Performance Evaluation of Low-Cost GPS Receivers

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Abstract
The GPS module expands the system to low-cost devices by producing low-price and energy-efficient devices, including being able to provide L1 satellite data equivalent to geodetic GPS. Although there has been a lot of research done on low-cost GPS evaluations around the world, similar feasibility studies need to be conducted in various locations and countries. Because GNSS satellites are not stationary and keep moving in space, and this can affect the signal quality and reliability of GPS receivers. In this study, an evaluation of the performance of the U-Blox M8T as a low-cost GPS receiver with a Geodetic receiver as a comparison. Using two different measurement methods, static and kinematic method, and T-test as an analysis of results. U-Blox M8T still cannot be used as GPS observation when compared to the geodetic receiver.

1. Introduction

Survey and mapping technology has recently experienced rapid development. GPS technology has been widely used for surveying and mapping activities with a high degree of accuracy. The GPS working system can run smoothly by utilizing the sending of signals from GPS satellites to the receiver. Not only to determine the position of a point, but GPS is also used to study the characteristics of changes in the ionosphere after an earthquake (Cahyadi and Prasetyo, 2019 and Cahyadi et al., 2018), changes in the ionosphere during volcanic activity (Cahyadi et al., 2020), and monitoring of sea level and tsunami levels (Muslim et al., 2020).

The use of GPS is certainly not with various obstacles. There are several obstacles that affect the accuracy of the data that cause GPS to be inaccurate, such as Multipath (Suzuki and Kubo, 2013), Cycle-Slip (Gu and Zhu, 2017), tropospheric bias (Cahyadi et al., 2017) and ionospheric bias (Cahyadi, 2014). Besides that, there are also efforts to reduce obstacles in GPS measurements, even providing a more accurate position such as by providing the Ionosphere-free Combination formula to reduce ionosphere bias (Cahyadi, 2014), and also integrating GNSS with IMU to get a position that is more accurate (Cahyadi and Rwabudandi, 2019). However, sometimes the use of GPS is also very limited because the components of a high-precision GPS receiver have a very high price. The GPS module expands the system to low-cost devices by producing low-price and energy-efficient devices, including being able to provide L1 satellite data equivalent to geodetic GPS. The GPS module is already available for around US $ 300 (Shannon et al., 1998). However, research is needed to test the Low-cost accuracy receiver to be used equivalent to the geodetic receiver.

(Keskin et al., 2009) analyzed the low-cost GPS receiver with a static method resulting in a standard deviation of less than 1.5 m, besides that the low-cost GPS receiver was tested by the circular area kinematic method and straight-line kinematics. For the circular area kinematic method using two circles with a diameter of about 40.7 m and 70.4 m marked in the open plane, the average standard deviation results are 1.350 m and 1.575 m for smaller and larger circles. Whereas the straight line kinematic method is performed at 2-speed levels, 1.5 m/s, and 2.5 m/s, the average standard deviation results are 1.393 m for low speed and 0.967 m for high speed.

Low-cost GPS receiver testing using RTK and kinematic methods has been done by (Skoglund et al., 2016) by testing three types of low-cost receivers, namely Skytraq NS-RAW, OxTs RT3002, and Ublox M8N. Static method testing shows the resulting standard deviation < 1 m, and the kinematic method reaches 20 cm accuracy in certain conditions for all types of low-cost receivers. During the measurement, there were more than ten satellites visible at any given time, and no multipath was observed. (Odolinski and Teunissen, 2017) use low-cost GPS Ublox EVK-M8T, which is connected with two different types of antennas, namely Patch antenna and Trimble Zephyr 2 antennas. The measurement results using the low-cost GPS + Patch antenna RTK method obtained a code accuracy of 49 cm and a phase accuracy of up to 2 mm. While the measurement results of low-cost GPS + Trimble Zephyr 2 antennas with the same method obtained a code accuracy of 34 cm and a phase accuracy of 2 mm. This is because patch antennas are proven to be less effective in receiving signals and handling multipath compared to survey level GPS antennas (Pesyna et al., 2014). Similar research was also carried out (Cahyadi and Handoko, 2019) by analyzing the accuracy and precision between the low-cost GNSS K706 Oem Board receiver and the Topcon HiperPro geodetic receiver. The data recording method used in this research is Real-Time Kinematic (RTK) which records 3 points of observation location. In this study, the results of the calculation of the standard deviation of the low-cost K706 have better quality than the Topcon HiperPro geodetic receiver. The results of the data recording were also analyzed the RMSE value obtained for the low-cost receiver vertical RMSE value was better than the geodetic receiver, while the horizontal RMSE value both had the same value.

Although there has been a lot of research done on low-cost GPS receiver evaluations around the world, similar feasibility studies need to be conducted in various locations and countries. Because GNSS satellites are not stationary and keep moving in space, and this can affect the signal quality and reliability of GPS receivers. Therefore, the purpose of this study is to test and evaluate Low-cost GPS receivers with two different methods, namely static and kinematic method.

2. Low-Cost GPS, Geodetic GPS Receivers and Antenna

A low-cost GPS receiver was procured, the cost of these receivers ranges from approximately $75 to $100. The geodetic receiver that is used as a comparison is Topcon Hiper Pro, below some basic properties of these receivers are presented. The antenna that uses is Topcon PGA-1 (Table 1). This antenna provides dual-frequency GPS + Glonass. Topcon PGA-1 has the precision micro center antenna technology to obtain the highest horizontal and vertical accuracies.

3. Research Location

The research location used in this study is Surabaya City. Geographically located at coordinates 7° 09′00″- 7° 21′00″ S and 112°36′00″- 112°54′00″ E. Figure 1 shows the location of the three benchmark points used in this study are TKGM, SIER, and WNKR. TKGM is the GPS base region of ITS 1 and has a central role as a binding point in this measurement, TKGM is located in the ITS Geomatics engineering department (Figure 1a), where the level of land subsidence that occurs in the area is -1.709 cm/year (Anjasmara and Mauradhia, 2019). SIER is located in the Rungkut Industri area (Figure 1a), where it is an area that has a high level of land subsidence reaching -3.418 cm/year (Anjasmara and Mauradhia, 2019). And WNKR, which is located in front of the Joyoboyo UPTD Terminal (Figure 1a), where the area is recorded to have a reasonably high level of land subsidence reaching -3.402 cm/year (Anjasmara and Mauradhia, 2019) because many are traversed by large vehicles with large loads too. The three benchmark points are used in the static Post Processing methods.

Table 1: Specification of Low-cost Receiver Ublox M8T and Geodetic Receiver Topcon HiperPro

Category	Ublox M8T	GPS Topcon Hiper Pro
Systems and augmentation supported	GPS, GLONASS, BeiDou, Galileo	GPS, GLONASS
Channels	72	40
Signals	Single Frequency (L1)	Dual Frequency (L1+L2)
Horizontal Position Accuracy	Autonomous: 2.5 m	Static, Rapid Static : 3mm+ 0.5ppm (x baseline length)
	SBAS: 2.0 m	RTK: 10mm+ 1.0ppm
Update Rate	10 Hz	20 Hz
Cost	75 - 100 USD	3,150 USD

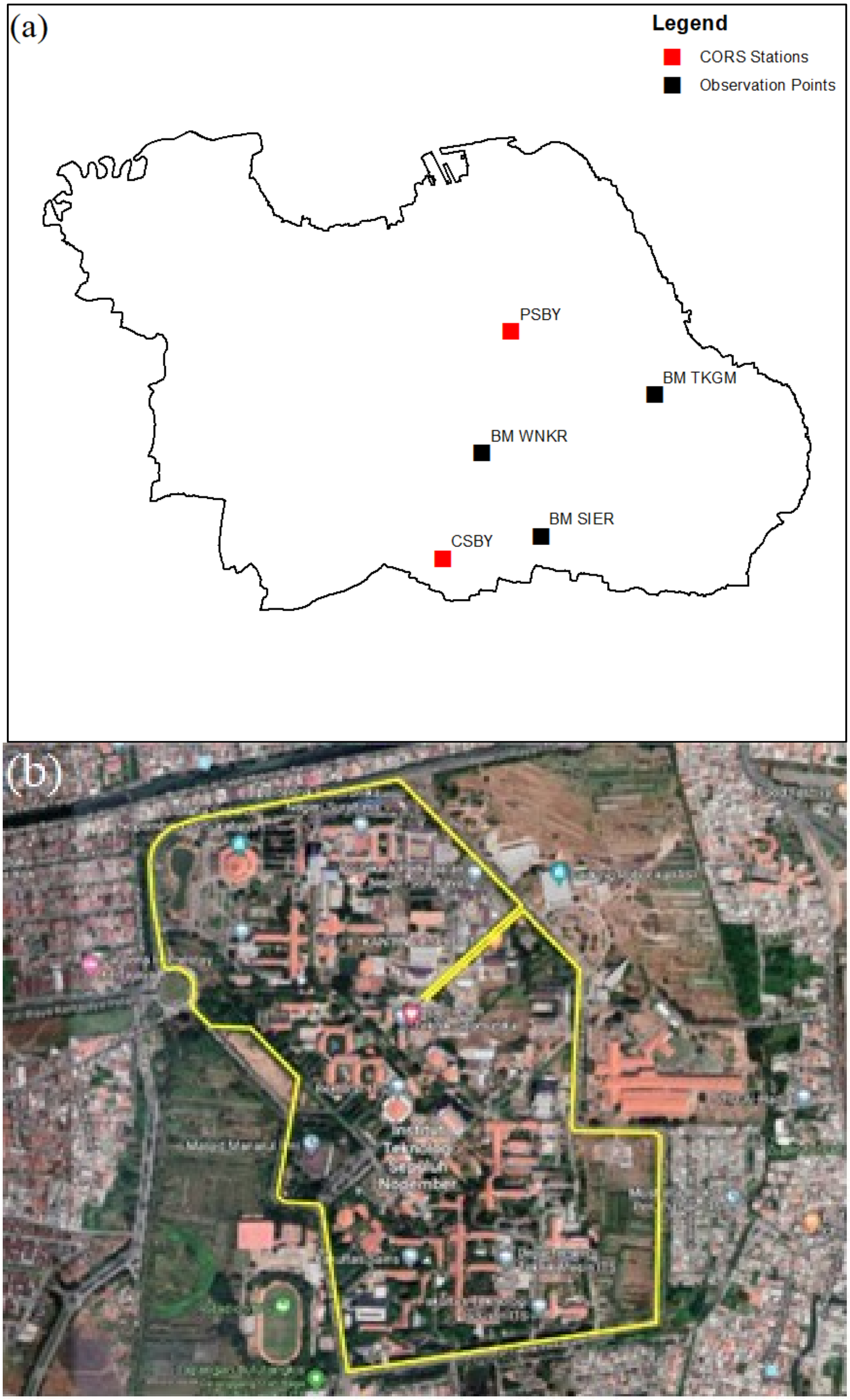

Figure 1: The location of this research (a), Track the kinematic method (b)

In GNSS observations using the static method, the receiver will be connected to a CORS (Continuously Operating Reference Stations) station, which functions to provide measurement correction data. The CORS used in this measurement are named CORS PSBY and CSBY. The two results of the measurements with the help of the CORS station will be evaluated. For Kinematic measurements done by placing the device on the vehicle and around the ITS Campus (Figure 1b) for both receivers. This method is intended to test the suitability of tracking between a low-cost receiver with Geodetic GPS receivers.

This study uses 2 CORS points, CSBY and PSBY, as the binding point of measurement. CORS CSBY is located at the Telkom Injoko Office located in Gayungan District, the distance between CORS CSBY and TKGM, SIER, and WNKR points used in this study is 9.86 KM, 3.70 KM, and 4.10 KM. The coordinates of the observation points are shown in Table 2.

Table 2: Coordinate of Observation Point

Observation Point	Coordinate	
	Latitude	Longitude
TKGM	7.279829633° S	112.795050738° E
SIER	7.326904353° S	112.757043516° E
WNKR	7.299235189° S	112.737403054° E

Whereas CORS PSBY is located in Surabaya City Government Office located in Genteng District, the distance between CORS PSBY and TKGM, SIER, and WNKR points used in this study is 5.76 KM, 7.43 KM, and 4.65 KM. The selection of the baseline length is intended to test the strength of the U-Blox sensor based on the length of the baseline. The results obtained were then carried out statistical tests to see the comparison between GPS U-Blox with GPS Topcon Hiper Pro. The results of the coordinate values and the results of the standard deviation are performed by the F test first to see whether the results are homogeneous or not, and then from these results, the T-Test calculation is used to test whether the GPS U-Blox can be used equivalent to GPS Geodetic.

4. Experiment and Analysis

In this research, the data measurements were carried out by using two receivers on three different locations are TKGM, SIER, and WNKR. The data measurement is carried out within about two hours with an interval time of one second within 15 degrees of cut-off elevation. The result of measurement data indicates the information about the number of satellites every second, the quality of measurement data, and the changes of coordinate every second. The analysis of measurement data shows an overview of the factors when measuring data affects the result get. Figure 2 shows the number of satellites every second and the quality of measurement data on TKGM. as well as an overview of the change in coordinates every second on TKGM is shown in Figure 3. This measurement data got a different result on the northing coordinate (the highest to the lowest) is about 4 m using low-cost receiver U-Blox M8T and is about 5 cm using geodetic receiver Topcon HiperPro. At the same time, the different result on the easting coordinate (highest to lowest) is about 30 m using low-cost receiver Ublox M8T and is about 5 cm using Topcon HiperPro.

The number of satellites per second and the quality of the measurement data on SIER are shown in Figure 4. Also an overview of the change in coordinates every second in SIER is shown in Figure 5. This measurement data got a different result on the northing coordinate (the highest to the lowest) is about 1 cm using low-cost receiver U-Blox M8T and is about 2 cm using geodetic receiver Topcon HiperPro. At the same time, the different result on the easting coordinate (highest to lowest) is about 2 cm using low-cost receiver Ublox M8T and is about 3 cm using Topcon HiperPro.

Figure 6 shows the number of satellites every second and the quality of measurement data on WNKR. as well as an overview of the change in coordinates every second on WNKR is shown in Figure 7. This measurement data got a different result on the northing coordinate (the highest to the lowest) is about 60 cm using low-cost receiver U-Blox M8T and is about 2 m using geodetic receiver Topcon HiperPro. At the same time, the different result on the easting coordinate (highest to lowest) is about 2 m using low-cost receiver Ublox M8T and is about 1 m using Topcon HiperPro.

4.1 The Analyze of Measurement Result

The result measurement data on three different locations (TKGM, SIER, and WNKR) shows the result that the low-cost receiver U-Blox M8T got the result more imperfect than the geodetic receiver Topcon HiperPro. That result can be effect by something like the specification of the receiver, the measuring data method, technical implementation, etc. Ublox M8T is a receiver that has to provide a single frequency signal. Single-frequency has any weakness like a slow to resolve the phase ambiguity on begin measurement and after cycle slip (Cosser, 2003). Receiver single frequency also needs the modeling of the ionosphere, which is different from receiver dual-frequency that's don't need the modeling of the ionosphere (Skournetou, 2011).

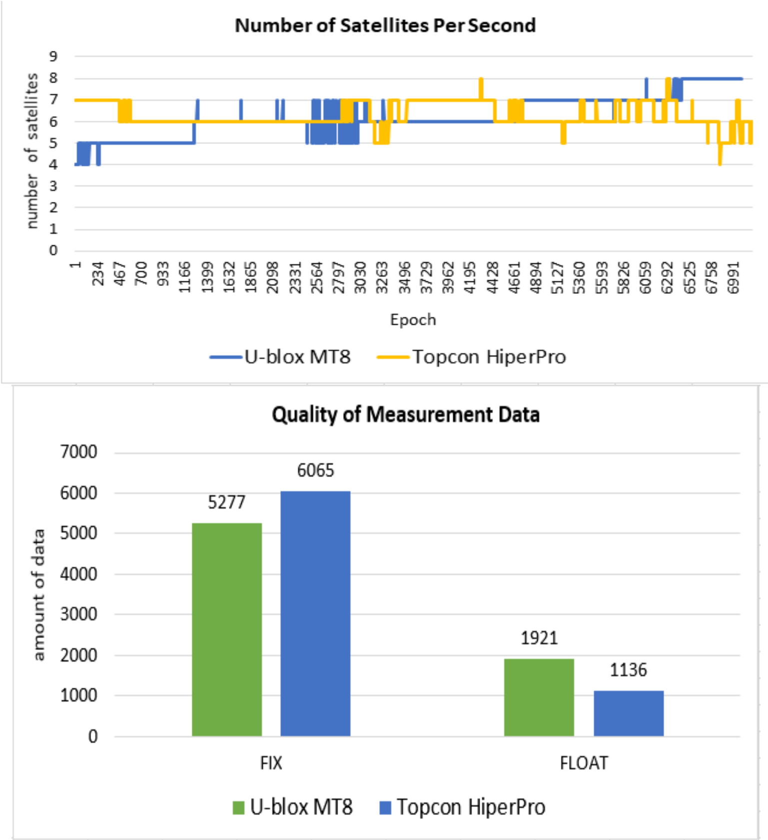

Figure 2: Graphic of the number of satellites and The quality of measurements data on TKGM

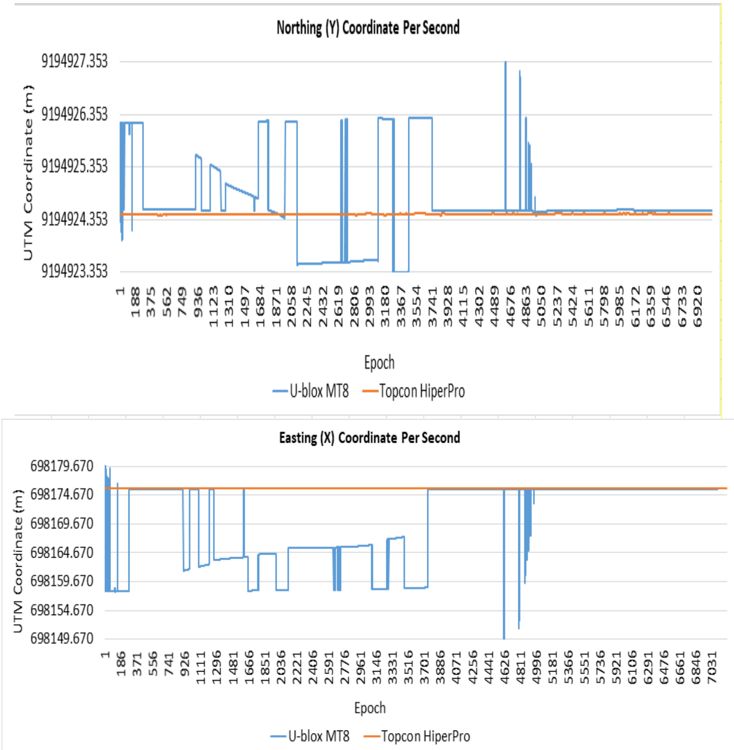

Figure 3: Graphic os the changes of coordinate every second (epoch) on TKGM

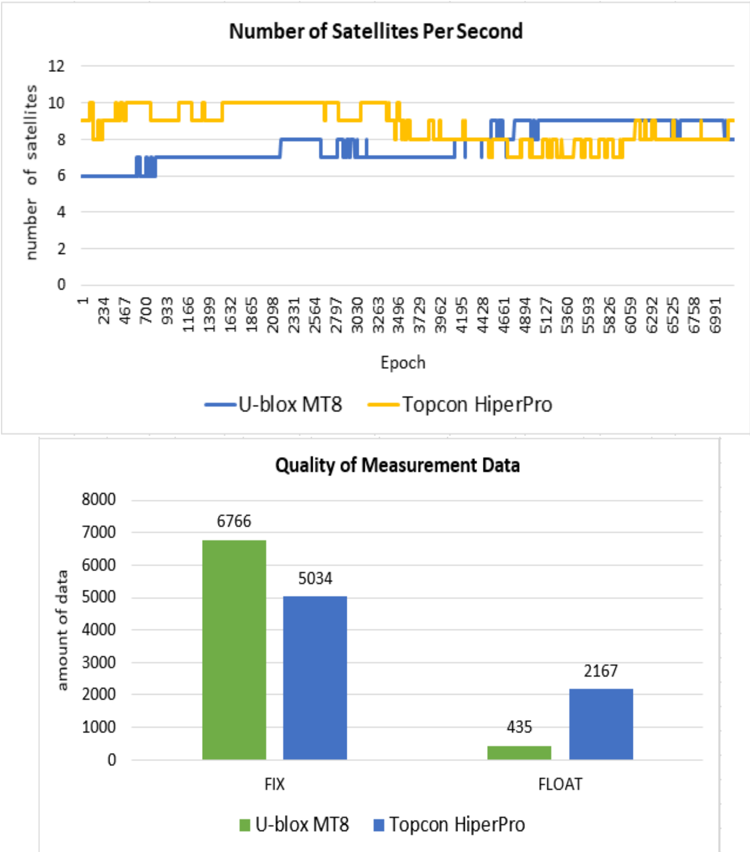

Figure 4: Graphic of the number of satellites and The quality of measurements data on SIER

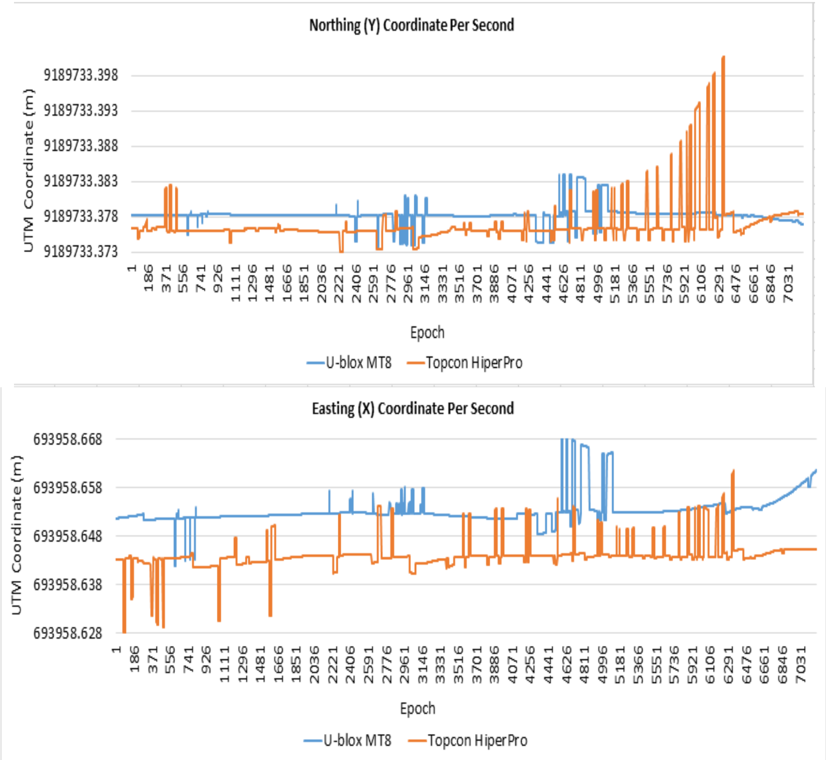

Figure 5: Graphic os the changes of coordinate every second (epoch) on SIER

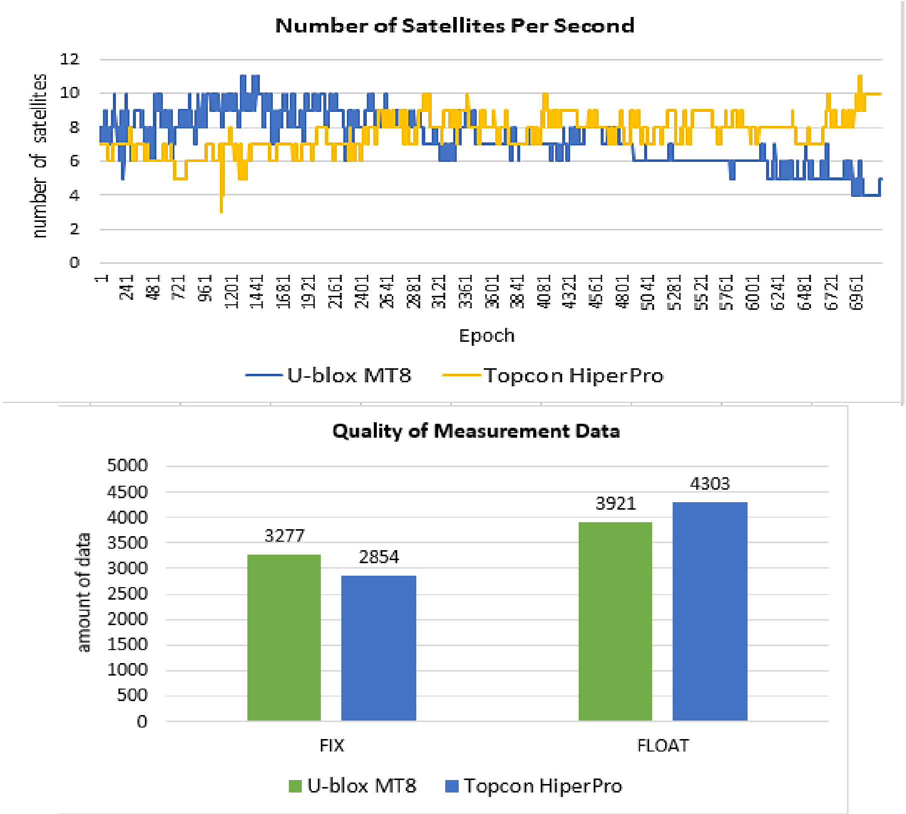

Figure 6: Graphic of the number of satellites and The quality of measurements data on WNKR

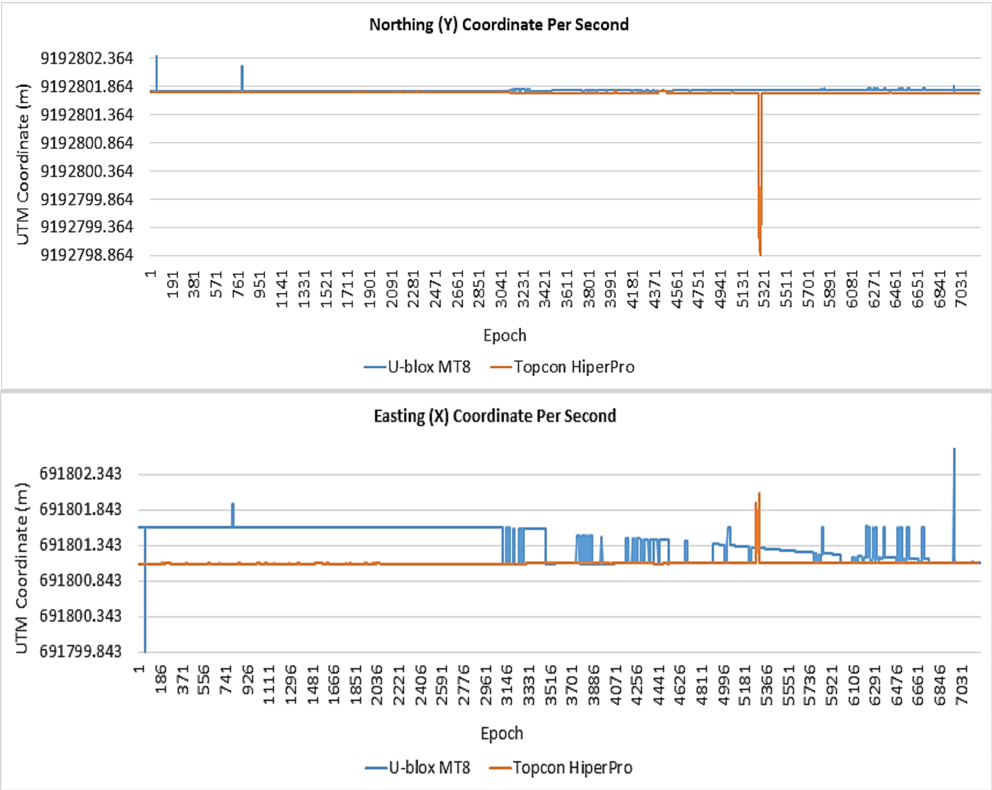

Figure 7: Graphic os the changes of coordinate every second (epoch) on WNKR

The Topcon HiperPro (dual frequency) receiver has the ability to eliminate ionosphere errors by using Ionosphere-free Combination (L3) with the following equation (Cahyadi 2014):

$$L_3 = f_1^2/\,(f_1^2 - f_2^2)L_1 - f_2^2/\,(f_1^2 - f_2^2)L_2$$
Equation 1

Where: f1 and f2 are the frequencies of the L1 band and L2 band of the carrier wave.

The research location also has some effect on the result. The two places (SIER and WNKR) have a close range with tall buildings and some trees. These objects can give the cycle slip effect on the result, while the result obtained imperfect because it includes some errors. The measuring that has a close range with that object also gives some effect to make inaccurate calculations or do not have enough satellites in common with the base station for the correction term to be valid. So that the data obtained has sufficient float data quality (solution) when compared to fixed data (solutions) (Hall, 2010).

5. Result

5.1 Static Observation

Table 3 shows that the horizontal standard deviation value of a low-cost receiver can reach 0.735 cm at baselines B1 and B4, which have lengths of 3.7 Km and 7.63 Km. While the vertical standard deviation achieved is 0.843 cm at the same baseline. The resulting standard deviation depends on the choice of measurement location, at baseline B1 and B4, the location of the SIER rover point is in an open park area that has a multipath effect lower than the other rover points. Whereas the TKGM and WNKR points are located in an area close to high-rise buildings, this causes a multipath effect greater than the measurements in SIER. The impact of choosing the measurement location also affects measurements using a geodetic receiver. Based on Table 3, the standard deviation values for the rover at SIER points (baseline B1 and B4) show relatively small values of 3.43 cm and 3.70 cm.

In Figure 8, it can be seen the standard deviation graph of measurement results using a low-cost receiver and geodetic receiver. Based on the graph, it can be seen the horizontal and vertical standard deviation values of the low-cost receiver are smaller than the geodetic receiver, with a difference of approximately 2 cm to 4 cm. Even on the graph at the baseline length of 9.86 Km, the standard deviation value of the low-cost receiver is better than the geodetic receiver. The T-test conducted in this study uses a significance level of 0.05, a two-way test, and a degree of freedom 12. If Ho is accepted and Ha is rejected, then the measurement results between the low-cost receiver and geodetic receiver have equivalent measurement results, but if Ho is rejected and Ha is accepted, then measurement results between a low-cost receiver and geodetic receiver have significant differences in measurement results.

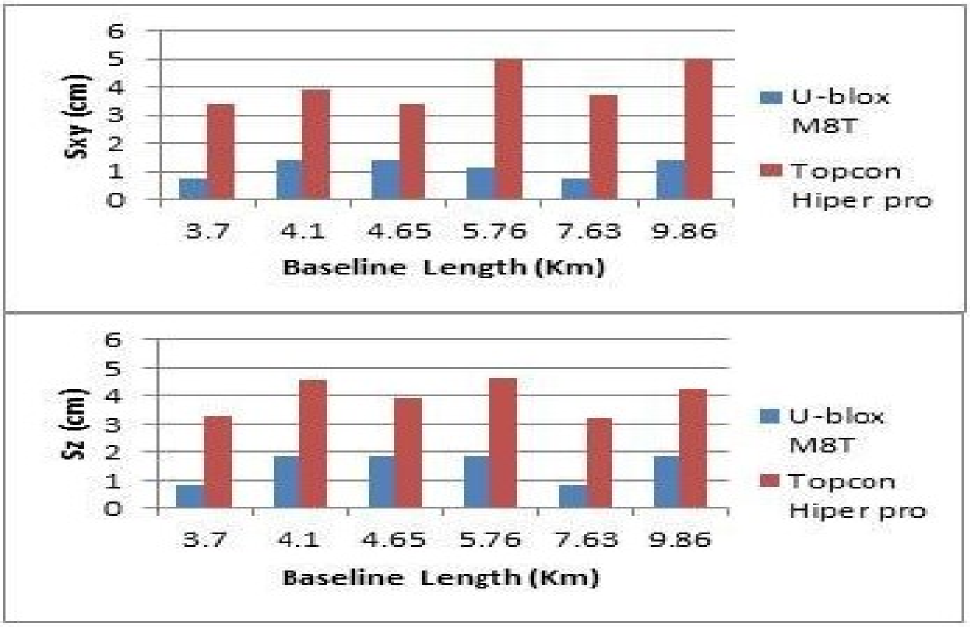

Figure 8: Horizontal standard deviation (up) and Vertical standard deviation (bottom) at each baseline

Table 3: Standard deviation values from the low-cost receiver and geodetic receiver measurements at each baseline

Benchmark - CORS	Time	Receiver	Standard Deviation		
			Northing (m)	Easting (m)	Ellipsoid Height (m)
TKGM - CSBY	1 hour	Ublox	0.0117	0.0243	0.0367
		Topcon	0.0363	0.0750	0.0770
Difference			0.0247	0.0507	0.0403
TKGM - CSBY	2 hour	Ublox	0.0057	0.0127	0.0187
		Topcon	0.0203	0.0460	0.0427
Difference			0.0147	0.0333	0.0240
TKGM - PSBY	1 hour	Ublox	0.0110	0.0197	0.0347
		Topcon	0.0317	0.0643	0.0673
Difference			0.0207	0.0447	0.0327
TKGM - PSBY	2 hour	Ublox	0.0053	0.0103	0.0183
		Topcon	0.0217	0.0450	0.0460
Difference			0.0163	0.0347	0.0277
SIER - CSBY	1 hour	Ublox	0.0103	0.0217	0.0270
		Topcon	0.0267	0.0513	0.0577
Difference			0.0163	0.0297	0.0307
SIER - CSBY	2 hour	Ublox	0.0030	0.0067	0.0084
		Topcon	0.0153	0.0307	0.0330
Difference			0.0123	0.0240	0.0246
SIER - PSBY	1 hour	Ublox	0.0103	0.0217	0.0270
		Topcon	0.0257	0.0570	0.0567
Difference			0.0153	0.0353	0.0297
SIER - PSBY	2 hour	Ublox	0.0030	0.0067	0.0084
		Topcon	0.0147	0.0340	0.0320
Difference			0.0116	0.0273	0.0236
WNKR - CSBY	1 hour	Ublox	0.0123	0.0227	0.0343
		Topcon	0.0307	0.0577	0.0823
Difference			0.0183	0.0350	0.0480
WNKR - CSBY	2 hour	Ublox	0.0067	0.0120	0.0183
		Topcon	0.0177	0.0347	0.0457
Difference			0.0110	0.0227	0.0273
WNKR - PSBY	1 hour	Ublox	0.0123	0.0227	0.0343
		Topcon	0.0287	0.0667	0.0777
Difference			0.0163	0.0440	0.0433
WNKR - PSBY	2 hour	Ublox	0.0067	0.0120	0.0183
		Topcon	0.0307	0.0150	0.0393
Difference			0.0240	0.0030	0.0210

Table 4: T-Test result for the static method

Benchmark - CORS	Time (hour)	Component	
		Horizontal (X, Y)	Vertical (Z)
TKGM - CSBY	1	H0 Rejected	H0 Rejected
	2	H0 Rejected	H0 Rejected
TKGM - PSBY	1	H0 Accepted	H0 Accepted
	2	H0 Accepted	H0 Accepted
SIER - CSBY	1	H0 Rejected	H0 Rejected
	2	H0 Accepted	H0 Accepted
SIER - PSBY	1	H0 Accepted	H0 Accepted
	2	H0 Accepted	H0 Accepted
WNKR - CSBY	1	H0 Rejected	H0 Rejected
	2	H0 Rejected	H0 Rejected
WNKR - PSBY	1	H0 Rejected	H0 Accepted
	2	H0 Accepted	H0 Accepted

T-test results based on Table 4, for the horizontal component at all baselines, contained six samples that showed the acceptance of Ho and rejection of Ha at the TKGM – PSBY (at all of the measurement time), SIER – CSBY (at 2 hours measurement time), SIER – PSBY(at all of the measurement time), WNKR – PSBY (at 2 hours measurement time, and component vertical 1 hour measurement time). While the sample at the other baseline shows the existence of Ho rejection and Ha acceptance, this means that the measurement results between a low-cost receiver and geodetic receiver have significant differences. So that low-cost receiver cannot be used on a par with the geodetic receiver. But, it can be considered to compare with the geodetic receiver.

Table 5 shows the coordinate result of the static method. The result gives some information about the northing, easting coordinate, and ellipsoid height. It can be seen that the northing and easting coordinate have a stable result, while the ellipsoid height has no stable result. According to Rothacher (2002), many different effects are contributing to the fact that station heights may be determined less accurately by GPS than horizontal positions. Many major error sources that can degrade the height estimates are tropospheric refraction, reference frame, geocenter and orbit errors, site displacements due to ocean and atmospheric loading, antenna phase center variations, and multipath.

5.2 Kinematic Observation

Measurement using the kinematic method is done by placing a low-cost GPS receiver and Geodetic receiver on vehicles and around the ITS campus (Figure 1b). There is an obstruction on low-cost receiver measurements due to the multipath effect of tall buildings and trees in the FMIPA area (Figure 9), this shows that the performance of low-cost receiver antennas is still not good compared to geodetic receiver antennas, especially in dealing with multipath effects. Figure 9 shows the biggest obstruction that happens when the measurement using the kinematic methods. In that picture, the green circles indicate the obstruction that causes by trees, and the blue square indicates the obstruction that causes by a tall building.

6. Conclusions

This research has evaluated the low-cost performance of the U-Blox M8T GPS receiver using a Geodetic GPS receiver (Topcon hyperpro) as a comparison. Two methods of observation that are static and kinematic. Based on the results of the T-test, the U-Blox receiver cannot be used as a GPS observation when compared to the Topcon Hiper Pro because the number of Ho received is less than half the number of samples tested in terms of accuracy and precision coordinate values. This is because the U-Blox antenna still cannot correct the multipath effect and depends on the short baseline length. Besides, U-Blox M8T is a single frequency type receiver, which needs additional correction to eliminate ionosphere bias. So there is still a need for further research on the performance of the U-Blox M8T as a low-cost GPS receiver. Future research may be able to use the other method to get an overview of the low-cost measurement results in other measurements.

Table 5: The coordinate result of the static method

Benchmark - CORS	Time	Receiver	Coordinate		
			Northing (m)	Easting (m)	Ellipsoid Height (m)
TKGM - CSBY	1 hour	Ublox	9194924.483	698175.722	32.094
		Topcon	9194923.313	698176.300	29.084
Difference			1.170	0.578	3.010
TKGM - CSBY	2 hours	Ublox	9194924.483	698176.300	32.127
		Topcon	9194923.282	698176.331	29.142
Difference			1.201	0.031	2.985
TKGM - PSBY	1 hour	Ublox	9194924.483	698175.630	32.209
		Topcon	9194924.646	698175.723	32.279
Difference			0.163	0.093	0.070
TKGM - PSBY	2 hours	Ublox	9194924.483	698175.569	32.213
		Topcon	9194924.555	698175.641	32.149
Difference			0.072	0.072	0.064
SIER - CSBY	1 hour	Ublox	9189733.364	693958.462	32.912
		Topcon	9189732.358	693959.031	30.256
Difference			1.006	0.569	2.656
SIER - CSBY	2 hours	Ublox	9189732.710	693958.163	36.829
		Topcon	9189732.328	693959.000	30.230
Difference			0.382	0.837	6.599
SIER - PSBY	1 hour	Ublox	9189733.364	693958.462	32.948
		Topcon	9189733.363	693958.687	32.863
Difference			0.001	0.225	0.085
SIER - PSBY	2 hours	Ublox	9189732.720	693958.163	36.865
		Topcon	9189733.374	693958.677	32.896
Difference			0.654	0.514	3.969
WNKR - CSBY	1 hour	Ublox	9192801.862	691801.336	36.940
		Topcon	9192800.583	691801.045	34.247
Difference			1.279	0.291	2.693
WNKR - CSBY	2 hours	Ublox	9192801.852	691801.326	37.019
		Topcon	9192800.614	691801.086	34.264
Difference			1.238	0.240	2.755
WNKR - PSBY	1 hour	Ublox	9192801.862	691801.336	36.976
		Topcon	9192801.710	691801.049	37.130
Difference			0.152	0.287	0.154
WNKR - PSBY	2 hours	Ublox	9192801.872	691801.428	37.055
		Topcon	9192801.953	691801.746	36.680
Difference			0.081	0.318	0.375

Figure 9: The biggest obstruction in the measurement of kinematic methods in the ITS Campus area

For the next research, the measurement data quality using low-cost GPS can be improved by choosing a location that frees from obstruction. On the other hand, it will be better to conduct the research when number of TEC is low that can minimize ionospheric bias effect. In addition, the future research may use more than one low-cost GPS and a medium-cost GPS, aiming to see how static and kinematic accuracy due to the difference receiver price.

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