A Survey on SQM for Sat-Nav Systems

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Abstract: ***Reduction of multipath effects on the satellite signals can be accomplished with innovative hardware design. Although such methods are effective in reducing multipath and the effects due to it, they are not practical enough, especially in varying environmental conditions. Implementation of Narrow Correlator spacing technique can reduce multipath effects to a great extent but has no advantage over carrier phase measurement accuracy. Pulse Aperture Correlator (PAC) although takes full advantage over Narrow correlator technique, it has low Signal to Noise ratio (SNR) and cannot remove close-in multipath. This paper provides an overview of early performance results obtained by using different correlator techniques for monitoring the quality of satellite signals. This paper proposes implementation of Vision Correlator for Signal Quality Monitoring of satellite signals. Vision Correlator is particularly useful in removing close-in multipath and also mitigates the effects of multipath on the signals in the line of sight. An experimental setup to check for the performance of Vision Correlator against the standard correlator has been proposed. Further, IRNSS architecture and frame format have been discussed.***

Keywords: IRNSS, SQM, PRN CODE, SHAPE, MMT, ICD, SPS, TLM, TOWC, CRC, MMT.

1. Introduction

Navigation is a process of monitoring and controlling the movement of a space vehicle from one place to another. The location of vehicles will be determined based on the latitude (equator) and longitude (prime meridian) values. For e.g. the latitude and longitude values of India is 22°00'N 77°00'E.The Indian Standard Timings (IST) is calculated based on 82.5°E longitude. Based on these latitude and longitude values, the location of a vehicle can be determined.

Following lists the different Navigation systems in use:
1) Automotive Navigation Systems.
2) Marine Navigation Systems.
3) Global Positioning Systems (GPS).
4) GPS Navigation Device.
5) Robotic Mapping Device.

The **Global Positioning System; i**ntroduced by the U.S Department of Defense in 1973, whose original purpose was to **provide accurate navigation** and **time transfer** to *military users*. In the past decade there has been a rapid growth in GPS civilian applications, which includes farming, marine, surveying and recreation purpose as well.

In concurrence with specially designed equipment on the ground, GPS can provide precision approach and landing capability for aircrafts. However, in 1993 due to the malfunctioning of one of the satellites, significant amount of distortion was introduced onto one of the pseudorandom (PRN) codes. This caused a large pseudorange error.

Signals that are received from the satellites might not always be clean. There could possibly be many anomalies in the signal. Anomalous signals are result of data transmission or hardware failures at or on the satellite itself. In addition to this, signal anomalies are also due to multipath, scintillation errors, Tropospheric and Ionospheric delays. In order to maintain the stringent integrity requirements of Wide area augmentation systems and large area augmentation systems, some kind of monitoring scheme needs to be in place at the reference receiver which will warn its users of potentially hazardous misleading information (HMI) within the Time to alarm (for avionics applications this is 6 seconds). This monitoring scheme is called SINGAL QUALITY MONITORING.

E.g. Signal anomaly on GPS Satellite SV19, observed in OCTOBER 1993.It caused differential pseudorange errors on the order of 3 to 8 meters. **Figure1** shows the signal anomaly observed due to the satellite hardware failure.

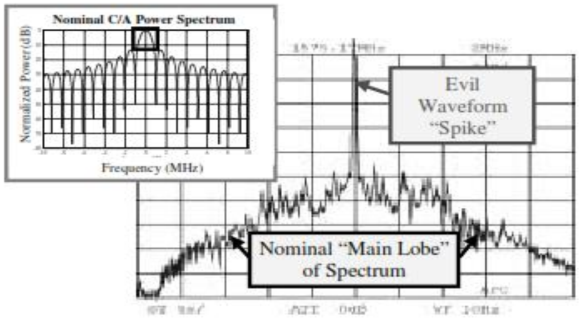

Figure 1: SV19 Signal Power Spectrum [1]

Why SQM→Signal anomaly occurs due to the failure of satellite or due to the failure of hardware at the receiver end. These anomalies will raise a distortion in the correlation curve resulting in a large positioning error. Hence; a monitoring scheme is needed to check for these anomalies prior to sending this information to SAT-NAV systems.SQM also protects the receivers from signal anomalies in the presence of multipath.

The SQM scheme would consist of one or more receivers having several correlators to sample the correlation peak at various locations to determine the level of distortion. An effective SQM design would keep the maximum differential pseudorange error below the maximum allowable error (MERR) in par with the elevation angles.

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2. Threats to Satellite Signal Quality

1) Evil waveforms (EWF):
EWF are due to the signal generating hardware failure. These failures introduce anomalous distortions onto the correlation peak **(figure2).** If such distortions are present on a satellite signals being tracked by a receiver; this could pose a severe threat to the integrity of that airborne user.

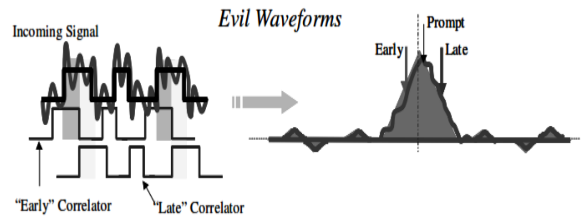


Figure 2: Effect of Evil Waveform on code tracking [1]

2) MULTIPATH
It causes significant distortion to the correlation peak (**Figure3**).The multipath is the reduced amplitude copy of the original signal. Since the relative delay, amplitude and multipath parameters are generally unknown; the superposition of these signals produces an unknown distortion of correlation peak.

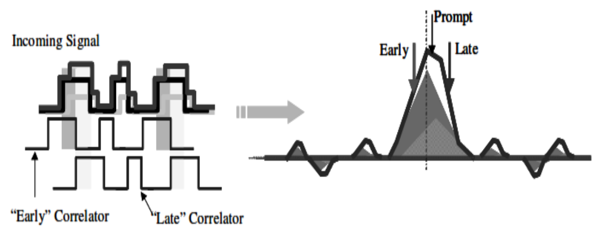


Figure 3: Effect of multipath on code tracking [1]

To reduce these threats on the satellite signal and to improve the quality and maintain the receiver integrity several correlator technologies have been implemented such as:
1) Narrow Band Correlator.
2) Wide Band Correlator.
3) Pulse Aperture Correlator (PAC).
4) Vision Correlator.

Importance of CORRELATION→Correlation is a statistical measure that indicates the extent to which two or more variables fluctuate together. Correlation analysis is one of the most widely used and reported statistical method in summarizing research data.

Correlation does not make any prior assumption about the dependency and relationship between the variables. If two variables are perfectly correlated then we can predict the value of one variable by making use of the other. It also checks for the interdependency of the variables.

Correlators are the key operation for navigation system receivers to synchronize with incoming signal and retrieve navigation message that will be used to provide navigation solution.

Although many attempts were made to improve the receiver performance using different correlator technologies, narrow correlator technology is proven to be more efficient and many of the receivers for sat-nav applications still make use of the same.

Narrow Correlator technology plays a very vital role in eliminating multipath error and while tracking the PRN code it reduces the code tracking errors in the presence of multipath. But, Narrow correlator spacing method has no advantage in terms of carrier phase measurement accuracy. Wider precorrelation bandwidth is required with higher sampling and DSP rates which has to be overcome with CMOS techniques. With all these advancements the bias due to multipath in GPS position calculations is still dominant.

PAC tracking loop is advantageous over narrow correlator spacing design. Additionally, PAC provides greater resistance to the multipath effects on the correlation function and reduces multipath bias on the pseudorange measurements. But, PAC has very low SNR and can't remove close-in multipath. Hence, another new correlator technology called **VISION CORRELATOR** has been introduced to reduce the effect of multipath on the signal.

VISION CORRELATOR is a method of measuring and processing synchronization signals of a received PRN code. It's very much useful in removing the *close-in multipath*.

Vision Correlator measures the phase transitions of modulated signal broadcasted from Satellite; measures the radio frequency characteristics of this broadcasted signal in time domain. It provides a very useful static that can be used for Signal Quality Monitoring of the received signal. This static is very much useful in filtering the unrepairable data. Following **Figure4** illustrates the baseband in-phase channel signal modulation in time domain during a sequence of PRN codes.

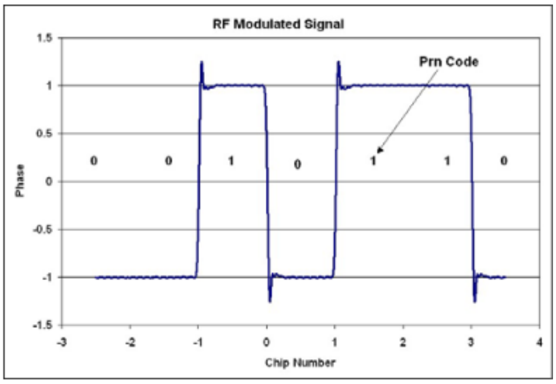


Figure 4: Time domain simulation of the in-phase channel of a GPS receiver. [3]

We can generate Vision Correlator output by filtering all transitions over a period of time. A **"shape"** can be extracted from all the transitions. **Figure5** shows average bit transition shape as measured from a specific satellite and GPS receiver.

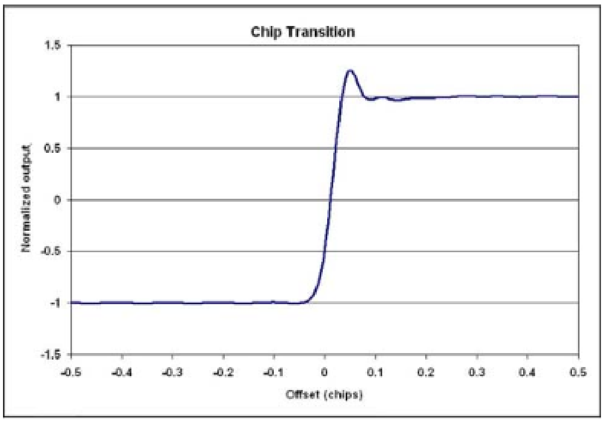


Figure 5: Avg chip transitions of GPS PRN 1 as measured using NovAtel ME3 GNSS receiver (VISION CORRELATOR MEASUREMENTS) [3]

Vision Correlator filters noise by overlapping chip transitions over a period of time and to get average chip transitions. This average chip transitions gives us Vision samples (shape). These vision samples are later processed through ***multipath mitigating technique (MMT).***

MMT process is an algorithm that process pulse shaped data array that helps in producing the best estimate of direct path signal and one or more multipath signal.

Each signal is represented by three parameters; amplitude, carrier phase and code delay.

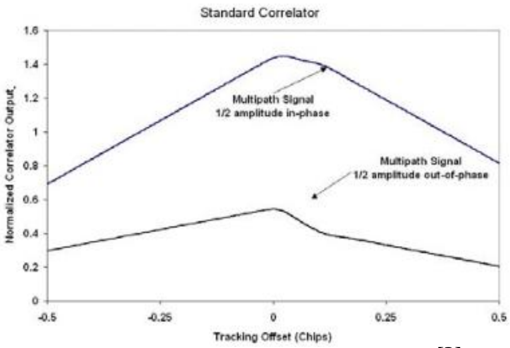
MMT algorithm estimates the best fit of the vision correlator vector by making use of different reference functions.

MMT requires a reference **"shape"** which is used to fit the incoming data with direct path and secondary path reference signals.

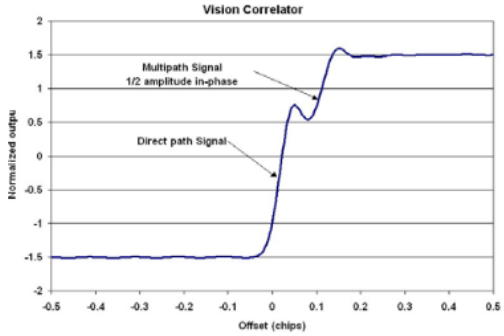
Once we establish a reference function, MMT algorithm can be used to separate vision correlation signal into direct path and multi path signals.

Vision Correlator is able to detect Evil waveform caused by unbalanced duty cycle, RF transition ringing and a combination of both.

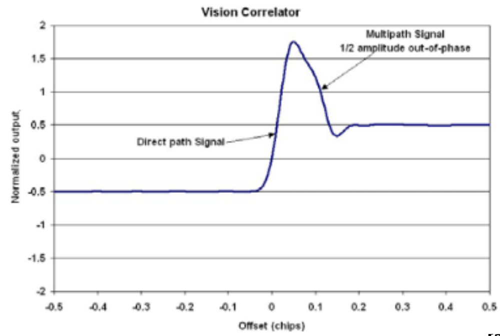
A standard correlation can be obtained by performing correlation operation between the incoming signal and locally generated PRN code. Here signal is assumed to be down converted to baseband. Following graphs A, B, C shows the performance of Vision Correlator compared to the standard correlator.



A:Output of standard Correlator [3]



B: Output of Vision correlator Inphase [3]



C: Output of Vision correlator out of phase [3]

Plots A, B, C show the correlator output with amplitude of multipath being half that of a direct path signal, having a delay of 0.1 chips. The effect of multipath on vision correlator is lesser when compared to that of a standard correlator. Vision Correlator removes the close-in multipath and it solves for more number of parameters.

Limitations

At higher elevation angle satellite data, vision correlator produces data which is similar to that of a Pulse aperture correlator (PAC).The data obtained will be a bit noisier because Vision correlator solves for more parameters.

3. Summary

CORRELATOR	INVENTORS	ADVANTAGES	LIMITATIONS
NARROW CORRELATOR	JUN MO, San Jose, CA(US) Shaowei Han, Palo Alto, CA(US)	Reduced code tracking errors in the presence of noise and multipath.	No advantage over carrier phase measurement accuracy.
PULSE APERTURE CORRELATOR	JASON JONES, PAT FENTON, BRIAN SMITH; NOVATEL Inc	Sharper and Narrower correlation function, signal is less prone to multipath. Provides pseudorange and position accuracies.	Low SNR and can't remove close-in multipath.
VISION CORRELATOR	JASON JONES, PAT FENTON, BRIAN SMITH; NOVATEL Inc	Removes close-in multipath and excellent signal quality monitoring capability. Less prone to noise and multipath	At higher elevation angle SAT data, VC produces results similar to that of a PAC.

The existing correlator technologies for SAT-NAV applications and their behavior are explained. Vision correlator has resistance towards noisy and multipath environment it can be implemented and used for Signal Quality Monitoring of SAT NAV systems. Using these initial survey results and performance measures of Vision Correlator we are proposing Vision Correlator Technology for SQM. Following **figure6** shows the method of work.

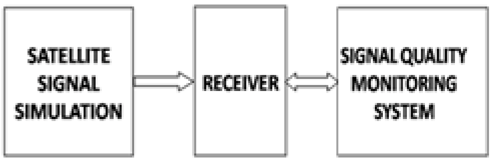


Figure 6: Block diagram of SQM system

It consists of a satellite signal simulation unit (simulator) which is responsible for generating the satellite signals. The necessary settings to get a signal, alike the real time ones are customized in the simulator. The parameters that apply for the satellites can be used.

The simulated signal is then fed to the receiver. The correlator inside the receiver gives the correlator a value using which correlation plot is obtained.

An SQM system in turn consists of a computer which is in full duplex communication with the receiver, gives the visual of the correlation peak.

An algorithm or program to monitor the receiver (correlator) is been developed from this system. Any deviation or spike in the correlation curve can be visualized in the SQM system.

Based on the correlation curve this data is further provided to the airborne users for navigation. If there are any deviation in correlation curve such signals will be mitigated. For error detection and correction we generate an IRNSS-SPS code by using INTERFACE CONTROLLER DOCUMENT (ICD). Using this code we generate a correlation curve which stands as a reference for SQM. The IRNSS architecture and frame structure is discussed in the following section.

4. IRNSS-SPS Signal Generation

1) IRNSS System Overview

Indian Regional Navigation Satellite System (IRNSS) is an independent, indigenously developed satellite navigation system fully planned, established and controlled by the Indian Space Research Organization (ISRO).

2) IRNSS Architecture

It majorly consists of:

- Space segment
- Ground segment.
- User segment.

3) IRNSS Space Segment:

The minimum numbers of satellites that are required for the IRNSS constellation are seven. Three satellites in the Geostationary Orbits (GSO) located at 32.5ºE, 83ºE and 131.5ºE. Four in Inclined Geosynchronous orbits (IGSO) with their longitude crossings 55ºE and 111.75ºE having two in each plane.

4) IRNSS Ground Segment:

This segment is liable for maintenance and operation of IRNSS constellation, which comprises of:

- ISRO Navigation Centre
- IRNSS Spacecraft Control Facility
- IRNSS Range and Integrity Monitoring Stations
- IRNSS Network Timing Centre
- IRNSS CDMA Ranging Stations
- Laser Ranging Stations
- Data Communication Network.

User Segment: The User segment mainly consists of:

- Single frequency IRNSS receiver capable of receiving SPS signal at L5 or S band frequency
- A dual frequency IRNSS receiver capable of receiving both L5 and S band frequencies.
- A receiver compatible to IRNSS and other GNSS signals.

Figure7 show the interface between space and user segments. IRNSS satellite provides standard positioning services (SPS) in L5 and S frequency bands.

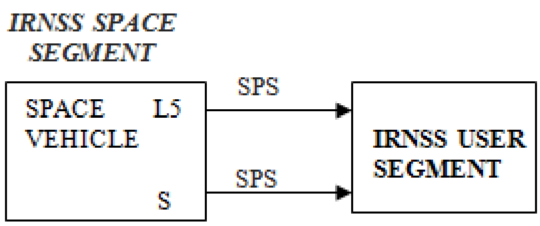


Figure 7: IRNSS Space and User Space Segment Interface

5) IRNSS Frequency Bands

The IRNSS SPS service is transmitted on two frequency bands, L5 (1164.45 – 1188.45 MHz) and S (2483.5-2500 MHz). The carrier frequency of IRNSS SPS-L5 is 1176.45 MHz and bandwidth is 24MHz (1164.45-1188.45 MHz). The carrier frequency of IRNSS SPS-S is2492.028MHz and bandwidth 16.5MHz (2483.50-2500 MHz).

6) IRNSS Frame Structure

IRNSS Signal in Space transmits Navigation message through SPS service, in L5 and S frequency bands. The IRNSS main frame is of 2400 symbols long which comprises of four sub frames. Each sub frame is 600 symbols transmitted at 50 symbols per second (sps). Each sub frame has 16 bit synchronization word followed by 584 bits of interleaved data. **Figure8** shows the IRNSS frame structure.

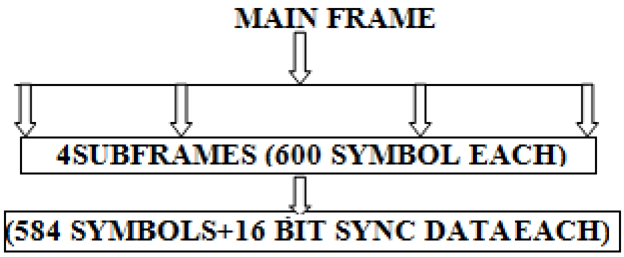


Figure 8: IRNSS Frame Structure

The sub frames 1 and 2 transmit primary navigation parameters which are fixed. The sub frames 3 and 4 transmit the secondary navigation parameters as messages.

All the sub frames transmit the Telemetry word (TLM), Time of Week Count (TOWC), Alert, AutoNav, Subframe ID, Spare Bit, Navigation data, Cyclic Redundancy Check (CRC) bits, and Tail bits. Subframe 3 and 4 in addition transmit Message ID and PRN ID.

All these information that are available from the ICD and be used to generate a signal from the simulator by configuring it using same parameters. The data that is obtained by the simulator will be same as that of a real time signal. Any changes with respect to the signal parameters can be made and test patterns can be generated which can be compared with the real time satellite data. This customized signal patterns and data can be made use for efficient SQM.

5. Conclusion

The Vision correlator characteristics have been discussed with its performance results. The effect of multipath interference on the vision correlator is lesser than the subtle variations that occur in the standard correlator. Vision Correlation process provides a significant improvement over older multipath mitigating techniques. Vision Correlator can remove the effects of multipath signal on the code and carrier measurements when the delay of multipath signal is less than 10meters of “Line of sight “of the signal and mitigate their effects to fraction of meter. It also provides a very useful static that can be used for Signal Quality Monitoring of the received signal. This static can be used to filter the data that is unrepairable.
The advanced Vision Correlator hardware filters the noise by super imposing successive chip transitions during a specific time interval to form an average chip transition (shape).Vision Correlator can detect Evil Waveforms caused by unbalanced duty cycle, RF transition ringing and a combination of the two.

Also the ICD helps by providing various satellite parameters such as Satellite ID, PRN code, frequency bands and satellite location which can be used to generate signals that are similar to the real time signals using a simulator. Using this signal generated from the simulator we can obtain correlator values which can be used to generate test patterns which help for improved SQM.

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