

A GLONASS Observation Message Compatible With The Compact Measurement Record Format

Leica Geosystems AG

1 Introduction

Real-time kinematic (RTK) Global Navigation Satellite System (GNSS) positioning has matured into an effective tool for applications that require precise (centimetre level) and near instantaneous estimates of the positions of points of interest. For more than a decade, GPS has been the system of choice for RTK positioning. However, the recent resurgence of GLONASS, the Russian Federation's equivalent to GPS, has seen the proliferation of combined GPS and GLONASS RTK equipment in the marketplace. Integrating the two systems can improve satellite availability and redundancy, which can lead to gains in productivity, reliability, precision and accuracy (Takac and Walford, 2006).

Typically, an RTK system comprises of a reference station, one or more rover units and a data link. The reference station is normally established at a fixed and known location and provides formatted information such as code and carrier phase measurements to rover units via the real-time data link. The reference station data is then combined with local measurements collected at the rover using proprietary differential processing techniques to yield precise relative coordinate estimates. The choice of data format used for the exchange of reference station information dictates the amount and quality of data received at the rover. In addition, the data format will also influence the time needed for transmission. These factors have a bearing on the time-to-fix as well as position latency, which are often key metrics used to measure the overall performance of an RTK system.

The majority of RTK system manufacturers implement proprietary data formats and protocols to distribute reference station data to the rover. Proprietary formats are normally compact and are designed to make best use of the integrated hardware and software features of the RTK system. However, proprietary formats do not facilitate interoperability between receiver types designed by different manufactures. For more than a decade, the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM-SC104) has actively addressed the issue of interoperability through the standardisation of real-time reference station data

transmissions. The latest embodiment of the standard is published in RTCM-SC104 v3.1; however, older versions, namely v2.1, v2.2 and v2.3, are still in use today.

In addition to the RTCM-SC104 standards, the Compact Measurement Record (CMR) format is another so-called open RTK data transmission protocol. CMR was first published in 1996 to provide a low-bandwidth (>2400 baud) alternative to the existing RTCM-SC104 standards of the day (Talbot, 1996). CMR has message types defined for GPS observations, reference station location and reference station description. In a modification, the scheduling of the station related information was altered to reduce the peak throughput (Talbot, 1997). The modified version is commonly referred to as CMR+.

One limitation of CMR and CMR+ is that neither format fully supports the new generation of combined GPS+GLONASS RTK systems such as the Leica System 1200. The CMR/CMR+ observation message is GPS specific and there are no published messages for GLONASS measurements. Despite the availability of practical alternatives that do support GLONASS RTK observables such as RTCM v3.1, CMR and CMR+ still remain de facto industry standards, especially in the US market. Even so, the operator of a dual GNSS reference station is forced to select a different protocol other than CMR/CMR+ in order to transmit GLONASS observations to the rover.

In this paper, a proprietary GLONASS observation message compatible with the CMR/CMR+ format is publicly disclosed. The new message is implemented in Leica System 1200 sensors and is transmitted in addition to the public CMR/CMR+ messages. The CMR/CMR+ has not been changed; therefore, existing sensors capable of decoding CMR are supported without a firmware upgrade, while GLONASS capable rovers will be able to realise the potential of a dual GNSS RTK system. The definition of a GLONASS observation message is an important step in the path to achieving interoperability. However, issues not addressed by the CMR data format such as receiver hardware biases must be tackled before full interoperability is attained.

2 CMR/CMR+

A brief overview of CMR and CMR+ is presented in this section. The reader is referred to Talbot (1996) and Talbot (1997) for a detailed description of each format and their design goals.

CMR is a broadcast (one-way) reference station data communication format. Therefore, the rover cannot request information and must wait for messages. All CMR messages are encapsulated within a six-byte frame structure that includes:

- Start of transmission identifier
- Type of CMR message
- Message length
- Data
- Checksum
- End of transmission identifier

Currently, there are three public CMR message types:

- Type 0 – Observations.
- Type 1 – Reference station location
- Type 2 – Reference station description

The reference location message is typically transmitted every 10 seconds. The reference station description is usually transmitted at the same rate interleaved between two type 1 messages. In the case of CMR+, the entire reference station location and description information is divided into sub-messages that are transmitted using the scrolling CMR message type 94h. The sub-messages are sent every second and it takes 15 seconds to transmit the full station information.

Generally the reference station information is not GNSS specific apart from the epoch time and datum of the reference station coordinates in message type 1. The coordinate datum is specified as WGS84 while the epoch time scale matches the time scale of the GPS observations. For a GPS-only sensor, the internal clock (oscillator) is steered to the GPS system time scale. Differences in the system time scales maintained by GPS and GLONASS are discussed in the next section.

For both CMR and CMR+, L1 and L2 code and carrier phase observations for RTK positioning are transmitted in message type 0. The observations are compressed in order to meet bandwidth requirements. The compression algorithm uses only measured data; therefore, the rover can readily reconstruct the raw reference station observations without the need for satellite ephemeris parameters. Typically, the observations are transmitted once per second.

Currently, there is no provision for GLONASS observations in message type 0. Although there are many similarities between GLONASS and its US counterpart, there are also some important differences between the two systems, such as coordinate datum, time

scale and signal structure, which should be considered in a message encapsulating GLONASS observations.

3 The GLONASS Signal Structure, Datum and Time Scale

Like GPS, the nominal GLONASS constellation consists of 24 satellites orbiting in near circular orbits at a nominal altitude of approximately 19100km (ICD, 2002). GLONASS satellites also broadcast signals in the L1 and L2 sub-bands of the radio frequency spectrum. However unlike GPS, GLONASS uses frequency division multiple access (FDMA) in both L1 and L2 frequency sub-bands. This means that each satellite modulates the same ranging code on carrier signals with slightly different frequencies and is identified by a slot number rather than a Pseudorandom Noise (PRN) number.

Despite the differences in the signal structures of GPS and GLONASS, L1 and L2 code and carrier phase observations represent the four basic observables that are obtained from each system for RTK positioning. Like GPS, GLONASS modulates a standard accuracy (C/A) code on L1 and a high accuracy (P) code on both the L1 and L2 carriers. Unlike GPS, the GLONASS P-code is not encrypted. New generation GLONASS M-type satellites also modulate the C/A code on L2 (ICD, 2002).

GPS and GLONASS each maintain their own coordinate reference frames. The GLONASS control and space segments use the PZ-90 reference frame (ICD, 2002). Owing in part to the differences between the definitions of the PZ-90 and the ITRS, a transformation of GLONASS satellite coordinates is required to ensure compatibility with the GPS WGS84 datum for high-precision positioning applications.

GPS and GLONASS also maintain independent time scales to each other. GPS uses a continuous time scale called *GPS time* (ICD-GPS-200, 2000) while *GLONASS time* is synchronized with the Russian national system time UTC (SU) (ICD, 2002). As a result, GLONASS time is discontinuous because of the periodic leap second corrections applied to UTC. Therefore, there is no integer-second difference between GLONASS time and UTC although there is a constant difference of three hours between the two time scales.

4 A CMR Compatible GLONASS Observation Message

In this section, a new message type is used to encapsulate GLONASS L1 and L2 code and carrier phase observations transmitted to the rover. The GLONASS observation message uses the CMR message frame structure described in section 1 and is assigned to type 3 since this number is undefined in the standard CMR/CMR+ format description. A detailed description of the message data fields is given in Appendix A.

An independent message was chosen for GLONASS observations in order to maintain backward compatibility with the published CMR/CMR+ format. Hence, existing sensors capable of decoding standard CMR/CMR+ messages are supported without the need for a firmware upgrade. However, existing sensors will require an upgrade in order to interpret the contents of the new message type.

In order to reduce data throughput, The GLONASS measurements are compressed using the observation compression algorithm mentioned in section 1. In fact, the GLONASS observation message has the same bandwidth requirements as the existing type 0 message. Since the compression algorithm uses only measured data, the formatted observations are not affected by the datum differences discussed in section 3.

The GLONASS satellites are uniquely identified by slot number rather than PRN number. The map of slot number to carrier frequency is broadcast to the rover in the satellite navigation data. Therefore, the frequency information is not sent specifically with the reference station observations.

There is no provision in the format to indicate to the rover that a GLONASS observation message is included in the transmission. Therefore, the sampling of GPS and GLONASS observations are synchronized and the corresponding messages sent at the same rate. Generally, an update rate once per second for reference station observations is recommended.

5 Hardware Biases

In addition to the ionosphere, the antenna and receiver electronics can also introduce frequency dependent biases into GNSS observations. For a particular sensor type, these hardware biases are usually constant for a given GPS L-band because all satellites transmit signals on the same carrier frequency. In contrast, variations in the frequency related GLONASS code and phase biases, or *inter-frequency* biases, may be introduced by the more complex GLONASS signal processing architecture (Walsh and Daly, 1996).

In RTK positioning, code and phase biases may cancel out during data processing when the reference and rover sensors are of the same type. However, if the observation sampling schemes used by the reference and rover sensors vary, as is typically the case for the sensors of different manufacturers, then residual code and phase biases may remain in the differenced observations. Significant hardware biases that are not accounted for by the data processing algorithm can have a detrimental effect on the overall performance of an RTK system.

Calibration of the code and phase offsets for different receiver types can be successful at reducing the impact of these biases on high-precision positioning perform-

ance (Walsh and Daly, 1996). Typically, RTK systems like the System 1200 incorporate proprietary methods to mitigate the effects of residual code and phase biases. However, a standardized solution to the problem is still lacking.

6 Conclusion

The Compact Measurement Record Format (CMR) is a de facto industry standard reference station data transmission protocol for RTK positioning. However, there is no provision in the format for GLONASS observations; hence, CMR/CMR+ does not fully support the new generation of combined GPS+GLONASS sensors such as the Leica System 1200.

A new CMR compatible message type that encapsulates GLONASS observations is described in this paper. The new GLONASS observables message, designated type 3, is implemented in GLONASS capable Leica System 1200 sensors and is transmitted together with the standard CMR/CMR+ messages.

The new message provides a mechanism for transporting GLONASS reference station observations to the rover for RTK positioning. However, the presence of residual hardware biases in the differenced observations is still an open problem that must be addressed when combining GNSS observations before full interoperability is achieved.

7 References

- ICD, (2002). Global Navigation Satellite System GLONASS Interface Control Document, version 5.0, Moscow, 51 pp.
- ICD-GPS-200, (2000), *Navstar GPS Space Segment / Navigation User Interfaces*, Revision C with IRN-200C-004, April 12, 137 pp.
- Radio Technical Commission For Maritime Services (RTCM), (2006), RTCM Standard 10403.1 For Differential GNSS Services – Version 3, *RTCM Paper177-2006-SC104-STD*, Developed by the RTCM Special Committee No. 104, October 27, 2006.
- Takac, F., and Walford, J., (2006), Leica System 1200 – High Performance GNSS Technology for RTK Applications, in: *Proc of the 19th International Technical Meeting of the Satellite Division of The Institute of Navigation*, Fort Worth, Texas, September.
- Talbot, N.C., (1996), Compact Data Transmission Standard for High-Precision GPS, in: *Proc. of the 9th International Technical Meeting of the Satellite Division of The Institute of Navigation*, Kansas City, Missouri, USA, September, pp. 861-871.

Talbot, N.C., (1997), Improvements in the Compact Measurement Record Format, *Trimble User's Conference*, San Jose, California, pp. 322-337

Walsh, D. and Daly, P., (1996), GPS and GLONASS Carrier Phase Ambiguity Resolution, in: *Proc. of the 9th International Technical Meeting of the Satellite Division of The Institute of Navigation*, Kansas City, Missouri, USA, September, pp. 899-907.

Appendix A – GLONASS Observations (Message Type 3)¹

The GLONASS observables message is divided into a header portion and data portion. The header contains timing information and satellite tracking information relevant to the observable block. The observable block is repeated for each GLONASS satellite tracked. There is no provision in the CMR format to indicate to the rover that a GLONASS observation message is included in the transmission. Therefore, GPS and GLONASS observations should be synchronized and broadcast at the same rate.

Table 1. GLONASS Observables Header Block

Parameter	# of bits	Range	Units and Scale factor	Description
Version Number	3	0 - 7	dimensionless	Defines the format version and allows for future expansion of the format. Currently version 3 is defined.
Station ID	5	0 - 31	dimensionless	Identifies the reference station from others working in the area.
Message Type	3	0 - 7	dimensionless	Describes the information that follows in subsequent data blocks. The GLONASS observables message type is 3.
Number of SVs	5	0 - 31	dimensionless	Number of satellites contained in the observable blocks that follow.
Epoch Time (UTC)	18	0 - 240,000	milliseconds	Receiver epoch time for the GLONASS measurements modulo 240 seconds in the UTC time scale. The epoch time is scaled into milliseconds and transmitted as an unsigned 18-bit integer. It is assumed that the rover receiver has a good knowledge of time and therefore can remove the 240-second ambiguity in the epoch time.
Clock Bias Validity	2	0 - 3	0 - invalid 3 - valid	Indicates that the reference receiver clock offset is valid or invalid.
Clock Offset	12	+/- 0.5 milliseconds	500 nanoseconds	The clock offset is given in the range -0.5 to +0.5 milliseconds. Two's complement representation.
Total	48			

Table 2. GLONASS Observables Block Header Structure.

msb															lsb
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Version			<--- Station ID --->					<-Type->		Num. of SVs					
<----- Epoch Time ----->															
<--->			ClkState		<----- Clock Offset ----->										

¹ Leica Geosystems AG reserves the right to modify the GLONASS observation message specification without notice.

Table 3. GLONASS Observables Block

Parameter	Number of bits	Range	Units and Scale factor	Description
Satellite ID	5	0 - 31	dimensionless	GLONASS Satellite identifier (Slot Number)
P-code / CA-code flag	1	0,1	0 - CA-code 1 - P-code	Indicates the type of code data being tracked on the L1 band.
L1 Phase data valid	1	0,1	0 - Invalid 1 - Valid	Indicates the validity of the phase data. Only use phase when the validity flag is set.
Extended L2 data follows	1	0,1	0 - L1 only 1 - L1 & L2	L2 data follows the L1 data if this flag is set.
CA-code pseudorange	24	0 - 2^{21} L1 cycles	1/8 L1 cycles	The L1 pseudorange is transmitted modulo 1 light millisecond (299792.458m), in units of 1/8 L1 cycles.
Carrier - Code	20	$\pm 2^{19}$ (1/256 L1 cycles)	1/256 L1 cycles	The carrier phase data is referenced against the full pseudorange as reconstructed from the code measurement field. The carrier phase is scaled in 1/256 L1 cycles and broadcast in the range $\pm 2^{19}$. Two's complement representation.
SNR	4	0 - 15	See description	The Signal-to Noise Ratio value is given in the range 0-15 where the following lookup table applies. SNR[parameter] = 0[0], 30[1], 32[2], 34[3], 36[4], 38[5], 40[6], 42[7], 44[8], 46[9], 48[10], 50[11], 52[12], 54[13], 56[14], 58[15].
Cycle slip count	8	0 - 255	dimensionless	Incremented every time there is a cycle slip on this satellite. The rover should assume that a cycle slip has occurred if the cycle slip count increments between measurement epochs.
Total	64			

Table 4. Observables Block Contents.

msb														lsb	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
<--- Slot Number --->				P/C Ph L2		<----- Pseudorange ----->									
----- Pseudorange (cont) ----->															
<----- Carrier - Code ----->															
<----->				<----- SNR ----->				<--- Cycle Slip Count --->							

Table 5. L2 GLONASS Data Block

GLONASS L2 data is appended directly to the L1 observable data for each satellite. Only full wave receiver types are supported.

Parameter	Number of bits	Range	Units and Scale factor	Description
L2 code available (A)	1	0,1	0 - no code available 1 - code available	Receivers capable of tracking L2 code during encryption should set this flag to indicate that L2 code data is available.
P-code / C/A code flag (B)	1	0,1	0 - P-code 1 - C/A code	Indicates the type of code data collected on L2. This bit is ignored if no code information is present.
Code Valid (C)	1	0,1	0 - False 1 - True	Indicates the validity of the L2 code information.
Phase Valid (D)	1	0,1	0 - False 1 - True	Indicates the validity of the L2 phase information.
Reserved	4	Reserved	Reserved	Reserved
L2 range - L1 range	16	+/- 2 ¹⁵ centimeters	0.01 meters	The L2 range measurement is referenced against the L1 range measurement and broadcast in terms of integer centimeters. Two's complement representation.
L2 carrier - L1 code	20	+/- 2 ¹⁹ (1/256 L2 cycles)	1/256 L2 cycles	The L2 carrier phase measurement is referenced against the L1 code measurement, in a similar fashion to the L1 carrier phase. The units for the L2 carrier minus L1 code is in terms of 1/256 L2 full cycles.
L2 SNR	4	0 - 15	See Description	The L2 Signal-to-noise Ratio where the following lookup table applies: SNR[parameter] = 0[0], 4[1], 8[2], 12[3], 16[4], 20[5], 24[6], 28[7], 32[8], 36[9], 40[10], 44[11], 48[12], 52[13], 56[14], 60[15].
L2 cycle slip count	8	0 - 255	dimensionless	The L2 cycle slip count is an accumulated sum of the number of cycle slips at the transmitting receiver.
Total	56			

Table 6. L2 Data Block Contents.

m s b													l s b		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A	B	C	D	Reserved				<-----L2-L1 Range-----							
-----L2-L1 Range (cont)----->								<---L2 Phase-L1 Code---							
-----L2 Phase-L1 Code (cont)----->											<---SNR---				
<---L2 Cycle Slip Count----->															