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Establishing a datum point at the crime scene using a single GPS device: detecting and minimizing error in a simulated case example

Summary

The Global Positioning System (GPS) is a standard tool for establishing a datum point at the outdoor crime scenes that lack fixed objects or landmarks. However, GPS is prone to multiple errors that occur with a different intensity in different time intervals and degrade the accuracy of the positioning. In the present simulated case, we have examined the error of establishing a position using a single hand-held GPS unit, as well as the efficiency of reducing the error by averaging multiple coordinates collected at the same spot through the time. The results have shown great variations between the actual position and position obtained by GPS through collection time, demonstrating that a single GPS reading is not a reliable tool for establishing an accurate datum point in a forensic context. However, when a sufficient number of fixes is averaged, periodical variations of GPS error less affect accuracy, and error linearly decreases. To minimize the error of positioning in forensic cases, we suggest developing a model for GPS application that considers the acceptable degree of error, available equipment, the specificity of the crime scene location and defining a detailed workflow for reducing the error with the averaging method.

Keywords: *forensic science, crime scene, Global Positioning System, mapping, fixed point, datum point.*

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1. INTRODUCTION

Crime scene mapping is among primary means for fixing the evidence and the scene of the crime, as it secures the legality of the evidence and enables the reconstruction of events in the future (Dupras, et al., 2012). Even though there are several methods to measure and map the scene, the crucial step is to identify a datum point or fixed reference point used to establish a position of the crime scene elements and evidence in reference to it (Mozayani and Noziglia, 2010). While it is relatively easy to determine a datum point at indoor crime scenes, it can be demanding at the outdoor scenes, especially in cases with no appropriate objects or landmarks that can serve as reference points (Kennao, 2018; Shaler, 2011). In such instances, the application of the Global Positioning System (GPS) is suggested as the standard means for establishing the geographic coordinates of the datum point (Dutelle, 2014; Suboch, 2016).

Although measurements at the crime scene are not intended to provide 100% accurate, but only approximate representation of the crime scene situation (Dutelle, 2014;Suboch, 2016), the issue of accuracy of positioning and measurements at the scene is underrepresented in the forensic studies and practice in comparison to the evidence examination standards. The same applies to the GPS, which is, as the technological system for satellite positioning, prone to various sources of error. Those errors can degrade the position accuracy in different ways and with varying intensity (Burkhart et al., 2018; Kennedy, 2009). According to the forensic literature, the error of the GPS is around 12 meters for average commercially available receivers and about 3-5 meters for better quality receivers (Dutelle, 2014), which is, without evidence-based studies, claimed to be adequate for outdoor crime scenes. Moreover, there are no general guidelines on how to properly use GPS unit at the crime scene and how to ensure repeatable accuracy, i.e., the possibility to return to a location whose coordinates have been determined previously.

As the authors are aware, only two studies deal with GPS application at the crime scene that partly considered the accuracy of establishing datum points (Listi et. al., 2007; Walter and Schultz, 2013). Listi et al. (2007) used a standard hand-held GPS device and obtained an average error of 3.5 m. In the second study, using a differential GPS (DGPS) unit and data postprocessing, researchers obtained even smaller average error between 9.5 and 11.6 cm (Walter and Schultz, 2013). However, although both results seem promising, such conditions do not always represent real-life scenarios. Firstly, it is not likely that all agencies will be equipped with a DGPS unit but a standard hand-held GPS unit. Secondly, in both studies GPS position and error are calculated by averaging multiple readings, 206 in the first (Listi et al., 2007), and 50 and 100 in the second (Walter and Schultz, 2013). It is also not likely to occur in the practice because, as authors are aware, there are no guidelines that suggest multiple readings in forensic practice. So, at the actual crime scene, the technician would probably take the first GPS reading and establish the position of the datum point, thus potentially introducing much greater error than stated.

One of the most common ways to reduce the GPS error when establishing coordinates of the static points is averaging multiple readings. When using this method, a GPS unit is positioned at the fixed point, and new coordinates are collected for a selected interval (e. g., each second). The set of the data is analyzed, and values of latitude and longitude are averaged. Generally, the higher is collection time, the error should be lower (Burkhart et al., 2018; Kennedy, 2009). This approach has proved to be a valuable tool to reduce error in different scientific fields (Abdi et al., 2014; Khan and Akhter, 2013; Mosavi, 2004; Sharif et al., 2004; Walter and Schultz, 2013). However, it still was not considered a means for minimizing the error of establishing a datum point in the forensic framework using the widely available equipment.

Therefore, our study aimed:

1) to examine the differences between the known position and positions established by GPS at the same point through time, i. e. to simulate the differences that might occur in real-life scenarios when returning to the crime scene,
2) to showcase how increasing the collection time and averaging method can reduce the error of GPS positioning.

2. MATERIALS AND METHODS

2.1. Settings

The data was collected on January 12, 2020, in the area of the University of Split Campus, Split, Croatia, in the open-field conditions from 3 PM to 9 PM. The recordings were taken at the geodetic control point whose coordinates have been provided to the authors by the Faculty of Civil Engineering, Architecture and Geodesy, University of Split, Split, Croatia. The research has been conducted in the Laboratory for Forensic Engineering at the University Department of Forensic Sciences, University of Split (Split, Croatia).

2.2. Data acquisition

We used hand-held GPS unit Garmin GPSmap 76cx (Garmin International, Olathe, Kansas, USA) with 12 channels and a 1-second update rate. Before the coordinate acquisition, we turned the unit on and waited for 15 minutes to ensure it has an uninterrupted signal path (Dupras et al., 2012; Wing et al., 2005). GPS unit was placed on the ground, at the center of the geodetic point in the horizontal orientation that provides greater accuracy than vertical (Walter and Schultz, 2013). A total of 21 600 readings were acquired at the same position by the Track Log function, which was set to record positions in one-second intervals. Track Log was saved and imported into the EasyGPS software (version 7.10, TopoGrafix, Stow, USA), which was used to export the track in .gpsx file format. Using the GPS Track Editor software (version 1.15 beta), .gpsx file was converted to .csv file that can be read in MS Excel.

2. 3. Data analysis

Differences between the two positions were calculated as differences in latitude (φ) and longitude (λ), and absolute distances. Differences in latitude and longitude were converted to distances in meters by multiplying differences with a length of a degree of latitude and longitude for a specific latitude.

A distance between two points in meters was calculated using the equation:

$$distance = \sqrt{\Delta x^2 + \Delta y^2} \quad (1)$$

(1) where Δx is the difference between two points of latitude and Δy is the difference between two points of longitude.

For each point, we calculated error as a difference between the coordinates of the reading and the geodetic control point. Using this data, we computed descriptive statistics for the differences in the latitude, longitude, and distance in meters, as well as circular error probable (CEP) and twice the distance root mean square (2dRMS). CEP, which is a radius of the circle that contains 50% of fixes, was calculated as a median value of absolute distances between known points. The second parameter, 2dRMS is the radius of the circle that contains 95% of fixes (Kennedy, 2009).

We averaged latitude and longitude values for different collection times ranging from 0 to 21 600 on interval n +10 seconds. Additionally, we repeated the same procedure, but without including the outlier values for each collection interval. Outliers were detected using the criteria by Hoaglin and Iglewicz (1987). In that method, the interquartile range is multiplied by 2.2 (g), and obtained value (g') is subtracted to Q1 to calculate the lower range and added to Q3 to calculate the upper range. To reveal if there are statistically significant differences between those two methods, we compared the errors using a paired-samples t-test with a level of statistical significance set at $P \leq 0.05$.

3. RESULTS

Figure 1 shows variations in errors for six hours for a one-second interval. The average discrepancy from the correct position was 3.1 m, while distance error ranged from 0 to 11.5 m (shown in Table 1). The distance between the two farthest points was 18.8 m. 50% of the fixes (CEP) were located in a circle of 3.1 m, and 95% of points were inside a radius of 7 m from the true position (Figure 2).

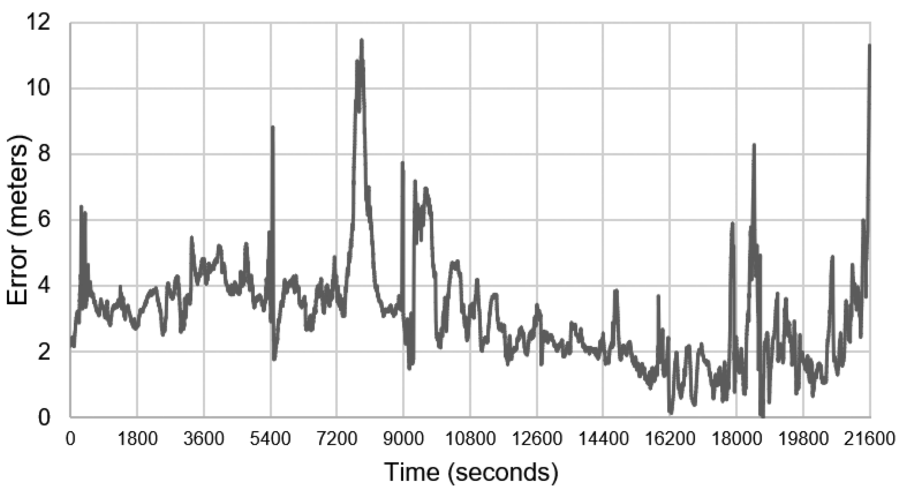

Figure 1. Changes of error through the 6 hours' collection time

Table 1. Descriptive statistics for differences between correct position in 6 hours' collection time

	x (m)	y (m)	distance (m)
min	0	0	0
max	10.78	8.50	11.46
mean	2.10	2.05	3.13
standard deviation	1.64	0.95	1.56

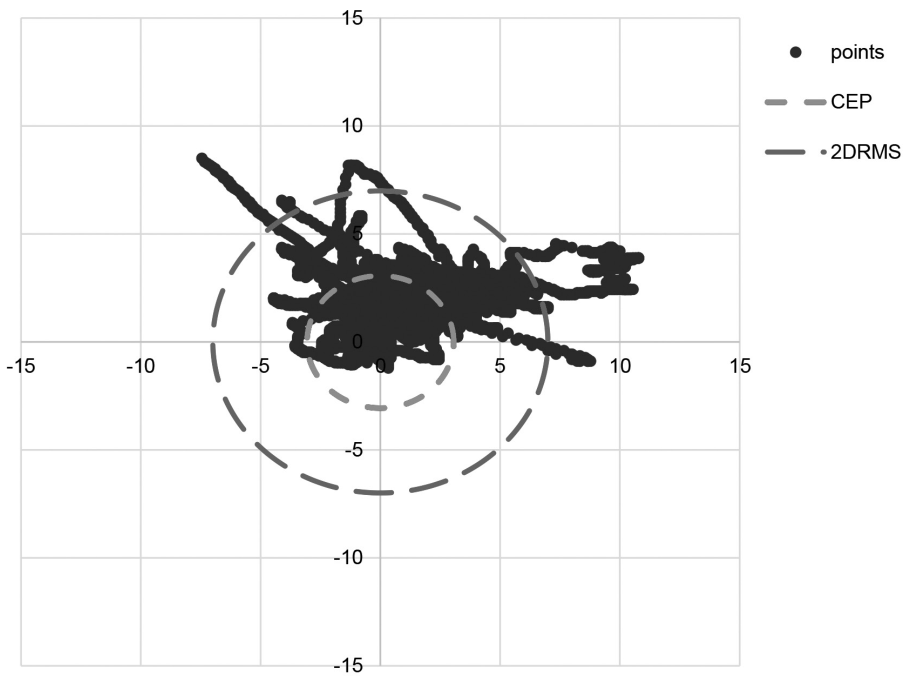

Figure 2. Spatial distribution of fixes collected in six hours (meters)

When the multiple collection time was considered (Figure 3, orange solid line), the most considerable error variation could be observed during the collection time between 10 s and 1 hour. After that, the error slightly increased and reached a maximum value that was almost constant until the collection time was increased to approximately 3 hours. Finally, after around 3 hours' collection time, the error started decreasing linearly. In the end, for six hours' collection time, the error was 2,59 m. Using the averaging method with exclusion of the outliers (Figure 3, blue dashed line) the mean error was significantly lower (Mean = 0.08 m; SD = 0.05 m) in comparison to the simple averaging method ($t = 71.768$, $P < 0.001$). Although data followed the same trend as for the simple method, the error at the end of the collection time was also slightly lower – 2.51 meters.

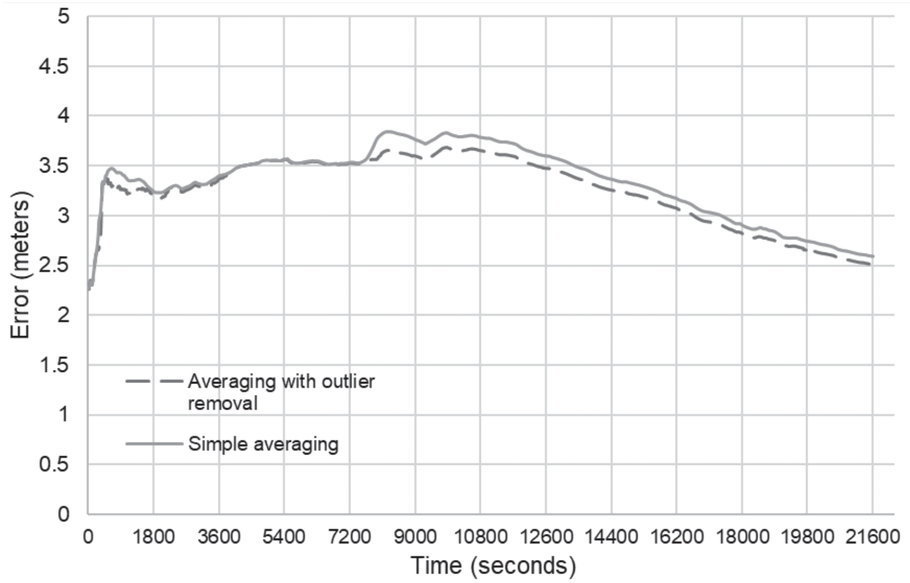

Figure 3. Error changes with collection time increase with averaged data

4. DISCUSSION

The case that has been presented demonstrated that although the average error of the GPS positioning might be in an acceptable range, it can be highly variable when the position is taken at different time points. Therefore, when using a single standard hand-held GPS device, the typical approach of turning the unit on and taking the one reading is not recommended for establishing a datum point during the crime scene investigation or finding previously determined points in the reconstruction process. The simulated case also showed that averaging the positions collected at the same spot during a longer period could reduce variability and improve accuracy, which is why that approach could be introduced to the forensic framework.

We analyzed how the distances between the actual position and position obtained by GPS fluctuated throughout the time to test the repeatable accuracy. The initial idea was to simulate real-life situations where it was necessary to return to the same crime scene, e.g., for reconstructing the event. The results during the six hours showed that in some time points, there was no error at all, whereas, in some points, the error exceeded 11 meters. Given that some of the established positions deviate from the true position in different directions, the difference between the two positions could be even higher (in our case, up to 18.8 m). In a real-life scenario, this would mean that forensic personnel could, by using the same device when returning to the crime scene, arrive at the point that is almost 19 meters away from the initially established point. Moreover, if evidence are not measured from the datum point and only GPS fixes are used to establish their position, the spatial relations could be even more degraded.

These findings concur with the study by Johnson and Barton (2004), that showed that differences between true position in open-field conditions could even more vary through time (960 points) up to +/- 20 meters of latitude and longitude. Such variability of error is not unexpected since GPS is prone to various error types that vary over time. They stem from the imprecise satellites' locations at a given time, errors of satellite and receiver clocks, atmospheric inferences, etc. (Burkhart et al., 2018; Kennedy, 2009). The number of visible satellites and satellite-receiver geometry is also an important factor. Those satellites and geometry "change with time due to the relative motion of the orbiting satellites," thus magnifying or lessening the error on different occasions (Yahya and Kamarudin, 2008).

As research showed that increasing the collection time and averaging multiple readings to obtain position could reduce the error (Abdi et al., 2014; Khan and Akhter, 2013; Mosavi, 2004; Sharif et al., 2004; Walter and Schultz, 2013), we collected 21600 points during the 6-hour interval to explore how the increasing collection time for 10 points affects the error. The error was most variable when including from 10 to around 10000 readings, while for more readings, error linearly decreased, and random variabilities were minimized (Figure 1). For example, for collection times between 5 and 6-hours (18000 – 21600 points), the error ranged from 2.84 to 2.59 meters. Finally, we could reduce the error to 2.59 meters and probably even more if the collection time increased.

Compared to the previous studies that used averaging to reduce the error (Abdi et al., 2014; Khan and Akhter, 2013; Mosavi, 2004; Sharif et al., 2004; Walter and Schultz, 2013), we demonstrated a slightly different approach. In those studies, researchers chose specific collection times (e. g. 1, 5, 10, and 15 minutes) and collected data only once or several times to establish an error rate for a particular collection interval. Figure 1 clearly depicts why this approach might be questionable. For example, suppose we averaged position in ten minutes' interval around collection times of 7500 and 8200. In that case, we could get an error greater than 8 meters. If we took the same interval between 16100 and 16800, we could obtain an error around 1 meter and conclude that this interval provides a high degree of accuracy. Therefore, by considering the relation of collection time increase and the error changes, we showcased that after enough recordings were acquired, random variations that occurred did not impact accuracy to a large extent and did not break the downward trend of error rates. In our case, it was visible that after 10000 points were collected, the error continued decreasing (Figure 3), despite several points with prominent variations (e. g. peaks around collection time of 18500 and 21000, Figure 1). We additionally reduced the error by excluding outliers for around 8 cm on average, which was statistically significant but modest error reduction. However, if the collection time had been additionally increased and error reduced, it might have had a greater impact. So, we suggest examining the method in further studies to maximize the precision and accuracy of the positioning.

Although after we collected 21600 readings, we could reduce the positioning error to a relatively acceptable 2.59 meters, the scope of the study was not to provide generalizable results and define a précised number of readings that is necessary to obtain a certain level of accuracy. In contrast, we aimed to draw attention to GPS error in forensic settings and provide a foundation for developing a general model for error reduction. The generalization of the results is not possible due to the number of variables that can affect positioning accuracy. Firstly, we used only one GPS unit, and the quality and the features of the specific type of GPS unit profoundly impact accuracy. It includes a level of the receiver noise, characteristics of the receiver clock, number of channels (that determines the maximum number of satellite signals that receiver can capture at once), etc. (Burkhart et al., 2018; Kennedy, 2009). For applying the averaging method, one of the essential features is also the update rate or a number of positions that can be established in a one-second interval. The update rate of the receiver used in our study was one position per second, while the update range of the newer models can be ten positions and or even higher. For example, if we had had that type of receiver, we could have obtained the same number of readings (21600) not in 6 hours but in 36 minutes, or if a 6-hours collection interval had been selected, we could have obtained 216 000 readings. Some receivers can also capture and combine signals from other satellite positioning systems, such as the Russian Global Navigation Satellite System (GLONASS), Chinese BDS or European Gallileo, which can additionally reduce the error (e. g., Cherniak and Zakharenkova, 2017). Therefore, more comprehensive testing should consider various types of devices to develop generalizable standards.

Secondly, an additional issue is that even though the same unit can be used, the GPS error will not be equal at all geographic areas and in all conditions. The main reasons for that are altitudes and inclination angles of satellites that result in better visibility of satellites and better satellites' geometry and lesser error in certain areas (e. g. equatorial and mid-latitudes) thus producing smaller error. Additionally, the earth control stations, which are intended for corrections and adjustments, are not equally distributed around the globe. The highest number of them is located in Northern America, while their coverage in the southern hemisphere is limited (Cherniak and Zakharenkova, 2017; Jensen and Sicard, 2010; Kvamstad et al., 2014; Official U.S. government information about the Global Positioning System (GPS) and related topics; Yahya and Kamarudin, 2008). Lastly, GPS is not always used only in unobstructed sky conditions like in the present study, which is why in specific areas such as forest and green regions, the variations and errors can be even larger due to the disruption of the signal (Abdi et al., 2014; Johnson and Barton, 2004). Therefore, these areas should be considered separately, and results should be regarded with caution.

To obtain more conclusive results and develop the standards and guidelines for the GPS application in the forensic context, future studies should consider the following: the acceptable degree of error, the specificity of the crime scene location, and available equipment. The first step requires agreement on the maximum acceptable degree of error of establishing a datum point. It can be a general degree of error or specified separately according to the national legislation and the crime severity. Then, the characteristics of the outdoor crime scene should be considered. For the scenes in the urban area, it is unnecessary to use a GPS because there are lots of objects and landmarks with already known coordinates. Moreover, in that case, it can be counterproductive to use GPS because high buildings can obstruct the visibility of satellites and induce additional multipath error that occurs when the signals are bounced off objects (Kennedy, 2009; Tabatabaei et. al., 2017). Lastly, studies should propose a method of choice considering the type, quality and quantity of available equipment and determine when to use differential GPS unit (DGPS), combine multiple GPS devices or a GPS device and known landmarks, and how to minimize error when a single device is available.

5. CONCLUSION

In the present study, we demonstrated that a hand-held GPS device should not be used to establish a datum point using a single reading and demonstrated a simple averaging method that can be used to reduce the error to a demanded degree. We believe that the presented approach will be considered in forensic settings and furtherly tested on other devices, geographical areas, and conditions, but that will primarily raise awareness about the necessity of establishing clear standards on the GPS application at the crime scene.

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Sažetak

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Određivanje fiksne točke mjerenja na mjestu događaja s pomoću jednoga GPS uređaja: utvrđivanje i minimiziranje pogrešaka na primjeru simuliranoga slučaja

Globalni položajni sustav (engl. *Global Positioning System - GPS*) standardno je sredstvo za određivanje fiksne točke mjerenja na vanjskim mjestima događaja na kojima nema fiksnih objekata i prepoznatljivih točaka. Ipak, GPS je osjetljiv na brojne pogreške koje se pojavljuju u različitim intenzitetima i u različitim vremenskim intervalima te nepovoljno utječu na točnost određivanja položaja. U izloženome slučaju, ispitana je pogreška određivanja položaja s pomoću jednoga GPS uređaja, kao i učinkovitost smanjenja pogreške s pomoću uprosječivanja većega broja koordinata prikupljenih na istoj točki u širemu vremenskom intervalu. Rezultati su pokazali znatne varijacije između stvarnoga položaja i položaja određenoga GPS-om tijekom razmatranoga vremena; što upućuje na to da jednostruko očitavanje GPS položaja nije prikladno za određivanje fiksne točke mjerenja u forenzičnome kontekstu. Međutim, kada se uprosječi određeni broj točaka prikupljenih na istome položaju – periodička kolebanja pogreške GPS-a manje utječu na točnost i pogreška linearno opada. Kako bi se pogreška utvrđivanja položaja svela na najmanju moguću mjeru, predlaže se razvijanje modela za primjenu GPS-a kojim bi se razmotrila prihvatljiva razina pogreške, dostupna oprema i posebnosti različitih mjesta događaja te potanko odredio način i tijek smanjenja pogreške metodom uprosječivanja.

Ključne riječi: forenzične znanosti, mjesto događaja, globalni položajni sustav, fiksna točka mjerenja, početna točka mjerenja.