TEKNIKA: JURNAL SAINS DAN TEKNOLOGI

Homepage jurnal: http://jurnal.untirta.ac.id/index.php/ju-tek/

Static and dynamic GPS receiver verification tests using software defined radio

Sri Kliwati[a,1], Romi Wiryadinata[b], Imamul Muttakin[b], Haris Setyawan[c], Rustamaji[a], Wahyu Widada[a]

[a]*Rocket Technology Research Center, National Research and Innovation, Bogor, Indonesia*
[b]*Department of Electrical Engineering, Universitas Sultan Ageng Tirtayasa, Cilegon, Indonesia*
[c]*Department of Information Technology, Universitas Muhammadiyah Yogyakarta, Yogyakarta, Indonesia*

[1]Corresponding author: srik002@brin.go.id

ARTICLE INFO

Article history:
Submitted 08 November 2023
Received 02 December 2023
Received in revised form 05 January 2024
Accepted 20 February 2024
Available online on 18 June 2024

Keywords:
GPS receiver test, Software Defined Radio (SDR), static and dynamic test, GPS simulator.

Kata kunci:
Pengujian penerima GPS, Software Defined Radio (SDR), Pengujian statis dan dinamis, simulator GPS.

ABSTRACT

Global Positioning System (GPS) is widely used in a variety of fields, including aircraft applications and rockets where speeds exceed standards. Signal simulators, which are relatively expensive, are required to test commercial GPS devices and GPS signal processing methods. The methodology for verifying GPS receiver specifications using a Software Defined Radio (SDR)-based simulator is described in this paper. Simulator tests are run in both static and dynamic modes. The test findings demonstrate that the system can measure altitude and speed, but only up to 50 km and 500 m/s, respectively, according to commercial GPS specifications. This simulator system can be used to evaluate future GPS processing algorithms in highly dynamic environments.

ABSTRAK

Global Positioning System (GPS) digunakan secara luas di berbagai bidang, termasuk aplikasi pesawat terbang dan roket yang kecepatannya melebihi standar. Simulator sinyal, yang relatif mahal, diperlukan untuk menguji perangkat GPS komersial dan metode pemrosesan sinyal GPS. Metodologi untuk memverifikasi spesifikasi penerima GPS menggunakan simulator berbasis Software Defined Radio (SDR) dijelaskan dalam makalah ini. Pengujian simulator dijalankan dalam mode statis dan dinamis. Temuan pengujian menunjukkan bahwa sistem dapat mengukur ketinggian dan kecepatan, tetapi hanya sampai 50 km dan 500 m/s, sesuai dengan spesifikasi GPS komersial. Sistem simulator ini dapat digunakan untuk mengevaluasi algoritme pemrosesan GPS di masa depan dalam lingkungan yang sangat dinamis.

Available online at http://dx.doi.org/10.62870/tjst.v20i1.22637.

1. Introduction

The GPS is an instrument for determining the position, speed and acceleration of an object. GPS is used in many fields, such as the military, industry, and others [1–3]. Nevertheless, in some aspects regarding elevation, speed, and acceleration, any GPS apparatus is restricted by the manufacturers and worldwide rules [4]. In GPS technology, the term "CoCom limit" is used to limit functionality when the device calculates that it is moving faster than 1,000 knots (1,900 km/h, 1,200 miles) and/or is moving at altitude. Refers to the limitations of GPS receivers that altitude over 18,000 meters (59,000 feet). If we want to use a GPS receiver for a specific purpose, we need to check the parameters according to our needs. For example, tracking balloons requires an altitude of more than 30 km, while tracking rockets requires a certain altitude and speed [5]. Simulations for high dynamic flight using a stand-alone single-frequency GPS receiver are developed, where the aircraft velocity is up to 7000 m/s, and the acceleration is up to 7 g (9.8m/s2) [6]. There are several types of GPS signal simulators on the market, however they are very expensive. Meanwhile, the signal simulator can employ SDR signals, such as GPS signals, which are less expensive. Researchers use SDR to build a GPS signal emulator to test the capabilities of a GPS receiver[7–9]. This paper concerns the examination criteria for a commercial GPS receiver that employs SDR as a transmitter emulator. The emulator assessments were executed in a stationary mode, ranging from an elevation of 0 to 80 km or in a dynamic mode from 0 to 750 m/s. The evaluated receiver is a commercial GPS receiver that features the u-blox-7 GNSS modules.

2. Research Methodology

Figure 1 depicts the GPS verification test setup. It comprises of a PC for generating GPS signals, an SDR for signal transmission simulation, and a GPS receiver for verification. We use an open-source software called gps-sdr-sim [10] to produce static and dynamic GPS signals. We utilize a PC with the Ubuntu 22.04 operating system. A PC with the Ubuntu 22.04 operating system is utilized. The SDR is connected to the PC via a USB connection, while the GPS receiver is attached via a serial interface at a data rate of 9600 bps. A GPS receiver can receive the signal from the simulator via a direct cable connection via an antenna. However, if utilize the antenna, the GPS satellite signals would most certainly interfere with it. As a result, the antenna must be installed in a room that is not susceptible to satellite transmissions. A RG174 coaxial cable to link it straight to the SDR's GPS receiver is used.

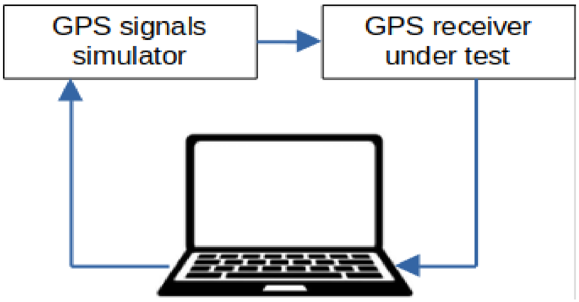

Figure 1. System testing for GPS verification.

The GPS signal is transmitted on two radio frequencies in the UHF band, namely 1.57542 GHz (L1) and 1.2276GHz (L2). As shown in Figure 2, in this simulator, the GPS signal transmitted only on frequency fL1 becomes the L1 carrier frequency of the signal transmitted from satellite k on the power PC as follows [11, 12].

$$s^k(t) = \sqrt{2P_C}C^k(t)D^k(t)\cos(2\pi f_{L1}t) \quad (1)$$

here $C^k(t)$ is the signal code C/A with a speed of 1 Mbps, and $D^k(t)$ is a navigation signal with a speed of 50 bps.

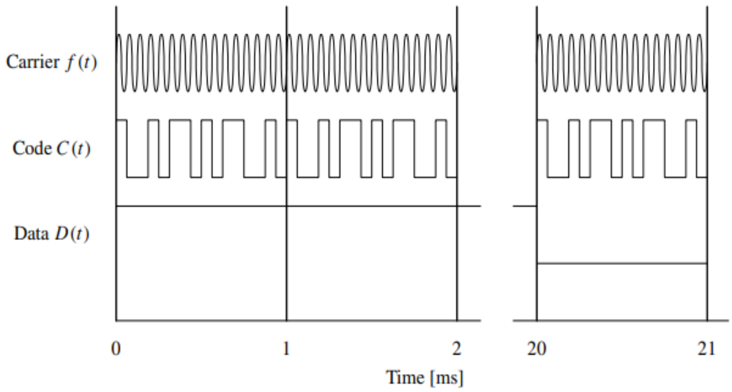

Figure 2. GPS signal that emitted by satellite [13].

3. Result and Discussion

3.1. Experimental Setup

The setup of Experiment 1 is static with elevation variations from 0 meters to 80 km, as shown in Table 1, with elevation variations while latitude and longitude are fixed. The coordinates for latitude and longitude are fixed with the values (-6.37448, 106.60593) at the laboratory site. The software gps-sdr-sim command is: gps-sdr-sim -e brdc3540.14n -s 4e6 -l -6.37448, 106.60593,1000. The last three numbers are latitude, longitude, and altitude, while the previous parameters are the RINEX navigation file for GPS ephemerides [14]. For a dynamic simulation of a circular motion, the command in the software is: gps-sdr-sim -e brdc3540.14n -u circlemotion.csv -s 4e6. All dynamic motion data is stored in a file that can be read and converted into a GPS signal. Table 1 shows the variable GPS type neo-7 with airborne specifications.

Table 1. Specification GPS Neo-6 U-Blox (Airborne).

Specification	Maximum Parameter
Max altitude	50,000 m
Max. Velocity	< 500m/s
Gravity	< 4g
Data update rate	5 Hz

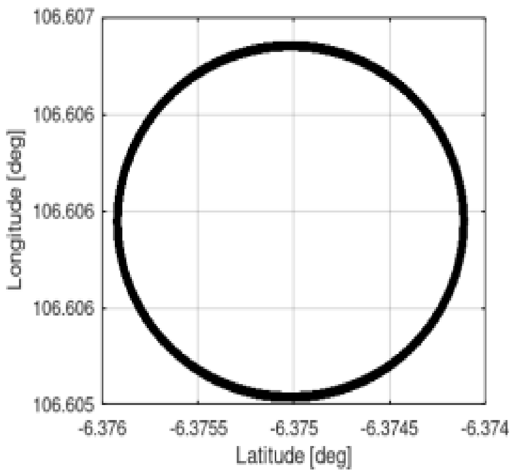

Figure 3. Dynamic experimental setup.

The second experimental setup is a dynamic condition with a radial velocity between 0 m/s and 750 m/s with an interval of 25 and 250, m/s, with the same altitude of 1 km, but with different latitudes and longitudes. In Figure 3 we can see the dynamic motion of circular objects at a certain altitude according to equation (2).

$$v = R\frac{d\theta}{dt} \quad (2)$$

Here, *R* is determined at 4 km, while θ is varied to obtain object velocities up to 750 m/s. The experimental setup shown in Figure 4 consists of a GPS simulator with a USRP B210 SDR and a Neo-7 GPS receiver. The GPS module is connected to a PC via a serial device (FTDI USB to serial) and sends signals to the SDR via a coaxial cable. Then the SDR is connected to the PC via USB 3.0, which increases the transfer speed stably to more than 15 MSPS.

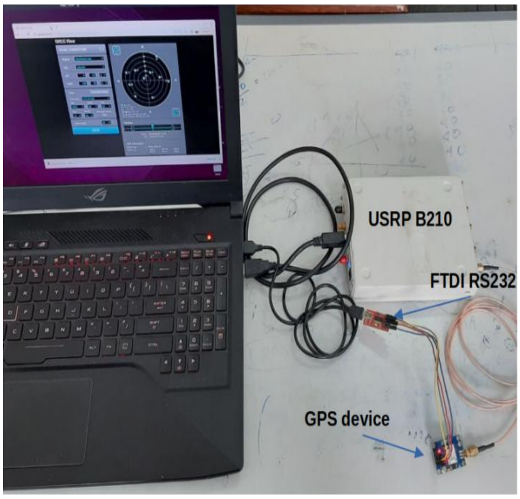

Figure 4. Experimental setup.

The SDR specifications range from 56 MHz to 6 GHz and cover all GPS signals. The GPS specifications can be found in Table 2. The maximum sampling rate for ADC and DAC is 61.44 MSPS at 12 bit resolution and 2 ppm stability.

Table 2. GPS Spesification**.**

Parameter	Value
Frequency range	70 MHz – 6 GHz
bandwidth	Up to 56 MHz
ADC Sample Rate	61.44 MS/s
DAC Sample Rate	61.44 MS/s
DAC Resolution	12 bit
Frequency Accuracy	2 ppm

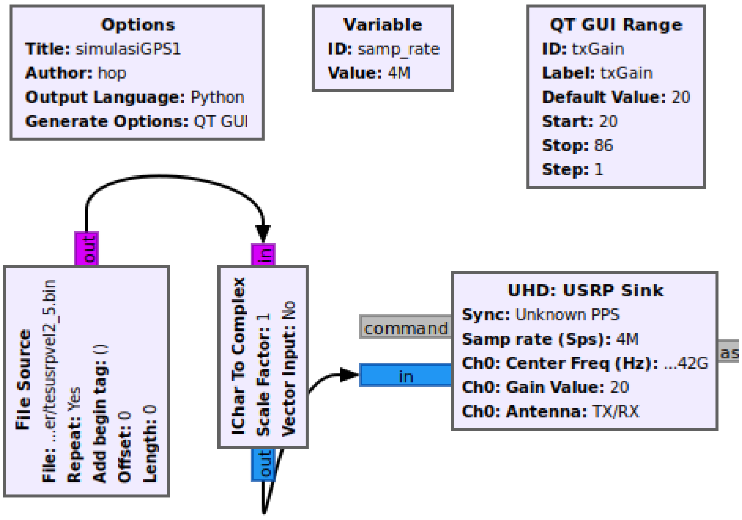

Figure 5. Block Diagram Software GNU-Radio.

The software used to control the SDR is GNU-Radio, which is based on the Python3 programming language. The block diagram of the software can be seen in Figure 5, with 4 MSPS data sampling. The function of this software is to read GPS signals and transmit them using the SDR at a frequency of 1.57542 GHz. The data of the GPS signal file is stored in 8 bits, because the USRP B210 supports only 8-bit files. For the transmission with SDR these data are read and converted into the form of complex numbers. Since the device is directly connected to a coaxial cable, the RF output power does not need to be very high, a power of about 1 dBm is sufficient. To monitor the results of the GPS receivers, we use the u-center software from U-block.

3.2. Result

Altitude and speed from the measurement results and input from GPS are shown in Table 3 and Table 4. In Table 3, the average number of detected satellites is 8, but the deviation is about 100 m. As in the dynamic simulation, the measured velocity differs from the simulation input by 1 m/s. There is a correlation between the number of satellites detected and the measurement deviation. The lower the number of detectable deviations, the lower the correlation and vice versa.

Figure 6 below describes the GPS satellites seen from the site at the time of the experiment, today Thursday at 13:35. The number of satellites detected by the system device is shown in blue in Figure 6. The visible satellite positions can be retrieved using the software available on the website [15].

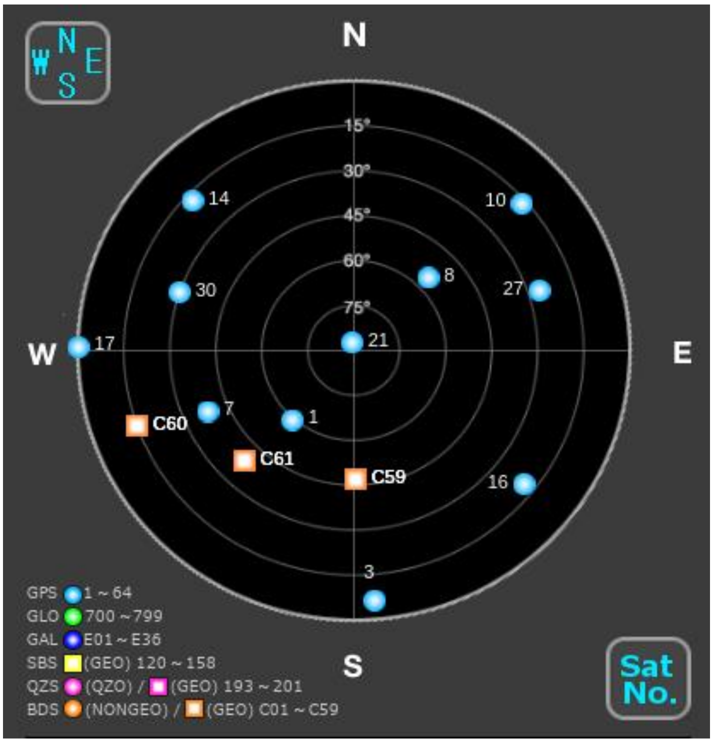

Figure 6. Appearance of GPS satellites at the experimental location.

Table 3 shows the altitude of the simulation result. It was shown that at altitudes 0 to 50 km, the satellite successfully locked and measured the data, and at an altitude of 80 km it failed to lock, this corresponds to the specifications of the receiver. It concluded that the altitude specification and simulation result was the same.

Table 3. Altitude Simulation Measurement Results.

Altitude (km)	Measured (km)	Satellite
0	0+0.1	1,7,8,27,30,10,14,21
1	1+0.1	1,7,8,27,30,10,14,21
10	10+0.1	1,7,8,27,30,10,14,21
20	20+0.1	1,7,8,27,30,10,14,21
40	40+0.1	1,7,8,27,30,10,14,21
50	50+0.1	1,7,8,27,30,10,14,21
80	fail	fail

Table 4 demonstrates that the GPS encounters a failure when the speed surpasses 750 m/s, rendering it unable to receive the signal. Furthermore, the implemented system successfully validates the GPS module. Both tables confirm that the usage of SDR in the GPS receiver, employing this particular algorithm, imposes limitations on measuring both the altitude and speed of the object, which should not exceed the provided specifications.

Table 4. Speed Simulation Measurement Results.

Velocity(m/s)	Measured (m/s)	Satellite
0	0.0 ± 0.1	1,7,8,27,30,10,14,21
25	25 ± 0.1	1,7,8,27,30,10,14,21
250	250± 0.1	1,7,8,27,30,10,14,21
500	500± 0.1	1,7,8,27,30,10,14,21
750	fail	fail

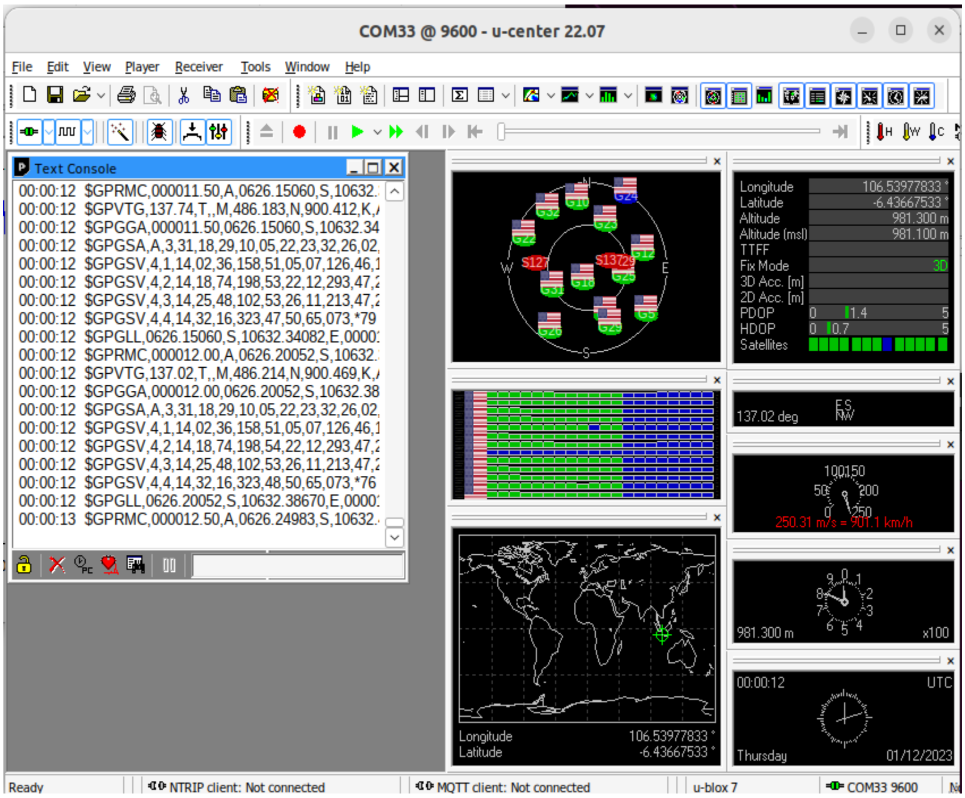

Figure 7. Output at GPS receiver.

To monitor the output of the GPS receiver, Figure 7 shows that the u-center software connected to the rs232/serial communication can clearly see the data and satellite position and other important parameter data [16].

4. Conclusion

The outcomes obtained from the experiments demonstrate that the suggested system possesses the ability to authenticate GPS receivers in both stationary and dynamic scenarios using software-defined radio (SDR). It is noteworthy that the altitude and velocity provided by the simulation results, obtained through SDR usage, are restricted to a maximum of 50 kilometers and 500 meters per second, respectively. In the future, novel algorithms developed internally could be employed to analyze extremely dynamic signal data and identify a higher number of GPS signals compared to conventional receivers available in the market.

Acknowledgements

The authors would like to thank BRIN (Rocket Technology Center) for the necessary assistance with this project.

References

[1] Peczalski, A., Kriz, J., Carlson, S. G., & Sampson, S. J. (2004). Military/civilian mixed-mode Global Positioning System (GPS) receiver (MMGR). In *2004 IEEE Aerospace Conference Proceedings (IEEE Cat. No.04TH8720)*, Vol. 4, pp.2697-2703.

[2] Ueki, T., Yoshii, K., Shimamoto, S., Mizuno, K., & Matsufuji, K. (2022). Evaluation of Impact of Intermediate GPS Spoofing to Mobile Terminals. In *2022 IEEE 19th Annual Consumer Communications & Networking Conference (CCNC)*, pp.717–718.

[3] Wang, F., Li, H., & Lu, M. (2017). GNSS Spoofing Countermeasure with a Single Rotating Antenna. *IEEE Access*, 5, 8039–8047.

[4] Yasuhara, Y. (1991). The Myth of Free Trade: The Origins of COCOM 1945–1950. *The Japanese Journal of American Studies*, 4: 127–148.

[5] Buist, P. J., Verhagen, S., Hashimoto, T., Sawai, S., Sakai, S., Bando, N., et al. (2010). GPS experiment on the Balloon-based Operation Vehicle. In *IEEE/ION Position, Location and Navigation Symposium*, pp.1287–1294.

[6] Li, F., Li, Q., & Liu, X. (2016). Research on velocity estimation in high dynamic flight simulation with a stand-alone single-frequency GPS receiver. In *2016 International Conference on Audio, Language and Image Processing (ICALIP)*, pp.727–732.

[7] Kim, W., & Seo, J. (2018). Low-cost software-defined GPS simulator with the capability of time synchronization. In *International Conference on Control, Automation and Systems*, pp.1087–1090.

[8] Yue-yun, G., Yong-hong, L., Qiao-ling, F., & Yu-long, W. (2012). Research of Intermediate Frequency GPS Signal Simulator Based on FPGA. In *2012 International Conference on Computer Science and Service System*, pp.1095–1098.

[9] Soghoyan, A., Suleiman, A., & Akopian, D. (2014). A Development and Testing Instrumentation for GPS Software Defined Radio With Fast FPGA Prototyping Support. *IEEE Trans Instrum Meas*, 63(8), 2001–2012.

[10] Ebinuma, T. (2023). Software-Defined GPS Signal Simulator. Retrieved September 2, 2023, from https://github.com/osqzss/gps-sdr-sim.

[11] Magiera, J. (2012). Design and implementation of GPS signal simulator. In *2012 International Conference on Localization and GNSS*, pp.1–4.

[12] Lin S., S, & Li Y, H. (2021). A SDR-based GPS Receiver with Low Accuracy of Local Oscillator. In *2021 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS)*, pp.1–2.

[13] Borre, K. (2003). The GPS Easy Suite–Matlab code for the GPS newcomer. *GPS Solutions*, 7(1), 47–51.

[14] EOSDIS Earthdata. (2023). RINEX Navigation File for GPS Ephemerides. Retrieved June 18, 2023, from https://cddis.nasa.gov/archive/gnss/data/daily/.

[15] Alma Linux. (2023). Software to Retrieve Visible Satellite Positions. Retrieved June 18, 2023, from https://app.qzss.go.jp/GNSSView/gnssview.html?t=1683169832236.

[16] U-Blox. (2023). GNSS Evaluation Software for Windows. Retrieved June 18, 2023, from https://www.u-blox.com/en/product/u-center.