Static and Dynamic Performance Evaluation of Low-Cost RTK GPS Receivers*

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Abstract— The performance of low-cost RTK (real-time kinematic) GPS receivers has been compared to a state-of-the-art system as well to each other. Both static and dynamic performances have been compared. The dynamic performance has been evaluated using a vehicle with driving robot on the AstaZero proving ground. The assembly of the low-cost RTK GPS receivers is presented, and the test set-ups described. Besides having a lower data output frequency, two of the low-cost receivers have static and dynamic performance not far from that of the state-of-the-art system.

I. INTRODUCTION

During the last couple of years a few low-cost navigation-grade RTK GPS receivers have emerged on the market. Connected to an RTK base station, these receivers promise sub-decimeter performance. Such receivers could play a vital role in a future intelligent transport system (ITS) where road and airborne vehicles such as automated cars and drones move and navigate autonomously, sometimes in a cooperative manner. Since cars are cost-sensitive, low-cost components are essential for market penetration. Low-cost RTK GPS receivers could also be a key component in systems where correction data is shared among vehicles using V2X communication [1].

In research projects, low-cost RTK GPS receivers have already been used to improve the positioning accuracy of unmanned aerial vehicles (UAVs) [2][3][4] and an unmanned surface vehicle (USV) [5]. Most of these papers report centimeter-level accuracy for static measurement and decimeter-level for dynamic measurements. Accuracy values come from comparison with an expensive geodetic-grade RTK GPS receiver.

The literature about performance evaluation of low-cost RTK GPS receivers includes a comparison between a pair of low-cost receivers and a pair of geodetic-grade receivers [6]. In this study, Andrei *et al.* used these receiver pairs to measure five different baselines (lengths from 0.5 to 22.8 km) in the Helsinki area. The error of the low-cost receivers was ±5 cm. Errors for absolute coordinates were also investigated and found to be ±6 cm.

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Sioulis *et al.* [7] propose to use the ISO 17123-8 standard [8] to evaluate the performance of low cost RTK GPS receivers. The test procedure of this ISO standard is normally used to test GNSS field measurement systems in RTK for geodetic and surveying instruments. Two roving point were selected and the ground truth distances were determined using a total station surveying and levelling. It was concluded that the low-cost RTK GPS had a horizontal accuracy of 3 cm.

In this paper, the assembly of low-cost RTK GPS receiver prototypes is described and the static and dynamic performance of the resulting receivers is evaluated. The prototypes uses low-cost RTK GPS evaluation boards as well as single-board computers running Linux with an open-source RTK processing library. The static and dynamic set-ups are introduced and the resulting performance presented. The authors were especially interested in the dynamic performance. Therefore, the evaluated receivers were compared with a state-of-the-art RTK GPS system which additionally employs an IMU to reach sufficient performance. To get repeatable and accurate dynamic test result a test vehicle with a steering robot was used on the AstaZero proving ground.

II. LOW-COST RTK GPS RECEIVERS

Four low-cost RTK-capable GPS receivers were procured. The cost of these receivers ranges from approximately $100 to $1000. Below some basic properties of these receivers are presented. The receivers can be seen in Figure 1.

A. NavSpark NS-RAW

The NS-RAW from NavSpark [9] is a carrier phase raw measurement output GPS receiver. The output is available via USB or serial.

TABLE I.   NAVSPARK NS-RAW PROPERTIES.

Update rate	Up to 20 Hz
Systems and augmentation supported	GPS, SBAS, and QZSS
Channels	167
Cost	$80

B. EMILD Navio+/ublox M8N

Navio+ [10] is an autopilot shield for the Raspberry Pi which is a small-sized computer. It is equipped with an IMU and an ublox M8N GPS receiver [11].

TABLE II.   NAVIO+/UBLOX M8N PROPERTIES.

Update rate	Up to 10 Hz
Systems and augmentation supported	GPS, QZSS, GLONASS, BeiDou, SBAS: WAAS, EGNOS, and MSAS
Channels	72
Cost	$170

C. ublox LEA-6T

The ublox LEA-6T [11] is an older RTK-capable GPS receiver. The output is available via USB or serial.

TABLE III.   UBLOX LEA-6T PROPERTIES.

Update rate	Up to 5 Hz
Systems and augmentation supported	GPS, SBAS: WAAS, EGNOS, and MSAS
Channels	50
Cost	$150

D. Swift Navigation Piksi

The SwiftNavigation Piksi [12] is an open-source RTK capable GPS receiver. The output is available via USB or serial.

TABLE IV.   SWIFT NAVIGATION PIKSI PROPERTIES.

Update rate	10 Hz
Systems and augmentation supported	GPS
Channels	N/A
Cost	$1000 (2 x Piksi + 433 MHz radio link)

Figure 1.   Evaluated GPS receivers (in order left to right, Piksi, NS-RAW, Lea-6t, Navio+)

E. RTKLib

RTKLIB [13][14] is an open source GNSS toolkit that can be used for precise positioning. The software supports all major file formats and satellite constellations (GPS, GLON-ASS, Galileo, BeiDou, SBAS, QZSS). In this evaluation, the RTKLIB toolkit was used to accurately determine positions by processing raw GNSS data in real-time under Linux installed on Raspberry Pi platforms [15].

III.   STATIC TEST SET-UP

A block diagram of the static positioning test set-up appears in Figure 2. The Leica AT503 [16], a dual-frequency choke ring antenna, was used on top of one of the buildings in the City Area of the AstaZero proving ground [17]. The antenna had a clear view of the sky. The received GPS signal was fed through a 20 m long cable to three receivers via a four way splitter (GPS Networking LDCBS1X4 [18] with 8.5 dB loss). RTK correction data was received from the AstaZero RTK base station via a radio modem and fed via a serial link to all three receivers.

Since it would be used as ground truth in the dynamic test, the RT3002 from Oxford Technical Solutions [20] was used a reference during the static tests as well. The OXTS with its

100 Hz output rate and IMU integration is de facto standard on proving grounds when it comes to dynamic testing.
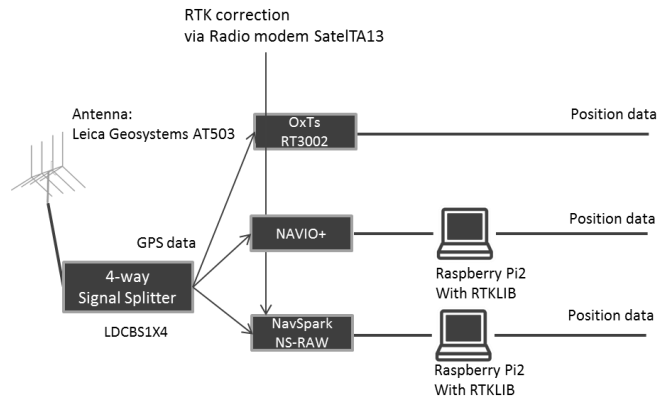

Figure 2.   Static test set-up

Used as a pair, with one of the receivers acting as the base station and the other one as a rover, the Piksi works fine. However, the Piksi could not handle the RTK correction data from the AstaZero base station. As we wanted to use the same correction data for all evaluated receivers, as a consequence the Piksi was omitted from the tests. Additionally, since the Navio+ has a newer GPS chip from ublox, no data from ublox LEA-6T is presented. The newer chip is expected to have superior performance.

During the static measurements, the EUREF/IGS network [21] for correction data was also tried since the SPT000SWE station is less than 10 km away from the AstaZero proving ground. It was, however, decided to stay with the base station at AstaZero for the evaluation.
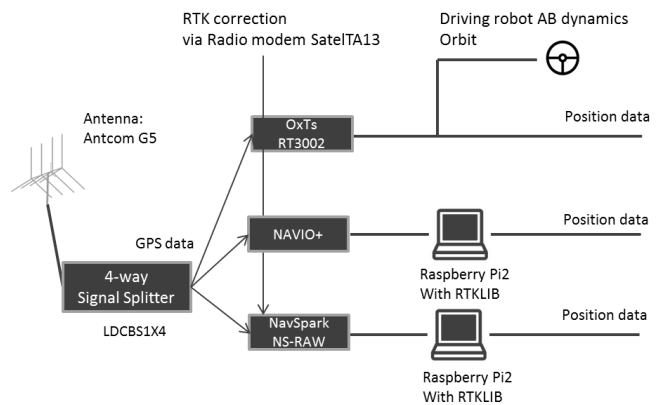
IV.   DYNAMIC TEST SET-UP

Figure 3.   Dynamic test set-up

The dynamic test set-up was similar to the static one. Its block diagram appears in Figure 3. The main difference was that another GPS antenna was used (ANTCOM G5 [22]); a GPS antenna that normally is used at AstaZero during tests. To control the test vehicle in a deterministic and repeatable way a steering robot from Anthony Best Dynamics was used, the Orbit. This robot has a maximum velocity of 2500°/s and a maximum torque of 70 Nm. All equipment was mounted in a Volvo V40.

For the same reasons as for the static tests, the Swiftnav Piksi and ublox LEA-6T was omitted from the dynamics tests as well.

Figure 4.   The test vehicle

V.   Results

The conditions for the satellite observability were almost perfect during all measurements, there were more than 10 satellites visible at any given time, and no blockage or multi-path was observed. Only GPS was used.

A.   Static Measurements

A phenomenon that was observed was that position is fairly inaccurate in the beginning of the measurements, Figure 5. One can see that the measurement error subside after about a 10 minutes. Therefore it is not possible to fully rely on the system in at the beginning of a measurement.
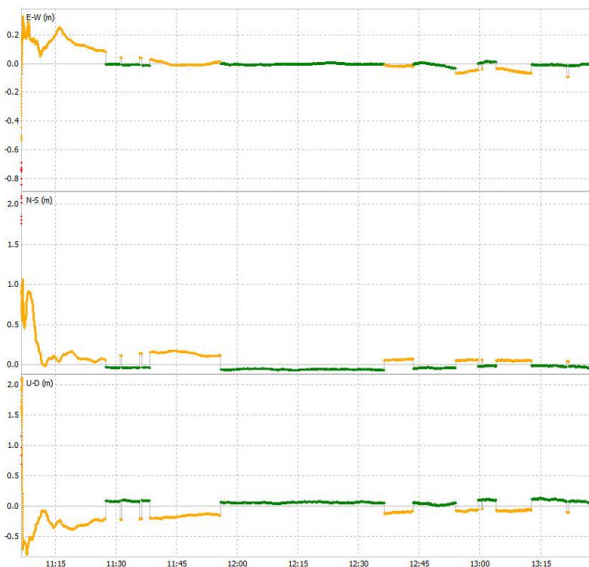

Figure 5.   Start-up incaccuracy, north-south (top), east-west (middle), and up-down (bottom).

The significant measurement errors at the beginning of the measurements (Figure 5.) are included in the results which are presented in Figure 6. The performance of the systems would be considerably better, if one waited until the systems have had time to acquire a fixed position.

We can also see that performance is compromised by the long cable and the signal splitter. The satellite signals are weak so the reduction in signal quality that is introduced by this, is significant compared to a short cable and no splitting

of the signal (Navio+ TW2400), even if these measurements is done with a comparatively inexpensive antenna.

No conclusions on which system is the best can be drawn; the Skytraq NS-RAW, ublox M8N, and OxTs systems seem to have similar performance during static conditions.
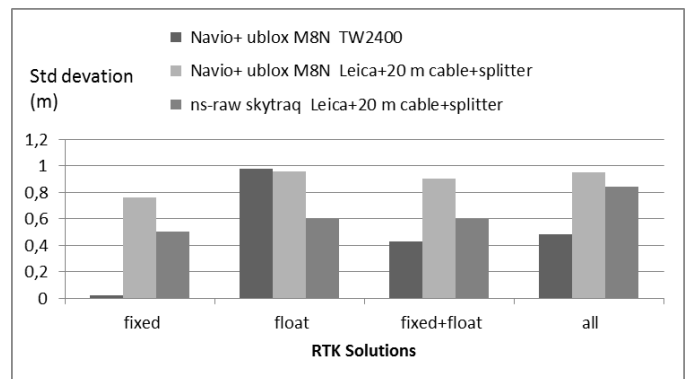

Figure 6.   Static test results, 370k datapoints.

B.   Dynamic measurements

It is difficult to show the dynamic performance of RTK GNSS in a good way. Generally speaking, the receivers are incredibly sensitive and quick to, relative a given position, detect changes. However, finding the correct absolute position to start from takes a little more time; typical around 10 minutes (see static measurements). The RTK GNSS technology has exceptional precision and decent accuracy. The accuracy improves given enough time to acquire a fixed position. To give an indication of the precision (here combined with the driving robot ability to drive) of the RTK systems one can study Figure 7. where the track consisted of an "eight" run two times in a set of three. The measurements show that the track was 3.77 km long and took 14 minutes to drive.
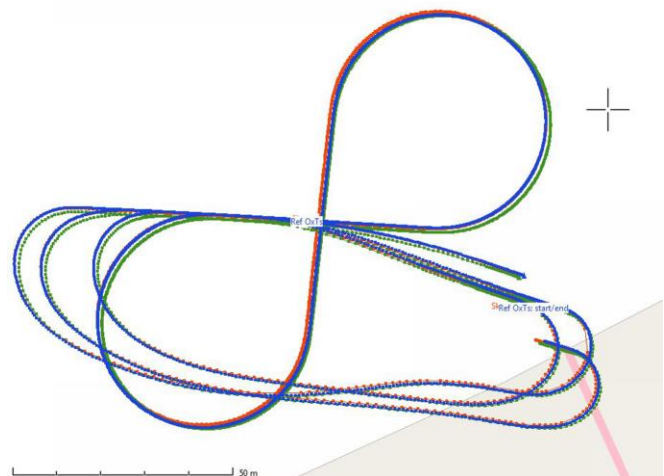

Figure 7.   Dynamic test results, robot driving a figure eight, two times in a set of three (Skytraq NS-RAW red, OxTs RT3002 blue, Ublox M8N green)

There are three sets of data we see in Figure 7. The Skytraq NS-RAW track is red, the blue track is the OxTs RT3002, and the green track is ublox M8N. We see a difference (offset of ~ 1m) between the three sets of measurements. This difference has to do with the fact that measurements

were started while only float solutions were acquired on the positions. A fixed position had not been achieved yet. However, the correlations between the systems own measurements are exceptionally good.
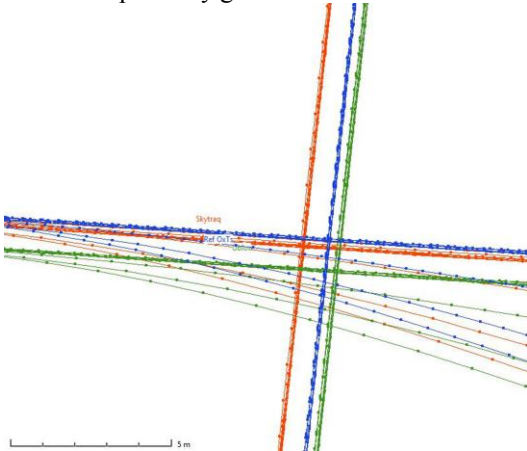

Figure 8.   Zoom in of the middle of the figure eight, dynamic test results. Each color in the cross represent six laps. (Skytraq NS-RAW red, OxTs RT3002 blue, Ublox M8N green)

In Figure 8. , each color represents three sets of measurements, two for each lap. The position tracks from each system contain themselves within a span of less than 20 cm between the laps. It can be concluded that the three systems have similar performance under dynamic conditions. A surprising result when considering the OxTs system costs 500 times more than the other two systems. However, one shall remember that the OxTs system outputs data at 100 Hz, whereas the other systems at one tenth of the rate.

VI.   Conclusion

We have shown that cheap RTK GPS modules has much better performance than standard GPS systems, and has a performance which is not far from expensive RTK GPS. The measured static performance has a standard deviation of less than one meter and typical less than half meters. In dynamic measurements, the cheap RTK GPS modules performed well with a precision of 20 cm under certain conditions.

The benefit of using RTK correction is best illustrated using a figure. In Figure 9. GPS tracks with (green) and without (yellow) RTK correction is presented. It is quite clear how much the precision is improved by employing RTK correction data.

Judging from their performance and their price trend, these affordable RTK receivers will find their way into many new applications. It is probable that many ITS actors will get one eventually, regardless if they move on land (roads), on sea, or in the air.
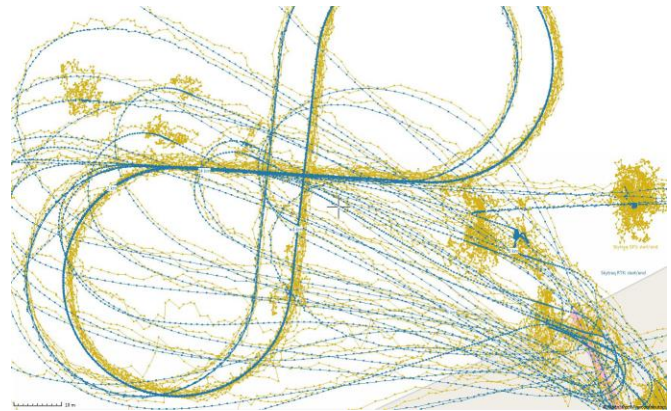
Acknowledgment

Figure 9.   GPS track with (green) and without (yellow) RTK correction.

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