"University of Turku Technical Reports, No.11 — August 2016"

EVALUATION OF THE GPS ACCURACY OF TABLETS

Leo Sakari | Mikko Forsman | Mika Taskinen | Tero Säntti | Teijo Lehtonen

Leo Sakari
University of Turku, Technology Research Center, 20014 Turun yliopisto, Finland
leo.sakari@utu.fi

Mikko Forsman
University of Turku, Technology Research Center, 20014 Turun yliopisto, Finland
mikko.forsman@utu.fi

Mika Taskinen
University of Turku, Technology Research Center, 20014 Turun yliopisto, Finland
mika.taskinen@utu.fi

Tero Säntti
University of Turku, Technology Research Center, 20014 Turun yliopisto, Finland
tero.santti@utu.fi

Teijo Lehtonen
University of Turku, Technology Research Center, 20014 Turun yliopisto, Finland
teijo.lehtonen@utu.fi

trc.utu.fi

ISSN 2341-8028 | ISBN 978-951-29-6561-8

Technology Research Center

Turun yliopisto
University of Turku

Abstract

Augmented Reality (AR) applications often require knowledge of the user's position in some global coordinate system in order to draw the augmented content to its correct position on the screen. The most common method for coarse positioning is the Global Positioning System (GPS). One of the advantages of GPS is that GPS receivers can be found in almost every modern mobile device.

This research was conducted in order to determine the accuracies of different GPS receivers. The tests included seven consumer-grade tablets, three external GPS modules and one professional-grade GPS receiver. All of the devices were tested with both static and mobile measurements. It was concluded that even the cheaper external GPS receivers were notably more accurate than the GPS receivers of the tested tablets. The absolute accuracy of the tablets is difficult to determine from the test results, since the results vary by a large margin between different measurements. The accuracy of the tested tablets in static measurements were between 0.30 meters and 13.75 meters.

Contents

1 Introduction

1.1 Background

The location of the user is often required in augmented reality (AR) applications to initialize augmented content to its correct position on a screen. Determining the initial position as accurately as possible is very important, since inaccuracy in estimating the initial position will cause the augmented content to be shown in the wrong place. Determining the position of the user in world coordinates is required in most markerless tracking systems, in which an initial position can not be derived from any pre-defined targets.

Many AR applications only require knowledge of a pose in a local coordinate system. This approach is fine in some small-scale applications, but it has its drawbacks, especially in large-scale use cases (e.g. construction sites). Setting up a custom positioning system often requires custom hardware and software, which can be difficult especially when developing applications for consumer-grade mobile devices. Using the global coordinate system also makes it easier to use the same system everywhere, since there is no need to set up a positioning system for each site where the application is used.

One of the most common positioning methods is the Global Positioning System (GPS). A major advantage in using GPS is that GPS receivers are available in almost all modern mobile devices. However, the accuracy of GPS can vary by a large margin and its accuracy is easily disturbed if the line-of-sight to the GPS satellites is obstructed. Some professional-grade GPS receivers report accuracies in the range of one centimeter, whereas the accuracy of basic consumer-grade mobile devices' GPS is usually reported to be in the range of a few meters. In order to find out if any consumer-grade mobile devices' GPS are accurate enough for AR use, a study was conducted to determine the GPS accuracies of different devices.

1.2 Positioning requirements for augmented reality

The error in the GPS accuracy has to be as small as possible so that the augmented content will appear in the correct initial position. In visualization tasks, where centimeter-level accuracy is not always needed, errors below one meter might be considered acceptable.

If multiple GPS locations are measured, GPS can also be used for determining the orientation (i.e. viewing direction) of the user. The orientation estimation can be accomplished by placing the used device on a known position, and pointing the device at a second known position. However, in order to attain an accurate estimation, GPS accuracy has to be high. The error in orientation estimation is proportional to the error in the used GPS locations. For example, if the required orientation accuracy is 1 degree, and the error in GPS is guaranteed to be below 10 meters, the two locations would have to be almost 1.1 kilometers apart to guarantee the required accuracy of 1 degree. If the maximum error of the GPS was 1 meter, the required distance would still have to be 115 meters.

2 Measurement Setup

2.1 Measured devices

Seven tablets, three external GPS modules and one professional-grade GPS receiver were tested. Each of the mobile devices were tested with both a native application, and a Unity3D [1] application. Unity3D applications were tested in order to find out whether Unity3D does filtering on the GPS data. The external GPS receivers were tested to compare them to the GPS receivers found in mobile devices. The professional-grade receiver Javad Triumph-2 [2] was used to serve as a reference for the other devices.

The following consumer-grade tablets were tested:

- Apple iPad Air 1 [3]
- Apple iPad Air 2 [4]
- Apple iPad 3 [5]
- HTC Nexus 9 [6]
- Samsung Galaxy Tab S2 [7]
- Sony Xperia Z4 Tablet [8]
- Nvidia Shield [9]

The following external GPS modules were tested:

- Garmin GLO [10]
- Ublox NEO-7P [11]
- Bad Elf GPS for Dock Connector [12]

The measurement data was collected with simple native and Unity3D applications that were developed for both iOS and Android devices. A modified version of the NTRIP client by Lefebure [13] was used with the Triumph-2 GPS receiver and the Garmin GLO. The modifications to the application were made in order to push the measurement data to a server. The Ublox NEO-7P was operated with custom software developed for a Windows laptop.

2.2 Static measurements

Static measurements were done by positioning the devices one by one on a known GPS location[1] that was selected from a map [14] provided by the city of Turku. A tripod with a tablet grip was set at the location so that each of the devices could be measured at the exactly same position. The static measurement setup is shown in Figure 1. The location was selected from a wide-open area with as few as possible tall, obstructing objects to minimize the effect of disturbance. Each device was measured for two minutes at a time. The measurements were done twice with eighteen hours in between to take into consideration the random nature of the signal strengths, caused by e.g. varying GPS satellite positions and weather conditions. Longer measurements would have resulted in more data, but when considering AR applications, standing still for multiple minutes just to get an accurate initialization is not an option.

2.3 Mobile measurements

Each device was carried through a predefined ~340 meter route. This test was conducted to find out whether there are any notable differences in accuracies when a stationary position can not be maintained. Two static spots were also selected from the route, where the measured device was held in place for 10 seconds. Javad Triumph-2 RTK (real-time kinematic) receiver was used as the reference measurement for the rest of the devices, since the commercial receiver (accompanied with an RTK correction signal [15]) promised an accuracy in the range of a few centimeters. An accurate device was required as a reference to account for involuntary deviations in the walking route during the measurements. Each of the measurements was done with the measured device being attached to the Triumph-2 via a tablet grip. Triumph-2 and the tablet grip can both be seen in Figure 2.

[1]Lat: 60.444588 Lon: 22.292784

Figure 1: The tripod setup during static measurements.

Figure 2: Javad Triumph-2 and the tablet grip that were used in the mobile measurements.

3 Results

3.1 Static measurements

The static measurements were used for calculating average error values for each of the devices. The results for these measurements can be seen in Table 1 for native applications, Table 2 for Unity applications and Table 3 for external sensors.

Several average error values have been calculated for each measurement by dividing the two minute measurements into five slots, each corresponding to one fifth of the measurement period. These average error values are presented in the columns labelled Error(t_n), where n equals the index of the time slot. This was done to make accuracy deviations over time more apparent. Some of the devices only reported coordinates in the beginning of the measurements, and some devices reported identical coordinates through the measurements. This means that some filtering is performed on said devices.

For reference, a graphical representation of the static measurements can be found in Appendix A.

Device	**M. Id.** #	**Error(t_1)** (m)	**Error(t_2)** (m)	**Error(t_3)** (m)	**Error(t_4)** (m)	**Error(t_5)** (m)
Apple iPad 3	1	11,22	**5,63**	5,63	5,63	5,63
	2	42,48	5,30	**5,09**	5,09	5,09
Apple iPad Air	1	4,43	**3,86**	3,86	3,86	3,86
	2	9,21	7,73	4,00	**1,89**	1,89
Apple iPad Air 2	1	16,53	17,94	14,42	**13,75**	13,75
	2	30,70	**9,11**	9,11	9,11	9,11
Sony Xperia Z4 Tablet	1	9,40	8,66	8,38	7,98	**7,56**
	2	12,17	12,47	12,28	11,98	**11,34**
Samsung Galaxy Tab S2	1	4,63	**3,32**	3,32	3,32	3,32
	2	**2,77**	2,77	2,77	2,77	2,77
NVIDIA SHIELD Tablet	1	**0,54**	0,54	0,54	0,54	0,54
	2	6,12	**3,55**	5,85	4,42	5,40
HTC Nexus 9	1	**10,19**	10,19	10,19	10,19	10,19
	2	2,59	**2,35**	2,35	2,35	2,35

Table 1: Average error in meters using native GPS applications. The first occurrence of the best accuracy is highlighted.

Device	M. Id. #	Error(t_1) (m)	Error(t_2) (m)	Error(t_3) (m)	Error(t_4) (m)	Error(t_5) (m)
Apple iPad 3	1	**4,98**	—	—	—	—
	2	**4,16**	—	—	—	—
Apple iPad Air	1	**10,27**	—	—	—	—
	2	**5,63**	—	—	—	—
Apple iPad Air 2	1	**2,02**	—	—	—	—
	2	**6,31**	—	—	—	—
Sony Xperia Z4 Tablet	1	4,75	4,75	4,75	4,75	**4,29**
	2	10,26	9,87	9,89	9,40	**8,73**
Samsung Galaxy Tab S2	1	**3,20**	3,20	3,20	3,20	3,20
	2	**2,57**	2,57	2,57	2,57	2,57
NVIDIA SHIELD Tablet	1	**0,30**	0,30	0,30	0,30	0,30
	2	7,37	10,76	7,32	5,87	**4,41**
HTC Nexus 9	1	6,81	**6,42**	6,42	6,42	6,42
	2	**6,75**	11,96	11,96	11,96	11,96

Table 2: Average error in meters using Unity GPS applications. The first occurrence of the best accuracy is highlighted. Apple devices only reported coordinates in the beginning of the measurement, resulting in missing coordinates ("—").

Device	M. Id. #	Error(t_1) (m)	Error(t_2) (m)	Error(t_3) (m)	Error(t_4) (m)	Error(t_5) (m)
Ublox NEO-7P	1	4,46	1,36	1,23	**0,61**	2,42
	2	3,05	**0,34**	0,54	1,46	1,32
Garmin GLO	1	2,56	**2,45**	3,36	4,11	2,74
	2	**1,19**	2,23	2,30	2,05	1,75
Badelf	1	8,66	7,56	7,51	7,41	**7,35**
	2	9,15	4,38	4,42	4,36	**4,03**

Table 3: Average error in meters using external GPS devices. The first occurrence of the best accuracy is highlighted.

3.2 Mobile measurements

The idea of the mobile measurements was to gather data that would make it possible to calculate error values over long periods of time and to create graphical representations of the measurements. A working RTK-GPS correction signal was needed to account for the random deviation in the reference device. However, technical issues with the correction signal meant that we could not gather the needed reference data for all different devices, making mathematical analysis between different devices unreasonable. Hence, accurate error values for the mobile measurements are not available. The problems with the correction signal can be seen clearly in Figure 4.

However, as plenty of preliminary measurements were completed, some observations can be made from the plotted data. The observations are in line with the results of the static measurements, as it clearly shows that the Javad Triumph-2—even without the correction signal—is notably more accurate than any of the tablet devices. The other external GPS receivers (Garmin GLO and Ublox-chip) also reported better accuracies compared to the mobile devices, while sometimes also surpassing the

Triumph-2. The defining feature for the tablet devices and the Bad Elf add-on is that their performance seemed to vary greatly depending on the day, time and weather.

On-device filtering was also evident during the mobile measurements, as nearly all devices performed better in the mobile measurements compared to the static measurements. Even though statistical data is not available, visual inspection of the plotted data revealed that none of the devices reported extreme (larger than five meters) deviation from the reference route. More pictures of the mobile measurements can be seen in Appendix A.

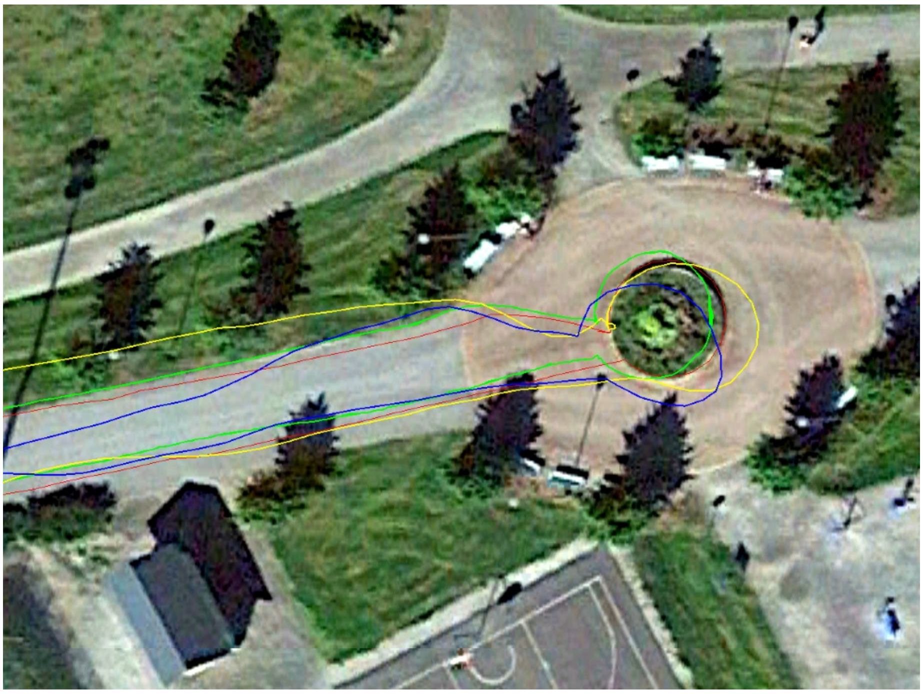

Figure 3: A subsample from the mobile measurements. Blue line is iPad Air 1, red line is Javad Triumph-2, yellow line is Sony Xperia Z4 Tablet, green line is Ublox

Figure 4: An image representing the effect of an RTK-GPS correction signal. The yellow line depicts Javad Triumph-2 with a working correction signal, the black line depicts the same device without a correction signal, and the red line depicts again the same device but with a bad signal quality. The red line can be seen bouncing between corrected and erroneous coordinates.

4 Conclusions

The accuracy of the GPS in consumer-grade tablets is not good enough for accurate initialization in AR applications. The accuracies of the devices vary too much and the errors are not systematic so they can not be compensated for. However, even inaccurate GPS coordinates can be useful in some scenarios; for example, they could be used to get a rough estimation of the users' location, which in turn could be used to download a 3D map of the area that is used for more accurate pose estimation.

While doing the static measurements, most devices reported different wildly varying coordinates even when standing still. The amount of deviation seemed to vary day-to-day and was different between devices. Even the cheapest devices sometimes managed to report very accurate coordinates (sometimes surpassing the external sensors), but most of the time it seemed that the consumer-grade devices were struggling to report accurate (less than five meters of error) coordinates.

Another observation was that some of the devices did on-device filtering to the received GPS data. Some devices reported the exact same GPS-coordinates during extended static measurement periods and most of the devices performed noticeably better during the mobile measurements, indicating the use of prediction filtering. This sort of functionality needs to be taken into account when developing applications that require specific, accurate GPS-functionality.

While specialized equipment (even relatively cheap) can generally attain much better accuracies and higher reliability than consumer-oriented tablet devices, even the most accurate devices were not without flaws. At best, centimeter-level accuracy could be attained, but reliable operation always required a working correction signal. Whenever the correction signal was not working, even the professional-grade reference device, Javad Triumph-2, reported high random deviation.

Appendix A Figures

Figure 5: Lines drawn of each static measurement. The "wandering" lines clearly show how each device reported varying coordinates during the measurements.

Figure 6: Average positions reported by the measured devices and the location of the reference point (the red pin) during static measurement 1.

Figure 7: Average positions reported by the measured devices and the location of the reference point (the red pin) during static measurement 2.

Figure 8: Mobile measurements for Apple iPad 3. The red line is the reference route, the yellow line is the native application measurement and the blue line is the Unity3D measurement with one meter step.

Figure 9: Mobile measurements for Apple iPad Air. The red line is the reference route, the yellow line is the native application measurement and the blue line is the Unity3D measurement with one meter step.

Figure 10: Mobile measurements for Apple iPad Air 2. The red line is the reference route, the yellow line is the native application measurement and the blue line is the Unity3D measurement with one meter step.

Figure 11: Mobile measurements for Sony Xperia Z4 Tablet. The red line is the reference route, the yellow line is the native application measurement and the blue line is the Unity3D measurement with one meter step.

Figure 12: Mobile measurements for Samsung Galaxy Tab S2. The red line is the reference route, the yellow line is the native application measurement and the blue line is the Unity3D measurement with one meter step.

Figure 13: Mobile measurements for NVIDIA SHIELD Tablet. The red line is the reference route, the yellow line is the native application measurement and the blue line is the Unity3D measurement with one meter step.

Figure 14: Mobile measurements for HTC Nexus 9. The red line is the reference route, the yellow line is the native application measurement and the blue line is the Unity3D measurement with one meter step.

Figure 15: Mobile measurements for Ublox NEO-7P. The red line is the reference route, the yellow line is the native application measurement and the blue line is the Unity3D measurement with one meter step.

Figure 16: Mobile measurements for Garmin GLO. The red line is the reference route, the yellow line is the native application measurement and the blue line is the Unity3D measurement with one meter step.

Figure 17: Mobile measurements for Bad Elf GPS for Dock Connector. The red line is the reference route, the yellow line is the native application measurement and the blue line is the Unity3D measurement with one meter step.

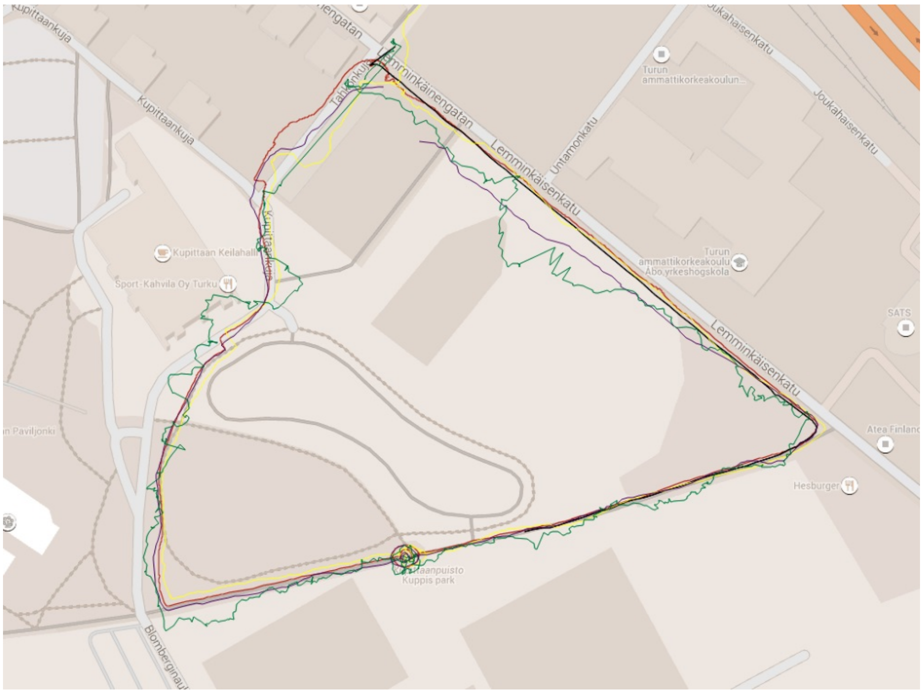

Figure 18: Preliminary mobile measurement test. The black, red, yellow, purple and green lines represent Javad Triumph-2, Garmin GLO, Nvidia Shield, Nexus 9 and an LG Spirit mobile phone respectively.

Acknowledgements

The research has been carried out during the MARIN2 project (Mobile Mixed Reality Applications for Professional Use) funded by Tekes (The Finnish Funding Agency for Innovation) in collaboration with partners; Defour, Destia, Granlund, Infrakit, Integration House, Lloyd's Register, Nextfour Group, Meyer Turku, BuildingSMART Finland, Machine Technology Center Turku and Turku Science Park. The authors are from Technology Research Center, University of Turku, Finland.

Bibliography

[1] Unity Technologies SF. *Unity - Game Engine*. http://unity3d.com/. [Accessed 23.6.2016].

[2] Javad GNSS Inc. *TRIUMPH-2*. https://www.javad.com/jgnss/products/receivers/triumph-2.html. [Accessed 1.6.2016].

[3] Apple Inc. *iPad Air 1 - Technical Specifications*. https://support.apple.com/kb/SP692?viewlocale=en_US&locale=en_US. [Accessed 1.6.2016].

[4] Apple Inc. *iPad Air 2 - Technical Specification*. https://support.apple.com/kb/SP708?viewlocale=en_US&locale=en_US. [Accessed 1.6.2016].

[5] Apple Inc. *iPad (3rd generation) - Technical Specifications*. https://support.apple.com/kb/SP647?locale=en_US. [Accessed 1.6.2016].

[6] HTC Corporation. *Google Nexus 9 Specs and Reviews | HTC United States*. http://www.htc.com/us/tablets/nexus-9/. [Accessed 1.6.2016].

[7] Samsung Group. *Samsung Galaxy Tab S2 - The Official Samsung Galaxy Site*. http://www.samsung.com/global/galaxy/galaxy-tab-s2/. [Accessed 1.6.2016].

[8] Sony Mobile Communications. *Xperia™ Z4 Tablet | Android Tablet - Sony Xperia (Global UK English)*. http://www.sonymobile.com/global-en/products/tablets/xperia-z4-tablet/. [Accessed 1.6.2016].

[9] Nvidia Corporation. *NVIDIA SHIELD | Android TV, Tablet, and Portable*. https://shield.nvidia.com/. [Accessed 1.6.2016].

[10] Garmin Ltd. *GLO™ | Garmin*. https://buy.garmin.com/en-US/US/prod109827.html. [Accessed 1.6.2016].

[11] u-blox Holding AG. *NEO-7P | u-blox*. https://www.u-blox.com/en/product/neo-7p. [Accessed 1.6.2016].

[12] Bad Elf. *Bad Elf GPS for Dock Connector*. http://bad-elf.com/collections/plug-in-gps/products/be-gps-1000. [Accessed 1.6.2016].

[13] Lefebure. *NTRIP client*. http://lefebure.com/software/ntripclient/. [Accessed 9.8.2016].

[14] Turun Kaupunki. *Turun karttapalvelu*. http://opaskartta.turku.fi/. [Accessed 1.6.2016].

[15] SmartNet Part of Hexagon. *SmartNet | Home*. http://www.smartnet-eu.com/. [Accessed 1.6.2016].