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Improving Height Accuracy of the Handheld GPS Receiver

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***Abstract:** Elevation of ground points is one of the parameters necessary in various surveying and engineering projects. One of the techniques of determining point elevation is the Global Positioning System (GPS). Accuracy of the obtained coordinates using GPS depends on particular reasons such as the type of GPS receiver used and observation technique adopted.*
Recently, handheld GPS receivers were manufactured mainly for the sake of navigation. These receivers are cheaper than geodetic GPS ones. However, the accuracy of point coordinates they produce needs to be checked.
Previous studies concluded that accuracy of elevations obtained using handheld receivers is worse than that of planimetry.
In this research work, investigation of improving elevation accuracy obtained using handheld GPS has been carried out using regression analysis. Results show that using simple linear regression and four points as control, height accuracy can be improved from 7.68m RMSE to 3.45m RMSE (55% improvement) and when using three control points accuracy is improved from 7.68m RMSE to 4.38m RMSE with 43% improvement.
Keywords: Handheld GPS; Vertical Accuracy; Horizontal Accuracy; Regression; control points

I. INTRODUCTION

No doubt the introduction of the Satellite Global Positioning System (GPS) in the field of geoinformation sciences made a huge development in the field and has become an important source of mapping data. It shows effective saving on time to provide accurate and reliable ground point coordinates needed in the field of surveying.

The first portable (Handheld) GPS unit was introduced by Magellan in 1988, known as NAV 1000. This unit is considered to be larger in size (19x8.9x5.3cm), heavier in weight (850gm) and more expensive (2500 US Dollar) than modern handheld GPS units. It was a single channel receiver, could only track four satellites and only supported Latitude/Longitude coordinates. Benlin, et al, 2002.

Portable, handheld GPS is becoming increasingly popular, since it is portable (light in weight and small) and cheaper than geodetic ones. However, handheld GPS has limitation in accuracy (i.e. within 10 meters).

More recent handheld GPS devices can receive signals from multi satellite constellations: GPS, GLONASS, BeiDou, Galileo, and QZSS. A broader constellation coverage means more geometry options for the receiver to compute a stronger positional fix. Another important issue is the frequency bands that the receiver can track. Dual frequency receivers that process both L1 and L2 signals, or L1 and L5 can model and eliminate ionospheric delay that distort single frequency positioning

Some researchers carried out geometric tests to evaluate the accuracy of data produced using older handheld GPS units (Halim Setan, et al.2010; Zomrawi and Essa, 2012; Mohammed Fator and Nagi Zomrawi, 2015; Zahraa Ezzaddin Hussein, 2016; Lachapelle, et al, 2018; Ibrahim Olatunji Raufu, et al, 2025).

Review of results of some of these works shows that height accuracy provided by different handheld units were worse than the horizontal data.

The objective of this paper is to develop a means for improving the obtained vertical data from handheld GPS.

II. HANDHELD GPS

GPS units made by Garmin International, Inc. (http://www.garmin.com/) are very popular for both research, recreational, and commercial work.

From the owner's manuals: Sokkia GSR2700 ISX RTK, Garmin eTrex summit HC and Garmin GPSMAP 60CS Dimensions, weight, accuracy and approximate current cost are shown in Table 1 to realize the difference between handheld and geodetic units. www.manualslib.com/manual/56157/Garmin-Etrex.html

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Table 1: Comparison between Handheld GPS Units and a Geodetic Unit

Unit	Dimensions (cm)	Weight (kg)	Autonomous Accuracy (m)	Altimeter Accuracy (m)	Approx. Cost Dollars
Sokkia gSR2700 ISX	22.5x10.5	1.800	1.5	0.01 RTK	40 000
Garmin eTrex HC	10.7x5.6x3.0	0.159	<10	± 3.0 to 0.3	300
Garmin GPSMAP 60CS	15.5x6.1x3.3	0.213	<15	± 3.0 to 0.3	400

Fig. 1: Geodetic and Handheld Units, Images from bench-mark.ca and garmin.com.
https://www.outdoorgearlab.com/topics/camping-and-hiking/best-handheld-gps

Different application scenarios and different accuracy levels require different receiver classes. They are separable by their technical possibilities, their accuracy level and their fields of application. Table 2 gives an overview about typical receiver classes.

Table 2: Receiver classes and their characteristics Volker Schwieger, 2003

Receiver class	Used signal	Accuracy/realtime	Special feature	application
Hand held	Code or phase smoothed code, 1 frequency	1 to 10m/yes	Navigation feature	Mass market, navigation, tourism
GIS	Phase-smoothed code, 1 frequency	0.5 to 3m/yes	Attribution of geometric data during field work	Geo data acquisition for GIS
Geodetic	Code and phase, in general 2 frequencies	0.001 to 0.1m /party	Post-processing software for high accuracies	Surveying, precise kinematic positioning

Source and receiver points for seismic lines recorded during the geophysics field school near Spring Coulee Alberta were surveyed with a Sokkia real time kinematic (RTK) GPS survey. The points were also surveyed with two hand-held Garmin GPS receivers. In order to determine what sort of station spacing could be adequately surveyed with the hand-held units, geophones were repeatedly surveyed with all three systems. The RTK system had a maximum error of 10 cm in x, y and z. Repeated hand-held measurements cannot resolve stations less than two meters apart in x and three meters apart in y (Hall, et al, 2008).

III. LITERATURE REVIEW

Here are some of the research that worked and tested geometric results from Handheld GPS:

Halim Setan, et al, 2010 developed a mapping procedure by combining the digitized images of Google Maps and the road features collected by handheld GPS (i.e. Garmin GPSMAP 76CSx). The accuracies of coordinates obtained from Google Maps and handheld GPS are compared against five known GPS points. The results show that the accuracy of Google Maps is between 1.3 to 10.5 meters, while the accuracy of handheld GPS is in the range of 0.2 to 3.5 meters.

Zomrawi and Issa, 2012 tested the field horizontal accuracy obtained using the handheld GPS receiver. Results obtained showed that the handheld GPS receiver can practically provide horizontal accuracy of about 4m. This result leads to the suitability of using it for collecting data to produce planimetric maps at scale 1:7,500 and smaller. Table 3 below shows the test results.

Table 3: Summary of the results, Zomrawi and Issa, 2012

Statistics	Differences (m)	
Maximum	E	N
Minimum	2.00	4.00
Average	-5.00	-5.00
RMSE (m)	3.65	2.98
Linear Accuracy (m)	3.98	

Kamruzzaman, et al, 2014 used both total station and handheld GPS in land use analysis at Campus of Rajshahi University of Engineering and Technology (RUET). Accordingly, the result of the handheld GPS survey is about 12% errors compared with the results of Total Station survey.

Zahraa Ezzaddin Hussein, 2016 aimed to improve the quality of satellites signals in addition to increase accuracy level delivered from handheld GPS data by building up a program to read and decode data. Where, the NMEA protocol file, which stands for the National Marine Electronics Association, was generated from handheld GPS receivers in real time using in-house design program. The NMEA protocol file provides ability to choose points positions with best status level of satellites such as number of visible satellites, satellite geometry, and GPS mode, which are defined as accuracy factors. In addition to fix signal quality, least squares technique was adopted in this study to minimize the residuals of GPS observations and enhance its accuracy. Moreover, one hundred reference control points were established using geodetic GPS receiver (GR5 receiver), and fixing them in a specified sites of the University of Baghdad, Al Jadriya campus, which has been selected as a study area, to evaluate positioning accuracy of handheld GPS before and after adjustment. The study findings showed significant decrease in root mean square error (RMSE) in both horizontal and vertical directions from 9.4 m to 3.2 m and 6.8 m to 2.4 m respectively, proving that the quality of handheld GPS signals can be enhanced and hence increase their positioning accuracy in planimetry and height.

Lachapelle,, et al, (2018)a A newly available portable unit with GNSS raw data recording capability is assessed to determine static and kinematic position accuracy in various environments. This unit is the GPSMap 66, introduced by Garmin in early September. It is all-weather and robust for field use, and comes with a helix antenna. The high sensitivity chipset is capable of acquiring and tracking signals in highly attenuated environments. It can track single frequency GPS, GPS + GLONASS or GPS + Galileo and record code, Doppler and carrier phase data every second in the RINEX format. The evaluation presented herein focusses on GPS and Galileo. Static and kinematic test results obtained under a wide range of realistic field conditions are reported.

Differential GNSS methods and Precise Point Positioning (PPP) are used to assess absolute position accuracy in ITRF coordinates, which is sufficiently close to the GPS and Galileo reference frame for the current purpose. Under low multipath conditions, measurements are found to be sufficiently accurate to provide single epoch, bias free position accuracy of a few meters. Accuracy is a function of signal attenuation and multipath conditions. The use of an external geodetic antenna significantly reduces measurement noise and multipath in high multipath environments. Carrier phase measurements, available more or less continuously under open sky conditions, significantly improve performance in differential mode. Accuracy in vehicular mode using code and carrier phase differential RTK solution is at the level of a few to several dm. Tests were conducted in parallel with a Huawei P10 Android 8.0 smartphone.

The code measurement noise of this unit was found to be significantly higher than that of the GPSMap 66, a major reason being its lower performance PIFA antenna; carrier phase was only available for short time intervals, significantly degrading differential position accuracy performance.

GPSMap 66 GPS latitude, longitude and height RMSE values are 6.5, 3.5 and 12.2m for the blue unit and 4.5, 3.0 and 10.1m for the green unit. The higher height RMS values are expected due to normal height observability and high multipath environment. Corresponding Galileo RMS values are 6.6, 2.4 and 8.4m for the blue and 6.6, 4.2 and 11.9m for the green unit: no significant difference from the GPS values.

Ibrahim Olatunji Raufu, et al, 2025 compared Android GPS applications on three smartphones (Samsung, Tecno, Infinix) and handheld GPS with the existing standard (DGPS). The study employed mobile topographers embedded in smartphones to acquire coordinates from existing survey beacons in three modes (airplane, offline, and online). Data were also collected using handheld GPS at the same control beacons.

Fifteen (15) stations were observed, and the acquired data were compared to determine the accuracy of the observations. The results of the analysis revealed a significant difference between the smartphone data and DGPS, with error ranging from 2 to 15 m for DGPS and 0.2 to 10 m for handheld GPS, depending on the observation modes.

In their research, Mohammed Fator and Zomrawi, 2015, tested Etrex Garmin handheld navigation GPS receiver to evaluate its accuracy and justify suitability of its collected coordinates mapping purposes. A number of 25 points were selected to cover the study area. These points were precisely observed in the field using Deferential Global Positioning System (DGPS) model R8- GNN from Trimble Company. Static mode was used every 45 minutes to observe each point providing accuracy 0.5 cm ±1ppm. The study area of this research work was extended to cover about 15×15 km of Khartoum capital area (Sudan).

IV. METHODOLOGY

In the paper published by Mohammed Fator and Nagi Zomrawi in 2015 [1] they have carried out handheld GPS observations in Khartoum district. The test data of the work done by Mohammed Fator and Zomrawi, 2015 were available to the authors.

Mohammed Fator and Zomrawi (2015) results showed that Etrex Garmin GPS receiver produces planimetric accuracy of ±3.16m. On the other hand, the vertical accuracy above ellipsoid was found to be ±7.68m.

Obtained elevations of test points will be subject to evaluation of the effectiveness of the regression method developed to increase the height accuracy from handheld GPS.

V. TEST DATA & PROCESSING

Mohammed Fator and Zomrawi, 2015 tested accuracy of etrex handheld unit using coordinates of 25 points distributed in Greater Khartoum, Sudan. The study area was extended to cover about 15×15 km of Khartoum. These points were precisely observed in the field using Differential Global Positioning System (DGPS) model R8-GNN from Trimble Company. Static mode systems are used every 45 minutes to observe each point. Least Mean Square Error (LMSE) accuracy was equal to 0.5 cm ±1ppm. Table (2) below is the result of Eastings (E), Northings (N) and Heights (H) of observed coordinates of the points. Distribution of locations of these 25 points is shown on figure 2.

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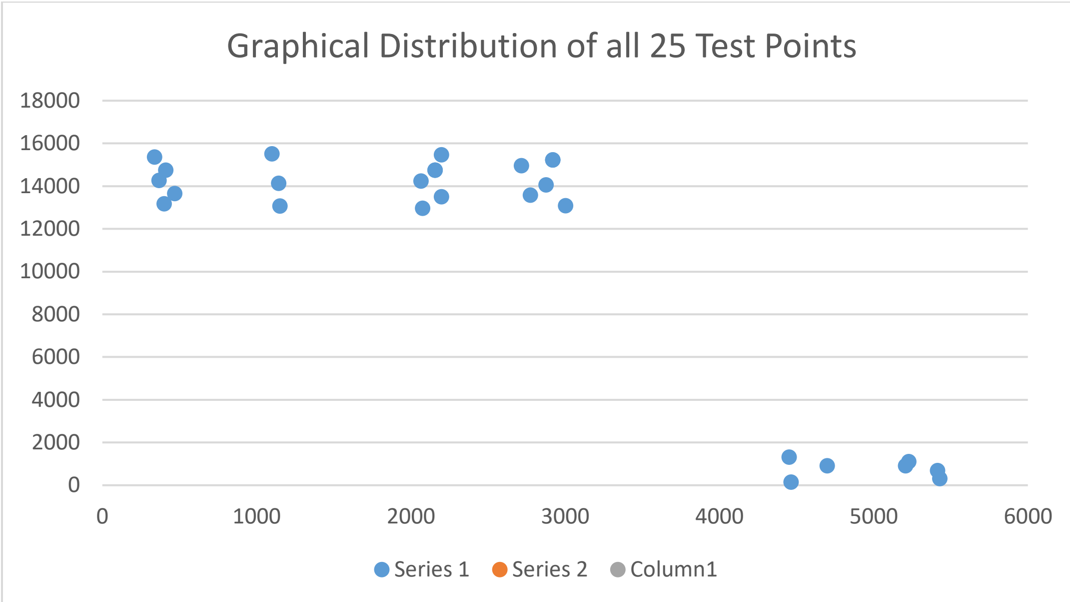

Fig. 2: Distribution of all test points (25 points)

Out of these 25 points 3 and 4 were chosen to be used as control points leaving the rest of the points (22 and 21 points, respectively) as check points.

Test 1: Using 3 control points: 6, 14, 25 shown on figure 3. Derived regression equation:

dh = -15.325 + 0.00364 x + 0.00137 y

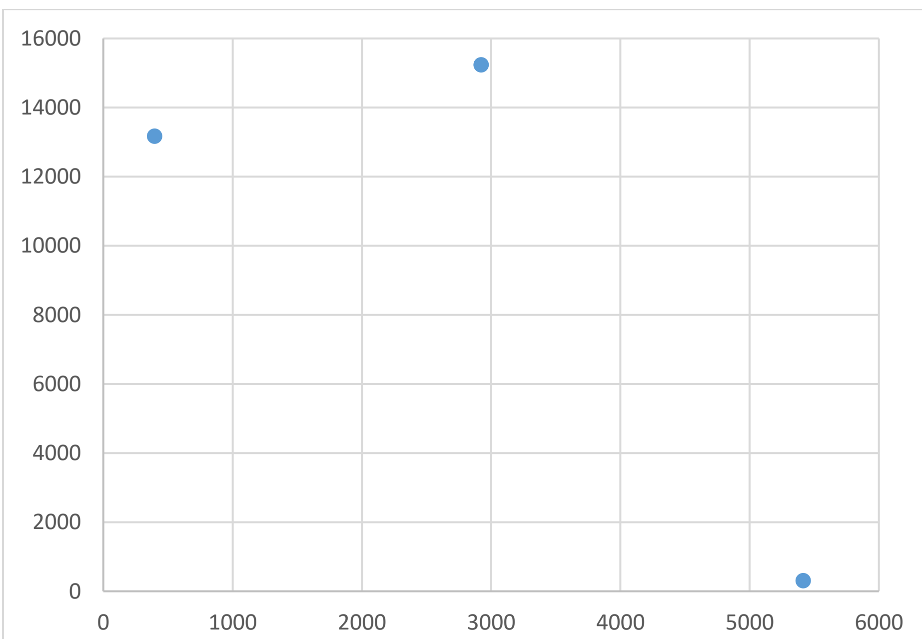

Fig. 3: Distribution of the 3 control points:6, 14 and 25 – Test 1

Test 2: Using 4 control points: 1, 4, 9, 14 shown in figure 4, derived regression equation is

dh = -11.8378 + 0.003 x + 0.0011 y

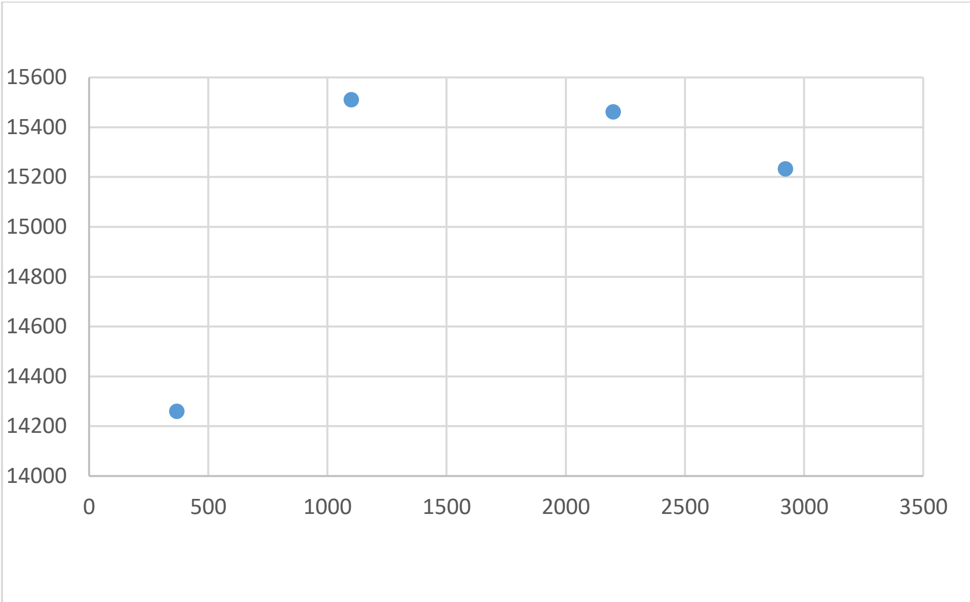

Fig. 4: Distribution of the 4 Control points 1, 4, 9, 14 – TEST 2

VI. RESULTS & ANALYSIS

Elevation Differences from precise values for all test points as determined by Mohammed Fator and Zomrawi, 2015 and as determined in this research using 3 and 4 control points (tests 1 and 2) are given in Table 3 below:

Table 3: Residuals of Test Points as from Fator and Zomrawi, 2015 and Tests 1 and 2 in the current research

Point	Errors in Elevation (m)		
	Fator and Zomrawi, 2015	3 controls	4 controls
1	3.887	-6.04	4.65
2	5.585	-1.38	0.50
3	4.481	- 2.48	1.13
4	9.149	3.59	-4.19
5	8.839	3.76	-4.26
6	4.190	-0.02	-0.34
7	3.23	-4.99	3.23
8	12.457	2.41	-6.46
9	12.216	1.64	-0.45
10	3.003	-9.74	7.86
11	14.571	2.87	-4.44
12	8.507	-2.64	1.09
13	6.168	3.84	2.50
14	16.620	0.44	-2.93
15	11.194	-3.85	1.57
16	5.230	-9.15	7.02
17	7.800	-5.58	3.68
18	4.741	-8.80	6.83
19	2.987	0.29	-0.01
20	2.518	-2.70	2.56
21	2.928	1.79	-1.21
22	3.100	0.07	0.16
23	2.539	-2.37	2.27
24	2.613	-2.70	2.55
25	4.860	0.06	-0.12

The most common statistical parameter used to describe accuracy of observations is the root-mean-square error (RMSE). It is determined from the differences, xi between observed values and given values for a population of n observed values and can be expressed by the formula:

$$\mathrm{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2}$$

Statistical summary of the of results for current tests and Fator and Zomrawi results, including maximum, minimum and RMSE are given in table 4.

Table 4: Summary of statistics of the results

Statistics	Method		
	Fator and Zomrawi, 2015	3 controls	4 controls
Maximum (m)	16.62	-9.74	7.02
Minimum (m)	2.52	0.02	-0.01
RMSE (m)	7.68	±4.38	±3.77
% improvement		43%	51%

Using 4 control points: C1, C4, C9 and C14 and regression equation: dh = -11.8378 + 0.003 x + 0.0011 y the resulting RMSE Height accuracy = ±3.77m
Using 3 control points: C6, C14 and C25 and regression equation:
dh = -15.325 + 0.00364 x + 0.00137 y, RMSE Height = ±4.38m
Regression equations and results:
Test 1: Control points: 6, 14 and 25
Derived Regression equation: dh = -15.325 + 0.00364X + 0.00137Y
Results: RMSE = ±4.38m
Test 2: Control points: 4, 14, 18 and 25
Derived Regression equation: dh = -2.245 + 0.00112X + 0.00073Y
Result: RMSE = ± 3.82m

VII. COMPARISON WITH PREVIOUS STUDIES

Table 5 below shows a summary of previous studies results for height accuracy obtained directly from handheld GPS units.

Table 5: Results of Geometric Tests of handheld units

Research	RMSE dH (m)
Fator and Zomrawi, 2015	±7.68
Zahraa Ezzaddin Hussein, 2016.	±2.4
Lachapelle, et al, 2018 [10c] - Blue	±12.20
Lachapelle, et al, 2018 [10c] - Green	±10.10
Elhassan, et al, (4 controls) 2026	±3.77
Elhassan, et al, (3 controls) 2026	±4.38

As seen in table 5 results from regression correction applied in this research put obtained result just below that obtained by Zahra, 2016 and 3 to 4 times better than those obtained by Fator and Zomrawi, 2015 and Lachapelle, et al, 2018.

VIII. ADVANCED UTILIZAYION OF HANDHELDGPS

Multi-band GNSS refers to a device's ability to track multiple signals from a single satellite across different frequency bands. Older units relied solely on the L1 signal, which is prone to atmospheric interference. Modern professional units utilize both L1 and L5 frequencies to cross-reference data and eliminate timing errors.

Modern high accuracy handheld GPS receivers can track multiple satellite constellations, including GPS, GLONASS, Galileo, and BeiDou. This multi-constellation capability significantly improves position accuracy and reliability, especially in challenging environments with limited sky visibility. Advanced receivers also feature multi-frequency capabilities, allowing them to track different satellite signals simultaneously. This technology helps minimize signal errors caused by atmospheric interference and multipath effects, resulting in more precise position measurements.

The level of accuracy of cm positioning can be achieved through various correction methods, including real-time kinematic (RTK) positioning and differential GPS (DGPS) capabilities as concluded in Abdallah and Amgad, 2018; Lachapelle et al, 2018b; Wanninger, et al, 2022 Alkan, et al, 2023; Alkan, et al, 2025.

IX. CONCLUSIONS

The height accuracy of points obtained using handheld GPS is not suitable for topographic mapping of contour interval less than 15m. So, it is not recommendable to use handheld GPS in any precise topographic survey, rather it can be used in preliminary surveys. However, if regression approach is applied using 3 control points the height accuracy of less than 5m can be obtained. This will allow production of 10m contour interval maps.

Using modern professional handheld units that can track multiple signals and applying correction using differential or PPP methods can allow accuracy of cm to decimeter level. Hence can be used to produce 1 meter contour interval topographic maps.

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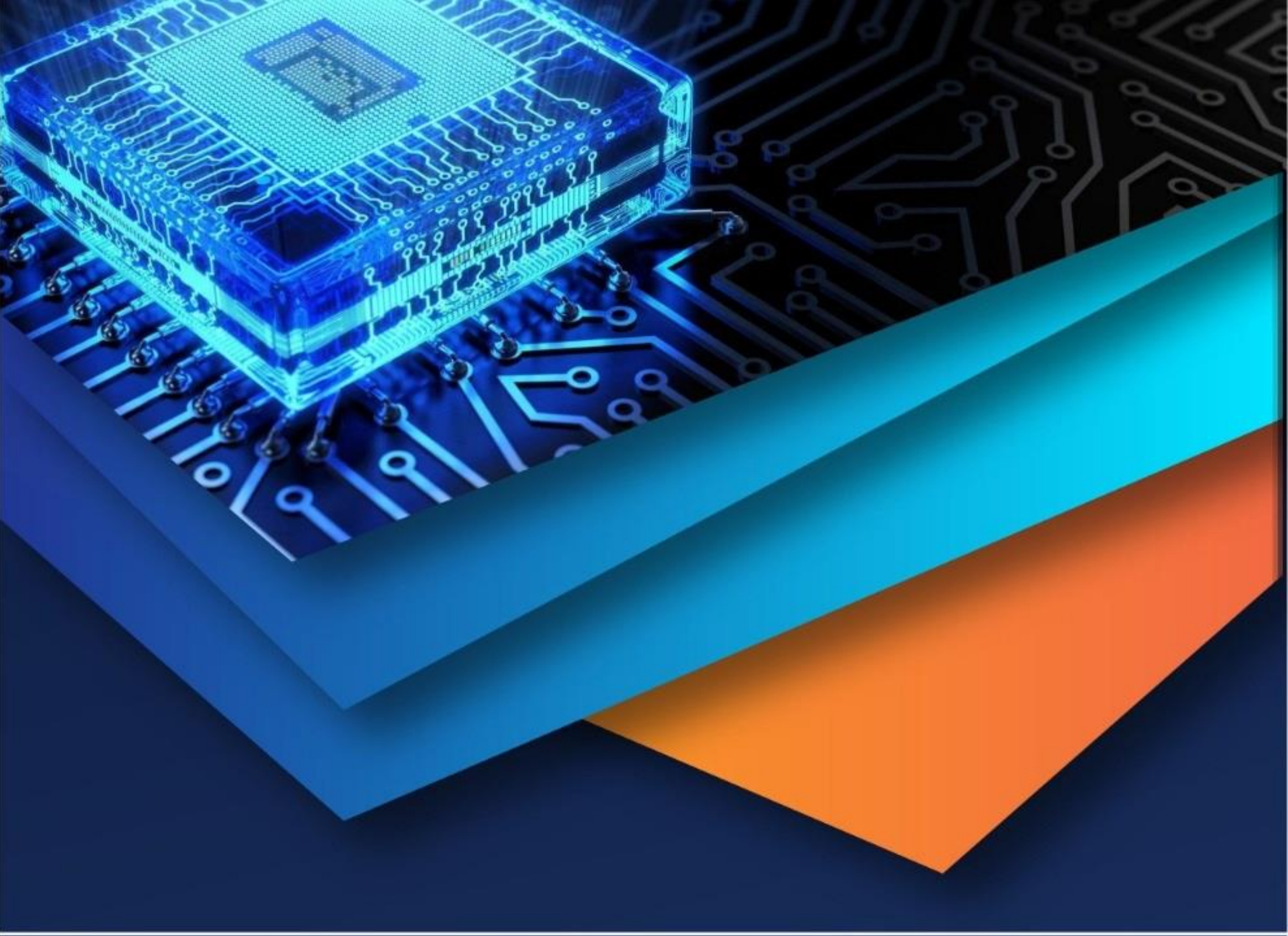

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