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Traversing by Smartphones and Assessing the Accuracy of their Results in Lengths and Area

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Abstract

Tracing is an essential process in geomatics (i.e., surveying) for different applications. It involves determining the positions of points from different measurements utilizing suitable techniques. Since the smartphone is a modern technology that can determine positions, assessing their results in traversing is necessary. For this purpose, the positions of 16 points in a closed traverse were collected with six different sets of measurements (five sets with smartphone devices and a standard set with traditional techniques). The smartphone devices are dual-frequency Samsung S22, and the other four are single-frequency, consisting of the iPhone 11, Xiaomi Note 8, the iPhone XS max, and the iPhone XS with Android application. The derived distances and computed area from each device were compared with the adjusted results of a standard set measured with theodolite and steel tape. The Root Mean Square Error (RMSE) of positioning with a dual-frequency device was found to be 0.700 m and 1.182 m for easting and northing, respectively, which is better than the positioning with single-frequency devices. The achieved RMSE in the extracted distance was 1.288m with dual frequency compared to 1.333 to 2.179m with other single-frequency devices. The standard computed area of the traverse was 47,824.54 m^2, while it was 47,866.95 m^2 for a dual-frequency device and 47,758.40 m^2 to 47,165.64 m^2 for other devices. This means the least difference in the area, 42.41 $m^{2,}$ was achieved with the dual-frequency device. It was proven that the results of a dual-frequency smartphone are better than that of single-frequency devices.

Keywords: Traversing, Smartphone, GNSS, Length, Area.

التضليع بواسطة الهواتف الذكية وتقييم دقة النتائج في الأطول والمساحات

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الخلاصة

يعد التضليع عملية أساسية في مجال الجيوماتكس (أي المسح) لتطبيقات مختلفة. ويتضمن تحديد مواقع النقاط من قياسات مختلفة باستخدام التقنيات المناسبة. وبما أن الهاتف الذكي من التقنيات الحديثة التي تتمتع بالقدرة على تحديد المواقع، فمن الضروري تقييم نتائجها في عملية التضليع. ولهذا الغرض، تم جمع مواقع 16 نقطة

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في مضلع مغلق باستخدام 6 مجموعات مختلفة من القياسات (5 مجموعات مع أجهزة الهواتف الذكية ومجموعة قياسية مع التقنيات التقليدية). أجهزة الهواتف الذكية هي Samsung S22 ثنائي التردد، أما الأجهزة الأربعة الأخرى ذات التردد الواحد فهي iPhone 11 و Xiaomi Note 8 و iPhone XS max و iPhone XS مع تطبيق Android. وتمت مقارنة النتائج المشتقة للمسافات والمساحة المحسوبة من كل جهاز مع النتائج المعدلة لمجموعة قياسية تم قياسها باستخدام المزواة والشريط الفولاذي. وقد وجد أن الخطأ التربيعي لمتوسط الجذر (RMSE) لتحديد المواقع باستخدام جهاز مزدوج التردد كان 0.700 متر و1.182 متر للشرق والشمال على التوالي، وهو أفضل من تحديد المواقع باستخدام الأجهزة أحادية التردد. وقد بلغت قيمة RMSE المتحققة في المسافة المستخرجة 1.288م مع التردد المزدوج مقارنة بـ (1.333 م إلى 2.179 م) مع الأجهزة الأخرى أحادية التردد. بلغت المساحة المحسوبة القياسية للمضلع 47,824.54 م^2، في حين كانت 47,866.95 م^2 لجهاز مزدوج التردد و(47,758.40 م^2 إلى 47,165.64 م^2) للأجهزة الأخرى. وهذا يعني أن أقل فرق في المساحة تم تحقيقه مع الجهاز ثنائي التردد (42.41 م^2). لقد ثبت أن نتائج الهاتف الذكي ثنائي التردد أفضل من نتائج الأجهزة ذات التردد الواحد.

1. Introduction

Survey data constitutes a fundamental element within the land administration system as a foundational factor in establishing and protecting land and property rights. The survey measurement utilization facilitates the establishment of legal borders for land parcels [1]. In this context, one of the primary applications of surveying is traversing, a technique for conducting control surveys by creating a framework of points connected by straight lines [2]. Point positions are determined by measuring angles and distances between consecutive lines that connect control stations [3] [4]. The survey can be conducted based on the available instruments [5]. Therefore, traditional measurements can be taken using theodolite, total stations, and other methods. New techniques can be used, such as the Global Navigation Satellite System (GNSS) [6] [7] [8], to overcome the challenges of survey fieldwork [9]. Therefore, the GNSS receiver can determine the position of any required point, even over long distances [10] [11].

Due to the high cost of geodetic GNSS receivers, many studies have tried to find an alternative low-cost technique with acceptance accuracy [12]. Therefore, the smartphone collected positioning with different generations [13]. These techniques are manufactured with added chips to track the constellation of GNSS. This enables smartphones to determine the positions from GPS [11] and GNSS [14]. Since the release of Android smartphones, data collection methods have seen additional development [15]. Another advantage of smartphones is their ability to log data, making them competitive with other GNSS devices [16] and [17] for different civil engineering applications [18].

In positioning capturing, several limitations exist to achieving accurate results with smartphones [19]; one of these limitations is the low strength of the device's built antennae, affecting satellite tracking [20], typically, passive antennas with linear polarization patterns are utilized instead of the right-hand circular polarization patterns used by geodetic receiver antennas [21]. Many studies examined the capabilities of smartphones in determining positions; for example, GAO and Ramandaniaina [22] studied the improved version of Android 8 with dual transmission frequencies (L1 and L2). He determined the position based on GPS-only and then computed the position with integrated systems of GPS, Galileo, and GLONASS. He found that the integrated system is more accurate than GPS-only positioning. FELIX [23] captured data with Apple and Samsung cellular devices in urban and rural environments to extract GPS standalone positioning, finding that the positioning in a rural environment is better than in urban areas. Also, Samsung's results were more accurate than Apple's positioning (see Easson [24]). Undheim [25] analyzed the measurements Samsung Galaxy S9+ took, which was affected by a multipath effect. He compared the results from the geodetic receiver with those from the smartphone. The Root Mean Square of the geodetic receiver was 25 times lower than that of the geodetic receiver.

On the other hand, Dovis and Marinaro [26] applied the double difference method of GNSS data to reduce errors when using smartphones in positioning. They accomplished the zero-baseline technique by connecting a pair of Xiaomi MI8 Pro devices. They compared the results when using non-smoothed pseudo-ranges and the results obtained from the double difference. In the first case, a significant difference was obtained from the results of the two devices, while improved positions were achieved with the double difference technique. Ibrahim et al. [27] used low-cost equipment at the University of Baghdad to determine the GPS positioning of a traverse of ten points. Firstly, the measurements were taken by a geodetic receiver in static mode, followed by real real-time kinematic RTK mode. After that, a third set was taken by a low-cost external antenna with a smartphone using the real-time extension RTX mode, followed by RTK mode. The final result was that positioning with an external antenna and smartphone can be used in mapping, forestry, and agriculture. This technique is suitable for the RTK mode with acceptance accuracy.

Jimenez [28] studied the Xiaomi M8 smartphone for positioning using dual frequency versus single frequency and the achieved accuracy. Therefore, three tests were performed, two in the static and one in the kinematic state. He selected a reference point of given coordinates and then observed their coordinates. The accuracy was assessed in each test. It was found that dual-frequency reduced errors, and measuring in an open environment was preferable, as seen by Shinghal [29] and Gomes and Krueger [30].

Monsur [31] evaluated the integration technique of the GPS algorithm with Wi-Fi using the Kalman filter algorithm based on raw measurements in blockage or poor signal. The (27) reference points were identified inside and outside a building. The first set was GPS-only, and then the integrated set of GPS+Wi-Fi was used on smartphone devices. The results indicate that the RMS of the integrated solution is less than that of the GPS-only solution. As for determining the area using a smartphone, Oluwadare and Salam [20], the study area is on religious association-allocated land at Obafemi Awolowo University's religious center in Ife Central Local Government Area; data acquisition of boundary to 46 point coordinates, representing ten parcels of land, was done with two different smartphones and a dual-frequency GPS receiver, resulting in determining the area by smartphones compare to geodetic receiver in percentage rate errors are reach(from 0.03436% to 0.04574%). While Guo et al. [32] the study area on the roof building of the School of Geodesy and Geomatics at Wuhan University to evaluate the one smartphone, compared to the observations obtained from the two geodetic receivers, the results (RMS) of the independent vertical and horizontal positional errors are 1.94 and 1.22 meters, respectively. Robustelli et al. [33] also evaluate the three most recent smartphones' positioning performance and quality of observations; they analyze the data compared to the observations obtained from the geodetic receiver. The multi-GNSS single-frequency has the best positioning accuracy, with a horizontal RMS from 3.24 m to 4.90 m.

A smartphone's GNSS module's positioning accuracy is usually 3–5 m, which has little effect in Multipath circumstances and more than 10 m in the impact of many multipath [34]. If most land surveying requires an accuracy of 1-3 m [35], is it possible to achieve this accuracy using smartphones that would allow traverse work? Therefore, several smartphone devices, including newly manufactured ones that receive a dual frequency, will be used to examine the possibility of achieving the required accuracy.

In this study, a closed traverse of 16 points in an open area will be used to assess the results of traversing by smartphones. Six measurements will be gathered to compare the standard results of traditional techniques (theodolite and steel tape) with those taken by 5 cases of smartphone devices. The smartphone devices are dual-frequency Samsung S22, and the other four are single-frequency, consisting of the iPhone 11, Xiaomi Note 8, the iPhone XS max, and the iPhone XS with Android application. Thus, the derived distances and computed area results from each device will be compared with the adjusted results of a standard set.

2. Methods and Materials

The methodology involves using smartphones to conduct one of the most essential surveying activities on the site: traversing an agricultural area and comparing the results with traversing using traditional survey devices.

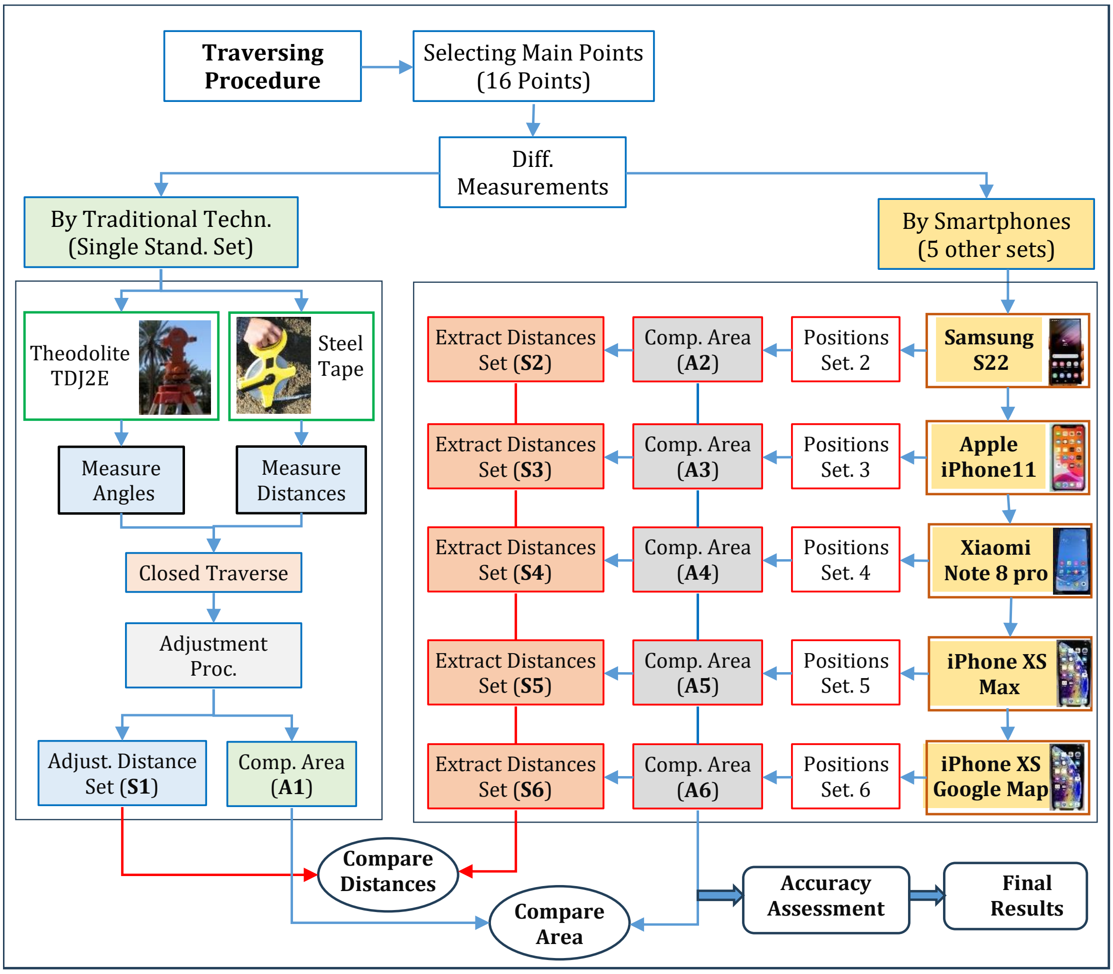

Figure 1 : Flowchart of the methodology

2.1 Methodology and Case Study

To evaluate the ability of smartphones to accomplish surveying work of traversing, the study area was chosen in an open agricultural land. The initial point was chosen and its coordinates determined, and then other points were selected to form a closed traverse of 16

points. Two primary techniques form the basis of the methodology, as shown in Figure 1; firstly, the forming traverse was measured using an accurate traditional technique as the base for comparison. Therefore, the distances between points were measured by steel tape, and the internal angles were observed with theodolite. Then, a procedure of compass adjustment was applied to the traverse to have standard elements (i.e., distances and coordinates).
Secondly, the coordinates of traverse points were observed with diverse smartphone devices from different manufacturers to assess the accuracy of the extracted values with each device. Consequently, five sets of measurements were taken with the Samsung S22, iPhone 11, Redmi Note 8 Pro, iPhone XS Max, and iPhone XS Max with Google Maps. Each set of traverse coordinates was conducted in a static mode based on the received signals from GNSS and converted to the UTM system. The extracted results of each smartphone (distances and computed area) from the coordinates were compared with the standard values from the above traditional technique to assess the final results, Figure 1.

The study area was chosen in an open environment far from cars and pedestrian traffic. In addition, there are no buildings and obstacles to avoid the effect of multipath and other error sources when coordinated by smartphones. Thus, an agricultural site in the province (7-Al-Alaq) in the Al-Medhatiyah district of Babylon Governorate was chosen for this study. The closed traverse consists of 16 points (P1, P2, …. and P16) of intervisibility to examine the accuracy of derived quantities, Figure 2.

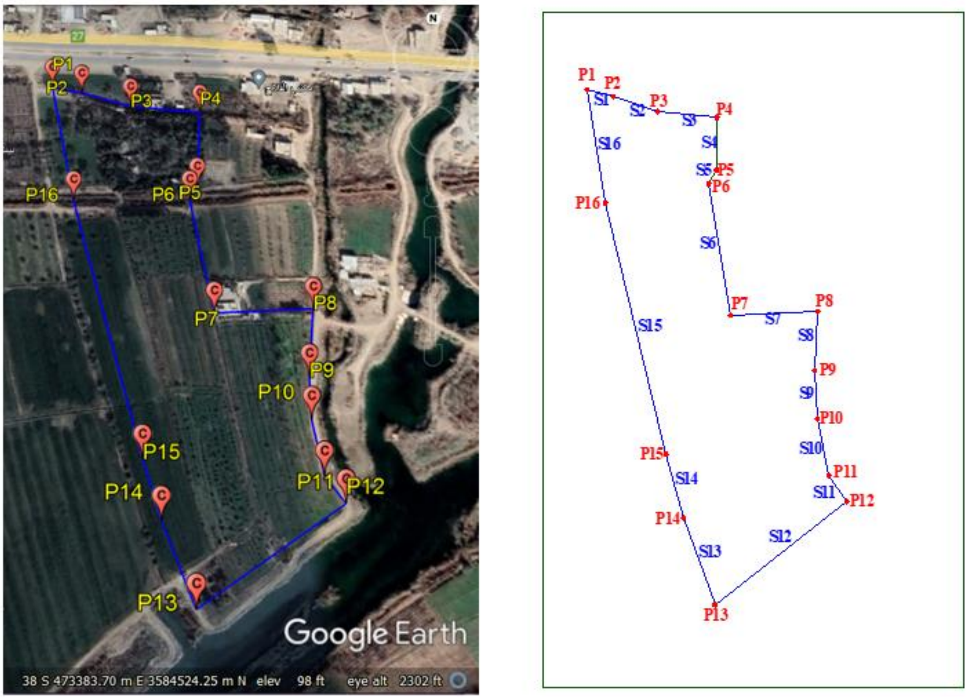

Figure 2 : The distribution of 16 points of closed traverse in this study

2.2 Data capturing

As explained in the above methodology, two leading data collection groups exist. The first data group was conducted using the traditional technique Figure 3-a of measuring distances using steel tape with an accuracy of one centimeter and internal angles using TDJ2E theodolite in the closed traverse with an accuracy of one second Table 1.

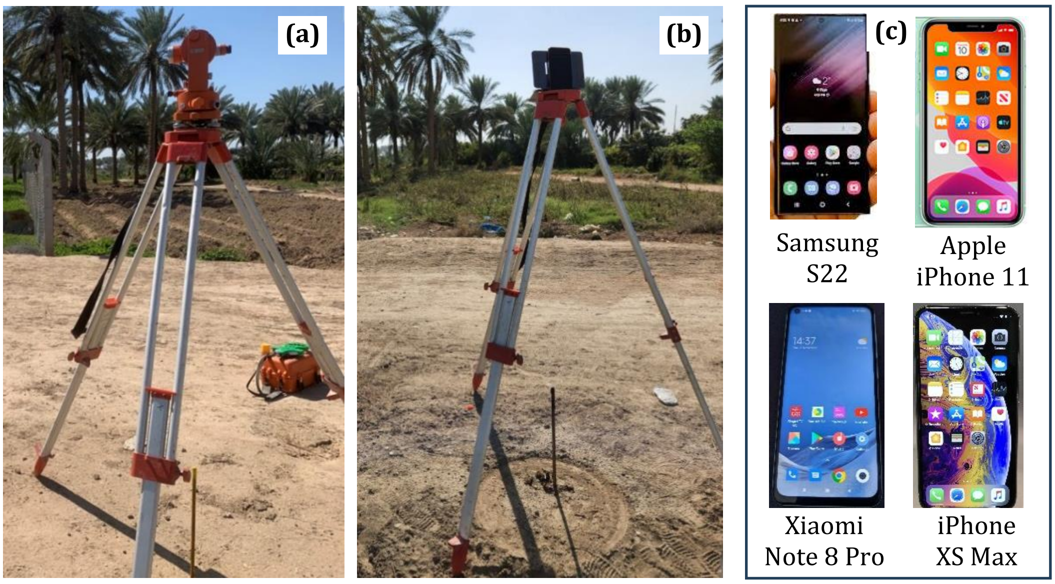

Figure 3 : (a) Installation of the theodolite on the traverse point (P1), **(b)** Installation of the smartphone, and (c) The leading smartphones used in this study

Table 1 : The details of the first group of measurements by theodolite and steel tape

Side	Measurements of the 1st set 1 by theodolite and steel tape					
	Length (m.)	**Angle**	**Interior Angle**	**Corre.**	**Adjusted Angle**	**Derived Direction**
S 1	26.39	<P 1	69° 10' 59"	-02"	69°10'57"	106°43'04"
S 2	44.05	<P 2	177° 16' 53"	-02"	177°16'51"	109°26'13"
S 3	58.82	<P 3	191° 54' 07"	-02"	191°54'05"	97°32'08"
S 4	79.72	<P 4	88° 57' 31"	-02"	88°57'29"	188°34'39"
S 5	17.51	<P 5	156° 02' 29"	-02"	156°02'27"	212°32'12"
S 6	104.68	<P 6	215° 03' 07"	-02"	215°03'05"	177°29'07"
S 7	77.66	<P 7	269° 48' 01"	-02"	269°47'59"	87°41'08"
S 8	60.30	<P 8	73° 51' 45"	-02"	73°51'43"	193°49'25"
S 9	36.16	<P 9	185° 25' 42"	-02"	185°25'40"	188°23'45"
S 10	40.47	<P 10	192° 35' 00"	-02"	192°34'58"	175°48'47"
S 11	25.16	<P 11	199° 49' 00"	-02"	199°48'58"	155°59'49"
S 12	136.26	<P 12	98° 52' 02"	-02"	98°52'00"	237°07'49"
S 13	64.97	<P 13	72° 08' 44"	-02"	72°08'42"	344°59'07"
S 14	46.82	<P 14	174° 54' 39"	-02"	174°54'37"	350°04'30"
S 15	227.10	<P 15	177° 59' 27"	-01"	177°59'26"	352°05'04"
S 16	122.92	<P 16	176° 11' 04"	-01"	176°11'03"	355°54'01"
sum			**2520°00'30"**	**-30"**	**2520°00'00"**	

According to Table 1, as the traverse is a closed figure, it should have an adjusted sum of internal angles, Eq. (1). The difference in the angles summation (closure Error) can be divided by the number of stations, Eq. (2). Therefore, the closure error was 30 sec for 16 internal angles, which mean every point took about 2 sec as a correction Table 1. Then, the values of the adjusted internal angles were used to compute the adjusted directions. The final values were contributed to computing the final adjusted coordinates.

$$Closure\ error\ =\ sum\ of\ interior\ angles\ -\ 180\,^{\circ}(n-2) \quad (1)$$

$$Correction\ to\ each\ interior\ angle\ =\ Closure\ error \div n \tag{2}$$

Where n: number of internal angles.

The second group of the collected data was the coordinates of traverse points with different smartphones, Figure 3b and Figure 3c. The first three smartphone devices (i.e., Samsung S22, Apple iPhone 11, and Redmi Note 8 Pro) have positioning applications loaded on the Android system. The fourth device (iPhone XS-Max) can work with both Apple and Android systems. Therefore, two main sets of observations were collected with this device. The final second group of data consists of five independent sets of recorded coordinates of the traverse points, Table 2, while the details of the different devices are shown in Table 3. Each station was observed by setting out the smartphone, Figure 3b, and taking its location after 5-10 min of static mode. The geodetic position is based on received signals from GNSS.

Consequently, each independent data set represents the observed horizontal coordinates with a specific smartphone of the 16 points of the closed traverse. It is possible to convert the geodetic coordinates where were recorded with an accuracy of 0.0000001 degrees to the UTM system with an accuracy of one millimeter based on online free software "(*Movable Type Scripts with link https://www.movable-type.co.uk/scripts/latlong-utm-mgrs*)." Thus, the final results of smartphones were ready to be compared with the results of traditional techniques.

3. Results and Discussion

To analyze the collected data of the fieldwork, each group was assessed as an independent part, and then the final results were compared.

3.1 Analyze the 1st group of the collected data using Traditional Techniques

Based on the coordinates of the initial point $P_1(E_1, N_1)$ and the measured distance (S_{12}) to the second station with the adjusted direction (α_{12}), it is possible to compute the coordinates of that point (Eq. (3) - Eq. (6)). Consequently, the coordinates of other points can be determined in the same way to have a traverse with known positions, Table 4.

Table 2 : The details of the five sets of measurements by different smartphones

Point	Extracted Coordinate in (m.) from different **smartphones**									
	2nd Set		**3rd Set**		**4th Set**		**5th Set**		**6th Set**	
	E	N	E	N	E	N	E	N	E	N
P 1	473637.323	3584820.872	473637.390	3584822.516	473637.777	3584820.760	473636.299	3584823.787	473636.835	3584823.711
P 2	473663.317	3584813.743	473662.525	3584816.782	473663.073	3584812.583	473663.244	3584818.173	473662.397	3584816.771
P 3	473704.424	3584799.546	473703.068	3584802.280	473706.308	3584799.356	473702.075	3584802.922	473702.206	3584802.556
P 4	473763.274	3584791.145	473763.837	3584794.288	473764.037	3584790.378	473760.986	3584793.530	473761.673	3584795.121
P 5	473751.337	3584710.931	473750.108	3584716.824	473749.518	3584712.946	473749.184	3584715.966	473750.158	3584715.368
P 6	473742.316	3584699.160	473742.138	3584703.144	473742.861	3584701.361	473739.434	3584703.428	473740.194	3584703.016
P 7	473746.961	3584594.305	473745.042	3584596.642	473749.709	3584592.950	473745.423	3584596.257	473745.077	3584596.978
P 8	473823.905	3584596.455	473823.129	3584601.689	473825.274	3584598.254	473822.241	3584601.229	473821.873	3584599.693
P 9	473810.513	3584538.781	473809.910	3584543.002	473811.172	3584541.436	473808.293	3584542.145	473807.291	3584541.428
P 10	473803.546	3584503.249	473804.793	3584506.557	473805.705	3584506.536	473804.126	3584507.054	473803.735	3584507.199
P 11	473806.844	3584462.226	473805.114	3584464.843	473806.909	3584463.238	473803.700	3584463.453	473804.985	3584463.786
P 12	473815.828	3584437.848	473816.148	3584444.236	473818.179	3584440.436	473815.559	3584443.100	473815.819	3584442.815
P 13	473702.322	3584364.959	473701.892	3584369.721	473701.786	3584368.454	473701.251	3584367.650	473701.290	3584366.974
P 14	473686.973	3584430.658	473685.130	3584430.866	473687.705	3584428.912	473685.111	3584429.399	473685.464	3584428.951
P 15	473678.770	3584476.583	473676.561	3584476.925	473679.822	3584473.779	473677.078	3584474.500	473677.239	3584476.033
P 16	473645.929	3584699.191	473646.292	3584702.567	473648.558	3584701.238	473645.070	3584701.458	473646.625	3584701.491
Area (m^2)	47,866.947		47,758.396		47,165.639		47,778.598		47,515.527	

Table 3 : The Specification of different instruments utilized in this study

NO.	Device	Manufacture date	Remarks
2nd Set	Samsung /Galaxy S22+ 5G	25/02/2022	Dual-frequency
3rd Set	Apple/ iPhone 11	26/09/2019	Single frequency
4th Set	Xiaomi Redmi/ Note 8-Pro	24/09/2019	Single frequency
5th Set	Apple/ iPhone XS Max	21/09/2018	Single frequency
6th Set	Apple/ iPhone XS Max /Android application	21/09/2018	Single frequency

$$Dep_i = S_i * \sin(\alpha_i) \tag{3}$$
$$Lat_i = S_i * \cos(\alpha_i) \tag{4}$$
$$E_2 = E_1 + Dep_1 \tag{5}$$
$$N_2 = N_1 + Lat_1 \tag{6}$$

Where: (Dep_i) is the departure of the side (S_i), and (Lat_i) is the latitude of the side (S_i)
(E_i) is the Easting coordinate of a specific point.
(N_i) is the Northing coordinate of a specific point.
(S_i) is the length of the side and (α_i) is the direction of that side.

Table 4 : The traverse computations from measurements of traditional techniques (first set)

Side	Length (m)	Direction	Dep. (m)	Lat. (m)	Point	Coordinates (m)	
						E	N
S 1	26.39	106°43'02"	25.27	-7.59	P 1	473637.808	3584821.865
S 2	44.05	109° 26' 09"	41.54	-14.66	P 2	473663.078	3584814.275
S 3	58.82	97° 32' 02"	58.31	-7.71	P 3	473704.618	3584799.615
S 4	79.72	188° 34' 31"	-11.89	-78.83	P 4	473762.928	3584791.905
S 5	17.51	212° 32' 02"	-9.42	-14.76	P 5	473751.038	3584713.075
S 6	104.68	177° 28' 55"	4.60	-104.58	P 6	473741.618	3584698.315
S 7	77.66	87° 40' 54"	77.60	3.14	P 7	473746.218	3584593.735
S 8	60.30	193° 49' 09"	-14.40	-58.55	P 8	473823.818	3584596.875
S 9	36.16	188° 23' 27"	-5.28	-35.77	P 9	473809.418	3584538.325
S 10	40.47	175° 48' 27"	2.96	-40.36	P 10	473804.138	3584502.555
S 11	25.16	155° 59' 27"	10.24	-22.98	P 11	473807.098	3584462.195
S 12	136.26	237° 07' 25"	-114.44	-73.97	P 12	473817.338	3584439.215
S 13	64.97	344° 58' 41"	-16.84	62.75	P 13	473702.898	3584365.245
S 14	46.82	350° 04' 02"	-8.08	46.12	P 14	473686.058	3584427.995
S 15	227.10	352° 04' 35"	-31.31	224.93	P 15	473677.978	3584474.115
S 16	122.92	355° 53' 31"	-8.81	122.60	P 16	473646.668	3584699.045
					Area	**47,829.945 m^2**	

It is possible to compute the total area of the closed traverse based on the known coordinates of the traverse points using **Eq. (7)** as explained below:

$$A = \frac{1}{2}[\{(E_1 * N_2) + (E_2 * N_3) + \cdots + (E_n * N_1)\} - \{(N_1 * E_2) + (N_2 * E_3) + \cdots + (N_n * E_1)\}] \quad (7)$$

However, the elements of this traverse should be standard quantities ready for comparison with the corresponding quantities derived from smartphones as another technique. Therefore, it can be checked if there is any difference in the closure of that traverse based on the Compass Rule. Thus, the resultant departures and latitude components in the whole traverse will be computed (Eq. (8) – Eq. (11)) to balance the final adjusted results, Table 5 below:

$$Correction\ \Delta E_i = \frac{-(\sum \Delta E)}{\sum S_i} * S_i \quad (8)$$

$$Correction\ \Delta N_i = \frac{-(\sum \Delta N)}{\sum S_i} * S_i \quad (9)$$

$$Adjusted\ (Dep_i) = Dep_i + Correction\ \Delta E_i \quad (10)$$

$$Adjusted\ (Lat_i) = Lat_i + Correction\ \Delta N_i \quad (11)$$

Table 5: The adjustment computations of traverse using compass rule (first set)

Side	Length (m)	Adjusted direction	Dep. (m)	Lat. (m)	Corrections		Adjusted		Adjusted Length (m)
					Δ E (m)	Δ N (m)	Dep. (m)	Lat. (m)	
S1	26.39	106˚43'04"	25.27	-7.59	-0.002	0.004	25.268	-7.586	26.382
S2	44.05	109˚26'13"	41.54	-14.66	-0.003	0.007	41.537	-14.653	44.046
S3	58.82	97˚32'08"	58.31	-7.71	-0.004	0.009	58.306	-7.701	58.812
S4	79.72	188˚34'39"	-11.89	-78.83	-0.006	0.012	-11.896	-78.818	79.711
S5	17.51	212˚32'12"	-9.42	-14.76	-0.001	0.003	-9.421	-14.757	17.508
S6	104.68	177˚29'07"	4.59	-104.58	-0.007	0.016	4.583	-104.564	104.664
S7	77.66	87˚41'08"	77.60	3.14	-0.005	0.012	77.595	3.152	77.659
S8	60.30	193˚49'25"	-14.41	-58.55	-0.004	0.009	-14.414	-58.541	60.289
S9	36.16	188˚23'45"	-5.28	-35.77	-0.003	0.006	-5.283	-35.764	36.152
S10	40.47	175˚48'47"	2.95	-40.36	-0.003	0.006	2.947	-40.354	40.461
S11	25.16	155˚59'49"	10.23	-22.98	-0.002	0.004	10.228	-22.976	25.150
S12	136.26	237˚07'49"	-114.45	-73.95	-0.009	0.021	-114.459	-73.929	136.258
S13	64.97	344˚59'07"	-16.83	62.75	-0.004	0.010	-16.834	62.76	64.978
S14	46.82	350˚04'30"	-8.07	46.12	-0.003	0.007	-8.073	46.127	46.828
S15	227.10	352˚05'04"	-31.27	224.94	-0.016	0.035	-31.286	224.975	227.140
S16	122.92	355˚54'01"	-8.79	122.61	-0.008	0.019	-8.798	122.629	122.944
Sum	**1,168.99**		**0.08**	**-0.18**	**-0.08**	**0.18**	**0**	**0**	**1,168.982**

Mathematically, the quantities of the adjusted close traverse (adjusted distances and computed area) will be ready to be the standard for comparison with other values derived from other techniques (smartphones).

3.2 *Analyze the 2nd group of the collected data from different smartphones.*

In this group, there were five sets of coordinates; each consisted of the 16-point coordinates of the closed traverse taken by a specific smartphone. Due to differences between the possibilities of the smartphone devices, the results will be different. It can extract the derived distances from each smartphone's recorded coordinates and compare the computed area. To assess the most accurate results with specific devices, the differences between the adjusted standard values from traditional techniques and the results of each smartphone. A statistical approach was used, which includes computations of average, maximum, minimum, median, standard deviation (σ), and root mean square error (RMSE) of all differences according to the following formulas and results in Table 6.

$$(\Delta E)_i = E_{(m)} - E_{(t)} \tag{12}$$

$$(\Delta N)_i = N_{(m)} - N_{(t)} \tag{13}$$

$$RMSE = \sqrt[2]{\frac{\sum_{i=1}^{n}(\Delta_i)^2}{n}} \tag{14}$$

$$\sigma = \sqrt[2]{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}} \tag{15}$$

Where: (ΔE_i) is the difference in the E-coordinate of a specific point, (ΔN_i) for N-coordinate.

$(E_{(m)})$ is the E-coordinate from a smartphone device, and $(N_{(m)})$ for Ncoordinate.

$(E_{(t)})$ is the E-coordinate from traditional techniques.

(n) is the number of total points.

$(RMSE)$ is the Root Mean Square Error.

(σ) is the Standard Deviation.

Table 6 : The differences in coordinates between positions derived from each smartphone and the adjusted coordinates from traditional techniques with statistical analysis

Pt #	Adjusted Coordinates		Difference in coordinate (m)									
	1st Set		2nd Set		3rd Set		4th Set		5th Set		6th Set	
	E (m.)	N (m.)	ΔE	ΔN	ΔE	ΔN	ΔE	ΔN	ΔE	ΔN	ΔE	ΔN
P1	473637.808	3584821.865	-0.485	-0.993	-0.418	0.651	-0.031	-1.105	-1.509	1.922	-0.973	1.846
P2	473663.076	3584814.279	0.241	-0.536	-0.551	2.503	-0.003	-1.696	0.168	3.894	-0.679	2.492
P3	473704.613	3584799.626	-0.189	-0.080	-1.545	2.654	1.695	-0.270	-2.538	3.296	-2.407	2.930
P4	473762.919	3584791.925	0.355	-0.780	0.918	2.363	1.118	-1.547	-1.933	1.605	-1.246	3.196
P5	473751.023	3584713.107	0.314	-2.176	-0.915	3.717	-1.505	-0.161	-1.839	2.859	-0.865	2.261
P6	473741.602	3584698.350	0.714	0.810	0.536	4.794	1.259	3.011	-2.168	5.078	-1.408	4.666
P7	473746.185	3584593.786	0.776	0.519	-1.143	2.856	3.524	-0.836	-0.762	2.471	-1.108	3.192
P8	473823.780	3584596.938	0.125	-0.483	-0.651	4.751	1.494	1.316	-1.539	4.291	-1.907	2.755
P9	473809.366	3584538.397	1.147	0.384	0.544	4.605	1.806	3.039	-1.073	3.748	-2.075	3.031
P10	473804.083	3584502.633	-0.537	0.616	0.710	3.924	1.622	3.903	0.043	4.421	-0.348	4.566
P11	473807.030	3584462.279	-0.186	-0.053	-1.916	2.564	-0.121	0.959	-3.330	1.174	-2.045	1.507
P12	473817.258	3584439.303	-1.430	-1.455	-1.110	4.933	0.921	1.133	-1.699	3.797	-1.439	3.512
P13	473702.799	3584365.374	-0.477	-0.415	-0.907	4.347	-1.013	3.080	-1.548	2.276	-1.509	1.600
P14	473685.965	3584428.134	1.008	2.524	-0.835	2.732	1.740	0.778	-0.854	1.265	-0.501	0.817
P15	473677.892	3584474.261	0.878	2.322	-1.331	2.664	1.930	-0.482	-0.814	0.239	-0.653	1.772
P16	473646.606	3584699.236	-0.677	-0.045	-0.314	3.331	1.952	2.002	-1.536	2.222	0.019	2.255
	Area = 47,824.535 m2											
	Statistical Analysis	Average	0.099	0.010	-0.558	3.337	1.024	0.820	-1.433	2.785	-1.197	2.650
		Median	0.183	-0.066	-0.743	3.093	1.376	0.868	-1.538	2.665	-1.177	2.623
		Max	1.147	2.524	0.918	4.933	3.524	3.903	0.168	5.078	0.019	4.666
		Min	-1.430	-2.176	-1.916	0.651	-1.505	-1.696	-3.330	0.239	-2.407	0.817
		RMS	0.700	1.182	0.989	3.526	1.600	1.922	1.673	3.082	1.369	2.841
	(σ) Standard deviation		0.693	1.182	0.828	1.397	1.254	1.749	0.931	1.482	0.726	1.210

According to Table 6, it is clear that the adjusted computed area of the traverse was computed with traditional techniques to be 47,824.535 m^2, which differs from the computed area before adjustment, which was 47,829.945 m^2. In addition, the more accurate results were derived from the second set of measurements the Samsung S22 device took. This dual-frequency device has the minimum standard deviation for Easting and Northing coordinates. Therefore, the most accurate coordinates were derived from this device.

On the other hand, when comparing the adjusted distances between points with those derived from the coordinates measured by each smartphone Table 7, it can be noticed that the minimum RMSE of the difference in distance was derived from the results with the Samsung S22 of the dual frequency. This means that the most accurate results of positioning, distances, and area of closed traverse Table 8 and Figure 4 can be achieved with smartphones of dual frequency than those of single frequency. The area was calculated from the coordinates recorded by smartphones and compared with the area calculated from adjusted traditional coordinates, finding differences in the area results. Table 8 represents the ability of dual-frequency smartphones compared to other single-frequency smartphones to determine the area where the graph was drawn in Figure 4.

Table 7 : The differences in lengths from the comparison between distances derived from each smartphone and the adjusted distance from the traditional technique with their analysis

Side	**Adj. Length**	**Derived length from smartphone positioning (m.)**					**Difference length (m.)**				
	1st Set	**2nd Set**	**3rd Set**	**4th Set**	**5th Set**	**6th Set**	**ΔS2**	**ΔS3**	**ΔS4**	**ΔS5**	**ΔS6**
S1	26.382	26.954	25.781	26.584	27.524	26.487	0.572	-0.601	0.202	1.142	0.105
S2	44.046	43.490	43.058	45.213	41.719	42.271	-0.556	-0.988	1.167	-2.327	-1.775
S3	58.812	59.447	61.293	58.423	59.654	59.93	0.635	2.481	-0.389	0.842	1.118
S4	79.711	81.097	78.671	78.781	78.457	80.580	1.386	-1.040	-0.930	-1.254	0.869
S5	17.508	14.830	15.833	13.362	15.883	15.870	-2.678	-1.675	-4.146	-1.625	-1.638
S6	104.664	104.958	106.542	108.627	107.339	106.150	0.294	1.878	3.963	2.675	1.486
S7	77.659	76.974	78.250	75.750	76.978	76.844	-0.685	0.591	-1.909	-0.681	-0.815
S8	60.289	59.208	60.157	58.542	60.708	60.063	-1.081	-0.132	-1.747	0.419	-0.226
S9	36.152	36.209	36.803	35.325	35.338	34.413	0.057	0.651	-0.827	-0.814	-1.739
S10	40.461	41.155	41.715	43.315	43.602	43.43	0.694	1.254	2.854	3.141	2.969
S11	25.150	25.981	23.375	25.435	23.557	23.604	0.831	-1.775	0.285	-1.593	-1.546
S12	136.258	134.894	136.407	136.853	136.964	137.364	-1.364	0.149	0.595	0.706	1.106
S13	64.978	67.468	63.401	62.076	63.823	63.966	2.490	-1.577	-2.902	-1.155	-1.012
S14	46.828	46.652	46.849	45.555	45.810	47.794	-0.176	0.021	-1.273	-1.018	0.966
S15	227.140	225.017	227.664	229.597	229.204	227.527	-2.123	0.524	2.457	2.064	0.387
S16	122.944	121.985	120.279	120.007	122.643	122.612	-0.959	-2.665	-2.937	-0.301	-0.332
Sum	1168.982	1166.319	1166.078	1163.445	1169.203	1168.905	-	-	-	-	-
					Statistical Analysis	Average	-0.166	-0.182	-0.346	0.014	-0.005
						Median	-0.060	-0.056	-0.608	-0.491	-0.061
						Max	2.490	2.481	3.963	3.141	2.969
						Min	-2.678	-2.665	-4.146	-2.327	-1.775
						RMS	1.288	1.376	2.179	1.576	1.333
					(σ)Stand. deviation		1.319	1.409	2.222	1.627	1.377

Table 8 : The differences in the area of traverse

Set No.	Area (m^2)	Diff. (m^2)
1st Set	47,824.535	00.000
2nd Set	47,866.947	42.412
3rd Set	47,758.396	-66.139
4th Set	47,165.639	-658.896
5th Set	47,778.598	-45.937
6th Set	47,515.527	-309.008

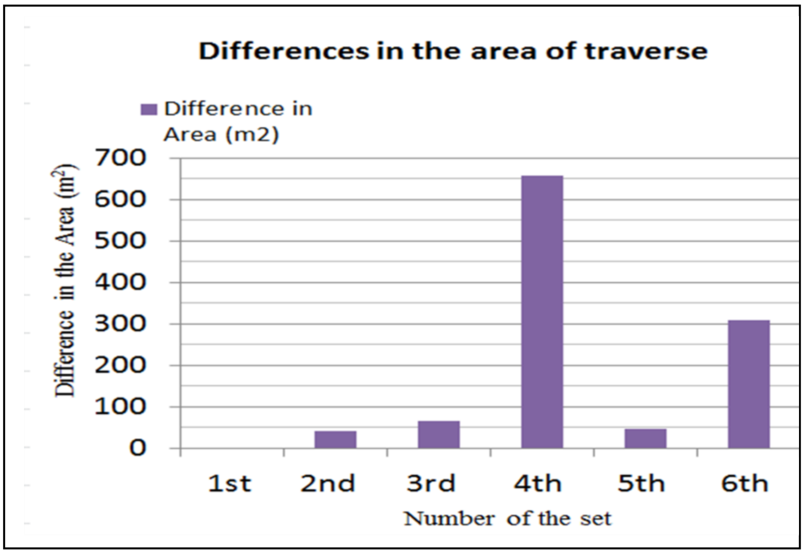

Figure 4 : The differences in the area of traverse

3.3 Discussion of Results

The collected data and statistical analyses were used to assess the accuracy of different results and enable a reliable evaluation of the determined positions, lengths, and computed area derived from conducted observations. It can be observed the following points:

1. Comparing the recorded coordinates of the traditional techniques with those conducted by smartphones, the most accurate result was recorded with the Samsung Galaxy S22 dual-frequency smartphone compared to other devices single-frequency. The RMSE of the Easting and Northing differences were 0.700 m. and 1.182m, respectively, with the S22 device (2nd set), while more than that result was observed with other devices. The degraded results were extracted from the Apple iPhone 11 smartphone (3rd set) with RMSE of 0.989 m and 3.526 m for differences in Easting and Northing coordinates, respectively, Table 6. While the results, if compared with bravoes research by Guo et al. [32] the (RMS) of the independent vertical and horizontal positional errors are 1.94 and 1.22 m, respectively, and by Robustelli et al. [33] are from 3.24 to 4.90 m.

2. Comparing the extracted lengths from the recoded coordinates by different smartphones with the adjusted ones from traditional techniques, the second set of data (Samsung S22) was closer to the standard set. The RMSE of the lengths with S22 was 1.288 m, Table 7. However, the RMSE of the sixth set was 1.377m, and the standard deviation of the second set was 1.319m, which was less than that for the sixth set was 1.377m. The worse

distance results were extracted from the Xiaomi device (4th set), which has an RMSE of 2.179m.

3. Comparing the computed area of the closed traverse with different smartphones, the closer value of the area to the standard one was computed from the data of the second set with a Samsung S22 dual frequency. The computed adjusted area was 47824.535 m^2, while it was 47866.947 m^2, which means the difference is 42.412 m^2, Table 8. This difference is accepted and suitable for this type of surveying to compute the area quickly. In this research, the percentage rate errors in determining the area in five smartphones are from 0.00089% to 0.01378%, while the results in bravoes research by Oluwadare and Salam [20] are (from 0.03436% to 0.04574%).

4. For statistical description, the "cumulative distribution functions (CDF)" can be used to represent the probability of different results according to Eq. (16). The random variable will statistically take a value less than or equal to a specified argument. As illustrated in Figure 5, the error in the derived length of sides was determined by smartphones and calculated from the average of three measurement campaigns. From the CDF statistical indicator, the Samsung S22 dual-frequency device achieved the best results sequentially by the Apple iPhone 11, the iPhone XS Max with Android application, the Xiaomi Note 8, and the iPhone XS Max.

$$CDF = Normal\ Distribution = \left\{\frac{(x_{i-\bar{x}})}{\sigma}\right\} \tag{16}$$

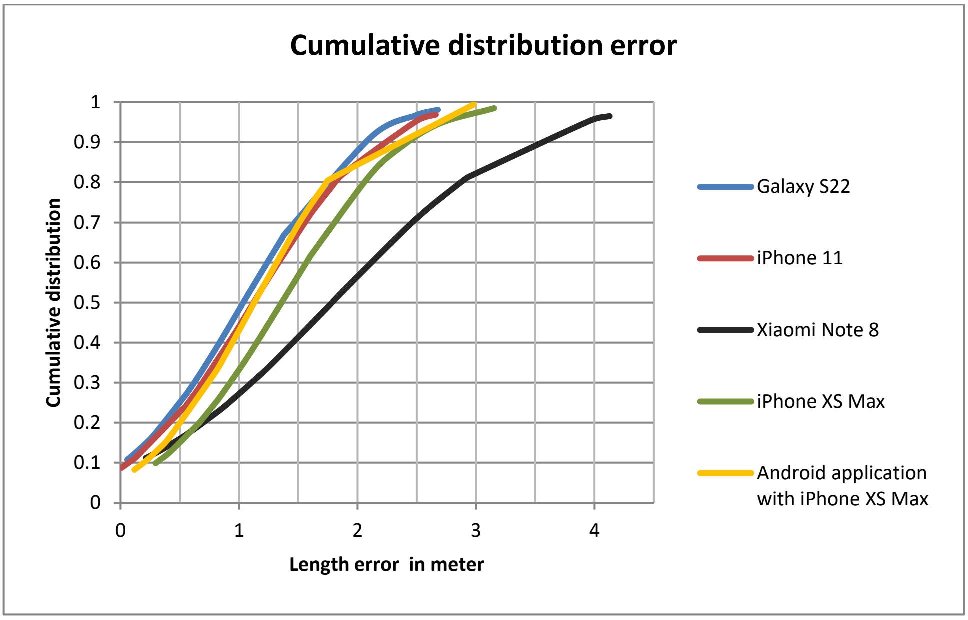

Figure 5 : The cumulative distribution function to the length error in sides was determined by smartphones and calculated from the average of three measurement campaigns

4. Conclusions

This paper investigates the capability of smartphones to conduct survey traverse. This includes collecting position data for points representing a closed polygon. It was successfully applied to determining the area and side lengths of land with specific boundaries. Four different smartphone devices were used in this research, and the results were different from one device to another, as the results depended on the type of device, the capability to record single or dual frequency, the date to release the smartphone, while the error in the latest versions is less than in earlier models. A significant improvement in accuracy was achieved through an Android smartphone device that receives the dual signal from the constellation GNSS in agricultural areas, and the error in the land area derived by this smartphone achieves 42,412 m^2. This difference is suitable for the agricultural lands survey to estimate the total area of these sites. However, resolving real estate ownership disputes in lands or estimating small areas could not be better.

As for the accuracy of working with a smartphone that receives the dual frequency, the value of the RMSE in determining the length of sides was 1.288-1.376 m, and in the positioning of 0.700-1.182 m, and the percentage of error in deriving the area was 0.00089%. These results are within the range 1-3 m; therefore, they are appropriate for topographic survey.

Comparing the cost of conducting the work showed that it becomes clear that the smartphone is limited compared to traditional surveying. As for adding applications to the smartphone, it was proven that Android applications with the iPhone XS Max improve accuracy in determining positions, length of sides, and area.

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