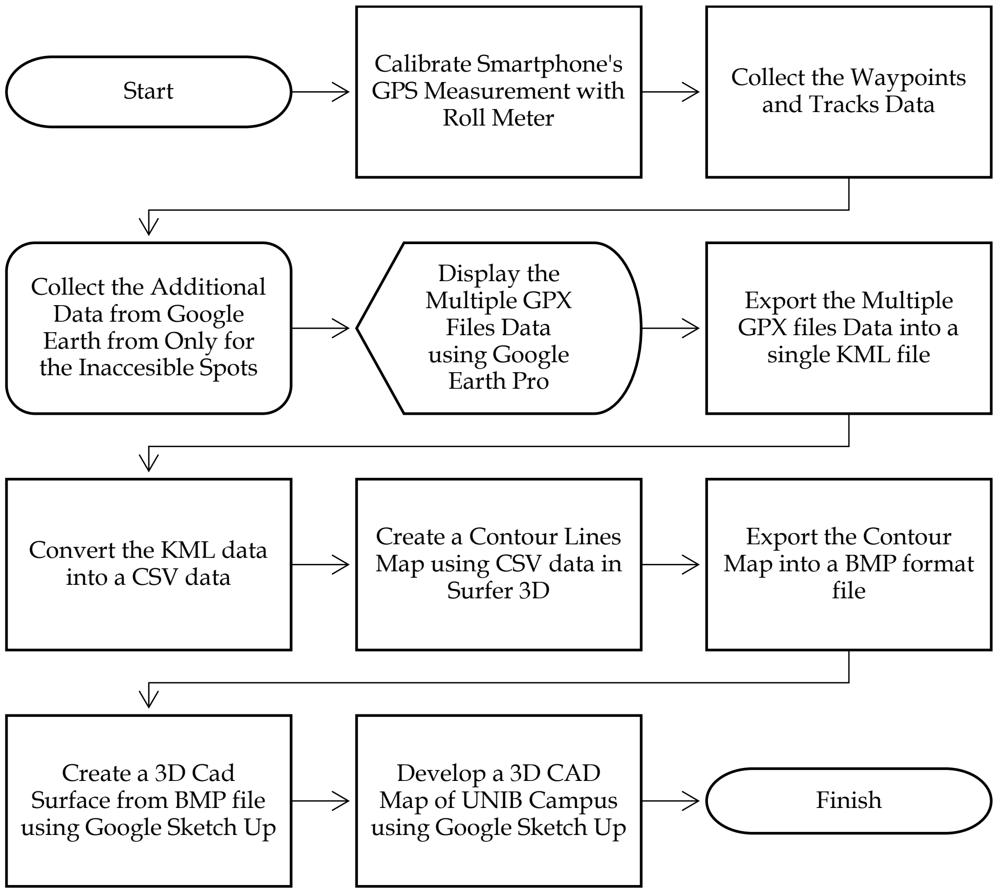

Figure 1. Flowchart of the research

Results and Discussion

Initially, the smartphone's GPS is calibrated with a 100-meter-long roll meter to verify the differences in linear measurements ranging from 30 m, 40 m, and 50 m to 100 m (Figure 2), and then the percent error of each measurement is calculated. The calibration is done in the campus soccer field (Figure 3) to avoid overhead obstacles and get as many satellites as possible tracking so we can obtain high-accuracy measurements.

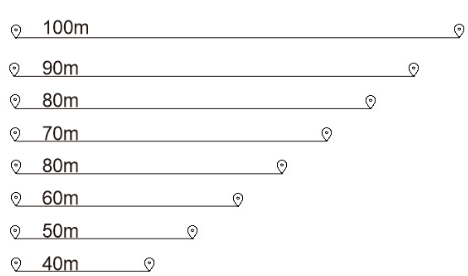

Figure 2. Calibration of the smartphone's GPS measurement

Figure 3. Calibration process in the soccer field

After the calibration, we attempted to measure the area of some public places in the eastern part of the University of Bengkulu campus and develop a map based on the collected data. Different areas within the UNIB campus necessitate distinct methods for obtaining GPS data. Overhead obstructions impeded tracking areas with buildings and dense vegetation, preventing the smartphone's GPS sensor from collecting enough GPS satellites. The area, still covered by bush and slum, was inaccessible for tracking. To overcome these issues, we marked some waypoints on the limited accessible points and obtained elevation data from Google Earth Pro. However, we tracked many areas without overhead obstacles, such as roads, open spaces, and water bodies, by walking along these roads and around their boundaries. We then obtained the data in the form of polygons or enclosed routes.

The 3D coordinates are obtained using free Android applications, such as GPS Waypoints and My Tracks, downloaded from the Google Play Store. These applications can log the data from the smartphone's GPS sensor and export it into a GPX or KML file that can be further processed using Google Earth Pro and Google Sketch Up. We then re-adjusted the GPX files on Google Earth Pro in case the tracking error level in some areas was unacceptable and to ensure that the tracking matched the actual location based on the satellite imagery provided by Google.

We proceed to the final step once we have completed all the aforementioned procedures. The GPX data is processed, and the map is developed by overlaying it onto high-resolution satellite imagery provided by Google. The development used the free version of Google SketchUp, a 3D CAD desktop application, to create a 3D landscape model with a 3D image of each building. The calibration smartphone's GPS calibration data is presented in Table 1.

From the data above, the smartphone's GPS performs a good measurement, with the error lying between 0.2 % and 6%, with the average error being 3.02 %. Furthermore, we examined the data to find a root mean square error (RMSE) to predict the standard deviation value for a series of measurements, and it was discovered that the RMSE is about 1.67 meters.

Table 1. Calibration of error in smartphone's GPS measurement

Smartphone's GPS (m)	Actual Length (m)	Difference (m)	Error (%)
27.44	30	-2.56	8.53
38.00	40	-2.00	5.00
47.00	50	-3.00	6.00
60.94	60	0.94	1.57
70.70	70	0.70	1.00
80.80	80	0.80	1.00
90.20	90	0.20	0.22
100.87	100	0.87	0.87
		Average error (%)	3.02

This result is better compared to the average accuracy of horizontal positions in the smartphone tracking research by K. Merry, which reached 7–13 m; however, K. Merry's values remain consistent[28]. The RMSE confirms that the ubiquitous smartphone's GPS sensor can provide a low-cost and readily available solution for land surveying activities. However, using the smartphone's GPS under overhead obstacles becomes problematic as it significantly reduces accuracy. Figure 4 presents the tracking data overlayed on Google Earth Pro.

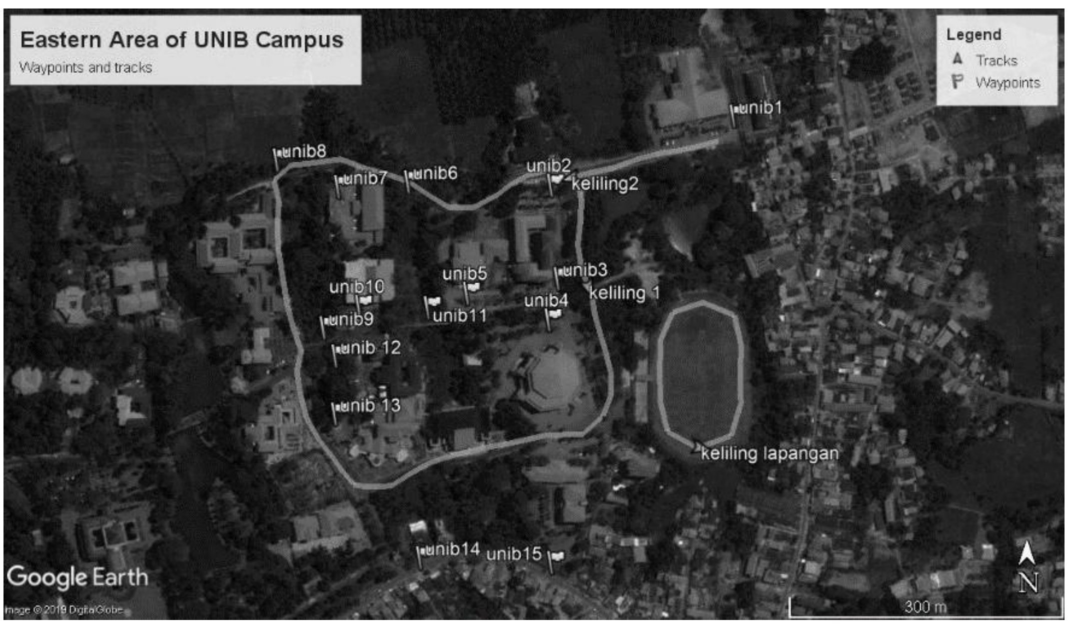

Figure 4. Waypoints and polygonal tracks of the UNIB campus

On the UNIB campus, the GPS waypoints and tracks can be easily collected. The data includes numerous parameters such as latitude, longitude, altitude, date, and time. These raw data were further processed into the final data using several steps in the flowchart above.

We then export the multiple GPX format files into a single KML file, convert them into CSV using the TCX Converter (Figure 4), and plot them into a Latitude, Longitude, and Altitude table (Table 2). The TCX Converter converts the complicated string in GPX file format into more straightforward comma-separated values so that the other software can quickly process the data.

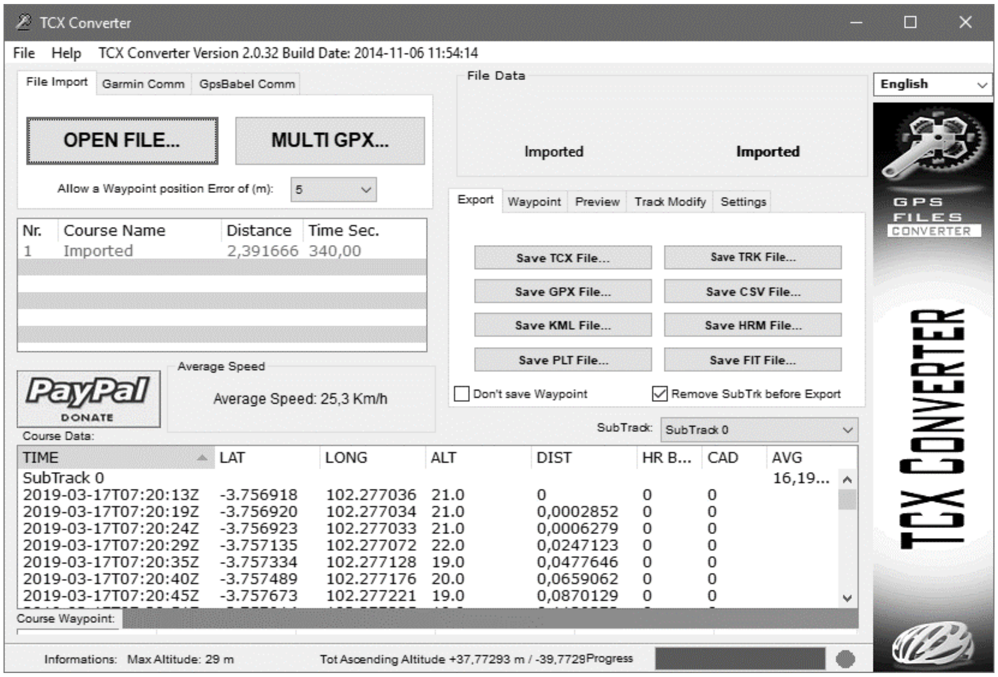

Figure 5. TCX converter

Table 2. The extracted GPX file's data

UNIX TIME	TIME	LAT	LONG	ALT
1.55E+09	019-03-17T07:20:13Z	-3.75692	102.277	21
1.55E+09	2019-03-17T07:20:19Z	-3.75692	102.277	21
1.55E+09	2019-03-17T07:20:24Z	-3.75692	102.277	21
1.55E+09	2019-03-17T07:20:29Z	-3.75714	102.2771	22
1.55E+09	2019-03-17T07:20:35Z	-3.75733	102.2771	19
1.55E+09	2019-03-17T07:20:40Z	-3.75749	102.2772	20
1.55E+09	2019-03-17T07:20:45Z	-3.75767	102.2772	19
1.55E+09	2019-03-17T07:20:51Z	-3.75791	102.2772	19
1.55E+09	2019-03-17T07:20:57Z	-3.75811	102.2771	21
1.55E+09	2019-03-17T07:21:03Z	-3.75829	102.2769	24
1.55E+09	2019-03-17T07:21:09Z	-3.7583	102.2766	24
1.55E+09	2019-03-17T07:21:14Z	-3.75835	102.2763	24
1.55E+09	2019-03-17T07:21:20Z	-3.75842	102.276	22
1.55E+09	2019-03-17T07:21:26Z	-3.75849	102.2757	20

The Lat, Long, and Alt data are further processed into a contour line terrain map of the UNIB campus, as shown in Figure 6. This process is done using Surfer 3D, and this file is used to create a 3D CAD terrain map of the UNIB campus (Figure 7) using Google SketchUp.

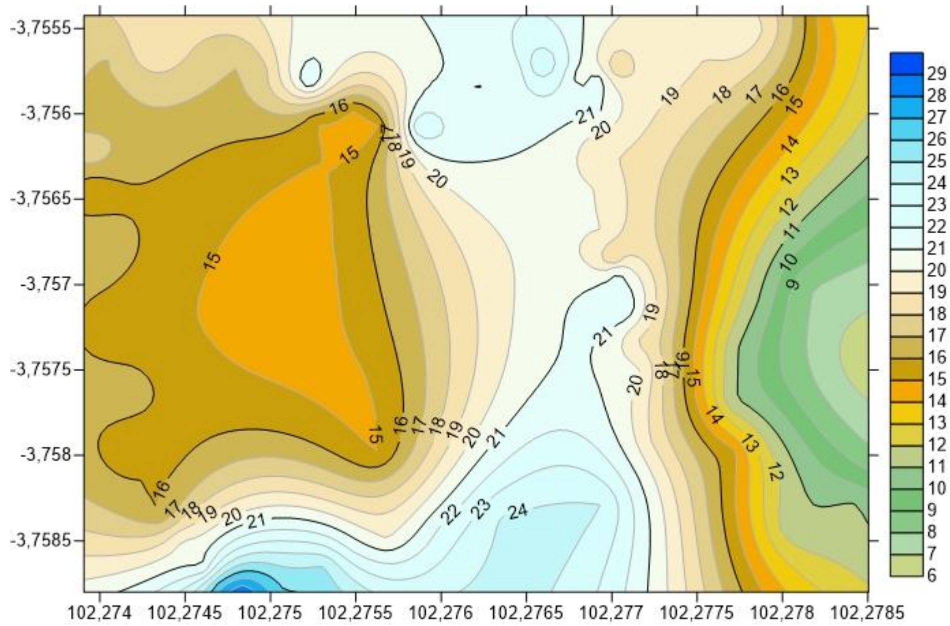

Figure 6. Map of UNIB campus Contour lines

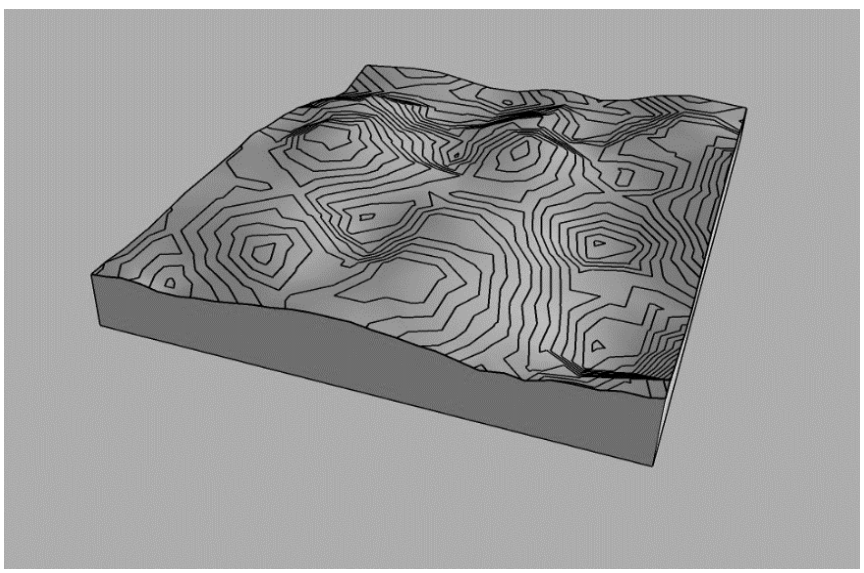

Figure 7. 3D terrain of UNIB campus

Finally, we developed the 3D map of the eastern part of the UNIB campus using 3D SketchUp, as shown in Figure 8.

Figure 8. Eastern part 3D view of UNIB campus developed using Google Sketchup

The developed 3D model is an inaccurate preliminary result of land surveying using a smartphone's GPS sensor that has been tested in the UNIB Campus. The model's accuracy is not the highest but can be used for educational purposes. This model is a valuable resource for students and professionals, allowing them to understand the fundamentals of land surveying and spatial design. As a CAD model, it can be modified for future projects, such as developing new buildings or landscape mock-up designs in any extension. While the smartphone GPS offers a convenient method for data collection, factors like environmental interference can affect accuracy, highlighting the need for further refinement in future applications. Nevertheless, it can be printed as a 2D flat model or presented as an animation video, providing versatile visual representation and analysis options.

Conclusion

GPS is a breakthrough invention that allows us to do several things that have been impossible to do. It is now used in many interdisciplinary applications, including mapping and land surveying activities. GPS has successfully replaced the conventional land surveying method, which requires much effort. The ubiquitous smartphone's GPS can be recommended for land surveys at the student or education level because it performs a good measurement with the error lying only between 0.2 % and 6%, with the average error being 3.02 %.

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References

[1] C. Lin, J. Xu, R. Ma, X. Duan, N. Liu, and X. Hou, "A mobile client-oriented to subjective and objective information collection for township land resources surveying," *Ecol. Inform.*, vol. 60, no. September, p. 101173, 2020.

[2] S. D. Chekole, "Surveying with GPS, total station and terrestrial laser scanner: a comparative study," *MSc Thesis Sch. Archit. Built Environ. R. Inst. Technol.*, no. 3131, pp. 1–55, 2014.

[3] J. Liu, L. Wei, D. Ettema, and M. Helbich, "Green commutes: Assessing the associations between green space exposure along GPS-track commuting routes and adults' self-perceived stress," *Sustain. Cities Soc.*, vol. 112, 2024.

[4] J. Sykes, J. Hendrikx, J. Johnson, and K. W. Birkeland, "Combining GPS tracking and survey data to better understand travel behavior of out-of-bounds skiers," *Appl. Geogr.*, vol. 122, no. June, 2020.

[5] S. Swanepoel, T. J. Scheckle, and D. Marlin, "Implementing land-based litter surveys through visual inspection of imagery using unmanned aerial vehicles," *Environ. Challenges*, vol. 13, no. May, 2023.

[6] A. Lago, S. Patel, and A. Singh, "Low-cost real-time aerial object detection and GPS location tracking pipeline," *ISPRS Open J. Photogramm. Remote Sens.*, vol. 13, no. May, 2024.

[7] M. Bohušík, M. Císar, V. Bulej, M. Bartoš, V. Stenchlák, and D. Wiecek, "Design of a beehive monitoring system with GPS location tracking," *Transp. Res. Procedia*, vol. 74, pp. 916–923, 2023.

[8] P. Sadeghian, J. Håkansson, and X. Zhao, "Review and evaluation of methods in transport mode detection based on GPS tracking data," *J. Traffic Transp. Eng. (English Ed.*, vol. 8, no. 4, pp. 467–482, 2021.

[9] M. R. James and J. N. Quinton, "Ultra-rapid topographic surveying for complex environments: The hand-held mobile laser scanner (HMLS)," *Earth Surf. Process. Landforms*, vol. 39, no. 1, pp. 138–142, 2014.

[10] N. Minallah, W. Khan, M. Zeeshan, and T. Ahmad, "GeoSurvey: A cloud-based mobile app for efficient land surveys and big data collection," *Softw. Impacts*, vol. 19, no. January, pp. 0–5, 2024.

[11] G. Lue and E. J. Miller, "Estimating a Toronto pedestrian route choice model using smartphone GPS data," *Travel Behav. Soc.*, vol. 14, no. September 2018, pp. 34–42, 2019.

[12] T. Stewart, J. Schipperijn, B. Snizek, and S. Duncan, "Adolescent school travel: Is online mapping a practical alternative to GPS-assessed travel routes?," *J. Transp. Heal.*, vol. 5, pp. 113–122, 2017.

[13] M. J. Shafei and M. M. Hossainali, "Application of the GPS reflected signals in tomographic reconstruction of the wet refractivity in Italy," *J. Atmos. Solar-Terrestrial Phys.*, vol. 207, p. 105348, 2020.

[14] B. S. Walter and J. J. Schultz, "Mapping simulated scenes with skeletal remains using differential GPS in open environments: An assessment of accuracy and practicality," *Forensic Sci. Int.*, vol. 228, no. 1–3, pp. e33–e46, 2013.

[15] P. Ellis, B. Griscom, W. Walker, F. Gonçalves, and T. Cormier, "Mapping selective logging impacts in Borneo with GPS and airborne lidar," *For. Ecol. Manage.*, vol. 365, pp. 184–196, 2016.

[16] M. Bergé-Nguyen *et al.*, "Mapping mean lake surface from satellite altimetry and GPS kinematic surveys," *Adv. Sp. Res.*, vol. 67, no. 3, pp. 985–1001, 2021.

[17] Kamruzzaman, T. Islam, and S. R. Poddar, "Accuracy of handheld GPS comparing with total station in land use survey: a case study in RUET campus.," *Int. J. Innov. Appl. Stud.*, vol. 7, no. 1, pp. 343–352, 2014, [Online]. Available: http://www.ijias.issr-journals.org/abstract.php?article=IJIAS-14-180-02

[18] A. C. Prelipcean and T. Yamamoto, "Workshop Synthesis: New developments in travel

diary collection systems based on smartphones and GPS receivers," *Transp. Res. Procedia*, vol. 32, pp. 119–125, 2018.

[19] P. R. Stopher, V. Daigler, and S. Griffith, "Smartphone app versus GPS Logger: A comparative study," *Transp. Res. Procedia*, vol. 32, pp. 135–145, 2018.

[20] G. Software, "Surfer Overview," *Golden Sofware*, 2019. https://www.goldensoftware.com/products/surfer (accessed Mar. 25, 2019).

[21] T. Szot, C. Specht, M. Specht, and P. S. Dabrowski, "Comparative analysis of positioning accuracy of Samsung Galaxy smartphones in stationary measurements," *PLoS One*, vol. 14, no. 4, pp. 1–19, 2019.

[22] N. Micheletti, J. H. Chandler, and S. N. Lane, "Investigating the geomorphological potential of freely available and accessible structure-from-motion photogrammetry using a smartphone," *Earth Surf. Process. Landforms*, vol. 40, no. 4, pp. 473–486, 2015.

[23] Y. Murayama and S. Dassanayake, "Fundamentals of Surveying: Theory and Samples Exercises," in *Graduate School Life and Environment Sciences University of Tsukuba*, pp. 109–128.

[24] F. Seraj, B. J. Van Der Zwaag, A. Dilo, T. Luarasi, and P. Havinga, "Roads: A road pavement monitoring system for anomaly detection using smart phones," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 9546, pp. 128–146, 2016.

[25] L. Joseph, A. Neven, K. Martens, O. Kweka, G. Wets, and D. Janssens, "Measuring individuals' travel behaviour by use of a GPS-based smartphone application in Dar es Salaam, Tanzania," *J. Transp. Geogr.*, vol. 88, no. June, p. 102477, 2020.

[26] S. Korpilo, T. Virtanen, and S. Lehvävirta, "Smartphone GPS tracking—Inexpensive and efficient data collection on recreational movement," *Landsc. Urban Plan.*, vol. 157, pp. 608–617, 2017.

[27] A. Hardy *et al.*, "Tracking tourists' travel with smartphone-based GPS technology: a methodological discussion," *Inf. Technol. Tour.*, vol. 17, no. 3, pp. 255–274, 2017.

[28] K. Merry and P. Bettinger, "Smartphone GPS accuracy study in an urban environment," *PLoS One*, vol. 14, no. 7, pp. 1–19, 2019.

[29] M. Taspika, L. Nuraeni, D. Suhendra, and F. Iskandar, "Using a smartphone's magnetic sensor in a low-cost experiment to study the magnetic field due to Helmholtz and anti-Helmholtz coil," *Phys. Educ.*, vol. 54, no. 1, 2018.

[30] T. Converter, "TCX Converter- The Multiconverter Tool," *TCX Converter*, 2014. http://www.tcxconverter.com/TCX_Converter/TCX_Converter_ENG.html