Detection of Anomaly Signal by Signal Quality Monitoring Receiver

Shinji SAITOH, Takayuki YOSHIHARA, Sonosuke FUKUSHIMA and Naoki FUJII

Electronic Navigation Research Institute,
Independent Administrative Institution, Japan

BIOGRAPHIES

Shinji SAITOH is a researcher at Electronic Navigation Research Institute (ENRI), independent administrative institution (IAI). He received M. Eng. in Electronic Engineering from the University of Electro-Communications (UEC) in 1998. He joined ENRI, the Ministry of Transport (MOT) in 1998. Currently, he is researching in the area of GPS and GBAS. He belongs to GBAS research group in ENRI. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE).

Takayuki YOSHIHARA is a researcher at ENRI, IAI. He received a Ph.D. in GPS application for meteorology from Kyoto University, 2001. His research interests are ionospheric and tropospheric effect on propagation delay of GPS signals. His research currently includes evaluation of atmospheric error on GBAS, and GPS down-looking occultation observation using aircraft. He is a member of IEICE and Japan Institute of Navigation (JIN).

Sonosuke FUKUSHIMA is a senior researcher at ENRI, IAI. He received M. Eng. in Electronic Engineering from the UEC. Since 1988 he is working at ENRI. He is currently working in the field of GBAS, Airport Pseudolite (APL) and QZSS (Quasi-Zenith Satellite System). He is a member of IEICE and JIN. Currently, he is also a doctor course student in the Tokyo University of the Marine Science and Technology.

Naoki FUJII is a principal researcher and the leader of GBAS research group at ENRI, IAI. He received M. Sc. from Kobe University in 1979. He was charged with development of siting criteria of ILS, MLS and aircraft address monitoring system. He is currently working in field of development of GBAS.

ABSTRACT

Electronic Navigation Research Institute (ENRI) in Japan has been developing and evaluating Ground-Based Augmentation System (GBAS) and Satellite-Based Augmentation System (SBAS). GBAS and SBAS require high accuracy and high integrity information. So, Signal Quality Monitoring (SQM) is necessary for GBAS and SBAS, to meet high accuracy and high integrity. ENRI and Furuno Electric Co., Ltd. (FURUNO) have developed a new GPS receiver with real-time correlation-curve monitoring capability. This is the first prototype of the GPS receiver with SQM (SQM receiver) in Japan.

The receiver has 16 channels including 3 SBAS dedicated channels for L1-C/A signal tracking and 2 SQM channels. Each SQM channel has 127 correlation points distributed evenly at 0.025575 chip step. The width of the correlation monitoring range is about 3.2 chips. It can be allocated at any part of 1023 chip width by user selection. Each correlation point outputs both In-phase and Quadrature at 5 Hz.

We acquired data in two different environments by the SQM receiver. One is pure signal environment using a parabolic antenna, the other is strong multipath environment. Moreover we carried out hardware simulation to check to detection capability of the SQM receiver using anomaly GPS pseudo signals, such as ICAO's three threat models, generated by an arbitrary waveform generator and a vector signal generator.

This paper describes the specification of our SQM receiver, and details of data collected by the SQM receiver in some environments and results of hardware simulation to check for detection capability of the SQM receiver.

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INTRODUCTION

ENRI has been conducting the studies, the researches, the developments of procedures and the prototype system, the tests and the evaluations on navigation system so as to provide Japan Civil Aviation Bureau (JCAB) of the Ministry of Land, Infrastructure and Transport (MLIT) with technical materials for their planning and implementation of navigation systems. ENRI has been developing and evaluating GBAS [1, 2] and SBAS.

In DGPS positioning, such as GBAS and SBAS, if anomaly of a signal waveform occurs by failure of a GPS satellite, distortion will arise in the correlation curve in a GPS receiver, and it will become the cause of bringing about a large positioning error. As an example, which such distortion occurred in a receiver correlation curve, the SVN19 satellite problem by degradation of the transmitted waveform accompanying RF circuit failure of SVN19 satellite occurred in 1993 is known [3]. It is reported that several 10 meters positioning error arose in the DGPS positioning between different models by signal degradation of this SVN19 satellite.

GPS is widely used in many applications now. Safety critical applications, such as aircraft navigation, require high accuracy and high integrity information. So, signal quality monitoring is necessary for GBAS and SBAS, to meet these two difficult requirements, high accuracy and high integrity. SQM must detect the distortion of the correlation curve caused by GPS signal anomalies, such as 'evil waveform'.

ENRI and FURUNO have developed prototype SQM receiver [4], which is a GPS receiver with real-time correlation-curve monitoring capability. This is the first prototype of the GPS receiver with SQM in Japan. The receiver has 16 channels including 3 SBAS dedicated channels for L1-C/A signal tracking and 2 SQM channels. Each SQM channel has 127 correlation points distributed evenly at 0.025575 chip step. The width of the correlation monitoring range is about 3.2 chips. It can be allocated at any part of 1023 chip width by user selection. Each correlation point outputs both In-phase and Quadrature at 5 Hz.

First, we acquired the correlation curve of the GPS signal in pure signal environment using the satellite tracking system of Sugadaira space radio observatory of the University of Electro-Communications (UEC), as preliminary observation of the correlation curve of a GPS signal to get foundations of anomalous signal detection in the signal quality monitoring. Moreover, in order to investigate the behavior in a multi-path environment, we acquired correlation curve in the environment that the strong reflective wave by the sea surface combined. Furthermore, in order to consider the detection method of anomaly signals, we generated the anomaly pseudo-signal by an arbitrary waveform generator and investigated distortion of the form of a correlation curve, the result is reported in this paper. And this paper also describes outline of the SQM receiver.

OUTLINE OF SQM RECEIVER

Transmitting-signal of a GPS satellite is modulated with a different C/A-code (PRN) by each GPS satellite, so the GPS satellite signal is tracked by following the peak of a correlation curve of a received signal and a C/A-code which generated in a GPS receiver (shown in figure 1). Fundamentally, since the correlation curve is symmetrical, in the general GPS receiver, tracking-point is a center point where a correlator pair output is the same level. The width of correlator pair is set to 1 chip at the wide-correlator receiver, and set to 0.1 chips at the narrow-correlator receiver. Moreover, there is also the method of following by slope of a correlation curve.

When anomaly occurs to a transmitted signal by a failure in process of generating the C/A-code and/or modulation of transmitting signal in a GPS satellite, distortion arises in the correlation curve in a GPS receiver, and it becomes the cause of a ranging error. Since the ranging error is different by difference of correlator width when a different model from reference station is being used especially in a DGPS user, it becomes the cause that produces a large positioning error. As the GPS degradation signal that should be detected by the SQM, three types of threat model corresponding to such failures are mentioned in ICAO GNSS SARPs [5]. Model A is failure of digital circuits, such as a shift of clock timing. Model B is failure of analog circuits, such as an amplification part and a transmitting part. Model C is composite of model A and model B.

In order to detect such anomalies of a GPS signal,

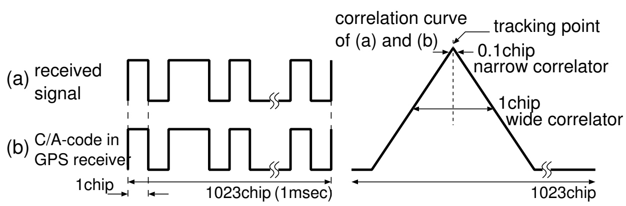

Figure 1: GPS signal and the correlation curve

Table 1: specification of the SQM receiver

receiving freq.	1575.42 MHz (L1-C/A)
num. of GPS channels	13
num. of SBAS channels	3
num. of SQM channels	2
sampling rate for SQM	0.025575 chips (40 MHz)
num. of samples	127 points/SQMch

Figure 2: Photo of the SQM receiver (middle of a rack)

and realize the SQM function for quality monitoring, we have been developing the SQM receiver, shown in figure 2, which can acquire a correlation curve. The SQM receiver is based on the GPS/SBAS receiver. The receiver has 16 channels including 3 SBAS dedicated channels for L1-C/A signal tracking and 2 SQM channels. Two satellites in a GPS satellite or the SBAS satellites are able to be assigned to SQM channels. A correlator output is sampled by 40 MHz and the receiver can output the correlator output level of the fixed interval (25 nsecs, 0.025575 chips) of 127 points centering on tracking-point every 200 msecs (5 Hz) fundamentally. The offset from tracking-point can be specified at 0.025575 chip step in the any part of 1023 chip width by user selection. Each correlation point outputs both In-phase and Quadrature at 5 Hz. Table 1 shows outline of the SQM receiver.

Table 2: outline of the satellite tracking system

receiving freq. range	1.4 GHz to 2.6 GHz
dish size	3.6 mϕ
beam width (-3 dB)	about 3 deg.

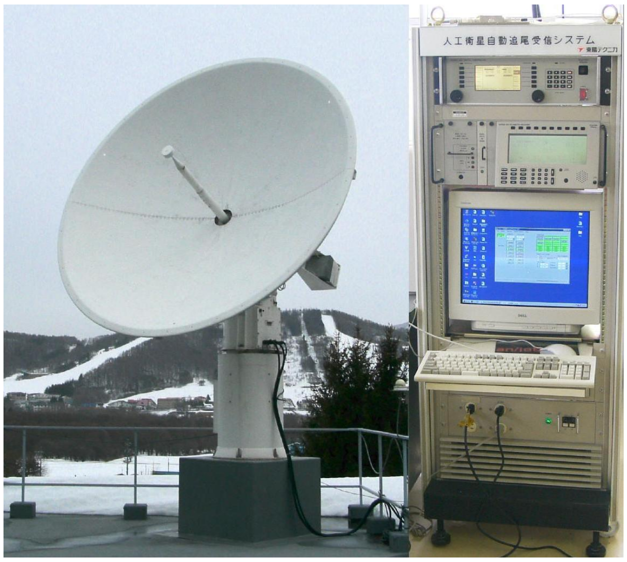

Figure 3: Photo of the satellite tracking system
left: parabolic antenna
right: control panel

ACQUISITION OF CORRELATION CURVE

Pure signal environment

In order to acquire the data in environment without distortion of the signal by the multi-path used as the basis waveform of detection of distortion using the developed SQM receiver, the signal acquisition by the parabolic antenna was conducted.C The correlation curve of each satellite was acquired using the satellite tracking system of Sugadaira space radio observatory of the UEC at Nagano prefecture. The observation was conducted from March 23 to 25, 2003 and from March 11 to 12, 2004, and the correlation curve data of a total of 30 GPS satellites and 1 SBAS satellite (POR) was able to be acquired.

The example of the acquired correlation curve (In-phase) is shown in figure 4 (PRN1) and figure 5 (SBAS satellite, PRN134). A horizontal axis is the gap from the tracking-point by chip, and a vertical axis is the correlation value that normalized in the value in the tracking-point. Compared with the example of the GPS satellite of PRN1, the correlation curve of the SBAS satellite of PRN134 is the form that became blunt. Since the transmitted signal bandwidth of a SBAS satellite (2.2 MHz) is narrower compared with the signal bandwidth (20 MHz) of a GPS satellite,

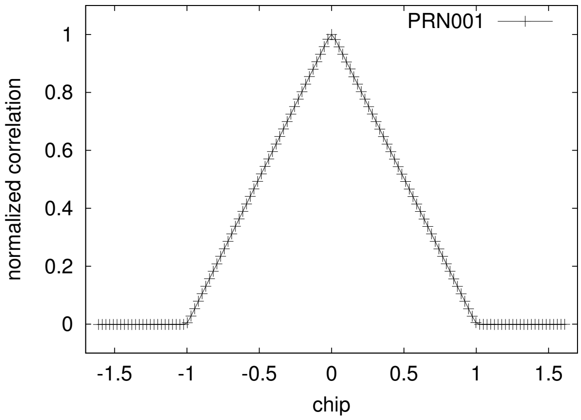

Figure 4: correlation curve of PRN1

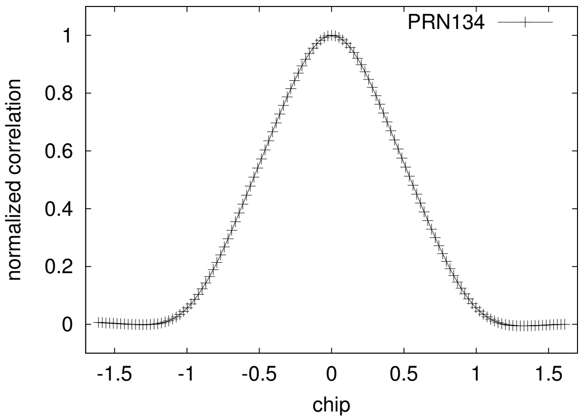

Figure 5: correlation curve of PRN134 (SBAS)

the bluntness is caused. From the such form of a correlation curve, in tracking of a SBAS satellite, when correlator width is narrow, it is considered that a ranging error tends to become large.

In GBAS that we are developing, not only in degradation signal detection but also in compensation information, since the signal of a SBAS satellite is to be used, it turns out that it is necessary to take into consideration of the difference in the signal characteristic of a SBAS satellite and GPS satellites. Moreover, it was checked by comparison of the correlation curve acquired with GPS satellites that the form of a correlation curve differ from PRN number, and this was in agreement with the calculation result by the simulation. It is necessary to investigate also about the influence by the difference in a correlation curve of each PRN number from now on.

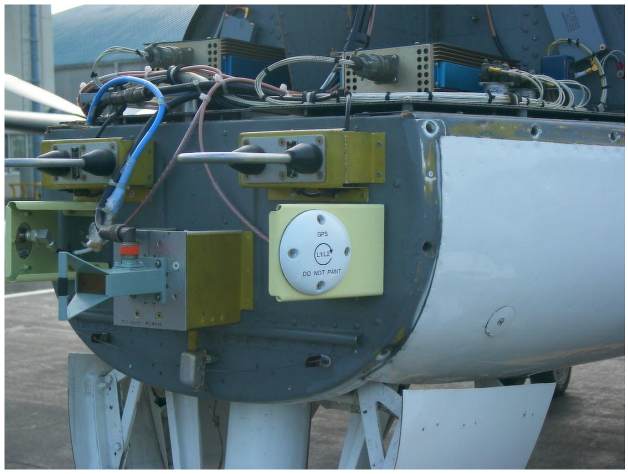

Figure 6: Photo of the GPS antenna attached into a nose of the experimental aircraft

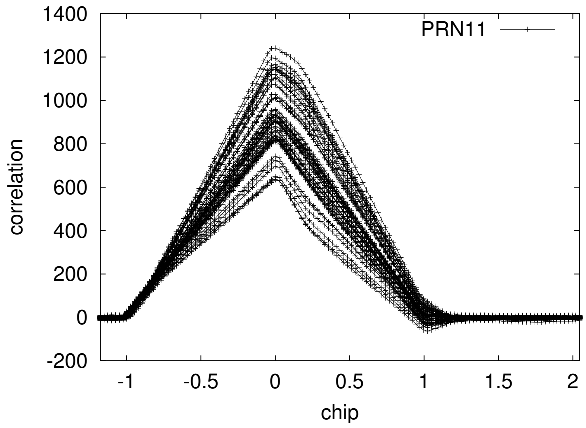

Figure 7: example of correlation curves of a signal with a reflective wave

Multi-path environment

The signal of the sea surface reflection which a strong multi-path produces, as the signal of the reflective wave combined, was acquired through the approach phase of an experimental aircraft. In order to acquire the reflective wave from a sea surface, we used the GPS antenna, shown in figure 6, attached inside of the nose of the experimental aircraft.

Figure 7 shows an example of a correlation curve of a signal with reflective wave. This figure shows correlation curve between 10 seconds in approach phase and vertical axis shows correlation value. Since a reflecting point is near compared with the distance to a GPS satellite, if the earth surface is assumed to be a plane, the path-length difference D of a direct wave and a reflective wave can express $D = 2H \sin\theta$ using height H and elevation angle θ. At the case of figure 7, the elevation angle of a satellite is about 6.0

degrees and the flight altitudes are 254 meters to 240 meters, so the path-length differences are 53 meters to 50 meters by calculation

On the other hand, from figure 7, reflective wave occurred about 7 points later from a direct wave, so it is $7 \times 0.025575 = 0.179$ chips delay. Since the C/A code signal of a GPS satellite are 1023 chips, and it is transmitted by 1.023 Mchip/sec, 0.179 chips is equivalent to 0.175 μsecs.

Therefore, multiplying 0.175 μsecs by the velocity of light, path-length difference of a direct wave and a reflective wave is calculated with about 52 meters, and is in agreement with the result of the geometric calculation. Thus, a signal with a reflective wave can distinguish from the correlation curve acquired with the SQM receiver comparatively easily, and application of the SQM receiver to development of the multi-path removal method etc. can be considered.

Anomalous pseudo-signal

In order to investigate about the influence by the signal of three threat model described in GNSS SARPs, using arbitrary waveform generator (Tektronix AWG420) and the vector generator (HP8979A), the degradation pseudo-signal corresponding to each model was generated, it inputted into the SQM receiver, and data acquisition was carried out.

Figures 8, 9 and 10 each show that anomalous signals, models A, B and C generated by the arbitrary wave form generator, the red solid line shows the anomalous signal and the blue dashed line shows a normal signal form. And figures 11, 12 and 13 each show that correlation curve acquired with the SQM receiver inputting the degradation pseudo-signal of models A, B and C, shown in figures 8, 9, and 10. Figure 11 shows the correlation curve of a signal with 0.1 chips delay of the falling edge. The curve became flat near the tracking-point, and the tracking-point shifted 0.05 chips from the original position, so the ranging error was about 15 meters. Figure 12 shows the correlation curve of the signal decreased with vibrating by 1/8 chips wavelength after the rectangle edge. Since the curve is changing greatly near the tracking-point, it is thought that it becomes a cause of the ranging error by difference of correlator width. The correlation curve of the model C is shown in figure 13. The signal of model C is composite of model A and B, and also the correlation curve of model C has two characteristic of model A and B.

As the technique of distinguishing such degradation signal, there is symmetry evaluation based on the ratio and difference of a correlation output of the pair from which correlator width differs. In the developed SQM receiver, since the correlator output of 127 points is obtained, examination of the detection technique by the combination of the correlator of various widths is possible, and it will carry out from now on.

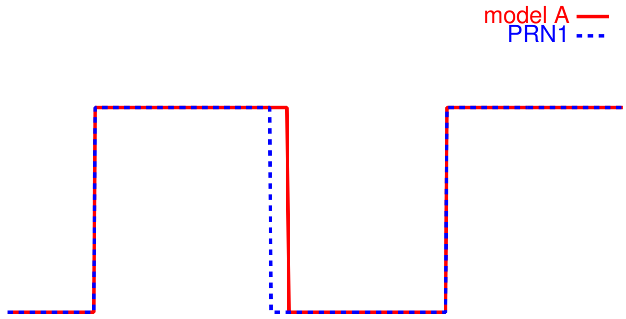

Figure 8: signal of the theat model A

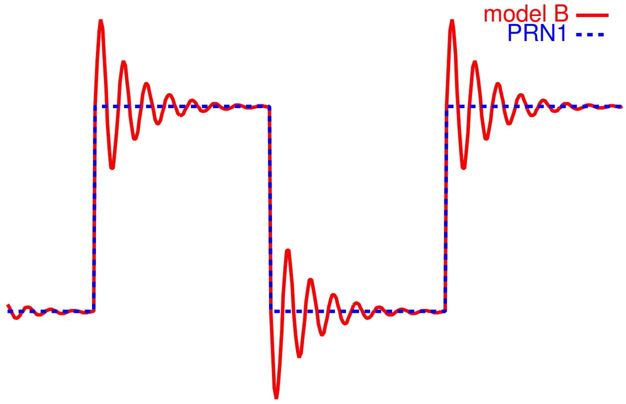

Figure 9: signal of the theat model B

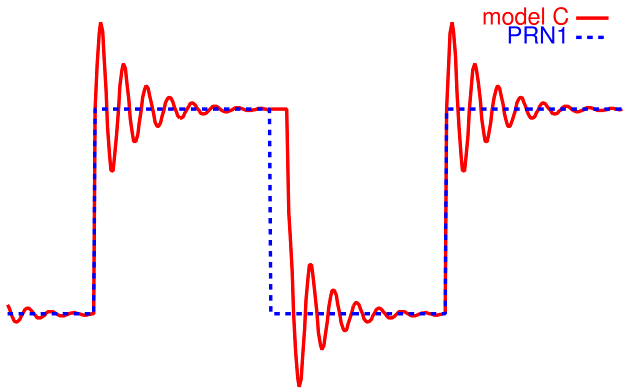

Figure 10: signal of the theat model C

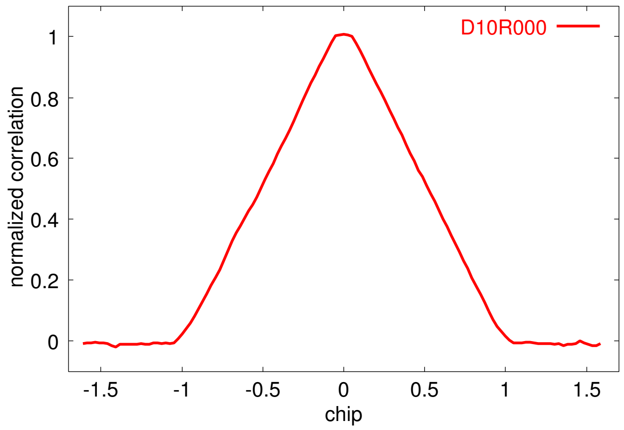

Figure 11: correlation curve of the theat model A

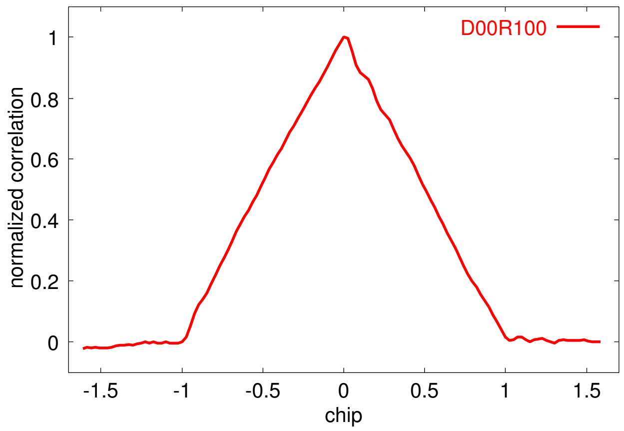

Figure 12: correlation curve of the theat model B

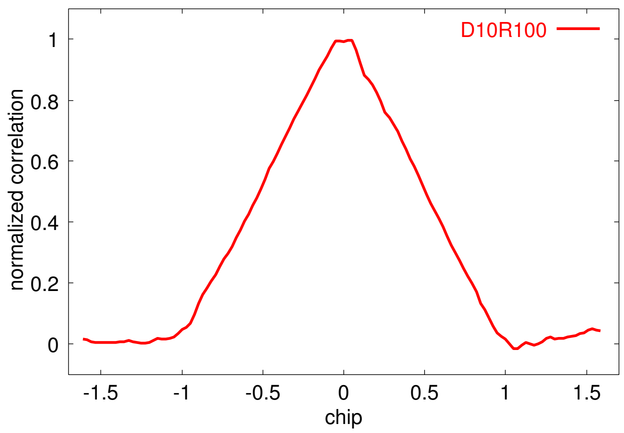

Figure 13: correlation curve of the theat model C

CONCLUSIONS

The SQM receiver that can acquire the correlation curve aiming at development of a GPS signal quality monitoring function was developed. Using the satellite tracking system of Sugadaira space radio observatory of the UEC, the correlation curve used as the basis of degradation signal detection was acquired by the SQM receiver. Moreover, signal acquisition in the multi-path environment by the sea-surface reflective-wave, and the hardware simulation at the case of the degradation signal input by arbitrary waveform generator were able to be conducted and the correlation curve by the degradation signal was able to be obtained.

From now on, we will perform the simulation by the degradation pseudo-signal that changed parameters, such as signal edge delay time, and vibration, attenuation, with the developed SQM receiver. Furthermore, we are due to develop about the degradation signal detection technique in which the difference in the characteristic of the signal of a GPS satellite and a SBAS satellite was taken into consideration.

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