ACCURACY OF IMAGE GPS EXIF DATA FROM APPLE AND SAMSUNG MOBILE DEVICES COMPARED TO GPS UNIT

by

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Thesis directed by Associate Professor Catalin Grigoras

ABSTRACT

Mostly every photo captured from a cellular device contains EXIF GPS coordinates associated to the location of where that photo was captured. This thesis will propose tests for accuracy of GPS EXIF data from different Apple, Samsung and Garmin GPS devices. Apple has used the same GPS satellites in their cellular devices within the past 4 generations of models released. Samsung has used the same GPS satellites from the past 3 generations of models released. Both Apple and Samsung use a total of 4 GPS satellites, but differ in one. The proposed tests will determine if this one different satellite may cause separate results to be produced.

Within this experiment two types of tests will be administered. The first test will involve a focus of a cellular device capturing photos by having cell service on, then switching to airplane mode. The second test will involve a focus of a cellular device capturing photos by having airplane mode on initially then switching to cell service active. Results of both tests will be analyzed and any anomalies will be addressed. NGS survey markers will be utilized to explore the idea of a more prominent point established when gathering test information. Image GPS data from cellular devices will be compared to a standalone GPS device readings. Experiments will take place in urban and rural environments and results will be analyzed.

The form and content of this abstract are approved. I recommend its publication.

Approved: Catalin Grigoras

This thesis is dedicated to my family. For always supporting me in any aspirations I wanted to pursue and for guiding me throughout life.

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I. INTRODUCTION

Photo EXIF data has become popular in the past couple of years to the general public. The illusion of a photo being simply a photo is not the case anymore. The data that can be captured by these image files can encompass personal information of a user. Within a photo, GPS metadata can be captured that contains the exact coordinates of where a person was previously located. This brings up questions of how a cellular device is creating an image file with this background information and the accuracy of this data.

Within this paper, the accuracy of EXIF data being captured from Apple and Samsung cellular devices will be compared to GPS standalone devices. Airplane mode is another feature within cellular devices that will be explored. This feature turns off cell service associated to the device. This function will be experimented on to see if GPS data is still captured and outputted to image metadata. Tests will be conducted in three different environments to determine if accuracy is swayed. Two tests will be done using NGS (National Geodetic Survey) marker locations to see if any different outcomes were noticed.

Tests will be analyzed and compared to determine any interesting trends and findings. These trends could be associated to environment, airplane mode, elevation and phone manufacturer associated to the device. Any anomalies will be addressed and analyzed to determine the reason an anomaly occurred.

This thesis will be organized by chapters and will outline the steps of the overall test process. Chapter I presents the introduction and literature review. Chapter II presents the methodology describing software, devices and methods used in acquiring data. Chapter III presents the testing locations and raw data associated to each location. Chapter IV presents the findings and results from each test. Chapter V presents future research that can be addressed. Chapter VI is the conclusion and key takeaways from this paper.

Literature Review

Previous research was conducted before administering tests to determine a specific methodology.

A thesis titled "*Visual Geo-Localization and Location-Aware Image Understanding*" by Amir Roshan Zamir was reviewed to see how geo-tags might be shown throughout experiments. Zamirs' thesis is mainly focused on location aware applications applying a geo tag to images. However, Zamir mentions that many of the procedures which use geo-tags as their input require a precise geo-location, particularly in the urban areas. In respects to other software applications, this data is important to be accurate for the software to run properly. This was acknowledged and the use of different tools will be utilized when processing the data to validate one another. In addition, this paper was helpful to see the different ways of displaying and picking test locations to conduct experiments at.

Another reference was titled "*Analysis of errors in EXIF metadata on mobile devices*" by Ana Lucila Sandoval Orozco and David Manuel Arenas Gonzalez. This piece was used as reference to see how EXIF metadata in photos might look like and what errors may arise from experiments. Orozco and Gonzalez mention that the area of image forensics analysis can be divided into two large branches: picture authentication and source authentication. Moreover, Orozco and Gonalez states if GPS tags are in place in metadata and display values from 0 to 1, this indicates that the data has a high probability of being wrong. This type of occurrence was not seen in all experiments conducted. However, was taken into account because some data did not capture GPS coordinates and did not display any information whatsoever. Orozco and Gonzalez explain forensic techniques for image analysis, describe image metadata and how this is reviewed.

A reference titled "*Smartphone GPS accuracy study in an urban environment*" by Krista Merry was another work that contributed to how the administration of photos will be handled to capture data at different points of interest. Merry explains how phone positioning can hinder the results. Merry states, that at the collection of the first point collected, the phones WIFI capability was disabled. Further, after the collection of the first point the WIFI was enabled and two minutes were allowed to pass before the second data point was collected. While administrating tests, it was confirmed that the tester would take this into consideration and to have devices have a certain time allotted for GPS to be acquired. Merry's main objective of her study was to determine the accuracy of an iPhone 6s location under GPS only and WIFI only settings.

II. METHODOLOGY

Description of Materials (Devices Used)

Devices were used in a series of two tests and eleven locations comparing either an Apple, Samsung or Garmin GPS unit. Figure 1 illustrates the type of device, release date, OS version, network tech, WLAN, Bluetooth and GPS satellites associated to each device. Details from each device is gathered by GSMarena.com, which is a well-known resource for device specifications. It is important to note the type of GPS associated to each device. This can be an indicator that results should vary between each test. For example, Apple devices use a GPS satellite system titled, QZSS, where Samsung utilizes the BDS GPS satellite.

Device	Release Date	OS Version	Network Tech	WLAN	Bluetooth	GPS
Apple iPhone 6s	Sept, 2015	12.4.2	GSM/CDMA/HSPA/ EVDO/LTE	WiFi 802.11 a/b/g/n/ac, dual band, hotspot	4.2, A2DP, LE	A-GPS, GLONASS, GALILEO, QZSS
Apple iPhone 7	Sept, 2016	12.4.2	GSM/CDMA/HSPA/ EVDO/LTE	WiFi 802.11 a/b/g/n/ac, dual band, hotspot	4.2, A2DP, LE	A-GPS, GLONASS, GALILEO, QZSS
Apple iPhone 7 Plus	Sept, 2016	12.4.2	GSM/CDMA/HSPA/ EVDO/LTE	WiFi 802.11 a/b/g/n/ac, dual band, hotspot	4.2, A2DP, LE	A-GPS, GLONASS, GALILEO, QZSS
Apple iPhone 8	Sept, 2017	12.4.2	GSM / HSPA / LTE	WiFi 802.11 a/b/g/n/ac, dual band, hotspot	5.0, A2DP, LE	A-GPS, GLONASS, GALILEO, QZSS
Samsung Galaxy S6	March, 2015	7	GSM / HSPA / LTE	WiFi 802.11 a/b/g/n/ac, dual band, Wi-FI Direct, hotspot	4.1, A2DP, LE , aptX	A-GPS, GLONASS, BDS
Samsung Note 9	Aug, 2018	10	GSM / CDMA / HSPA / EVDO / LTE	WiFi 802.11 a/b/g/n/ac, dual band, Wi-FI Direct, hotspot	5.0, A2DP, LE, aptX	A-GPS, GLONASS, BDS, GALILEO
Garmin GPSmap 62s	June, 2010	5.3	--	--	--	GPS, WAAS
Garmin eTrex 20x	May, 2015	2.00	--	--	--	GPS, GLONASS

Figure 1: Devices Used

Software

Multiple types of software were used throughout testing. Many were chosen to validate other tools used. The different type of software and online resources used were Pic2Map, Google Earth, SARTOPO and JPEGSnoop. Below will list each software with a brief description and their function throughout the experiments.

Pic2Map

Pic2Map is an online EXIF data viewer with GPS support which allows the user to locate and view your photos on Google maps. Throughout these experiments this tool was utilized for ease of displaying EXIF data within test photos. Also, this tool featured the ability to extract and view GPS coordinates associated to test photos. Pic2Map can be accessed by https://pic2map.com and from there a user can upload image files for EXIF viewing.

Google Earth

Google Earth is a computer program that renders a 3D representation of Earth based primarily on satellite imagery. This tool was utilized to validate other tools in the testing environment. Google Earth is a great tool for GPS coordinate plotting as it displays each point throughout its updated satellite maps. Google Earth version 7.3 was used.

SARTOPO

SARTOPO is a mapping and trip planning tool for the back country. This tool is widely used in search and rescue operations where it provides simple ease of GPS coordinate plotting. SARTOPO utilizes different type of maps ranging from Google satellite imagery to elevation maps. SARTOPO was a tool mainly used for displaying GPS coordinates and was compared to Google Earth for verification. SARTOPO is an online tool and can be accessed from https://sartopo.com/.

JPEGSnoop

JPEGSnoop is a software that scans the image and offers the user all the detailed information called EXIF data. EXIF data contains information about the camera, edition program, date, color histogram, compression formats and other details associated to the image metadata. JPEGSnoop was used within these experiments as another tool to test data for accuracy and to provide another way for viewing test photos. JPEGSnoop software version 1.7.3 was used.

Matlab

Matlab is a software that combines a desktop environment turned for iterative analysis and design processes with a programming language that expresses matrix and array mathematics directly (https://www.mathworks.com/products/matlab.html). Matlab was used through these experiments to calculate the distance between actual known points against coordinates gathered from the test photos. Matlab version 9.7.0.1190202 was used.

GPS Explanation

Understanding a basic idea of how GPS satellites talk to a device is important to grasp a sense of what kind of processes a device may be experiencing in the background. A brief explanation from 'gps.gov' explains the type of process most devices on utilize on Earth for acquiring GPS.

GPS is a group of 24 or more satellites flying above the surface of Earth. Each one circles the planet twice a day in one of six orbits to provide continuous, worldwide coverage. GPS satellites broadcast radio signals providing their locations, status, and precise time from on-board atomic clocks. GPS radio signals travel through space at the speed of light, more than 299,792 km/second. GPS devices on Earth receive the radio signals noting their exact time of arrival and use these to calculate its distance from each satellite in view. Once a GPS device knows its distance from at least four satellites, it can use geometry to determine its location on Earth in three dimensions (https://www.gps.gov/multimedia/poster/).

The different satellite systems used throughout the tests are A-GPS, GLONASS, GALILEO, QZSS and BDS. Below is a brief description of each satellite system associated to devices in this experiment that are listed in Figure 1.

A-GPS

A-GPS (Assisted Global Position System) is a procedure GPS chips use to provide accurate positioning. Use of cell service, WIFI and latest GPS system available to provide an location as soon as possible to the device (https://www.windowscentral.com/gps-vs-agps-quick-tutorial)

GLONASS

GLONASS (Globalnaya Navigazionnaya Sputnikovya Sistema) is a global navigations satellite system owned and operated by the Russian Federations (https://www.gps.gov/system s/gnss/)

GALILEO

GALILEO is a global navigations satellite system owned and operated by the European Union (https://www.gps.gov/system s/gnss/)

QZSS

QZSS (Quasi-Zenith Satellite System) is a global navigations satellite system owned by the Government of Japan and operated by the QZS System Service Inc. (QSS). QZSS complements GPS to improve coverage in East Asia and Oceania (https://www.gps.gov/system s/gnss/)

BDS

BDS (BeiDou Navigation Satellite System) is a regional global navigations satellite system owned and operated by the People’s Republic of China. (https://www.gps.gov/system s/gnss/)

EXIF Photo GPS Explanation from JPEGSnoop

EXIF photo data is the metadata associated to the photo. Focusing on EXIF GPS data can provide quite a bit of details relating to the image file. Figure 2 is an example of a photo being uploaded to JPEGSnoop and the output referencing GPS EXIF data. JPEGSnoop reads the GPS data associated by its offset in hex relating to the GPS Latitude Ref, GPS Latitude, GPS Longitude Ref, GPS Longitude, GPS Altitude Ref, GPS Altitude, GPS Timestamp, GPS Processing Method and GPS Date Stamp. The alteration of this data cannot be done, as it would change the metadata and ultimately become a new image file. Below is a brief explanation of each type of result JPEGSnoop produces from the GPS EXIF data.

- GPS Latitude Ref gives the direction between 'North' and 'South' of what coordinates are being captured from the device.
- GPS Latitude displays the latitude of the image file in degree and meters (varies on device and how GPS is being captured)
- GPS Longitude Ref gives the direction between 'East' and 'West' of what coordinate are being captured from the device.
- GPS Longitude displays the longitude of the image file in degree and meters (varies on device and how GPS is being captured)
- GPS Altitude Ref gives the indication that the elevation is based upon an 'Above Sea Level' parameter
- GPS Altitude displays the elevation of the photo being captured usually in meters
- GPS Time Stamp displays the time by hours, minutes and seconds
- GPS Processing Method records the name of the method used for location finding (https://www.exiv2.org/tags-xmp-exif.html)

- GPS Date Stamp displays the date of the image file being captured by Year, Month and date

```
EXIF GPSIFD @ Absolute 0x0000075C
  Dir Length = 0x000F
  [GPSLatitudeRef                    ] = "N"
  [GPSLatitude                       ] =    deg 31' 25.970"
  [GPSLongitudeRef                   ] = "W"
  [GPSLongitude                      ] =     deg 40' 49.570"
  [GPSAltitudeRef                    ] = Above Sea Level
  [GPSAltitude                       ] = 13.433 m
  [GPSTimeStamp                      ] = 1:58:3.00
  [GPSSpeedRef                       ] = "km/h"
  [GPSSpeed                          ] = 0.570
  [GPSImgDirectionRef                ] = "True direction"
  [GPSImgDirection                   ] = 520198/5165
  [GPSDestBearingRef                 ] = "True direction"
  [GPSDestBearing                    ] = 520198/5165
  [GPSDateStamp                      ] = "2019:09:20"
```

Figure 2: EXIF GPS Example: JPEGSnoop

Figure 3 displays the hex view of this information from the given offset seen in information provided by JPEGSnoop. This offset is the start of the EXIF GPSIFD for this image file. Even following the next parameter, GPSLatitudeRef, it can be shown in Figure 3 ACSII view that the latitude reference of ‘N’ is shown. From results within tests administered, EXIF GPS headers did not display in an image file if that file did not capture any GPS coordinates.

```
00000730  00 00 00 05 41 70 70 6C 65 00 69 50 68 6F 6E 65  ....Apple.iPhone
00000740  20 38 20 62 61 63 6B 20 63 61 6D 65 72 61 20 33   8 back camera 3
00000750  2E 39 39 6D 6D 20 66 2F 31 2E 38 00 00 0F 00 01  .99mm f/1.8.....
00000760  00 02 00 00 00 02 4E 00 00 00 00 02 00 05 00 00  ......N.........
00000770  00 03 00 00 08 0A 00 03 00 02 00 00 00 02 57 00  ..............W.
```

Figure 3: EXIF Hex View (HxD)

Method Used to Acquire Data

In the test phase, two different ways of administering tests were done at eleven different locations. This was due to finding out new information and curiosities that arose from previous tests and locations. Initial Test series #I, focused on the structure order of having cell service active, first photo taken, device switching to airplane mode then second photo taken. This process was working, however was later theorized that the devices could be saving information from previous locations and applying that information to newly created images. In turn of this curiosity, the administration of two more tests were done. Test series #II was conducted to see if having airplane mode on initially would make a difference in results.

Additionally, actual point locations between Test series #I was acquired by plotting the point on SARTOPO and making that point the baseline for each test location. Test series #II, introduced the adoption of NGS survey markers, as the actual location parameter to use against the tested image files.

Below are the steps used for the two different types of tests that were administered throughout this experiment.

Test #I – Locations #I-IX

I. Both cellular devices and GPS units were placed at a stationary position at the location being used as the ‘actual point location’. The tester then waited for the GPS unit to display a GPS coordinate.

II. Then a cellular device was used to take a picture of the GPS unit with cell service on (if cell service was available on the device). This triggers taking a picture of known GPS coordinates with the device creating in the picture the test GPS coordinates.

III. The cellular device was then put in airplane mode under the device settings. Then another photo was taken.

IV. The second GPS standalone device was handled and set in the same location. Steps #II-III were repeated with the cellular device and the second GPS device.

V. With a new cellular device, Steps #II-IV were repeated

VI. Tests concluded once all cellular devices followed steps #II-IV

Figure 4: Photo Example from Cell Phone Device

VII. Extraction of images from each cellular device was done by plugging each phone into a computer and extracting images to a USB device. This was to ensure best practices in preserving any metadata associated to the image files.

VIII. Image files were then examined using JPEGsnoop and Pic2map. EXIF data was extracted and organized in Microsoft Excel.

IX. Once all data points were extracted, each point was plotted by latitude and longitude locations from the EXIF data using SARTOPO.

X. Once plotted, maps were extracted from SARTOPO to a .kml file format to view using Google Earth.

Test #II Locations #X – #XI: NGS Locations and Initial Airplane Mode Tests

I. Cellular device was put into airplane mode and then powered off. Cellular device was then powered back on ensuring airplane mode was still active.

II. GPS unit was placed on top of NGS location marker and tester waited for a GPS coordinate to be displayed on the GPS unit.

III. Photo taken from cellular device of GPS unit on top of NGS survey marker. This triggers taking a picture of known GPS coordinates with the device creating in the picture the test GPS coordinates

IV. With a new cellular device, Steps #I-III were administered.

V. Extraction of images from each cellular device was done by plugging each cellular device into a computer and extracting images to a USB device. This was to ensure best practices in preserving any metadata associated to the image files.

VI. Image files were then examined using JPEGsnoop and Pic2map. EXIF data was extracted and organized in Microsoft Excel.

Analysis to Determine Elevation Error

Elevation error at each location was determined in two different ways. Test series #I, elevation was determined by the known elevation at the ‘actual location’ that was acquired from SARTOPO. This actual location elevation was compared to the elevation being displayed by each test images EXIF data. With Test series #II, elevation was determined by the known elevation listed in the NGS survey marker data sheets. The elevation listed in the data sheets were compared to the elevation being displayed by each test image’s EXIF data.

With having a known and test data values, we can determine the percent error associated to each image by using the percent error formula listed in Figure 5. This formula was conducted in each test data set and a percent error was addressed for each test image file. After each test image file had a percent error associated to it, an average percent error was gathered for each device. These values are displayed in each test location data set.

$$\boldsymbol{Percentage\ Error} = \left|\frac{v_A - v_E}{v_E}\right| \times \mathbf{100\%}$$

$$v_A = \boldsymbol{approximate\ (measured)\ value}$$
$$v_E = \boldsymbol{exact\ value}$$

Figure 5: Percent Error Formula

Analysis to Determine Distance from Actual Location

In order to calculate an error between GPS coordinates, the distance between two points was the best way to display this type of error. From having an actual location coordinate and coordinate from each photo we can determine the length in meters between both coordinates. This calculation was done using a Matlab script. This script is associated to the distance formula and Matlab defines the script as computing the lengths of the great circle arcs connecting pairs of points on the surface of a sphere, in each case the shorter arc is assumed (https://www.mathworks.com/help/map/ref/ distance.html#d117e2 0321).

Matlab Script: *[arclen, az] = distance(lat1,lon1,lat2,lon2)*1000*

The above script produced the number of meters from the actual location against the coordinates extracted from the experimental images. In each test, 'lat1' and 'lon2' were the same values and represented the actual location point. They were measured against 'lat2' and 'lon2', which represented the latitude and longitude coordinates produced by each test image.

In each test data set, all coordinates gathered were converted to decimal degrees GPS format. This degree format does not change the location of the original acquired coordinate. This conversion was necessary for Matlab to be able to process the distance difference.

The distance from actual location from each image file and average actual location for each device test is displayed in each test data set in Chapter III.

III. TESTING LOCATIONS AND RESULTS FROM TEST #I & #II

All tests will display a raw data table pertaining to the image file results and lists columns by file name, the device, the GPS satellite that device uses, date, time displayed in GMT-07:00, GPS latitude reference, latitude, GPS longitude reference and elevation. All tests latitude and longitude coordinates are redacted by only the initial degrees portion of the coordinate.

Color coordination is also implemented to show a constant color for each device being tested. This color coordination stays consistent with the image file pertinent to the device used to show a source of where information originated from for the Garmin device photos.

For each test another table will follow that focuses on using the raw data to display what was analyzed. The analyzed data are in relation to the elevation percent error, average percent error of elevation, the distance each image file from the actual point (meters) and the average distance from the actual point (meters) relating to the device.

Test #I – Rural Location #I

Rural Location #I, used the iPhone 6s, iPhone 7 Plus, Samsung SM-N960U, Garmin eTrex 20x and the Garmin GPSmap62s. The raw data associated to this test is displayed in Table 1. Below will list some observations listed in these data sets.

Table 1: Test #I – Rural Location #I Coordinates and Elevation

File Name	Device	GPS Sat	Date	Time(GMT - 07:00)	GPS Lat	Latitude	GPS Long	Longitude	Elevation (M)
Actual Location					**N**	**32'22"**	**W**	**°14'40"**	**227.99**
						53944444444		**0.244444444**	
IMG_0118.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:03:04	N	34' 24.80"	W	19' 26.06"	87
IMG_0119_Airplane.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:03:05	N	34' 24.80"	W	19' 26.06"	87
IMG_0120_Airplane.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:03:06	N	32' 21.81"	W	14' 40.53"	232
IMG_0121.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:03:07	N	32' 21.81"	W	14' 40.53"	232
IMG_0122_Airplane.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:03:14	N	32' 21.93"	W	14' 40.72"	226
IMG_0123.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:03:14	N	32' 21.93"	W	14' 40.72"	226
IMG_0124_Airplane.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:03:17	N	32' 21.93"	W	14' 40.72"	226
IMG_0125.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:03:18	N	32' 21.93"	W	14' 40.72"	226
IMG_1934.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:02:04	N	32' 21.98"	W	14' 40.58"	222
IMG_1935.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:02:12	N	32' 21.98"	W	14' 40.50"	222
IMG_1936.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:02:33	N	32' 22.03"	W	14' 40.61"	221
IMG_1937.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:02:38	N	32' 22.04"	W	14' 40.64"	222
20190916_100147.jpg	Samsung SM-N960U	A-GPS, GLONASS, GALILEO, BDS	9/16/2019	10:01:47	N	32' 22.02"	W	14' 40.58"	207
20190916_100218.jpg	Samsung SM-N960U	A-GPS, GLONASS, GALILEO, BDS	9/16/2019	10:02:18	N	32' 22.03"	W	14' 40.58"	206
20190916_100248_Airplane.jpg	Samsung SM-N960U	A-GPS, GLONASS, GALILEO, BDS	9/16/2019	10:02:48	N	32' 22.04"	W	14' 40.56"	204
20190916_100257_Airplane.jpg	Samsung SM-N960U	A-GPS, GLONASS, GALILEO, BDS	9/16/2019	10:02:57	N	32' 22.03"	W	14' 40.58"	206
IMG_0118.JPG	Garmin Etrex 20x	Garmin Default	9/16/2019	10:03:04	N	32.367'	W	14.677'	222.504
IMG_1935.JPG	Garmin Etrex 20x	Garmin Default	9/16/2019	10:02:12	N	32.366'	W	14.677'	222.199
IMG_0120_Airplane.JPG	Garmin GPSmap 62s	Garmin Default	9/16/2019	10:03:06	N	32'22.7"	W	14'36.4"	223.723
IMG_1934.JPG	Garmin GPSmap 62s	Garmin Default	9/16/2019	10:02:04	N	32'22.7"	W	14'36.5"	224.333

Table 2 reveals that the iPhone 6s, 'IMG_0119_Airplane.jpg' and 'IMG_0120_Airplane .jpg' had a change of distance from 7256.8 meters to 12.9379 meters from the actual location. By referencing Figure 6 the difference gap is shown. This is mainly due to the device trying to update its location to a much more precise one. This is worth noting because the device was in airplane mode and possibly still trying to update its own location.

Figure 6: Rural Location #I – Anomaly 'IMG_0119_Airplane.jpg' Location Compared to Actual Location (SARTOPO Map)

Consistent distance of approximate 12 meters – 15 meters away from the actual location are acquired from the iPhone 6s, iPhone 7 Plus, Samsung SM-N960U and the Garmin eTrex 20x. Garmin GPSmap 62s displays a location roughly 80 meters away and stays consistent with producing that result. Figure 7 and 8, display SARTOPO and Google Earth maps displaying an overall view of all image file GPS coordinates plotted compared to the actual location.

Figure 7: Rural Location #I – Image GPS Coordinates vs Actual Location (SARTOPO map)

Figure 8: Rural Location #I – Image GPS Coordinates vs Actual Location (Google Earth map)

As for elevation, the percent error across all devices is consistent pertaining to each device. Anomalies with the iPhone 6s were displayed initially with 'IMG_0118.jpg' and 'IMG_0119_Airplane.jpg' showing an initial percent error of 61.81%. This is then adjusted to a .87% error from 'IMG_0122_Airplane.jpg' and stays consistent with the three image files that followed. It is worth noting that the Samsung SM-N960U's elevation error was the worse with an approximate elevation percent error of 9% - 10%.

Table 2: Rural Location #I – Percent Error Elevations and Average Distance from Actual

File Name	Device	% Error Elevation	Average % Error Elevation	Distance From Actual (m)	Average Distance from Actual (m)
IMG_0118.JPG	iPhone 6s	61.84%		7256.8	
IMG_0119_Airplane.JPG	iPhone 6s	61.84%		7256.8	
IMG_0120_Airplane.JPG	iPhone 6s	1.76%		12.9379	
IMG_0121.JPG	iPhone 6s	1.76%		12.9379	
IMG_0122_Airplane.JPG	iPhone 6s	0.87%		15.7345	
IMG_0123.JPG	iPhone 6s	0.87%		15.7345	
IMG_0124_Airplane.JPG	iPhone 6s	0.87%		15.7345	
IMG_0125.JPG	iPhone 6s	0.87%	**16.34%**	15.7345	**1825.301725**
IMG_1934.JPG	iPhone 7 Plus	2.63%		12.5108	
IMG_1935.JPG	iPhone 7 Plus	2.63%		10.9602	
IMG_1936.JPG	iPhone 7 Plus	3.07%		13.2867	
IMG_1937.JPG	iPhone 7 Plus	2.63%	**1.80%**	14.063	**12.705175**
20190916_100147.jpg	Samsung SM-N960U	9.21%		12.5108	
20190916_100218.jpg	Samsung SM-N960U	9.65%		12.5108	
20190916_100248_Airplane.jpg	Samsung SM-N960U	10.52%		12.5108	
20190916_100257_Airplane.jpg	Samsung SM-N960U	9.65%	**6.25%**	12.5108	**12.5108**
IMG_0118.JPG	Garmin Etrex 20x	2.41%		13.2867	
IMG_1935.JPG	Garmin Etrex 20x	2.54%	**6.21%**	13.2867	**13.2867**
IMG_0120_Airplane.JPG	Garmin GPSmap 62s	1.87%		80.6975	
IMG_1934.JPG	Garmin GPSmap 62s	1.60%	**5.93%**	78.4449	**79.5712**

Test #I – Rural Location #II

Rural Location #II used the iPhone 6s, iPhone 7 Plus, Garmin eTrex 20x and the Garmin GPSmap62s. It is worth noting that a Samsung device was not utilized in this test. The raw data associated to this test is displayed in Table 3. Below will list some observations listed in these data sets.

Table 3: Rural Location #II – Coordinates and Elevation

File Name	Device	GPS Sat	Date	Time (GMT - 07:00)	GPS Lat	Latitude	GPS Long	Longitude	Elevation
Actual Location						32'23"		°07'01"	788.2128
						32.384'		07.015'	
IMG_0131.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/17/2019	11:12:25	N	32' 22.81"	W	7' 1.68"	801
IMG_0132_Airplane.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/17/2019	11:12:31	N	32' 22.84"	W	7' 1.79"	799
IMG_0134_Airplane.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/17/2019	11:12:58	N	32' 22.79"	W	7' 1.74"	796
IMG_0135.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/17/2019	11:13:05	N	32' 21.56"	W	7' 0.89"	795
IMG_1950.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/17/2019	11:09:29	N	32' 41.60"	W	23' 44.54"	5
IMG_1951_Airplane.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/17/2019	11:09:42	N	32' 23.43"	W	7' 1.88"	794
IMG_1952_Airplane.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/17/2019	11:11:52	N	32' 24.02"	W	7' 1.68"	849
IMG_1953.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/17/2019	11:12:01	N	32' 23.28"	W	7' 1.35"	813
IMG_0131.JPG	Garmin eTrex 20x	Garmin Default	9/17/2019	11:12:25	N	32.372'	W	7.028'	793.6992
IMG_0132_Airplane.JPG	Garmin eTrex 20x	Garmin Default	9/17/2019	11:12:31	N	32.370'	W	7.035'	793.6992
IMG_1952.JPG	Garmin eTrex 20x	Garmin Default	9/17/2019	11:11:52	N	32.369'	W	7.026'	775.1064
IMG_1953.JPG	Garmin eTrex 20x	Garmin Default	9/17/2019	11:12:01	N	32.370'	W	7.029'	790.6512
IMG_0134_Airplane.JPG	GPSmap 62s	Garmin Default	9/17/2019	11:12:58	N	32' 23.5"	W	06' 57.5"	779.6784
IMG_0135.JPG	GPSmap 62s	Garmin Default	9/17/2019	11:13:05	N	32' 23.3"	W	06' 57.5"	786.6888
IMG_1950.JPG	GPSmap 62s	Garmin Default	9/17/2019	11:09:29	N	32' 23.4"	W	06' 56.8"	645.5664
IMG_1951.JPG	GPSmap 62s	Garmin Default	9/17/2019	11:09:42	N	32' 23.5"	W	06' 56.4"	665.988

Table 4 and Figure 9 display an anomaly taking place. Starting with the iPhone 6s and looking at 'IMG_0131.jpg' and 'IMG_0135.jpg'. There is a change of distance from actual, starting from a close distance and exceeding to one that is more than double. Between these two image files, airplane mode is being turned on and producing similar coordinates to file 'IMG_0131.jpg'. This change to airplane mode might be the cause for the sudden increase of distance possibly having the device relying on other connections.

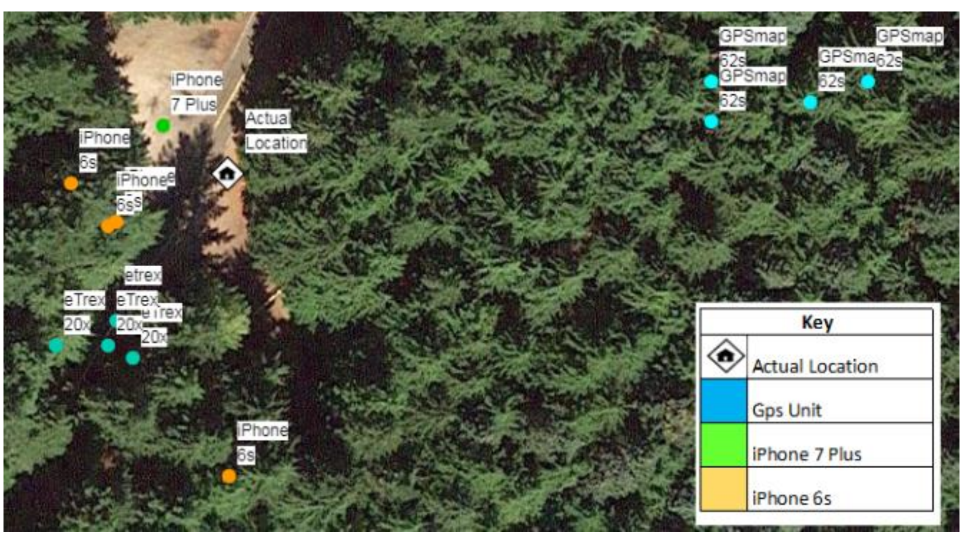


Figure 9: Rural Location #II – Image GPS Coordinates vs Actual Location (SARTOPO map)

Looking at the iPhone 7 Plus and at ‘IMG_1950.jpg’, we have an initial distance of 21,717.1 meters away from the actual location. Within 13 seconds after that image file was taken, ‘IMG_1951_Airplane.jpg’ produced an image that was 22.9658 meters away from the actual location. This brings out another observation being made with the switch to airplane mode. Continuing with the same device the GPS coordinates from images produced after the previous image are displayed and narrowing in on the actual location where the device is present (Figure 11).

Figure 10: Rural Location #II – Anomaly IMG_1950.jpg Distance from Actual Location (SARTOPO map)

Figure 11: Rural Location #II Anomaly #2 – iPhone 7 Plus Distance Corrections to Actual Location (SARTOPO Map)

Garmin eTrex 20x was stable in respect to its distance data points. The Garmin GPSmap62s had distances displaying approximately 77 meters away from the actual location and possessed jumps to approximately 100 meters.

Elevation was consistent with all devices except for the iPhone 7 Plus and 'IMG_1950 .jpg'. The image file produced an elevation of 5 meters, which in turn produced a 99.37% error from the actual elevation. Again, 13 secs after that image file was taken, 'IMG_1951_Airpla ne.jpg' produced an image that was 0.73% error from the actual elevation. Again, another trend with airplane mode change creating a more accurate result.

Table 4: Rural Location #II – Percent Error Elevations and Average Distance from Actual

File Name	Device	% Error Elevation	Average % Error Elevation	Distance From Actual (m)	Average Distance from Actual (m)
IMG_0131.JPG	iPhone 6s	1.62%		16.2322	
IMG_0132_Airplane.JPG	iPhone 6s	1.37%		18.0136	
IMG_0134_Airplane.JPG	iPhone 6s	0.99%		17.6638	
IMG_0135.JPG	iPhone 6s	0.86%	**1.21%**	44.5393	**24.112225**
IMG_1950.JPG	iPhone 7 Plus	99.37%		21717.1	
IMG_1951_Airplane.JPG	iPhone 7 Plus	0.73%		22.9658	
IMG_1952_Airplane.JPG	iPhone 7 Plus	7.71%		34.4722	
IMG_1953.JPG	iPhone 7 Plus	3.14%	**27.74%**	11.8232	**5446.5903**
IMG_0131.JPG	Garmin eTrex 20x	0.70%		25.7939	
IMG_0132_Airplane.JPG	Garmin eTrex 20x	0.70%		34.3707	
IMG_1952.JPG	Garmin eTrex 20x	1.66%		29.4528	
IMG_1953.JPG	Garmin eTrex 20x	0.31%	**0.84%**	29.4267	**29.761025**
IMG_0134_Airplane.JPG	GPSmap 62s	1.08%		77.1332	
IMG_0135.JPG	GPSmap 62s	0.19%		76.068	
IMG_1950.JPG	GPSmap 62s	18.10%		91.9398	
IMG_1951.JPG	GPSmap 62s	15.51%	**8.72%**	100.8977	**86.509675**

Test #I – Rural Location #III

Rural Location #III used the iPhone 6s, Samsung Galaxy S6, iPhone 7 Plus, Garmin eTrex 20x and the Garmin GPSmap62s. The raw data associated to this test is displayed in Table 5. Below will list some observations listed in these data sets.

Table 5: Rural Location #III – Coordinates and Elevation

File Name	Device	GPS Sat	Date	Time (GMT - 07:00)	GPS Lat	Latitude	GPS Long	Longitude	Elevation
Actual Location						32'23"		07'01"	**788.213**
						32.384		07.015'	
IMG_0150.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/20/2019	10:47:58	N	32' 21.49"	W	7' 0.06"	701
IMG_0151.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/20/2019	10:48:03	N	32' 22.08"	W	7' 0.34"	737
20190920_105509.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	9/20/2019	10:55:09	N	32' 23.00"	W	7' 1.00"	761
20190920_105513.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	9/20/2019	10:55:13	N	32' 23.00"	W	7' 1.00"	761
IMG_1974.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/20/2019	10:47:36	N	32' 21.64"	W	7' 1.77"	791
IMG_1975.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/20/2019	10:47:42	N	32' 21.90"	W	7' 1.82"	790
IMG_1976.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/20/2019	10:48:56	N	32' 22.03"	W	7' 1.55"	791
IMG_1977.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/20/2019	10:49:16	N	32' 22.45"	W	7' 1.52"	790
IMG_1978.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/20/2019	10:49:30	N	32' 22.49"	W	7' 1.98"	790
20190920_105513.jpg	Garmin eTrex 20x	Garmin Default	9/20/2019	10:55:09	N	32.376'	W	7.025'	809.853
IMG_0150.JPG	Garmin eTrex 20x	Garmin Default + Glonass	9/20/2019	10:47:58	N	32.375'	W	7.018'	802.843
IMG_1974.JPG	Garmin eTrex 20x	Garmin Default + Glonass	9/20/2019	10:47:36	N	32.376'	W	7.021'	801.624
IMG_1978.JPG	Garmin eTrex 20x	Garmin Default	9/20/2019	10:49:30	N	32.381'	W	07.020'	811.682
IMG_0151.JPG	GPSmap 62s	Garmin Default	9/20/2019	10:48:03	N	32' 23.0"	W	6' 57.0"	799.795
20190920_105509.jpg	GPSmap 62s	Garmin Default	9/20/2019	10:55:09	N	32' 23.1"	W	6' 57.1"	818.083
IMG_1977.JPG	GPSmap 62s	WAAS/EGNOS	9/20/2019	10:49:16	N	32' 22.9"	W	6' 56.8"	812.292
IMG_1975.JPG	GPSmap 62s	Garmin Default	9/20/2019	10:47:42	N	32' 22.9"	W	6' 56.8"	802.234

From referencing Table 6, the iPhone 6s had the worse cellular device average distance from actual location.

The Samsung Galaxy S6 had no error in relation to distance. This device was administered strictly on airplane mode and did not have cell service active. With this stipulation the Samsung Galaxy S6 took roughly 30 secs to 5 mins to acquire a GPS coordinate. This eludes to the device being able to produce a more than accurate coordinate. Mainly considering the coordinate being produced is being solely reliant on the GPS chip on the device.

The iPhone 7 Plus and Garmin eTrex 20x had variations between its distance, but nothing too alarming. Garmin GPSmap 62s again produced far distances from actual location results staying within approximately 80 meters – 91 meters.

Figure 12 displays a SARTOPO map of the image GPS coordinates compared to actual location.

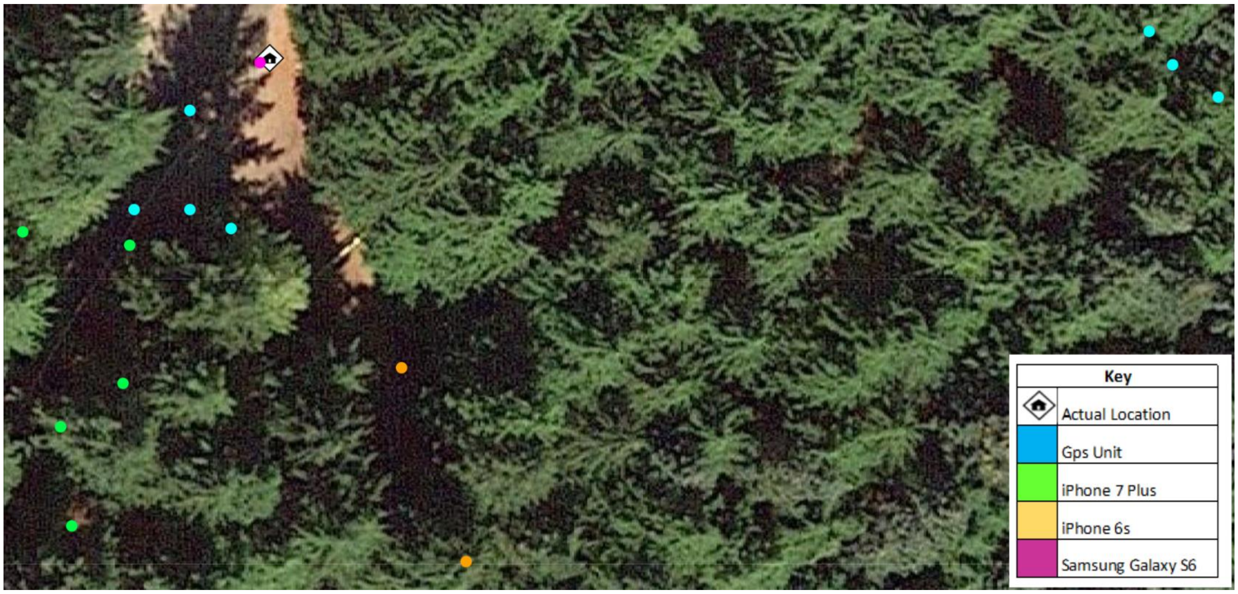


Figure 12: Rural Location #III – Image GPS Coordinates vs Actual Location (SARTOPO Map)

Elevation showed the iPhone 6s had the worse average percent error and this might share a correlation with that phone also producing poor distance results within this test. The other devices produced elevation errors that were not worth addressing.

Table 6: Rural Location #III – Percent Error Elevation and Average Distance from Actual

File Name	Device	% Error Elevation	Average % Error Elevation	Distance From Actual (m)	Average Distance from Actual (m)
IMG_0150.JPG	iPhone 6s	11.06%		50.9029	
IMG_0151.JPG	iPhone 6s	6.50%	**8.78%**	32.1303	**41.5166**
20190920_105509.jpg	Samsung Galaxy S6	3.45%		0	
20190920_105513.jpg	Samsung Galaxy S6	3.45%	**3.45%**	0	**0**
IMG_1974.JPG	iPhone 7 Plus	0.35%		45.309	
IMG_1975.JPG	iPhone 7 Plus	0.23%		38.847	
IMG_1976.JPG	iPhone 7 Plus	0.35%		32.2155	
IMG_1977.JPG	iPhone 7 Plus	0.23%		20.866	
IMG_1978.JPG	iPhone 7 Plus	0.23%	**0.28%**	26.1635	**32.6802**
20190920_105513.jpg	Garmin eTrex 20x	2.75%		17.3806	
IMG_0150.JPG	Garmin eTrex 20x	1.86%		15.645	
IMG_1974.JPG	Garmin eTrex 20x	1.70%		14.4142	
IMG_1978.JPG	Garmin eTrex 20x	2.98%	**2.32%**	6.4513	**13.472775**
IMG_0151.JPG	GPSmap 62s	1.47%		86.4496	
20190920_105509.jpg	GPSmap 62s	3.79%		84.1793	
IMG_1977.JPG	GPSmap 62s	3.05%		91.1837	
IMG_1975.JPG	GPSmap 62s	1.78%	**2.52%**	91.1837	**88.249075**

Test #I – Rural Location #IV

Rural Location #IV used the iPhone 6s, Samsung Galaxy S6, iPhone 7 Plus, Garmin eTrex 20x and the Garmin GPSmap62s. The raw data associated to this test is displayed in Table 7. Below will list some observations listed in these data sets.

Table 7: Rural Location #IV – Rural #IV Coordinates and Elevation

File Name	Device	GPS Sat	Date	Time (GMT - 07:00)	Location	GPS Lat	Latitude	GPS Long	Longitude	Elevation
Actual Location							32'22"		14'40"	**227.99**
							32.367'		14.669'	
IMG_0152.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/20/2019	11:16:42	Vista	N	32' 21.87"	W	14' 40.75"	217
IMG_0153.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/20/2019	11:16:46	Vista	N	32' 21.76"	W	14' 40.53"	223
20190920_111700.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	9/20/2019	11:17:00	Vista	N	32' 22.00"	W	14' 40.00"	193
20190920_111705.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	9/20/2019	11:17:05	Vista	N	32' 22.00"	W	14' 40.00"	193
IMG_1979.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/20/2019	11:16:22	Vista	N	32' 22.36"	W	14' 39.70"	793
IMG_1980.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/21/2019	11:16:27	Vista	N	32' 21.72"	W	14' 40.50"	196
IMG_1981.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/22/2019	11:16:31	Vista	N	32' 21.82"	W	14' 40.33"	222
IMG_1982.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/23/2019	11:17:46	Vista	N	32' 21.08"	W	14' 39.81"	223
IMG_1983.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/24/2019	11:18:15	Vista	N	32' 21.79"	W	14' 40.47"	222
IMG_1984.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/25/2019	11:18:18	Vista	N	32' 21.83"	W	14' 40.39"	219
IMG_0153.JPG	Garmin eTrex 20x	Garmin Default	9/26/2019	11:16:46	Vista	N	32.365'	W	14.675'	224.63
IMG_1981.JPG	Garmin eTrex 20x	Garmin Default	9/27/2019	11:16:31	Vista	N	32.365'	W	14.675'	223.418
IMG_1982.JPG	Garmin eTrex 20x	Garmin Default + GLONASS	9/28/2019	11:17:46	Vista	N	32.366'	W	14.674'	220.675
IMG_0152.JPG	GPSmap 62s	Garmin Default	9/29/2019	11:16:42	Vista	N	32' 22.6"	W	14' 36.4"	222.8
IMG_1980.JPG	GPSmap 62s	Garmin Default	9/30/2019	11:16:27	Vista	N	32' 22.5"	W	14' 36.4"	222.809
IMG_1984.JPG	GPSmap 62s	Garmin Default	10/1/2019	11:18:18	Vista	N	32' 22.5"	W	14' 36.4"	229.21

Referencing Table 8 and Figure 13, it is shown that the iPhone 7 Plus displays the worse average distance from actual location for a cellular device. The Samsung Galaxy S6 again displayed no error regarding distance. The iPhone 6s and the Garmin eTrex 20x produced a semi constant result. GPSmap 62s again stayed within its approximately 80 meter distance error.

Figure 13: Rural Location #IV – Image GPS Coordinates vs Actual Location (SARTOPO Map)

Figure 14: Rural Location #IV – Image GPS Coordinates vs Actual Location (Google Earth Map)

Figure 14 displays a Google Earth map to display a visual of the type of environment where this test was conducted. From data in Table 8, the iPhone 7 Plus had the worse average percent error. This again eludes to the elevation and distance error sharing the same error correlation.

However, what goes against this correlation is the Samsung Galaxy S6. The Galaxy S6 produced no error whatsoever with distance but displayed a 15.35% error in elevation. This further can elude to this type of trend being noticed based on the devices itself, rather than the distance and elevation error sharing the same type of error rate.

Table 8: Rural Location #IV – Percent Error Elevation and Average Distance from Actual

File Name	Device	% Error Elevation	Average % Error Elevation	Distance From Actual (m)	Average Distance from Actual (m)
IMG_0152.JPG	iPhone 6s	4.82%		16.9494	
IMG_0153.JPG	iPhone 6s	2.19%	3.50%	14.038	15.4937
20190920_111700.jpg	Samsung Galaxy S6	15.35%		0	
20190920_111705.jpg	Samsung Galaxy S6	15.35%	15.35%	0	0
IMG_1979.JPG	iPhone 7 Plus	247.82%		12.7461	
IMG_1980.JPG	iPhone 7 Plus	14.03%		14.072	
IMG_1981.JPG	iPhone 7 Plus	-2.63%		29.1718	
IMG_1982.JPG	iPhone 7 Plus	2.19%		29.1718	
IMG_1983.JPG	iPhone 7 Plus	2.63%		12.1253	
IMG_1984.JPG	iPhone 7 Plus	3.94%	44.66%	10.2131	17.91668333
IMG_0153.JPG	Garmin eTrex 20x	1.47%		11.2254	
IMG_1981.JPG	Garmin eTrex 20x	2.01%		11.2254	
IMG_1982.JPG	Garmin eTrex 20x	3.21%	2.23%	9.3783	10.6097
IMG_0152.JPG	GPSmap 62s	2.28%		79.4234	
IMG_1980.JPG	GPSmap 62s	2.27%		79.4	
IMG_1984.JPG	GPSmap 62s	0.54%	1.69%	79.4	79.4078

Test #I – Suburb Location #I

Suburb Location #I was used the iPhone 6s, Samsung SM-N960U, iPhone 7 Plus, Garmin eTrex 20x and the Garmin GPSmap62s. The raw data associated to this test is displayed in Table 9. Below will list some observations listed in these data sets.

Table 9: Suburb Location #I – Coordinates and Elevation

File Name	Device	GPS Sat	Date	Time(GMT -07:00)	GPS Lat	Latitude	GPS Long	Longitude	Elevation
Actual Location						31'50"		26'20"	60.96
						31.836',		26.332'	
IMG_0126.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:29:54	N	31' 50.71"	W	26' 19.06"	58
IMG_0127.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:29:58	N	31' 51.09"	W	26' 19.81"	65
IMG_0128_Airplane.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:30:05	N	31' 50.47"	W	26' 19.70"	63
IMG_0130_Airplane.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:30:09	N	31' 50.47"	W	26' 19.70"	62
IMG_1938.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:28:35	N	31' 50.48"	W	26' 19.70"	60
IMG_1939.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:29:05	N	31' 50.23"	W	26' 19.72"	60
IMG_1940.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:29:15	N	31' 50.12"	W	26' 19.94"	60
IMG_1941.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	10:29:44	N	31' 50.28"	W	26' 20.08"	60
20190916_102840.jpg	Samsung SM-N960U	A-GPS, GLONASS, GALILEO, BDS	9/16/2019	10:28:40	N	31' 50.57"	W	26' 19.76"	35
20190916_102850.jpg	Samsung SM-N960U	A-GPS, GLONASS, GALILEO, BDS	9/16/2019	10:28:50	N	31' 50.57"	W	26' 19.76"	35
20190916_102906_Airplane.jpg	Samsung SM-N960U	A-GPS, GLONASS, GALILEO, BDS	9/16/2019	10:29:06	N	31' 50.57"	W	26' 19.76"	35
20190916_102914_Airplane.jpg	Samsung SM-N960U	A-GPS, GLONASS, GALILEO, BDS	9/16/2019	10:29:14	N	32' 22.04"	W	14' 40.56"	204
IMG_0126.JPG	Garmin GPSmap 62s	Garmin Default	9/16/2019	10:29:54	N	31' 50.8"	W	26' 15.7"	60.6552
IMG_1940.JPG	Garmin GPSmap 62s	Garmin Default	9/16/2019	10:29:15	N	31' 50.8"	W	26' 15.6"	61.8744
IMG_0127.JPG	Gamin eTrex 20x	Garmin Default	9/16/2019	10:29:58	N	31.837'	W	26.332'	58.8264
IMG_0130_Airplane.JPG	Gamin eTrex 20x	Garmin Default	9/16/2019	10:30:09	N	31.836'	W	26.331'	58.2168
IMG_1938.JPG	Gamin eTrex 20x	Garmin Default	9/16/2019	10:28:35	N	31.837'	W	26.331'	58.8264

In referencing Table 10, the biggest anomaly that stands out is image file '20190916_102914_ Airplane.jpg' from the Samsung SM-N960U. This image file was 15,164.6 meters from the actual location and a 90.60% error rate regarding elevation. It is interesting that this image file was the last image taken during the test. The SM-N060U previously captured image files producing a 18.3948 meter distance from actual and a 42.59% elevation error rate. The cellular device was placed in airplane mode. However, this could be something going on in the background in the device priority list of how it acquires location and was trying to correct itself. Figure 15 displays the distance between the two points.

Figure 15: Suburb Location #I – Anomaly Samsung Note 9 '20190916_102914_Airplane.JPG' Distance from Actual Location (SARTOPO Map)

Another anomaly was with the iPhone 6s. This initially produced an approximate 30 meter distance from actual location, but then corrected to an approximate 15 meter from actual point. The other devices stayed consistent with the trends being associated to them in previous tests. Figures 16 and 17 displays the test image GPS coordinates vs actual location.

Figure 16: Suburb Location #I – Image GPS Coordinates vs Actual Location (SARTOPO Map)

Figure 17: Suburb Location #I – Image GPS Coordinates vs Actual Location (Google Earth Map)

Table 10: Suburb Location #I – Percent Error and Average Distance from Actual

File Name	Device	% Error Elevation	Average % Error Elevation	Distance From Actual (m)	Average Distance from Actual (m)
IMG_0126.JPG	iPhone 6s	4.86%		30.079	
IMG_0127.JPG	iPhone 6s	6.63%		33.5851	
IMG_0128_Airplane.JPG	iPhone 6s	3.35%		15.7413	
IMG_0130_Airplane.JPG	iPhone 6s	1.71%	**4.13%**	15.7413	**23.786675**
IMG_1938.JPG	iPhone 7 Plus	1.57%		15.7413	
IMG_1939.JPG	iPhone 7 Plus	1.57%		8.6164	
IMG_1940.JPG	iPhone 7 Plus	1.57%		3.4256	
IMG_1941.JPG	iPhone 7 Plus	1.57%	**1.57%**	9.1974	**9.245175**
20190916_102840.jpg	Samsung SM-N960U	42.59%		18.3948	
20190916_102850.jpg	Samsung SM-N960U	42.59%		18.3948	
20190916_102906_Airplane.jpg	Samsung SM-N960U	42.59%		18.3948	
20190916_102914_Airplane.jpg	Samsung SM-N960U	234.65%	**90.60%**	15164.6	**3804.9461**
IMG_0126.JPG	Garmin GPSmap 62s	0.50%		95.8688	
IMG_1940.JPG	Garmin GPSmap 62s	1.50%	**1.00%**	98.1301	**96.99945**
IMG_0127.JPG	Gamin eTrex 20x	3.50%		6.8512	
IMG_0130_Airplane.JPG	Gamin eTrex 20x	4.50%		6.0309	
IMG_1938.JPG	Gamin eTrex 20x	3.50%	**3.83%**	7.7019	**6.861333333**

Test #I – Suburb Location #II

Suburb Location #II used the Samsung SM-N960U, iPhone 7 Plus, Garmin eTrex 20x and the Garmin GPSmap62s. The raw data associated to this test is displayed in Table 11. Below will list some observations listed in these data sets.

Table 11: Suburb Location #II – Coordinates and Elevation

File Name	Device	GPS Sat	Date	Time(GMT - 07:00)	GPS Lat	Latitude	GPS Long	Longitude	Elevation
Actual Location						31'50"		26'20"	**60.96**
						31.836'		26.332'	
IMG_1943.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	16:46:22	N	31' 50.22"	W	26' 20.03"	60
IMG_1944.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	16:46:26	N	31' 50.40"	W	26' 20.08"	60
IMG_1945.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/16/2019	16:46:43	N	31' 50.18"	W	26' 19.86"	60
20190916_164615.jpg	Samsung SM-N960U	A-GPS, GLONASS, GALILEO, BDS	9/16/2019	16:46:15	N	31' 50.45"	W	26' 20.02"	36
20190916_164635 Airplane.jpg	Samsung SM-N960U	A-GPS, GLONASS, GALILEO, BDS	9/16/2019	16:46:35	N	31' 50.45"	W	26' 20.02"	36
20190916_164659.jpg	Samsung SM-N960U	A-GPS, GLONASS, GALILEO, BDS	9/16/2019	16:46:59	N	31' 50.45"	W	26' 20.02"	36
20190916_164714 Airplane.jpg	Samsung SM-N960U	A-GPS, GLONASS, GALILEO, BDS	9/16/2019	16:47:14	N	31' 51.34"	W	26' 19.55"	36
IMG_1944.JPG	GPSmap 62S	Garmin Default	9/16/2019	16:46:26	N	31' 50.2"	W	26' 16"	78.0288
IMG_1945.JPG	GPSmap 62S	Garmin Default	9/16/2019	16:46:43	N	31' 50.3"	W	26' 16"	72.5424
20190916_164615.jpg	GPSmap 62S	Garmin Default	9/16/2019	16:46:15	N	31' 50.3"	W	26' 16.1"	87.1728
20190916_164659.jpg	Gamin eTrex 20x	Garmin Default	9/16/2019	16:46:59	N	31.835'	W	26.332	62.1792

In reference to Table 12, the iPhone 7 Plus had a slight fluctuation from close distances to actual location to farther ones. This is not so alarming seeing this type of movement due to the device constantly trying to adjust its location to provide a precise location.

It is worth noting that the Samsung device provided the worse average distance from actual location and the worse elevation percent error compared to the iPhone 7 Plus. The Garmin eTrex provided the best average distance from actual point.

Figures 18 and 119 display SARTOPO and Google Earth maps displaying distances between each device image file coordinates.

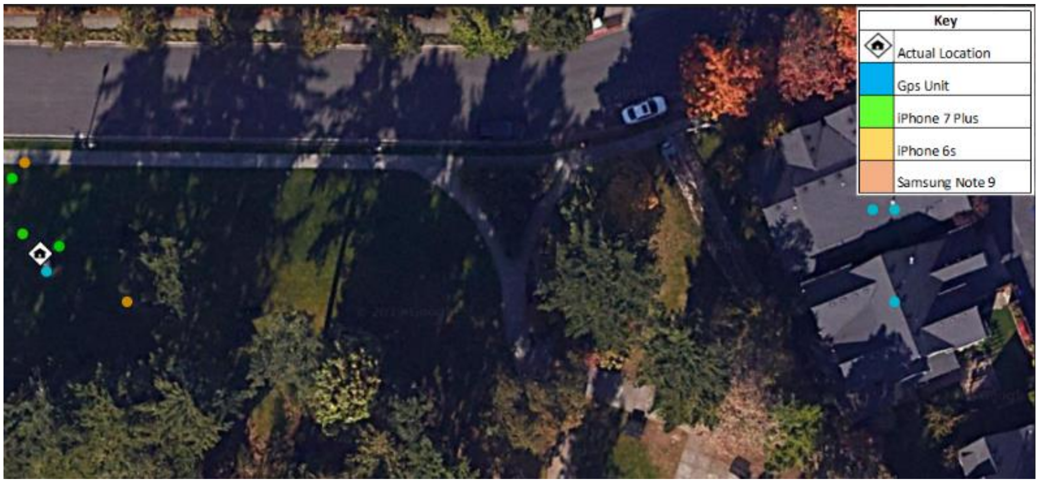


Figure 18: Suburb Location #II – Image GPS Coordinates vs Actual Location (SARTOPO Map)

Figure 19: Suburb Location #II – Image GPS Coordinates vs Actual Location (Google Earth Map)

With elevation the iPhone 7 Plus provided the best percent error of 1.57% compared to all devices. The Samsung device and Garmin units surprising provided relatively high percent errors compared to the iPhone 7 Plus, ranging from 22.50% to 40.94%.

Table 12: Test #VI Suburb #II – Percent Error Elevation and Average Distance from Actual

File Name	Device	% Error Elevation	Average % Error Elevation	Distance From Actual (m)	Average Distance from Actual (m)
IMG_1943.JPG	iPhone 7 Plus	1.57%		6.717	
IMG_1944.JPG	iPhone 7 Plus	1.57%		12.4527	
IMG_1945.JPG	iPhone 7 Plus	1.57%	**1.57%**	6.0309	**8.4002**
20190916_164615.jpg	Samsung SM-N960U	40.94%		14.4763	
20190916_164635 Airplane.jpg	Samsung SM-N960U	40.94%		14.4763	
20190916_164659.jpg	Samsung SM-N960U	40.94%		14.4763	
20190916_164714 Airplane.jpg	Samsung SM-N960U	40.94%	**40.94%**	42.1906	**21.404875**
IMG_1944.JPG	GPSmap 62S	28.00%		86.7207	
IMG_1945.JPG	GPSmap 62S	19.00%		86.9201	
20190916_164615.jpg	GPSmap 62S	43.00%	**30.00%**	84.2085	**85.94976667**
20190916_164659.jpg	Gamin eTrex 20x	2.00%	**22.50%**	3.6817	**3.6817**

Test #I – Suburb Location #III

Suburb Location #III used the iPhone 6s, Samsung Galaxy S6, iPhone 7 Plus, Garmin eTrex 20x and the Garmin GPSmap62s. The raw data associated to this test is displayed in Table 13. Below will list some observations listed in these data sets.

Table 13: Suburb Location #III – Coordinates and Elevation

File Name	Device	GPS Sat	Date	Time	GPS Lat	Latitude	GPS Long	Longitude	Elevation
Actual Location						31'50"		°26'20"	**60.96**
						31.836		°26.333'	
IMG_0138.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:50:16	N	31' 50.41"	W	26' 20.27"	36
IMG_0139.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:50:22	N	31' 50.19"	W	26' 19.70"	59
IMG_0141.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:50:50	N	31' 50.12"	W	26' 19.83"	60
IMG_0140JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:50:50	N	31' 50.12"	W	26' 19.83"	60
IMG_0142JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:51:00	N	31' 49.81"	W	26' 19.45"	61
IMG_0143.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:52:32	N	31' 50.08"	W	26' 19.67"	62
IMG_0144.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:52:32	N	31' 50.08"	W	26' 19.67"	62
IMG_1955.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:49:52	N	31' 51.29"	W	26' 20.36"	61
IMG_1956.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:50:00	N	31' 50.48"	W	26' 20.11"	60
IMG_1957.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:50:01	N	31' 50.48"	W	26' 20.11"	60
IMG_1958.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:51:08	N	31' 50.08"	W	26' 20.30"	60
IMG_1959.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:51:15	N	31' 50.03"	W	26' 19.75"	60
IMG_1960.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:52:21	N	31' 50.19"	W	26' 19.89"	56
IMG_1961.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	10:52:21	N	31' 50.19"	W	26' 19.89"	56
20190919_110559.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	9/19/2019	11:05:59	N	31' 50.00"	W	26' 20.00"	38
IMG_0141.JPG	Garmin eTrex 20x	Gamin Default	9/19/2019	10:50:50	N	31.837'	W	26.332'	51.2064
IMG_0142.JPG	Garmin eTrex 20x	Gamin Default	9/19/2019	10:51:00	N	31.836'	W	26.332'	56.388
IMG_0143.JPG	Garmin eTrex 20x	Gamin Default + GLONASS	9/19/2019	10:52:32	N	31.836'	W	26.331'	59.436
IMG_1958.JPG	Garmin eTrex 20x	Gamin Default	9/19/2019	10:51:08	N	31.837'	W	26.333'	51.816
IMG_1961.JPG	Garmin eTrex 20x	Gamin Default + GLONASS	9/19/2019	10:52:21	N	31.837'	W	26.330'	60.0456
IMG_0138.JPG	GPSmap 62s	Gamin Default	9/19/2019	10:50:16	N	31' 50.8"	W	26' 15.7"	58.2168
IMG_1955.JPG	GPSmap 62s	Gamin Default	9/19/2019	10:49:52	N	31' 50.5"	W	26' 15.1"	59.7408
IMG_1956.JPG	GPSmap 62s	Gamin Default	9/19/2019	10:50:00	N	31' 50.5"	W	26' 15.5"	70.7136

Table 14 shows the Samsung Galaxy S6 possessed no error rate regarding distance but displayed a 37.66% error rate regarding elevation.

The iPhone 6s and iPhone 7 Plus average distances from actual location did not produce alarming results. They were consistent and close to the actual location with 8 meter to 13 meter differences.

Garmin eTrex 20x had a better average distance from actual location than the iPhone 7 Plus and iPhone 6s. Garmin GPSmap 62s still produced poor results by have the worse average distance from actual location.

Figure 20 displays the SARTOPO map of all image file GPS coordinates compared to actual location.

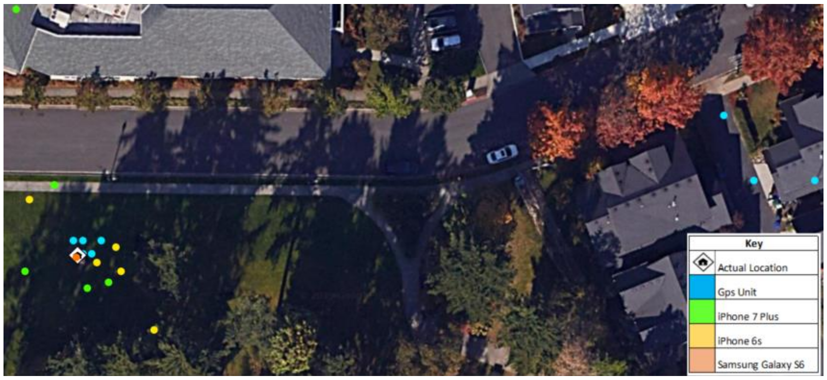


Figure 20: Suburb Location #III – Image GPS Coordinates vs Actual Location (SARTOPO Map)

With elevation, the iPhone 6s and iPhone 7 Plus had a different elevation profile that was not too similar. The iPhone 6s produced an average elevation percent error of 7.26% and the iPhone 7 Plus produced an average percent error of 3.23%. From these devices being only a year device generation apart, it was interesting to see that these error rates will not be relatively closer.

The Garmin eTrex 20x did not produce a good elevation profile in comparison to the cellular devices. Garmin GPSmap 62s again produced poor results by having the worse average elevation percent error.

Table 14: Suburb Location #III – Percent Error Elevation and Distance from Actual

File Name	Device	% Error Elevation	Average % Error Elevation	Distance From Actual (m)	Average Distance from Actual (m)
IMG_0138.JPG	iPhone 6s	40.94%		13.7274	
IMG_0139.JPG	iPhone 6s	3.22%		8.3513	
IMG_0141.JPG	iPhone 6s	1.57%		4.5647	
IMG_0140JPG	iPhone 6s	1.57%		4.5647	
IMG_0142JPG	iPhone 6s	0.07%		12.9396	
IMG_0143.JPG	iPhone 6s	1.71%		7.3549	
IMG_0144.JPG	iPhone 6s	1.71%	**7.26%**	7.3549	**8.408214286**
IMG_1955.JPG	iPhone 7 Plus	0.07%		40.781	
IMG_1956.JPG	iPhone 7 Plus	1.57%		14.643	
IMG_1957.JPG	iPhone 7 Plus	1.57%		14.643	
IMG_1958.JPG	iPhone 7 Plus	1.57%		7.3549	
IMG_1959.JPG	iPhone 7 Plus	1.57%		5.5649	
IMG_1960.JPG	iPhone 7 Plus	8.14%		6.0309	
IMG_1961.JPG	iPhone 7 Plus	8.14%	**3.23%**	6.0309	**13.57837143**
20190919_110559.jpg	Samsung Galaxy S6	37.66%	**37.66%**	0	**0**
IMG_0141.JPG	Garmin eTrex 20x	16.00%		6.8512	
IMG_0142.JPG	Garmin eTrex 20x	48.39%		5.7739	
IMG_0143.JPG	Garmin eTrex 20x	56.41%		6.0309	
IMG_1958.JPG	Garmin eTrex 20x	36.36%		6.6717	
IMG_1961.JPG	Garmin eTrex 20x	58.01%	**43.03%**	7.7253	**6.55045**
IMG_0138.JPG	GPSmap 62s	53.20%		95.8688	
IMG_1955.JPG	GPSmap 62s	57.21%		107.0751	
IMG_1956.JPG	GPSmap 62s	86.09%	**65.50%**	98.6055	**100.5164667**

Test #I – Suburb Location #IV

Suburb Location #IV used the iPhone 6s, Samsung Galaxy S6, iPhone 7 Plus, Garmin eTrex 20x and the Garmin GPSmap62s. The raw data associated to this test is displayed in Table 15. Below will list some observations listed in these data sets.

Table 15: Suburb Location #IV – Coordinates and Elevation

File Name	Device	GPS Sat	Date	Time(GMT - 07:00)	GPS Lat	Latitude	GPS Long	Longitude	Elevation
Actual Location						31'50"		26'20"	**60.96**
						31.836'		26.332'	
IMG_0145.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	16:18:33	N	31' 50.76"	W	26' 19.42"	58
IMG_0146.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	16:18:33	N	31' 50.76"	W	26' 19.42"	58
IMG_0147.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	16:19:10	N	31' 50.85"	W	26' 19.59"	58
IMG_1962.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	16:18:42	N	31' 50.76"	W	26' 19.67"	58
IMG_1963.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	16:18:42	N	31' 50.76"	W	26' 19.67"	58
IMG_1965.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	16:18:48	N	31' 50.58"	W	26' 20.08"	56
IMG_1966.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	16:19:22	N	31' 50.23"	W	26' 20.00"	59
20190919_161930.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	9/19/2019	16:19:30	N	31' 49.00"	W	26' 19.00"	40
20190919_161940.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	9/19/2019	16:19:40	N	31' 49.00"	W	26' 19.00"	40
IMG_1962.JPG	Garmin eTrex 20x	Gamin Default + GLONASS	9/19/2019	16:18:42	N	31.836'	W	26.333'	54.5592
IMG_1963.JPG	Garmin eTrex 20x	Gamin Default + GLONASS	9/19/2019	16:18:42	N	31.836'	W	26.332'	54.5592
IMG_0145.JPG	Garmin eTrex 20x	Gamin Default + GLONASS	9/19/2019	16:18:33	N	31.838'	W	26.333'	51.816
20190919_161940.jpg	Garmin eTrex 20x	Gamin Default + GLONASS	9/19/2019	16:19:40	N	31.832'	W	26.330'	57.3024
20190919_161940.jpg	GPSmap 62s	Gamin Default	9/19/2019	16:19:40	N	31' 50.8"	W	26' 15.7"	57.3024
IMG_0147.JPG	GPSmap 62s	Gamin Default	9/19/2019	16:19:10	N	31' 50.9"	W	26.333' 7"	59.436

Table 16 displayed the Samsung Galaxy S6 producing the worse average distance from actual location within cellular devices and the worse average elevation percent error categories. The two image files that were produced by the Galaxy S6 were also taken with 10 seconds apart and did not produce different results.

The iPhone 7 Plus outperformed all devices in distance and the GPSmap 62s outperformed all devices in elevation. Figure 21 displays an overall view of all image GPS coordinates vs the actual location.

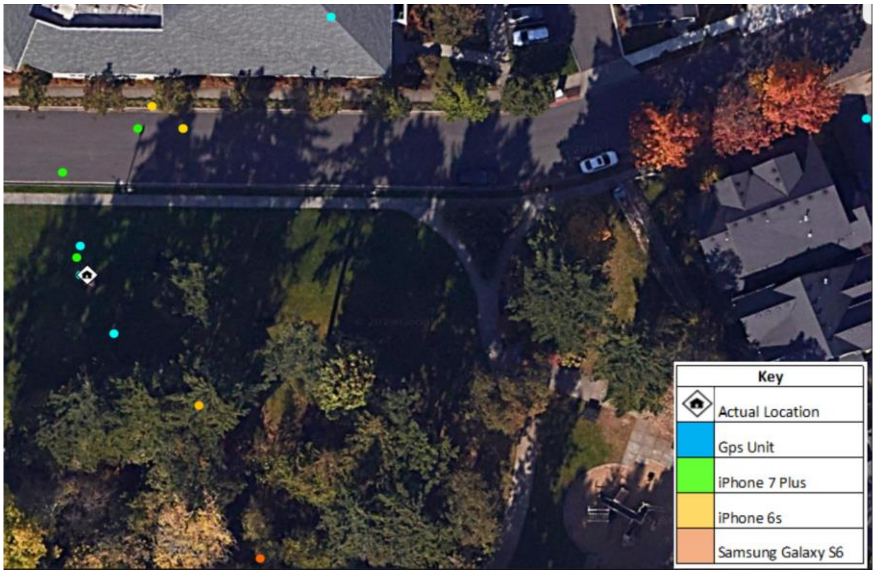


Figure 21: Suburb Location #IV – GPS Coordinates vs Actual Location (SARTOPO Map)

There was one distinct change in distance with one device showing the device correcting itself closer to the actual location. The iPhone 7 Plus 'IMG_1966.jpg' file produced a distance of 6.717 meters from actual location. Previous images associated to this device produced an approximate 17 meter – 24 meter distance from actual location. The amount of time the device took for this correction was 40 seconds.

Table 16: Suburb Location #IV – Percent Error and Average Distance from Actual

File Name	Device	% Error Elevation	Average % Error Elevation	Distance From Actual (m)	Average Distance from Actual (m)
IMG_0145.JPG	iPhone 6s	4.86%		26.8444	
IMG_0146.JPG	iPhone 6s	4.86%		26.8444	
IMG_0147.JPG	iPhone 6s	4.86%	**4.86%**	28.2765	**27.32176667**
IMG_1962.JPG	iPhone 7 Plus	4.86%		24.6159	
IMG_1963.JPG	iPhone 7 Plus	4.86%		24.6159	
IMG_1965.JPG	iPhone 7 Plus	8.14%		17.8593	
IMG_1966.JPG	iPhone 7 Plus	3.22%	**5.27%**	6.717	**18.452025**
20190919_161930.jpg	Samsung Galaxy S6	34.38%		38.0141	
20190919_161940.jpg	Samsung Galaxy S6	34.38%	**34.38%**	38.0141	**38.0141**
IMG_1962.JPG	Garmin eTrex 20x	10.50%		5.614	
IMG_1963.JPG	Garmin eTrex 20x	10.50%		6.0309	
IMG_0145.JPG	Garmin eTrex 20x	15.00%		8.9296	
20190919_161940.jpg	Garmin eTrex 20x	6.00%	**10.50%**	5.1758	**6.437575**
20190919_161940.jpg	GPSmap 62s	6.00%		96.222	
IMG_0147.JPG	GPSmap 62s	2.50%	**2.50%**	152.886	**124.554**

Test #I – Urban Location #I

Urban Location #I used the iPhone 7, iPhone 8, iPhone 6s, Samsung Galaxy S6, iPhone 7 Plus, Garmin eTrex 20x and the Garmin GPSmap62s. The raw data associated to this test is displayed in Table 17. Below will list some observations listed in these data sets.

Table 17: Urban Location #I – Coordinates and Elevation

File Name	Device	GPS Sat	Date	Time	GPS Lat	Latitude	GPS Long	Longitude	Elevation
Actual Location						31'26"		**40'49"**	**13.1064**
						31.426'		40.814'	
IMG_2722.JPG	iPhone 7	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	18:58:39	N	31' 23.43"	W	40' 45.36"	45
IMG_2723.JPG	iPhone 7	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	18:58:51	N	31' 25.01"	W	40' 48.03"	16
IMG_0691.JPG	iPhone 8	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	18:58:03	N	31' 25.97"	W	40' 49.57"	13
IMG_0692.JPG	iPhone 8	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	18:58:14	N	31' 25.61"	W	40' 48.96"	14
IMG_0148.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	18:57:06	N	31' 25.71"	W	40' 48.96"	14
IMG_0149.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	18:57:23	N	31' 25.25"	W	40' 48.83"	15
IMG_1967.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	18:56:47	N	31' 25.56"	W	40' 48.88"	29
IMG_1968.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	9/19/2019	18:57:31	N	31' 20.74"	W	40' 42.95"	12
20190919_190059.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	9/19/2019	19:00:59	N	31' 26.00"	W	40' 49.00"	0
20190919_190106.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	9/19/2019	19:01:06	N	31' 26.00"	W	40' 49.00"	0
IMG_0149.JPG	Garmin eTrex 20x	Gamin Default + GLONASS	9/19/2019	18:57:23	N	31.424'	W	40.815'	27.1272
IMG_0691.JPG	Garmin eTrex 20x	Gamin Default + GLONASS	9/19/2019	18:58:03	N	31.425'	W	40.816'	28.3464
20190919_190106.jpg	Garmin eTrex 20x	Gamin Default + GLONASS	9/19/2019	19:01:06	N	31.432'	W	40.819'	13.716
IMG_2723.JPG	GPSmap62s	Gamin Default	9/19/2019	18:58:51	N	31' 25.8"	W	40' 44.0"	65.2272
IMG_0692.JPG	GPSmap62s	Gamin Default	9/19/2019	18:58:14	N	31' 25.6"	W	40' 43.9"	64.008
IMG_0148.JPG	GPSmap62s	Gamin Default	9/19/2019	18:57:06	N	31' 25.8"	W	40' 44.0"	60.0456
IMG_1967.JPG	GPSmap62s	Gamin Default	9/19/2019	18:56:47	N	31' 25.7"	W	40' 44.2"	56.9976
20190919_190059.jpg	GPSmap62s	Gamin Default	9/19/2019	19:00:59	N	31' 25.3"	W	40' 43.7"	57.6072

From looking at results from Table 18, iPhone 7 Plus had the worse results of average distance from actual location. By comparing ‘IMG_1967.jpg’ to ‘IMG_1968.jpg’ the initial image file produced a 13.5465 meter distance from actual location. Then an image taken 1 min and 16 seconds later produced a 208.5322 meter distance from actual location. This was the biggest jump seen in this test.

However, the iPhone 7 produced a similar type of circumstance comparing ‘IMG_2722.jpg’ and ‘IMG_2723.jpg’. This circumstance was opposite from the iPhone 7 Plus, where the image file coordinate was first providing a far distance but then corrected to a closer distance.

It was of interest to see the iPhone 8, iPhone 6s, Samsung Galaxy s6 and the Garmin eTrex 20x were able to provide a distance stable to one another.

Samsung Galaxy S6 was able to produce no error in distance again, which was surprising with being in an urban environment. However, its elevation percent error was 100%, in which the device was not able to produce an elevation whatsoever.

Figures 22 and 23 display SARTOPO and Google Earth maps displays image GPS coordinates compared to actual location.

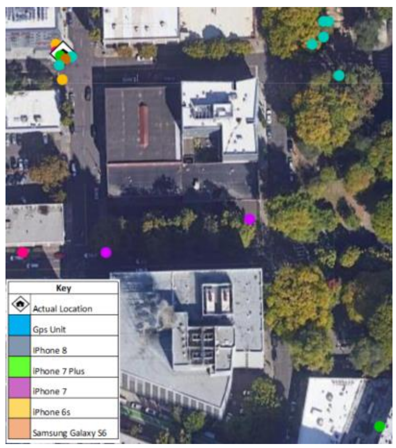


Figure 22: Urban Location #I – Image GPS Coordinates vs Actual Location (SARTOPO Map)

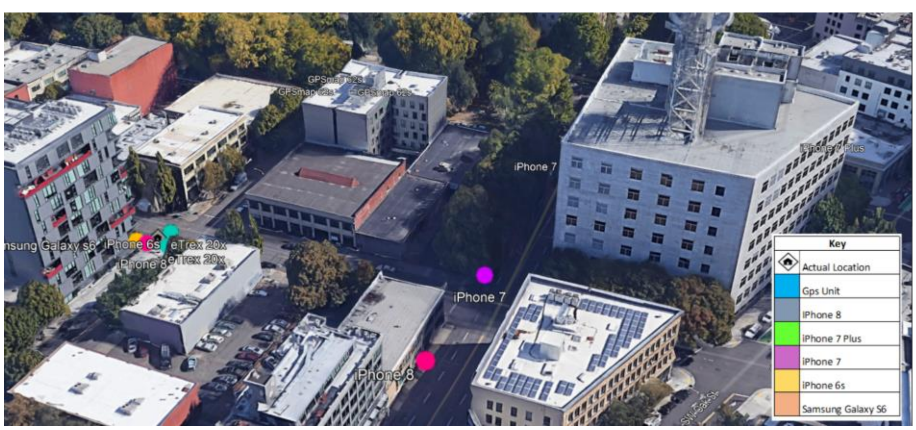


Figure 23: Urban Location #I – Image GPS Coordinates vs Actual Location (Google Earth Map)

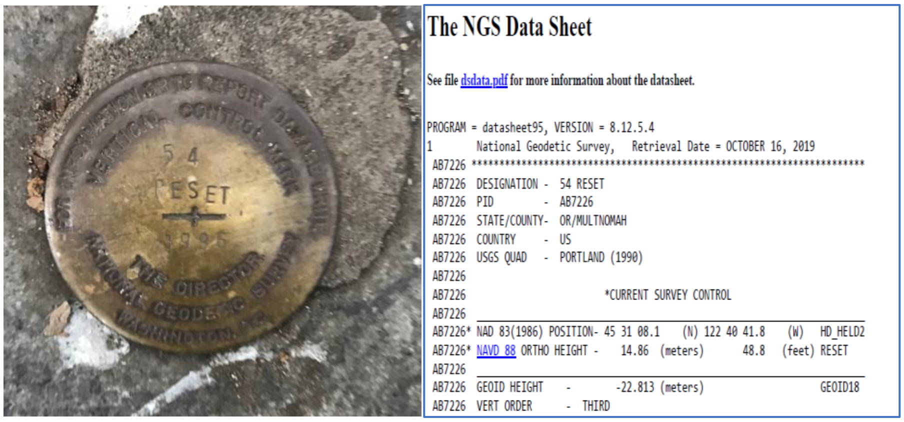
Moving to overall elevation in this test, the Garmin GPSmap 62s produced the worse average elevation percent error rate at a 363.72%. The worse cellular device elevation percent error was the iPhone 7 at a 132.71%. The iPhone 8 was able to produce the best elevation average percent error profile at a 3.81%.

Table 18: Urban Location #I – Percent Error Elevation and Average Distance from Actual

File Name	Device	% Error Elevation	Average % Error Elevation	Distance From Actual (m)	Average Distance from Actual (m)
IMG_2722.JPG	iPhone 7	243.34%		111.4631	
IMG_2723.JPG	iPhone 7	22.08%	**132.71%**	36.6579	**74.0605**
IMG_0691.JPG	iPhone 8	0.81%		12.4647	
IMG_0692.JPG	iPhone 8	6.82%	**3.81%**	11.1467	**11.8057**
IMG_0148.JPG	iPhone 6s	6.82%		8.9296	
IMG_0149.JPG	iPhone 6s	14.45%	**10.63%**	22.4562	**15.6929**
IMG_1967.JPG	iPhone 7 Plus	121.27%		13.5465	
IMG_1968.JPG	iPhone 7 Plus	8.44%	**64.85%**	208.5322	**111.03935**
20190919_190059.jpg	Samsung Galaxy S6	100.00%		0	
20190919_190106.jpg	Samsung Galaxy S6	100.00%	**100.00%**	0	**0**
IMG_0149.JPG	Garmin eTrex 20x	106.98%		16.7519	
IMG_0691.JPG	Garmin eTrex 20x	116.28%		14.4763	
20190919_190106.jpg	Garmin eTrex 20x	4.65%	**75.97%**	3.8284	**11.68553333**
IMG_2723.JPG	GPSmap62s	397.67%		108.4299	
IMG_0692.JPG	GPSmap62s	388.37%		110.5243	
IMG_0148.JPG	GPSmap62s	358.14%		107.8075	
IMG_1967.JPG	GPSmap62s	334.88%		103.9942	
20190919_190059.jpg	GPSmap62s	339.53%	**363.72%**	**116.3724**	**109.42566**

Test #II – NGS Location #I Urban #II

NGS Location #I Urban #II, used the iPhone 6s, Samsung Galaxy S6, iPhone 7 Plus, Garmin eTrex 20x and the Garmin GPSmap62s. This was the first test that utilized the NGS survey markers. The survey marker was in downtown Portland, Oregon, USA. Figure 24 displays a photo of the NGS survey maker with the NGS data sheet that displays the GPS coordinates and the elevation of the marker. This test was the initial implementation of putting our devices on airplane mode, powering off device, powering on device ensuring airplane mode is still active and capturing the initial photo in the test series. The raw data associated to this test is displayed in Table 19. Below will list some observations listed in these data sets.



The NGS Data Sheet

See file dsdata.pdf for more information about the datasheet.

```
PROGRAM = datasheet95, VERSION = 8.12.5.4
1        National Geodetic Survey,   Retrieval Date = OCTOBER 16, 2019
 AB7226 ***********************************************************************
 AB7226  DESIGNATION -  54 RESET
 AB7226  PID         -  AB7226
 AB7226  STATE/COUNTY-  OR/MULTNOMAH
 AB7226  COUNTRY     -  US
 AB7226  USGS QUAD   -  PORTLAND (1990)
 AB7226
 AB7226                         *CURRENT SURVEY CONTROL
 AB7226  ___________________________________________________________________
 AB7226* NAD 83(1986) POSITION- 45 31 08.1    (N) 122 40 41.8    (W)   HD_HELD2
 AB7226* NAVD 88 ORTHO HEIGHT -    14.86  (meters)       48.8   (feet) RESET
 AB7226  ___________________________________________________________________
 AB7226  GEOID HEIGHT    -       -22.813 (meters)                      GEOID18
 AB7226  VERT ORDER      -  THIRD
```

Figure 24: NGS Location #I Urban #II – NGS Data Sheet Rural Environment and Survey marker 54 RESET

Table 19: NGS Location #I Urban #II – Coordinates and Elevation

File Name	Device	GPS Sat	Date	Time	GPS Lat	Latitude	GPS Long	Longitude	Elevation
Actual Location						31'08.1"		40'41.8"	**14.86**
						0.5189		0.6783	
IMG_0160-Airplane.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	10/5/2019	6:16:30 PM (Unknown)	N		W		--
IMG_0161.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	10/5/2019	18:18:19 (GMT -07:00)	N	0.518883	W	0.678275	17
20191005_182353-Airplane.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	10/5/2019	18:23:53 (GMT -07:00)	N	0.519167	W	0.678333	0
IMG_2013-Airplane.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	10/5/2019	18:15:41 (Uknnown)	N	--	W		--
IMG_2014-Airplane.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	10/5/2019	18:15:44 (Unknown)	N	--	W		--
IMG_2015.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	10/5/2019	18:17:37 (GMT -07:00)	N	0.518536	W	0.681397	111
IMG_2016.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	10/5/2019	18:17:52 (GMT -07:00)	N	0.518975	W	0.678589	17
IMG_0160-Airplane.JPG	Garmin eTrex 20x	Garmin Default + GLONASS	10/5/2019	6:16:30 PM (Unknown)	N	31.150'	W	40.697'	21.336
20191005_182353-Airplane.jpg	Garmin eTrex 20x	Garmin Default + GLONASS	10/5/2019	18:23:53 (GMT -07:00)	N	31.145'	W	40.701'	18.5928
IMG_2013-Airplane.JPG	Garmin eTrex 20x	Garmin Default + GLONASS	10/5/2019	18:15:41 (Unknown)	N	31.150'	W	40.694'	14.3256
IMG_0161.JPG	GPSmap 62s	Garmin Default	10/5/2019	18:18:19 (GMT -07:00)	N	31'09.7"	W	40'37.0"	9.144
IMG_2015.JPG	GPSmap 62s	Garmin Default	10/5/2019	18:17:37 (GMT -07:00)	N	31'09.7"	W	40'37.0"	10.0584
IMG_2016.JPG	GPSmap 62s	Garmin Default	10/5/2019	18:17:52 (GMT -07:00)	N	31'09.7"	W	40'37.0"	11.2776

Table 20 shows the iPhone 7 Plus with both the worse average distance from actual location and average elevation percent error. This could be due to the fact of this device initially having problems acquiring a location. By looking at ‘IMG_2013-Aiplane.jpg’ and ‘IMG_2014-Airplane.jpg’ you can see that these initial photos did not obtain a GPS location or elevation. This is due to the devices camera app location settings set to ‘while using the app’, which in turn takes approximately 25 secs for the device to acquire any GPS location. I believe this same result happened with the iPhone 6s ‘IMG_0160-Airplane.jpg’ file. However, its next image file was able to provide a pretty accurate distance from actual location. Figure 25 displays the image GPS coordinates compared to the actual GIS survey marker location.

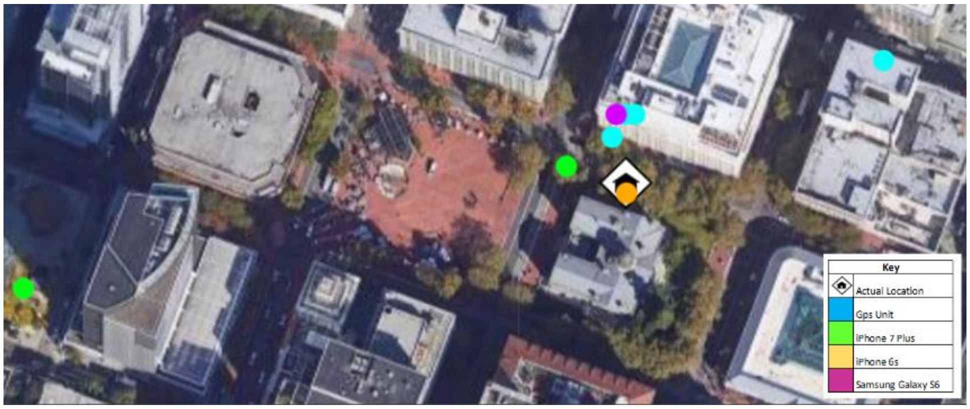


Figure 25: NGS Location #I Urban #II – Image GPS Coordinates from Actual Location (SARTOPO Map)

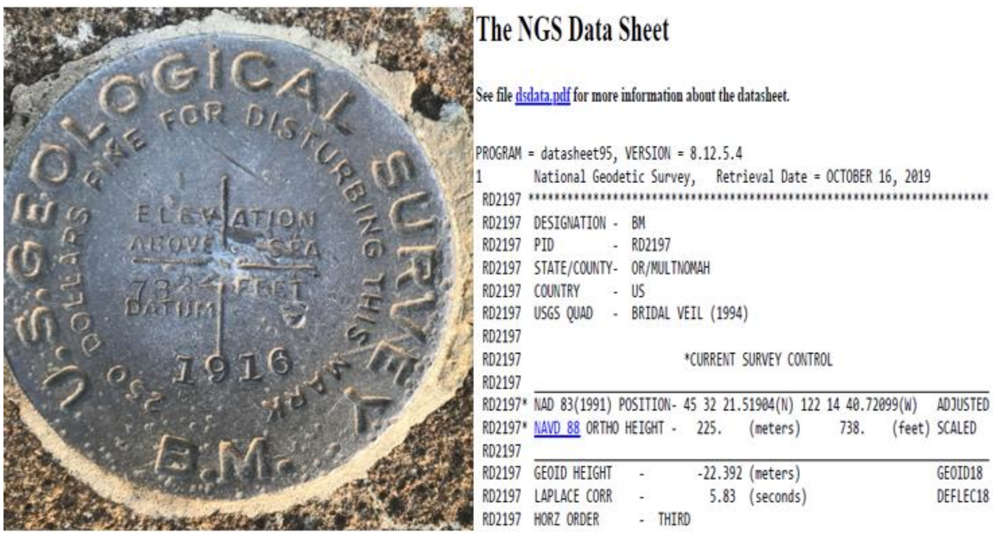
It is worth noting that the Samsung Galaxy S6 was not able to provide an elevation profile. However, did provide a location point of 29.8002 meters from actual location. The stand-alone GPS units produced similar results as previous tests administered.

Table 20: NGS Location #I Urban #II – Percent Error and Average Distance from Actual

File Name	Device	% Error Elevation	Average % Error Elevation	Distance From Actual (m)	Average Distance from Actual (m)
IMG_0160-Airplane.JPG	iPhone 6s	--		--	
IMG_0161.JPG	iPhone 6s	14.40%	**14.40%**	2.7142	**2.7142**
20191005_182353-Airplane.jpg	Samsung Galaxy S6	100.00%	**100.00%**	29.8002	**29.8002**
IMG_2013-Airplane.JPG	iPhone 7 Plus	--		--	
IMG_2014-Airplane.JPG	iPhone 7 Plus	--		--	
IMG_2015.JPG	iPhone 7 Plus	646.97%		244.6635	
IMG_2016.JPG	iPhone 7 Plus	14.40%	**330.69%**	24.0112	**134.33735**
IMG_0160-Airplane.JPG	Garmin eTrex 20x	43.58%		29.673	
20191005_182353-Airplane.jpg	Garmin eTrex 20x	25.12%		20.751	
IMG_2013-Airplane.JPG	Garmin eTrex 20x	3.60%	**24.10%**	30.0349	**26.81963333**
IMG_0161.JPG	GPSmap 62s	38.47%		117.7073	
IMG_2015.JPG	GPSmap 62s	32.31%		117.7073	
IMG_2016.JPG	GPSmap 62s	24.11%	**31.63%**	117.7073	**117.7073**

Test #II – NGS Location #II Rural #V

NGS Location #II Rural #IV, used the iPhone 6s, Samsung Galaxy S6, iPhone 7 Plus, Garmin eTrex 20x and the Garmin GPSmap62s. This was the second test that utilized the NGS survey markers. The survey marker was at a rural site used in a couple previous tests in our rural environment series outside of Portland, Oregon, USA. Worth noting, this test was a couple meters away from the previous tests' actual location. Figure 26 displays a photo of the NGS survey maker with the NGS data sheet that displays the GPS coordinates and the elevation of the marker. This test also implemented our second test putting our devices on airplane mode first, powering off device, powering on device and capturing a photo. The raw data associated to this test is displayed in Table 21. Below will list some observations listed in these data sets.



The NGS Data Sheet

See file dsdata.pdf for more information about the datasheet.

```
PROGRAM = datasheet95, VERSION = 8.12.5.4
1        National Geodetic Survey,   Retrieval Date = OCTOBER 16, 2019
 RD2197 *********************************************************************
 RD2197  DESIGNATION -  BM
 RD2197  PID         -  RD2197
 RD2197  STATE/COUNTY-  OR/MULTNOMAH
 RD2197  COUNTRY     -  US
 RD2197  USGS QUAD   -  BRIDAL VEIL (1994)
 RD2197
 RD2197                         *CURRENT SURVEY CONTROL
 RD2197  ___________________________________________________________________
 RD2197* NAD 83(1991) POSITION- 45 32 21.51904(N) 122 14 40.72099(W)   ADJUSTED
 RD2197* NAVD 88 ORTHO HEIGHT -   225.    (meters)     738.    (feet) SCALED
 RD2197  ___________________________________________________________________
 RD2197  GEOID HEIGHT    -        -22.392 (meters)                     GEOID18
 RD2197  LAPLACE CORR    -          5.83  (seconds)                    DEFLEC18
 RD2197  HORZ ORDER      -  THIRD
```

Figure 26: NGS Location #II Urban #V – NGS Data Sheet Urban Environment and Survey Marker RD 2197

Table 21: NGS Location #II Rural #IV – Coordinates and Elevation

File Name	Device	GPS Sat	Date	Time	GPS Lat	Latitude	GPS Long	Longitude	Elevation
Actual Location						32'21.52"		14'40.72"	**225**
						32.359'		14.679'	
IMG_0162-Airplane.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	10/6/2019	07:54:54 (GMT -07:00)	N	0.539264	W	0.244714	222
IMG_0163-Airplane.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	10/6/2019	07:54:55 (GMT -07:00)	N	0.539264	W	0.244714	222
IMG_0164.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	10/6/2019	07:55:01 (GMT -07:00)	N	0.539331	W	0.244683	221
IMG_0165.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	10/6/2019	07:55:02 (GMT -07:00)	N	0.539331	W	0.244683	221
IMG_0166.JPG	iPhone 6s	A-GPS, GLONASS, GALILEO, QZSS	10/6/2019	07:55:17 (GMT -07:00)	N	0.539344	W	0.244644	223
20191006_075656.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	10/6/2019	07:56:56 (GMT -07:00)	N	0.539444	W	0.244722	224
20191006_075658.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	10/6/2019	07:56:57 (GMT -07:00)	N	0.539444	W	0.244722	224
20191006_075659.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	10/6/2019	07:56:59 (GMT -07:00)	N	0.539444	W	0.244722	224
20191006_075705.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	10/6/2019	07:57:05 (GMT -07:00)	N	0.539444	W	0.244722	224
20191006_075707.jpg	Samsung Galaxy S6	A-GPS, GLONASS, BDS	10/6/2019	07:57:07 (GMT -07:00)	N	0.539444	W	0.244722	224
IMG_2030-Airplane.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	10/6/2019	7:53:28 AM (Unknown)	N		W		--
IMG_2031-Airplane.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	10/6/2019	07:53:36 (GMT -07:00)	N	0.539414	W	0.244575	215
IMG_2032.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	10/6/2019	07:54:01 (GMT -07:00)	N	0.539322	W	0.244622	224
IMG_2033.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	10/6/2019	07:54:12 (GMT -07:00)	N	0.539331	W	0.244622	224
IMG_2034.JPG	iPhone 7 Plus	A-GPS, GLONASS, GALILEO, QZSS	10/6/2019	07:54:27 (GMT -07:00)	N	0.539336	W	0.244636	224
IMG_0164.JPG	Garmin eTrex 20x	Garmin Default + GLONASS	10/6/2019	07:55:01 (GMT -07:00)	N	32.359'	W	14.681'	220.98
IMG_0165.JPG	Garmin eTrex 20x	Garmin Default + GLONASS	10/6/2019	07:55:02 (GMT -07:00)	N	32.359'	W	14.681'	220.98
IMG_0166.JPG	Garmin eTrex 20x	Garmin Default + GLONASS	10/6/2019	07:55:17 (GMT -07:00)	N	32.359'	W	14.681'	221.285
20191006_075705.jpg	Garmin eTrex 20x	Garmin Default + GLONASS	10/6/2019	07:57:05 (GMT -07:00)	N	32.359'	W	14.680'	217.018
20191006_075707.jpg	Garmin eTrex 20x	Garmin Default + GLONASS	10/6/2019	07:57:07 (GMT -07:00)	N	32.359'	W	14.680'	217.322
IMG_2033.JPG	Garmin eTrex 20x	Garmin Default + GLONASS	10/6/2019	07:54:12 (GMT -07:00)	N	32.358'	W	14.680'	220.37
IMG_2034.JPG	Garmin eTrex 20x	Garmin Default + GLONASS	10/6/2019	07:54:27 (GMT -07:00)	N	32.359'	W	14.680'	220.675
IMG_0162-Airplane.JPG	GPSmap 62s	Garmin Default	10/6/2019	07:54:54 (GMT -07:00)	N	32'22.2"	W	14'36.6"	222.199
IMG_0163-Airplane.JPG	GPSmap 62s	Garmin Default	10/6/2019	07:54:55 (GMT -07:00)	N	32'22.2"	W	14'36.6"	222.199
20191006_075656.jpg	GPSmap 62s	Garmin Default	10/6/2019	07:56:56 (GMT -07:00)	N	32'22.1"	W	14'36.5"	220.675
20191006_075658.jpg	GPSmap 62s	Garmin Default	10/6/2019	07:56:57 (GMT -07:00)	N	32'22.1"	W	14'36.5"	221.285
20191006_075659.jpg	GPSmap 62s	Garmin Default	10/6/2019	07:56:59 (GMT -07:00)	N	32'22.2"	W	14'36.6"	221.59
IMG_2032.JPG	GPSmap 62s	Garmin Default	10/6/2019	07:54:01 (GMT -07:00)	N	32'22.4"	W	14'36.4"	220.37

From Table 22, it is displayed that mostly all devices provided an elevation and GPS profile. It was discovered for this test that the iPhone Camera App option for location needed to have the location setting set to 'Ask next time'. This prompts the app to ask the user if location is desirable for the users' app session. This seems to enable GPS right away when enabled, as the device was mostly receiving GPS coordinates right after exiting that prompt.

The only anomaly with this location setting was from the iPhone 7 Plus 'IMG_2030-Airplane.jpg', which did not provide a GPS coordinate or elevation profile. However, a GPS coordinate was produced 8 seconds later with 'IMG_2031-Airplane.jpg'. With 'IMG_2030-Airplane.jpg' it was interesting to see that the time offset was not listed like the other photos EXIF data, as it produced an 'unknown' offset.

Within this location test the GPSmap 62s provided the worse average distance from actual location followed by the Samsung Galaxy S6, which provided the worse distance for a cellular device.

It was surprising that after the location setting switch to ‘Ask next time’ devices produced good results in the distance category. As the iPhone 6s received an average distance of 3.1061 meters from actual location and the iPhone 7 Plus received an average distance of 2.36365 meters from actual location. The Garmin eTrex 20x provided the best average distance of 1.5547 meters from actual location. Reference Figure 27 for all image GPS coordinates compared to the actual GPS survey marker location.

Figure 27: NGS Location #II Urban #V – Image GPS Coordinates vs Actual Location (SARTOPO Map)

Figure 28: NGS Location #II Urban #V – Image GPS Coordinates vs Actual Location (Google Earth Map)

With elevation the Samsung Galaxy S6 provided the best average elevation percent error of 0.44%. Surprisingly the Garmin eTrex 20x provided the worse elevation percent error of 2.31%. It was interesting to see that all devices did well in both elevation and distance compared to previous data sets. Figure 27 displays a Google Earth map to show the type of elevation associated to the environment type.

Table 22: NGS Location #II Urban #V – Percent Error Elevation and Average Distance from Actual

File Name	Device	% Error Elevation	Average % Error Elevation	Distance From Actual (m)	Average Distance from Actual (m)
IMG_0162-Airplane.JPG	iPhone 6s	1.33%		7.634	
IMG_0163-Airplane.JPG	iPhone 6s	1.33%		7.634	
IMG_0164.JPG	iPhone 6s	1.78%		3.0639	
IMG_0165.JPG	iPhone 6s	1.78%		3.0639	
IMG_0166.JPG	iPhone 6s	0.89%	**1.42%**	3.1483	**3.1061**
20191006_075656.jpg	Samsung Galaxy S6	0.44%		15.2978	
20191006_075658.jpg	Samsung Galaxy S6	0.44%		15.2978	
20191006_075659.jpg	Samsung Galaxy S6	0.44%		15.2978	
20191006_075705.jpg	Samsung Galaxy S6	0.44%		15.2978	
20191006_075707.jpg	Samsung Galaxy S6	0.44%	**0.44%**	15.2978	**15.2978**
IMG_2030-Airplane.JPG	iPhone 7 Plus	--		--	
IMG_2031-Airplane.JPG	iPhone 7 Plus	4.44%		12.3639	
IMG_2032.JPG	iPhone 7 Plus	-0.44%		11.8774	
IMG_2033.JPG	iPhone 7 Plus	-0.44%		2.2505	
IMG_2034.JPG	iPhone 7 Plus	-0.44%	**0.78%**	2.4768	**2.36365**
IMG_0164.JPG	Garmin eTrex 20x	1.79%		2.5701	
IMG_0165.JPG	Garmin eTrex 20x	1.79%		2.5701	
IMG_0166.JPG	Garmin eTrex 20x	1.65%		2.5701	
20191006_075705.jpg	Garmin eTrex 20x	3.55%		1.2461	
20191006_075707.jpg	Garmin eTrex 20x	3.41%		1.2461	
IMG_2033.JPG	Garmin eTrex 20x	2.06%		2.1721	
IMG_2034.JPG	Garmin eTrex 20x	1.92%	**2.31%**	1.2461	**1.55476667**
IMG_0162-Airplane.JPG	GPSmap 62s	1.24%		91.8726	
IMG_0163-Airplane.JPG	GPSmap 62s	1.24%		91.8726	
20191006_075656.jpg	GPSmap 62s	1.92%		93.3716	
20191006_075658.jpg	GPSmap 62s	1.65%		93.3716	
20191006_075659.jpg	GPSmap 62s	1.52%		91.8726	
IMG_2032.JPG	GPSmap 62s	2.06%	**1.61%**	97.4642	**93.3042**

IV. FINDINGS AND RESULTS EXPLANATION

Below will describe findings relating to distance and elevation error depending on device and environment type. The findings between Apple and Samsung device will the discussed. Observations with airplane and other notable findings will be addressed.

Distance Error

By acquiring the average distance in meters from each photo taken against the known actual location using the Matlab script: *[arclen, az] = distance(lat1,lon1,lat2,lon2)*1000*. Figure 29 displays each test location in respect to each device that was used. An overall average distance was calculated to display another figure of accuracy between all tests associated to the device. Additionally, an overall average distance for each environment type per each device was calculated and displayed to show which device excelled in different environment types. Below will explain what was observed in the device and environment types regarding distance.

iPhone 6s		iPhone 7		iPhone 7 Plus		iPhone 8	
Location	Avg Distance From Actual (m)	Location	Avg Distance From Actual (m)	Location	Avg Distance From Actual (m)	Location	Avg Distance From Actual (m)
Test #1 Rural #1	1825.30175	Test #1 Rural #1	-	Test #1 Rural #1	12.705175	Test #1 Rural #1	-
Test #2 Rural #2	24.112225	Test #2 Rural #2	-	Test #2 Rural #2	5446.5903	Test #2 Rural #2	-
Test #3 Rural #3	41.5166	Test #3 Rural #3	-	Test #3 Rural #3	32.6802	Test #3 Rural #3	-
Test #4 Rural #4	15.4937	Test #4 Rural #4	-	Test #4 Rural #4	17.91668333	Test #4 Rural #4	-
Test #5 Suburb #1	23.786675	Test #5 Suburb #1	-	Test #5 Suburb #1	9.245175	Test #5 Suburb #1	-
Test #6 Suburb #2	-	Test #6 Suburb #2	-	Test #6 Suburb #2	8.4002	Test #6 Suburb #2	-
Test #7 Suburb #3	8.408214286	Test #7 Suburb #3	-	Test #7 Suburb #3	13.57837143	Test #7 Suburb #3	-
Test #8 Suburb #4	27.32176667	Test #8 Suburb #4	-	Test #8 Suburb #4	18.452025	Test #8 Suburb #4	-
Test #9 Urban #1	15.6929	Test #9 Urban #1	74.0605	Test #9 Urban #1	111.03935	Test #9 Urban #1	11.8057
Test #10 Urban #2	2.7142	Test #10 Urban #2	-	Test #10 Urban #2	134.33735	Test #10 Urban #2	-
Test #11 Rural #5	3.1061	Test #11 Rural #5	-	Test #11 Rural #5	2.36365	Test #11 Rural #5	-
Overall	198.7454131	Overall	74.0605	Overall	527.9371345	Overall	11.8057
Overall Rural	381.906075	Overall Rural	-	Overall Rural	1102.451202	Overall Rural	-
Overall Sub	19.83888532	Overall Sub	-	Overall Sub	12.41894286	Overall Sub	-
Overall Urban	9.20355	Overall Urban	74.0605	Overall Urban	122.68835	Overall Urban	11.8057

Samsung Galaxy S6		Samsung SM-N960U		Garmin GPSmap 62s		Garmin Etrex 20x	
Location	Avg Distance From Actual (m)	Location	Avg Distance From Actual (m)	Location	Avg Distance From Actual (m)	Location	Avg Distance From Actual (m)
Test #1 Rural #1	-	Test #1 Rural #1	12.5108	Test #1 Rural #1	79.5712	Test #1 Rural #1	13.2867
Test #2 Rural #2	-	Test #2 Rural #2	-	Test #2 Rural #2	86.509675	Test #2 Rural #2	29.761025
Test #3 Rural #3	0	Test #3 Rural #3	-	Test #3 Rural #3	88.249075	Test #3 Rural #3	13.472775
Test #4 Rural #4	0	Test #4 Rural #4	-	Test #4 Rural #4	79.4078	Test #4 Rural #4	10.6097
Test #5 Suburb #1	-	Test #5 Suburb #1	3804.9461	Test #5 Suburb #1	96.99945	Test #5 Suburb #1	6.8613333
Test #6 Suburb #2	-	Test #6 Suburb #2	21.404875	Test #6 Suburb #2	85.9497667	Test #6 Suburb #2	3.6817
Test #7 Suburb #3	0	Test #7 Suburb #3	-	Test #7 Suburb #3	100.5164667	Test #7 Suburb #3	6.55045
Test #8 Suburb #4	38.0141	Test #8 Suburb #4	-	Test #8 Suburb #4	124.554	Test #8 Suburb #4	6.437575
Test #9 Urban #1	0	Test #9 Urban #1	-	Test #9 Urban #1	109.42566	Test #9 Urban #1	11.68553333
Test #10 Urban #2	29.8002	Test #10 Urban #2	-	Test #10 Urban #2	117.7073	Test #10 Urban #2	26.8196333
Test #11 Rural #5	15.2978	Test #11 Rural #5	-	Test #11 Rural #5	93.3042	Test #11 Rural #5	1.55476667
Overall	11.87315714	Overall	1279.620592	Overall	96.56314485	Overall	11.88374469
Overall Rural	5.099266667	Overall Rural	12.5108	Overall Rural	85.40839	Overall Rural	13.73699333
Overall Sub	19.00705	Overall Sub	1913.175488	Overall Sub	102.0049209	Overall Sub	5.882764575
Overall Urban	14.9001	Overall Urban	-	Overall Urban	113.56648	Overall Urban	19.25258332

Figure 29: Distance Error from Actual Location

Device

From data in Figure 29, it can be shown that the Samsung Galaxy S6, iPhone 8 and the Garmin Etrex 20x displayed an average distance closest to the actual location (0). However, the iPhone 8 was only used in one experiment, so it cannot be proven that it displayed a better GPS accuracy. The next runner up would be the Samsung Galaxy S6, which makes sense merely that on some tests the phone displayed no distance error.

The worse devices displayed from Figure 29 were the Samsung SM-N960U and the iPhone 7 Plus. These were most likely due to anomalies of GPS locations putting the devices in very far out places when trying to secure a promising GPS coordinate. Two instances, one from each device showed this anomaly and will be explained in the other findings section later throughout the paper. However, I believe these two outliers contributed to these devices performing poorly by providing the overall worse average distance from actual location.

Environment

Apple	
	Avg Distance From Actual (m)
Overall	203.1371869
Overall Rural	742.1786383
Overall Sub	16.12891409
Overall Urban	43.55162

Samsung	
	Avg Distance From Actual (m)
Overall	645.7468744
Overall Rural	12.5108
Overall Sub	966.0912688
Overall Urban	14.9001

Garmin GPS Units	
	Avg Distance From Actual (m)
Overall	54.22344477
Overall Rural	49.57269167
Overall Sub	53.94384271
Overall Urban	113.56648

Apple + Samsung	
	Avg Distance From Actual (m)
Overall	424.4420307
Overall Rural	377.3447192
Overall Sub	491.1100914
Overall Urban	29.22586

Environment (All Devices)	
Rural	225.7768765
Sub	201.0655325
Urban	57.3394

Figure 30: Device Average Distance Pertaining to Environment

From Figure 30, Garmin devices appear to have the most accurate distances. Apple being second closest and Samsung being the farthest away from the actual. However, these differ from each type of environment. This figure also paints a picture of how these environment types vary as far as accuracy all together.

Looking the overall rural figure for both companies. Apple's overall rural figure is 742.1786 meters from actual location and Samsung's overall rural figure is 12.5108 meters from actual location. But in a suburb environment these two companies both switched roles. Samsung's overall suburb figure being 966.091 meters from actual location to Apple's overall suburb figure to 16.1289 meters from actual location. Below will outline each environment type for the best and worse devices for each setting.

Rural

From Figure 30 and looking at overall rural results. Samsung devices appear to be closest to the actual location, with Garmin GPS units following and Apple devices being the farthest from actual location. Apple and Samsung devices collectively have a rural overall average distance of 377.3447192 meters. All devices in this environment have an average distance of 225.7768765 meters.

Figure 31 displays a scatter plot of all rural location tests compared to the actual location point. A trend of plots staying consistent with a longitude point '-122.2446' is shown. It seems the latitude point in this graph is the major defining factor of where that point would lie in relation to the actual point plot.

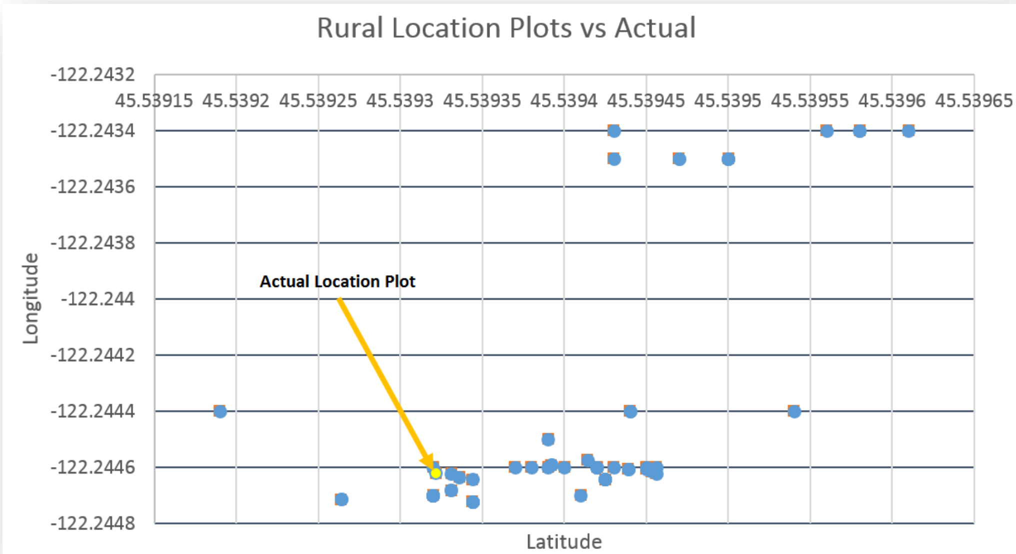


Figure 31: Rural Distance Image GPS Plot vs Actual Location Plot Scatterplot Graph

Suburb

From Figure 30 and looking at overall suburb results. Apple devices appear to be closest to the actual location, with Garmin GPS units following and Samsung devices being the farthest from actual location. Apple and Samsung devices collectively have a suburb overall average distance of 491.1100914 meters. All devices in this environment have an average distance of 201.0655325 meters.

Figure 32 displays a scatter plot of all suburb location tests compared to the actual location point. Again a trend is displayed of the longitude staying consistent for the actual point plot longitude. Latitude has a gap displayed from approximately '45.5303' – '45.5310'.

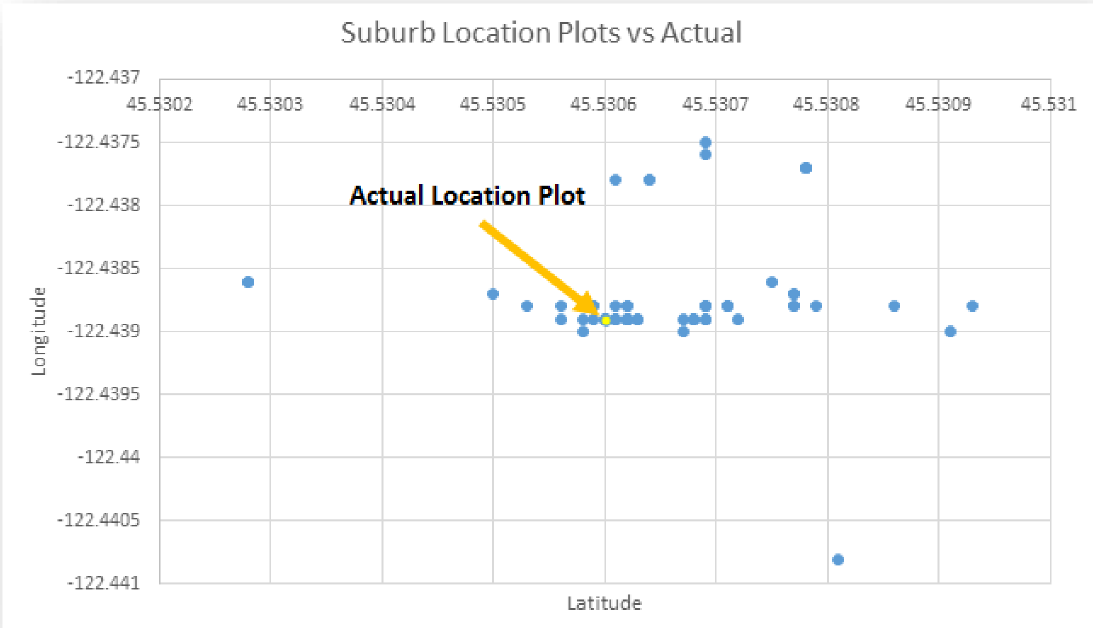


Figure 32: Suburb Distance Image GPS Plot vs Actual Location Plot Scatterplot Graph

Urban

From Figure 30 and looking at overall urban results. Samsung devices appear to be closest to the actual location, with Apple devices following and Garmin GPS units being the farthest from actual location. Apple and Samsung devices collectively have an urban overall average distance of 29.22586 meters. All devices in this environment have an average distance of 57.3394 meters.

Figure 33 displays a scatter plot of the urban location test compared to the actual location point. This provides a nice visual of the inconsistencies that arose from the different devices and what trends were demonstrated. From previous scatter plots graph the same trend that devices seem to follow are shown.

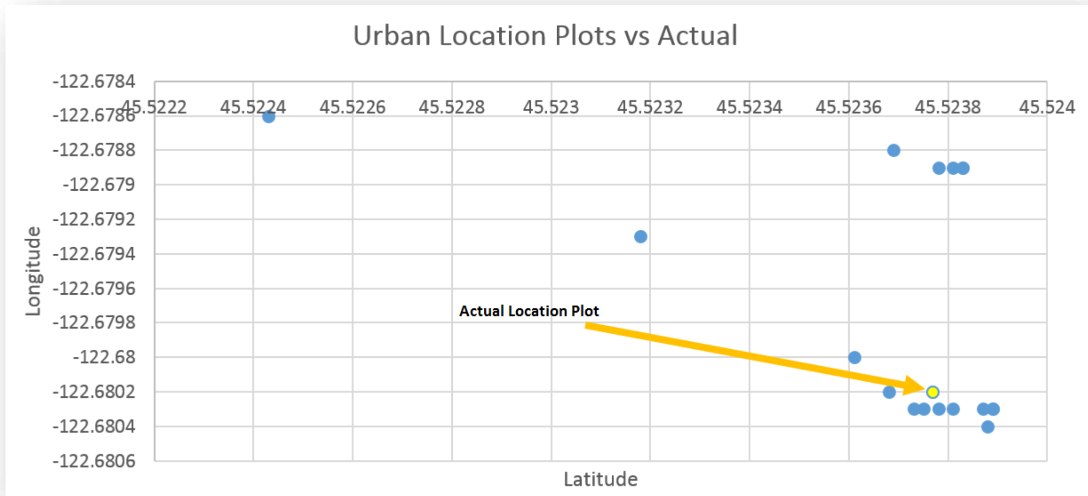


Figure 33: Urban Distance Image GPS Plot vs Actual Location Plot Scatterplot Graph

Elevation Error

Elevation Error was determined by using the percent error formula displayed in Figure 4. This was used to come up with a percent error for each elevation data point from each test image. An average percent error from each device test was plotted in Figure 34. An overall percent error for each environment was calculated and displayed in Figure 34.

iPhone 6s	
Location	Avg % Error
Test #1 Rural #1	16.34%
Test #2 Rural #2	1.21%
Test #3 Rural #3	8.78%
Test #4 Rural #4	3.50%
Test #5 Suburb #1	4.13%
Test #6 Suburb #2	-
Test #7 Suburb #3	7.26%
Test #8 Suburb #4	4.86%
Test #9 Urban #1	10.63%
Test #10 Urban #2	14.40%
Test #11 Rural #5	1.42%
Overall	7.25%
Overall Rural	6.25%
Overall Sub	5.42%
Overall Urban	12.52%

iPhone 7	
Location	Avg % Error
Test #1 Rural #1	-
Test #2 Rural #2	-
Test #3 Rural #3	-
Test #4 Rural #4	-
Test #5 Suburb #1	-
Test #6 Suburb #2	-
Test #7 Suburb #3	-
Test #8 Suburb #4	-
Test #9 Urban #1	132.71%
Test #10 Urban #2	-
Test #11 Rural #5	-
Overall	132.71%
Overall Rural	-
Overall Sub	-
Overall Urban	132.71%

iPhone 7 Plus	
Location	Avg % Error
Test #1 Rural #1	1.80%
Test #2 Rural #2	27.74%
Test #3 Rural #3	0.28%
Test #4 Rural #4	44.66%
Test #5 Suburb #1	1.57%
Test #6 Suburb #2	1.57%
Test #7 Suburb #3	3.23%
Test #8 Suburb #4	5.27%
Test #9 Urban #1	64.85%
Test #10 Urban #2	330.69%
Test #11 Rural #5	0.78%
Overall	43.86%
Overall Rural	15.05%
Overall Sub	2.91%
Overall Urban	197.77%

iPhone 8	
Location	Avg % Error
Test #1 Rural #1	-
Test #2 Rural #2	-
Test #3 Rural #3	-
Test #4 Rural #4	-
Test #5 Suburb #1	-
Test #6 Suburb #2	-
Test #7 Suburb #3	-
Test #8 Suburb #4	-
Test #9 Urban #1	3.81%
Test #10 Urban #2	-
Test #11 Rural #5	-
Overall	3.81%
Overall Rural	-
Overall Sub	-
Overall Urban	3.81%

Samsung Galaxy S6	
Location	Avg % Error
Test #1 Rural #1	-
Test #2 Rural #2	-
Test #3 Rural #3	3.45%
Test #4 Rural #4	15.35%
Test #5 Suburb #1	90.60%
Test #6 Suburb #2	-
Test #7 Suburb #3	38%
Test #8 Suburb #4	34%
Test #9 Urban #1	100%
Test #10 Urban #2	100%
Test #11 Rural #5	0.44%
Overall	47.74%
Overall Rural	6.41%
Overall Sub	54.21%
Overall Urban	100.00%

Samsung SM-N960U	
Location	Avg % Error
Test #1 Rural #1	6.25%
Test #2 Rural #2	-
Test #3 Rural #3	-
Test #4 Rural #4	-
Test #5 Suburb #1	-
Test #6 Suburb #2	40.94%
Test #7 Suburb #3	-
Test #8 Suburb #4	-
Test #9 Urban #1	-
Test #10 Urban #2	-
Test #11 Rural #5	-
Overall	23.60%
Overall Rural	6.25%
Overall Sub	40.94%
Overall Urban	-

Garmin Etrex 20x	
Location	Avg % Error
Test #1 Rural #1	6.21%
Test #2 Rural #2	0.84%
Test #3 Rural #3	2.32%
Test #4 Rural #4	2.23%
Test #5 Suburb #1	1.00%
Test #6 Suburb #2	22.50%
Test #7 Suburb #3	43.03%
Test #8 Suburb #4	9.60%
Test #9 Urban #1	75.97%
Test #10 Urban #2	24.10%
Test #11 Rural #5	2.31%
Overall	17.28%
Overall Rural	2.78%
Overall Sub	19.03%
Overall Urban	50.04%

Garmin GPSmap 62s	
Location	Avg % Error
Test #1 Rural #1	5.93%
Test #2 Rural #2	8.72%
Test #3 Rural #3	2.52%
Test #4 Rural #4	1.69%
Test #5 Suburb #1	3.83%
Test #6 Suburb #2	23.50%
Test #7 Suburb #3	65.50%
Test #8 Suburb #4	2.50%
Test #9 Urban #1	363.72%
Test #10 Urban #2	31.63%
Test #11 Rural #5	1.61%
Overall	46.47%
Overall Rural	4.09%
Overall Sub	23.83%
Overall Urban	197.68%

Figure 34: Overall Elevation Percent Error

Device

Figure 35 ranks each device from overall lowest average elevation percent error.

Elevation Average Percent Error	
Device	Avg % Error
~~iPhone 8~~	~~3.81%~~
iPhone 6s	7.25%
Garmin Etrex 20x	17.28%
Samsung SM-N960U	23.60%
iPhone 7 Plus	43.86%
Garmin GPSmap 62s	46.47%
Samsung Galaxy S6	47.74%
~~iPhone 7~~	~~152.71%~~

Figure 35 : Elevation Average Percent Error Device Ranking

Both the iPhone 8 and iPhone 7 have a red line through their results, due to both devices only being tested in one experiment. These devices cannot be shown as either the best or worse device in respect to average percent error for all tests and will not be taken account for the ranking.

Glancing over each device shows that there is no constant percent error rate relating to each environment. There is much of a change depending on the device itself and not solely on any environment type.

Environment

From Figure 34, each environment had different devices that excelled over others. Within this section each environments percent error for devices will be addressed.

In a rural setting the Garmin eTrex had the lowest percent error. For cellular devices, the iPhone 6s had the lowest percent error. The worse device in this category was the iPhone 7 Plus. Having a Garmin unit providing the lowest percent error rate in this test was not too surprising as this is a stand-alone GPS unit and its main function is to be able to provide ultimate accuracy in this type of environment setting.

In a suburb setting the iPhone 7 Plus had the lowest percent error. The worse device in this category was the Samsung Galaxy S6. It was interesting that the Apple devices did not produce similar results overall. Since they are pretty on par in respects to the device models not having a huge generation gap difference.

In an urban setting the iPhone 8 had the lowest percent error but was only used in one test. This leads to the runner up, the iPhone 6s having the lowest percent error. The worse device in this category was the Garmin GPSmap 62s. It was intriguing to see that in a urban environment the Garmin devices did not excel, which might be due to other interference of devices and buildings that encompass an urban setting.

Apple vs Samsung

Apple and Samsung have varied results when compared to overall average distance from an actual location and different environments. Figure 36 displays each environment with an overall distance from an actual location. Apple devices are favored overall in accuracy from the tests in acquiring an average distance from an actual location and overall in a suburb environment. Where Samsung devices are favored in a rural and urban environment.

Apple	
	Avg Distance From Actual (m)
Overall	203.1371869
Overall Rural	742.1786383
Overall Sub	16.12891409
Overall Urban	43.55162

Samsung	
	Avg Distance From Actual (m)
Overall	645.7468744
Overall Rural	12.5108
Overall Sub	966.0912688
Overall Urban	14.9001

Figure 36: Apple vs Samsung Distance from Actual

This is an interesting observation since these two companies use 3 similar satellites, however different in one. Maybe the BDS satellite system that Samsung utilizes favors rural and urban environments over suburbs? Or the same could be said over Apple's QZSS satellite systems favoring suburb environments over rural and urban. It would make sense that these results would be different because one satellite system, in theory, should mean different results between these two companies.

Airplane Mode

From Test series #I, each cellular device followed the procedure of cell service on, then switching to airplane mode, then a photo being captured. However, it was then realized that the cellular device might be keeping a known location within the cache of the phone. This suggests after having the device change to airplane mode, the device may rely on the previous known location. Which in theory, the previous known location would be attached to the metadata of any new images.

Test series #II were tests focused on how airplane mode alters GPS metadata to photos and if tests can prove that a cellular device might retain known locations from previous photos.

From referencing section, Tests series #II: NGS Locations and Initial Airplane Mode Tests, the phones were first put into airplane mode, powered off and then turned back on ensuring airplane mode was still active. From tests administered, this revealed the phone does still capture GPS metadata, depending on device location settings.

For Apple Devices, a user has three options to choose from under location services for capturing locations from the device's camera app. These three options are to allow location access to the camera app by either 'never', 'ask next time' or 'while using the app'. Under NGS Location #I, the iPhone 6s and iPhone 7 Plus did not initially provide a photo GPS coordinate, but the next photo did provide a GPS coordinate. This is because the 'while using the app' option takes roughly 30 secs for the Camera app to trigger the GPS in the device to acquire a location for the photo. However, in NGS Location #II, when testing the 'ask next time' option. This option triggers the camera app to regularly turn on GPS right away displaying GPS coordinates in photo metadata.

For Samsung devices, three options are available to choose under location settings. These three options are 'high accuracy', 'battery saving' and 'device only'. Under Test series #II, the 'device only' option was utilized and made the test solely based on the devices GPS. This process did take about five minutes for the device to acquire a GPS coordinate. However, a GPS coordinate was produced within photo metadata.

Other Notable Findings

Random anomalies would occur with some of the GPS metadata associated to the photos. Within this section a discussion of notable anomalies will be addressed.

One in particular was in Test #I Rural Location #II, with the iPhone 7 Plus. The test environment was rural and the first photo on that device displayed a coordinate that was 21717.1 meters away from the actual location. This could have been from the device taking some time to catch up to acquire a GPS satellite. However, most of the time this type of encounter that was this far of a distance in tests administered were not seen.

Another anomaly had to do with Test #I Suburb Location #I, with a Samsung SM-N960U device. The interest in this anomaly shows a total of four photos taken within this test series. The first three photos were near the actual location of the test series. However, the last photo brought the GPS coordinate all the way to a previous test location that was 15,164.6 meters away. Speculation thinks that maybe the phone lost connection to a previous GPS satellite and only fell back to a previous known coordinate. Further cellular device forensics would have to be conducted to determine any other background processes causing this change.

Previously noted before in this paper, the Samsung Galaxy S6 with no cell service activated will take roughly 45 secs to 5 mins to acquire a GPS coordinate. However, that coordinate most of the time was accurate to the actual location being tested. My assumption is that other connection types i.e. cell service, WIFI and Bluetooth could in fact hinder the device to determine a precise location. It was assumed that a device also utilizing these other connections would provide accuracy to the device. This could differ for each device model or software update and will need further testing.

During tests, a situation came up when a photo taken in a rural location was displaying GPS coordinates of a residential area. The Samsung device had the location setting of ‘high accuracy’ implemented, which means that it will acquire a location from all connection types available. After some research of the GPS coordinate, it was determined that the device pulled GPS coordinates from the connection to a WIFI router. Further cellular forensics would have to be done to explain any background processes occurring. But it is strange for this the cellular device to provide a location in this fashion.

V. FUTURE RESEARCH

Much more future research could be conducted on this topic focusing many different types of details photo EXIF data exhibits.

Analysis of each device and operating system software versions from each cellular company could be a study to see if one operating system differs from another. It is possible for device architecture or software updates to be different and could change the priority list of how a device is determining a location. Also, a software update could maybe implement a new technology for the device to utilize connections more efficiently.

Types of weather tests could further be done to determine if this causes GPS interferences. Maybe there can be a trend identified to determine any error offsets that could be done to account for this type of circumstance.

Tests being catered around the anomalies that were being experienced throughout the paper would be another good research study. Mainly around what specific parameters are taking place in different devices and to explain how a device will output a certain GPS coordinate. It would probably be clear to have a forensic download of each cellular device and analyze what processes the phone is going through when an anomaly occurs.

Being able to pinpoint what GPS satellites or satellite systems a device is talking to would be interesting to see if a device is for certain connecting to the closest satellites. This eludes from previous statements focusing on further research between Samsung's BDS satellite system difference over Apple's QZSS satellite system.

Diving deeper into tests involving airplane mode would be another option. It was touched briefly with the last two tests administered and could be expanded to acquire more of overall determination of what processes may be happening in the background. Test on solely WIFI GPS coordinates would be beneficial to see the accuracy of device is a factor to known WIFI router locations. With the implementation of 5G this could become a trend in GPS accuracy.

VI. CONCLUSION

This study came forth with the intention to determine how accurate photo GPS data is from cellular devices compared to GPS coordinates from a standalone GPS unit in different environments. It was administered in two different ways to determine location accuracy, utilize calibrated known location coordinates and test airplane mode possible restrictions to provide a valid data set.

Distance errors, elevation errors and anomalies were addressed. When these errors were compared to devices to see what trends or accuracy could be revealed. It was mainly addressed that device accuracies depended on different factors. The type of environment, cell service and other functions that may be going on in the background of the device could contribute to the cause of these anomalies. It cannot be said if one device is more accurate than the other for this reason.

Satellite systems that Apple and Samsung use within their device architecture were addressed and provided results that displayed different GPS coordinates and elevation profiles. Suggesting that Apple and Samsung satellite choice may excel in different environment types and each device could be useful in different ways depending on the environment.

Airplane mode was experimented in administering tests. The first series of tests had devices with cell service active first then switched over to airplane mode. The second series of tests had the device powered off with airplane mode and powered back on with airplane mode active. It was found that depending on the device location settings, determines how fast the device may acquire a GPS coordinate. Both series of tests types and still produced results that led to a GPS coordinate being created. However, there is still a chance that after a device has been powered on and initial photos taken. There will not be a GPS coordinate produced depending on location settings used.

Environment tests were administered and does play a role in devices being able to acquire an accurate GPS coordinate and elevation profile. Throughout tests it was displayed that devices favored an urban environment for GPS accuracy and least favored a rural environment. Many anomalies were involved in each test and seemed each device exceled in certain environments differently than others.

Ultimately, many considerations come into play with GPS accuracy on smartphones. From research, it should be considered that claims made from GPS data in image files should be examined carefully. All factors of cell service, WIFI connection, environment and device models play a role of an overall GPS coordinate created from a device. A GPS coordinate could be accurate or can have a random anomaly applied to it due to one of these factors. It has been displayed that different outputs of GPS coordinates are produced by different devices. Additionally, these outputs can be produced by simply having a cellular device in airplane mode. Different devices excel in different types of environments relating to rural, suburb and urban areas.

Photo GPS data can be very beneficial in an investigation, especially if other forensic practices or key information of an investigation support any findings from GPS image data. From different anomalies previously addressed, having a validation standard implemented would be beneficial for the digital forensics community to have best practices set into place for use of EXIF image data. Even having a clearinghouse of cellular devices being tested against current GPS satellites would be a benefit for the digital forensic community. This type of GPS data within images will become even more popular with new technologies being implemented in our way of life.

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