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DATA INTEGRITY AND QUALITY ANALYSIS OF LOW COST ZED-F9P U-BLOX GNSS RECEIVER

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Highlights

- Data integrity and quality of low-cost GNSS receiver were investigated.
- Data integrity and SNR of low-cost GNSS recevier are comparable to the geodetic-one.
- The number of cycle slips of low-cost GNSS receiver is higher than the geodetic-one.

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ABSTRACT: Thanks to the rapidly emerging low-cost dual-frequency GNSS receivers, a feasible alternative for geodetic-grade GNSS receivers became available for some GNSS applications. In this study, the performance of data integrity and quality of a low-cost ZED-F9P u-blox GNSS receiver was investigated by comparing it with a geodetic-grade GNSS receiver. Availability of the epoch and phase/code signal channels, signal-to-noise ratio (SNR), code multipath, and cycle slips were analyzed for the geodetic-grade and low-cost ZED-F9P u-blox GNSS receivers. One month's data of GPS, GLONASS, and Galileo constellations were analysed using the RINEX files of the receivers. The results showed that the epoch availability of the geodetic-grade and u-blox GNSS receiver is comparable to each other, while the availability of phase/code signal channels of the geodetic-grade receiver is higher than the u-blox receiver. In terms of data quality, SNR values from both receivers are comparable, while the multipath level of the u-blox GNSS receiver is significantly higher than the geodetic-grade one. The results also showed that the number of cycle slips of the u-blox receiver is significantly higher than the geodetic-one.

Keywords: *Cyle Slip, GNSS, Low-cost, Multipath, U-blox*

1. INTRODUCTION

Since low-cost Global Navigation Satellite System (GNSS) receivers have been available for a relatively short time compared with the geodetic ones, the GNSS market share of low-cost GNSS receivers, especially for dual-frequency ones, is gradually increasing [1]. Precise Point Positioning (PPP) and relative positioning using low-cost dual frequency receivers became available due to the mitigation of the first-order ionospheric effect as one of the biggest error sources [2,3,4].

The major drawback of the geodetic-grade GNSS receivers is their high costs, such as several thousand to tens of thousands of dollars, whereas low-cost dual-frequency GNSS receivers usually cost several hundred dollars. One of the most commonly used low-cost GNSS receivers is u-blox ZED-F9P module (https://www.u-blox.com/en/product/zed-f9p-module). Due to the dual-frequency and multi-constellation (GPS+GLONASS+Galileo+BeiDou-2) availability, u-blox ZED-F9P GNSS receivers support a variety of GNSS applications. Since only the civil signals L1 and L2C are available for the u-blox GNSS receiver, the second frequency of some GPS satellites belonging to older than BLOCK IIR-M cannot be tracked by the u-blox GNSS receiver [5]. As of January 2023, seven GPS satellites (G02, G13, G16, G19, G20, G21, G22) are not broadcasting the L2C civil signal (https://www.navcen.uscg.gov/gps-constellation). This causes the loss of the number of the tracked dual-frequency GPS satellites by u-blox GNSS receiver compared with the geodetic ones. This may affect the positioning accuracy of the u-blox GNSS receiver, especially for constrained satellite visibility. This GPS BLOCK dependent for second civil signal frequency is not existing for GLONASS, Galileo, and BeiDou constellations. Besides the GPS

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second civil frequency restriction, the total GNSS channel number of low-cost GNSS receivers is significantly lower than the geodetic ones.

Generally, studies mainly focused on the positioning performance of the u-blox GNSS receiver [6,7,8]. To the best of the authors' knowledge, no comprehensive assessment on the data integrity and quality of the u-blox GNSS receiver was conducted. Here, we present one-month observations of a u-blox and a geodetic-grade GNSS receiver that were placed in close proximity to each other. The paper is organized as follows: first, we elaborate on a detailed methodology for assessing data integrity, multipath levels, signal-to-noise ratios (SNR), and cycle slips. Next, we discuss the main findings and their possible causes. Finally, we provide general remarks in the concluding section.

2. MATERIAL AND METHODS

To thoroughly evaluate the u-blox and geodetic-grade GNSS receivers' data, two receivers were placed on the roof of the Necmettin Erbakan University Engineering Faculty. The antennas are approximately 3 meters away from each other. Figure 1 shows the antennas of the receivers mounted on the pillars. For this ultra-short baseline, tropospheric, ionospheric effects, multipath, and satellite geometry are safely assumed identical for each receiver.

Figure 1. The u-blox and geodetic-grade antennas, which were placed on the Faculty of Engineering, Necmettin Erbakan University

CHC P5-U receiver and C220GR2 choke ring antenna were used for the geodetic-grade receiver and antenna configuration. For the u-blox receiver, low-cost Survey GNSS Multiband antenna (https://www.ardusimple.com/product/survey-gnss-multiband-antenna/) was used. This antenna is usually preferred over the u-blox ANN-MB L1/L2 multi-band GNSS patch antenna (https://www.u-blox.com/en/product/ann-mb-series?legacy=Current) due to the higher signal-to-noise ratio (SNR) and low multipath.

The u-blox receiver was configured to work as a Continuously Operating Reference Station (CORS) using Raspberry Pi. One month of RINEX 3.0,4 data (from DOY 347, 2022 to DOY 11, 2023) was collected from both receivers. GPS, GLONASS and Galileo data with 30-s sampling rate was collected for each receiver. 30-s interval was intentionally chosen because most of the CORS stations data interval is 30-s and it is suitable for data capacity. Since the u-blox receiver cannot support BDS-3 data and BDS-2 satellite visibility is significantly low in Turkey the data of BDS satellites were ignored.

The u-blox receiver only supports L1 C/A and L2C, G1 and G2 C/A, and E1 (B+C) and E5b (I+Q) for

GPS, GLONASS, and Galileo constellations, respectively. Unlike the u-blox receiver, the geodetic-grade receivers can support multi-frequency and multi-modulation channels. Most of the geodetic-grade receivers support L1 C/A and L2 (Z-tracking), G1 (C/A) and G2 (P), and E1 and E5a frequency bands. These frequency bands are also used in International GNSS Service (IGS) and most of the Analysis Centers (ACs) conventions [9,10,11] and also mainly used for PPP [12,13]. To follow the IGS conventions and better represent the geodetic-grade receivers, these frequency bands were chosen for the CHC P5-U receiver.

RINEX data of the receivers was investigated in terms of the data integrity and quality. The data integrity consists of the epoch and phase/code frequency availability. Epoch availability is computed as the ratio between the theoretically expected number of epochs (i.e., 2880 epochs for 30-sec sampled observations for a daily RINEX file) and the actual number of epochs recorded by the receivers. Phase/code frequency availability is computed by counting the missing observations on the first and second phase/code frequencies.

Data quality analysis consists of code multipath level from the continuous cycle-slip free arcs, the number of observed cycle slips, and SNR values.

SNR value indicates the signal strength of the direct signal from GNSS antenna. In other words, SNR refers to the ratio of the direct signal power and noise power in a corresponding signal channel for the receivers.

For each chosen frequency bands, epoch/frequency signals availability, code multipath, cycle slips, and SNR analysis were conducted for the u-blox and CHC P5-U receivers. In-house software was used for the data integrity and quality analyses. In addition to these analyses, the average number of tracked satellites during a one-month period for each GNSS constellation was also analyzed. The cutoff angle and sampling rate of each receiver were set 7° (to collect enough satellite data) and 30-sec, respectively. The findings were discussed in detail in the Results section.

3. RESULTS AND DISCUSSION

Table 1 provides the analysis of the phase and code frequency availability for each receiver and GNSS constellation during the one-month period. Table 2 shows the mean, maximum, and minimum number of observed satellites in each epoch for the receivers.

Table 1. The results of the phase and code frequency availability (Unit: %)

Receivers	GPS				GLONASS				Galileo			
	G_{p1}	G_{p2}	$G_{\varphi 1}$	$G_{\varphi 2}$	R_{p1}	R_{p2}	$R_{\varphi 1}$	$R_{\varphi 2}$	E_{p1}	E_{p2}	$E_{\varphi 1}$	$E_{\varphi 2}$
CHC P5-U	100	96.7	99.9	96.5	100	87.5	100	87.5	100	99.8	99.9	99.1
U-blox	99.6	77.3	99.6	77.3	97.2	87.0	97.2	87.0	99.1	95.6	99.1	95.6

Table 2. The results of the satellite visibility

Receivers	GPS			GLONASS			Galileo		
	mean	max	min	mean	max	min	mean	max	min
CHC P5-U	9.3	12	8	7.3	10	4	8.1	12	5
U-blox	9.0	12	6	7.4	10	4	8.0	12	5

For simplicity, sub-indexes of P and φ in Table 1 denote the code and phase observations in the corresponding signals. 1C/2W, 1C/2P, 1C/5Q (for the CHC P5-U receiver) and 1C/2X, 1C/2C, 1X/7X (for the u-blox receiver) code/phase observations were processed for GPS, GLONASS, and Galileo, respectively. The first and second observations of the receivers were denoted as 1 and 2 for brevity.

As shown in Table 1, CHC P5-U data availability of code and phase observations is much more compared with the u-blox receiver. This can be more evident for GPS because u-blox only tracks L2C observation that is broadcasting only BLOCK IIR-M and later block types as described in the ıntroductıon section. For the older block types, GPS L2C observation is not available, and this causes the data loss of the second frequency code/phase observations of the u-blox receiver, while the first frequencies of the u-blox receiver are not affected by this phenomenon. Except for this restriction, the performance of the u-blox and CHC P5-U receivers are close to each other for GLONASS and Galileo receivers.

When the second frequency availability of GLONASS is investigated, it is seen that approximately 13% of second frequency code/phase data are lost for each receiver. When some IGS stations' data are investigated, it is seen that the second frequency code/phase data of R06 and R23 GLONASS satellites are not available during the test period. The frequency and epoch availability are more critical for kinematic applications than those of static applications.

The satellite visibility results show that the performances of each satellite visibility are nearly identical for each GNSS constellation. But it should be kept in mind that some recorded GPS satellites from the u-blox receiver are not broadcasting the second L2C civil frequency.

When the epoch availability of the CHC P5-U receiver is investigated, it is observed that epoch availability of the CHC P5-U receiver is 100% for each day. For the u-blox receiver, the mean epoch availability is nearly 100% (99.7%) which proves the nearly same tracking performance as the geodetic-grade receivers. The minimum epoch availability was observed as 98.7% in a daily RINEX file for the u-blox receiver.

The mean code multipath and SNR values of the receivers during one-month period were given in Figures 2 and 3. Code multipath value was computed using the generalized formula for all frequencies similar to G-Nut/Anubis [14].

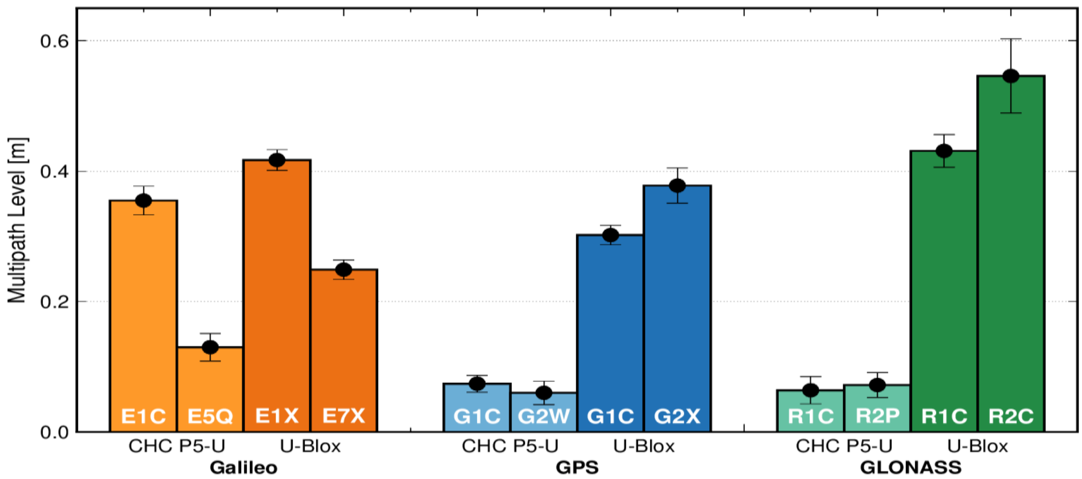

Figure 2. Code multipath levels of the CHC P5-U and u-blox receivers for GPS, GLONASS and Galileo

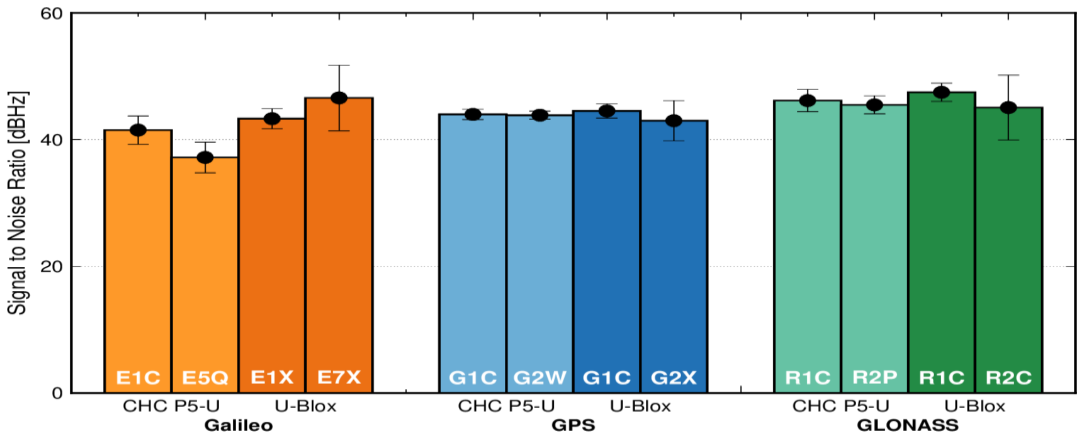

Figure 3. SNR values of the CHC P5-U and u-blox receivers for GPS, GLONASS and Galileo

Code multipath values were computed for each arc with no data gap and cycle slip. In this way, constant ambiguity was kept for each arc during the multipath computation. As shown in Figure 2, the code multipath level of the CHC P5-U receiver is significantly lower than the u-blox receiver which is using the low-cost external Survey GNSS multiband antenna. It is thought that if the u-blox patch antenna was used, the code multipath level would be much higher for the u-blox receiver because the patch antenna is more vulnerable to multipath. Multipath is dependent on the antenna environment, receiver, antenna, signal channel, type of modulation, and the multipath suppression algorithm. Most of the geodetic receivers, including the CHC P5-U receiver support the multipath mitigation algorithm (https://www.surveying-company.net/c220gr2-details). The u-blox ZED-F9P receiver also employs a similar multipath mitigation technique [15]. However, due to the low-cost antenna effect, the multipath level of the u-blox receiver is still higher than the geodetic one. When the signal channels are investigated, the multipath level of the second frequencies of Galileo (E5Q for CHC P5-U and E7X for u-blox) from the receivers is smaller than the first frequencies of Galileo. For GPS and GLONASS, the multipath level of each frequency within each receiver is comparable. Due to the quality difference between low-cost and geodetic receivers, as expected, the multipath level of geodetic-grade receiver is significantly low compared to the low-cost receiver.

When SNR values are investigated, it is seen that mean SNR values from CHC P5-U and u-blox receivers are comparable, and no significant differences of SNR values between the GNSS constellations are observed for each receiver.

The number of cycle slips was computed for each receiver using the Geometry-Free phase and Melbourne-Wubenna combination [16,17]. When detecting the cycle slips, data gaps within the continuous arcs were also accepted as cycle slip. The total number of cycle slips over one month was converted to the mean cycle slip number of each satellite and each day. The results are given in Figure 4.

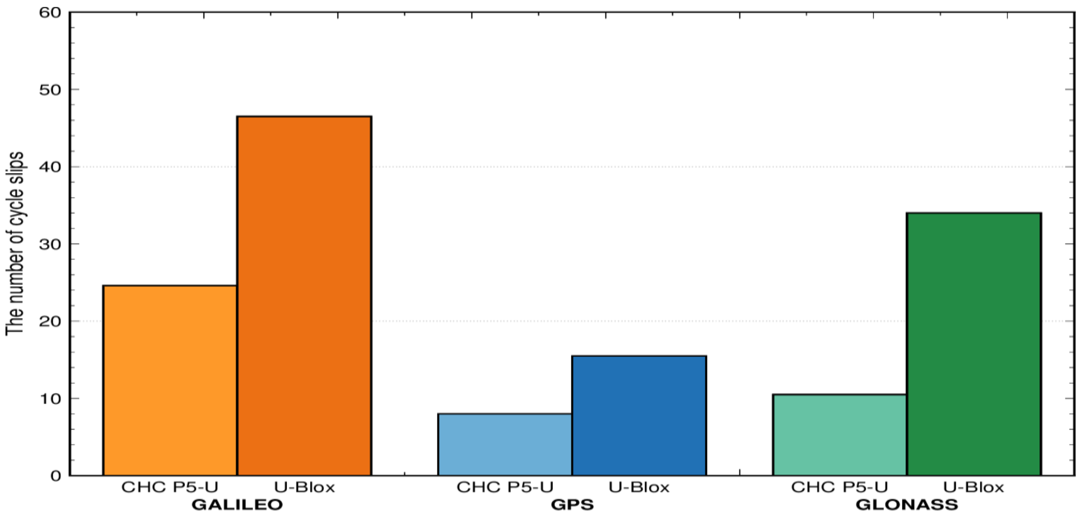

Figure 4. Average cycle slips per day for GPS, GLONASS and Galileo

As seen in Figure 4, the number of detected cycle slips from the u-blox receiver is significantly higher than the CHC P5-U receiver. When each GNSS constellation is considered, the lowest number of cycle slips was observed for GPS, while the highest number of cycle slips was observed for Galileo. Cycle slips can happen due to various factors, such as loss of line-of-sight, high ionospheric activity, and some receiver problems. A cycle slip causes a jump in carrier-phase measurements. Frequent cycle slips can be problematic for precise positioning due to re-initializing ambiguity parameters [18]. This effect can be more pronounced, especially in an environment where satellite visibility is constrained. Ambiguity re-convergence during cycle slips can be mitigated by the exact estimation of the size of the cycle slips (repairing process), but this requires a robust and computationally intensive process, and exact estimation of the size is not possible all the time. If triple-frequency GNSS observations are available, reliable estimation of the size of cycle slips can be utilized using extra-wide lane (EWL), wide lane (WL), and narrow lane (NL) combinations as a cascading step [19]. However, this approach cannot be feasible for low-cost receivers due to the lack of the third frequencies.

4. CONCLUSIONS

This experiment presented the performance of the RINEX data integrity and quality of the low-cost u-blox receiver while comparing it with the geodetic-grade CHC P5-U receiver. Low-cost Survey GNSS Multiband antenna was used for the u-blox receiver instead of the patch antenna. RINEX data was collected over a one-month period under the same conditions for each receiver. Data integrity analysis consisted of the epoch and dual frequencies phase/code availabilities of each GNSS constellation. Data quality analysis consisted of the code multipath, SNR, and cycle slips analysis. The main findings can be summarized as follows:

-) The epoch availability of the u-blox and CHC P5-U receivers was computed as 99.7% and 100%. This can prove that nearly all required epochs in the test period were recorded by the u-blox receiver.

-) The frequency availability analysis showed that the u-blox receiver recorded less dual frequency phase/code observations compared to the CHC P5-U receiver. The loss of the observations is more evident for GPS because u-blox receiver only tracks L2C observation as a second GPS frequency. For GLONASS and Galileo, the results are more comparable, a maximum 4% difference was observed for the second frequency of Galileo between the u-blox and CHC P5-U receivers.

-) Multipath results show that the u-blox receiver significantly exhibited higher code multipath values with respect to the CHC P5-U receiver for GPS, GLONASS, and Galileo. Nevertheless, code multipath values from the u-blox receiver are within the acceptable range for most of the receivers.

-) SNR values of each receiver were found to be comparable, and no significant differences were observed. It is shown that SNR values of each GNSS constellation are close to each other for each receiver.

-) Cycle slip analysis showed that the u-blox receiver exhibited significantly low performance compared to the CHC P5-U receiver. Approximately two times higher cycle slip numbers from the u-blox receiver were computed compared to the CHC P5-U receiver. The differences were found to be much higher for GLONASS. Despite all observations were collected under clear sky visibility, cycle slips can be occurred regardless of the interruptions of line-of-sight between satellite and receiver.

This should be emphasized that the low-cost external antenna was used for the u-blox receiver in this study. The data quality metrics found from the u-blox receiver in this study may be much worse if the patch antenna was used.

Declaration of Ethical Standards

As the authors of this study, we declare that all ethical standards have been complied with.

Credit Authorship Contribution Statement

Author contribution rates in this study as follows: Sermet Ogutcu 30%, Salih Alcay 20%, Huseyin Duman 20%, Behlül Numan Ozdemir 15%, and Ulkunur Koray 15%.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Data Availability

All data used for this study are available from the corresponding author upon reasonable request.

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