

Andrea Valmorbida

Denis Zanutto

Smart Antenna GPS Matlab Software

Responsibility:	Name:	Date:	Approval:
Prepared by:	Valmorbida A. (CISAS) Zanutto D. (CISAS)		
Checked by:	Caporali A. (CISAS)		
Product Assurance:			
Program Responsible:			
Configuration Control:			

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SUMMARY

1 INTRODUCTION	9
1.1 Purpose of the document	9
1.2 Purpose of the software	9
1.3 Acronyms	10
1.3.1 Acronyms.....	10
1.4 References	10
1.4.1 Reference documents	10
1.5 Overview of the document.....	10
2 GPS SYSTEM ARCHITECTURE	11
2.1 Space segment	11
2.2 Control segment	12
2.3 User segment.....	13
2.4 GPS signal.....	13
2.5 Navigation MSG	14
2.6 Position calculation.....	15
2.6.1 Least Square Fitting	15
3 HW/SW ARCHITECTURE.....	17
3.1 CMC Smart Antenna RS232	17
3.1.1 Main Features	18
3.1.2 Interconnections	18
3.1.3 Data interfaces	18
3.1.4 Detailed specifications.....	19
3.1.5 Interface characteristics.....	20
3.1.6 Physical characteristics	20
3.1.7 Environmental characteristics	20
3.1.8 Receiver State	21
4 INTERFACE CONTROL DOCUMENT (ICD)	23
4.1 General Description.....	23
4.2 Communication Protocol	23
4.2.1 GPS receivers (IF1).....	23
4.2.2 Binary Protocol Input MSGs	24
4.2.3 Binary Protocol Output MSGs	25
4.2.4 CMC Binary Protocol decoding (IF2).....	29

5	SW DESCRIPTION.....	31
5.1	SW OVERVIEW.....	31
5.2	SW FLOW CHART	31
5.3	MSG STRUCTURES	35
5.3.1	Example.....	38
5.4	GPS RAW DATA DECODING	40
6	FEASIBILITY AND RESOURCE ESTIMATE.....	41
7	TEST PLAN	43
7.1	Kinematic testing	43
8	CONCLUSION	51

FIGURE LIST

Figure 2-1	GPS Architecture	11
Figure 2-2	Satellite Constellation.....	12
Figure 2-3	Control Segment	12
Figure 2-4	Signal structure	13
Figure 2-5	Navigation MSG	14
Figure 3-1	HW/SW elements.....	17
Figure 3-2	CMC Smart Antenna RS232	18
Figure 3-3	Receiver geometrical features	19
Figure 4-1	MATLAB program interface.....	23
Figure 5-1	Matlab - kml file - link file - Google Earth network.....	31
Figure 5-2	Main Program Flow Chart RT mode	32
Figure 5-3	Main Program Flow Chart PB mode	33
Figure 5-4	Main LOOP Flow Chart.....	34
Figure 7-1	Google Earth plot of the path along via Venezia.....	44

TABLE LIST

Table 4-1	CMC MSGs	25
Table 4-2	CMC output MSGs	28
Table 5-1	MSG Header Vectors	35
Table 5-2	MSG Structure.....	37
Table 5-3	Decoding Functions.....	40
Table 7-1	Raw data flux from the GPS receiver in the first 2 seconds of the kinematic test	46
Table 7-2	First MSG 20 structures decoded.....	47
Table 7-3	First MSG 21 structures decoded.....	47
Table 7-4	First MSG 23 structures decoded.....	48
Table 7-5	First MSG 33 structure decoded	48
Table 7-6	Pseudo Range measurements (km) of the SV's in view corresponding to the first 21 seconds of the kinematic test	49
Table 7-7	Coordinates list corresponding to initial and final part of path on via Venezia. Initial UTC time 10:53:14, finale UTC time 10:56:09	50

1 INTRODUCTION

1.1 Purpose of the document

This document presents a detailed description about the activity during the PhD course “Il GPS e sue applicazioni”, at Doctoral School in Science, Technology and Measurement for Space of the University of Padova.

The aim of the work is to establish communication with a GPS receiver by means of serial port in order to download the data flow and to plot in real time the receiver position in a GoogleEarth map. The information transmitted is divided in several message blocks, identified by a header. Every message contains specific information about the receiver, sent signals, health status of satellites constellation and their ephemeris.

Our study has been focused on defining the communication with the serial port in Matlab environment, so decoding and elaborating the raw data in way to obtain the position of the receiver.

The aim of the document is to illustrate:

- Software Requirements
- Interface Control Document
- Architecture Design
- Test Plan

1.2 Purpose of the software

The developed Matlab SW must acquire in RT the flux data from the ALLSTAR SMART ANTENNA RS232 GPS receiver; decode the raw data in order to obtain the position in terms of longitude, latitude and altitude; and lastly plot the position in RT on GoogleEarth.

The SW lets to the user to establish a communication with the receiver and process the data both in RT and PB mode. The first is the typical example of a navigation system, as that typically used in our car drawing the position in a map; the second is useful when we want to only acquire the data and process them afterwards. In fact the SW save also the raw data in a log file as binary format, which can be elaborate faster, because it hasn't to wait for the GPS signal.

The SW implemented and here shown can become a starting point for future development and applications. In fact improving the connection between PC and receiver in order that downloading and data processing are made in parallel, rather than series, the computational time required decreases. So also programming language typically defined slow, but very useful and friendly, like Matlab, can be used for more elaborated operations.

1.3 Acronyms

1.3.1 Acronyms

CPU	Central Processing Unit
I/O/C	Input/Output/Configuration parameters
ICD	Interface Control Document
MSG	Message
N/A	Not Available
OS	Operating System
PB	Playback
RT	Real Time
SV	Spacecraft Vehicle
SW	Software

1.4 References

1.4.1 Reference documents

Id	Title	Doc. No.	Company	Issue	Date
01	ESA SW engineering standard	PSS-05-00	ESA	2	
02	Allstar user's manual	1200-GEN-0101B	BAE sys		17/4/2000
03	Navstar GPS space segment/Navigation User Interface	ICD-GPS-200	Navstar	5R1	14/1/2003

1.5 Overview of the document

The document is structured as follows:

- Chapter 1: **Introduction** specifies the purpose and the scope of this document. It provides the references, the definitions and the acronyms used in the entire document.
- Chapter 2: **GPS System Architecture** provides an overview of GPS system segments.
- Chapter 3: **HW/SW Architecture** numbers every components used and describes the main features of GPS receiver.
- Chapter 4: **Interface Control Document** defines how the receiver communicates with the pc by means serial port.
- Chapter 5: **SW Description** provides specification and a detailed description of the SW developed to read the data flow from the receiver.
- Chapter 6: **Feasibility and Resource Estimate** provides a list of OS where the SW has been tested.
- Chapter 7: **Test Plan** shows the results obtained during the SW validation.
- Chapter 8: **Conclusion** comments the work made and the future developments.

2 GPS SYSTEM ARCHITECTURE

The Global Positioning System is a space-based global navigation system formed by a 24-satellite constellation that can tell you where you are in three dimensions. GPS navigation and position determination is based on measuring the distance from the user position to the precise locations of the GPS satellites as they orbit. By measuring the distance to four GPS satellites, it is possible to establish three coordinates of a user's position (latitude, longitude, and altitude) as well as GPS time.

Originally developed by the American Department of Defense to meet military requirements, GPS was quickly adopted by the civilian world even before the system was operational. Nowadays it is maintained by the USA government and is freely accessible by anyone with a GPS receiver.

The GPS system is composed by three main elements: space segment, control segment and user segments.

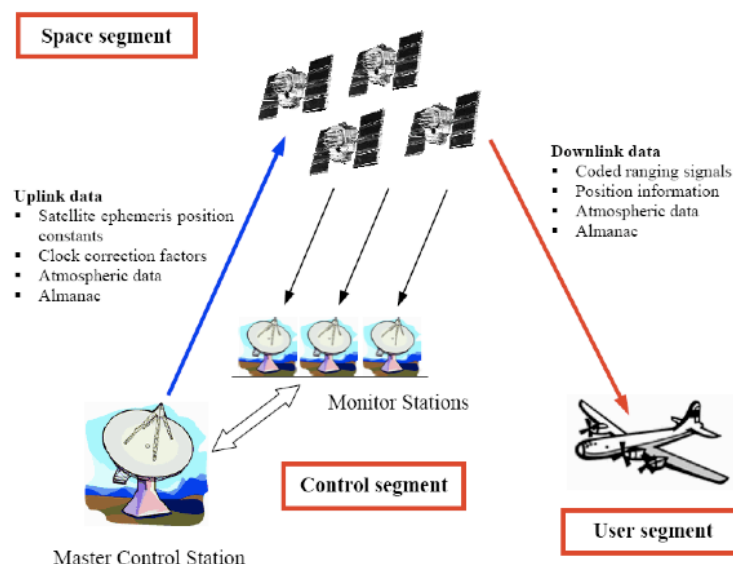


Figure 2-1 GPS Architecture

2.1 Space segment

The space segment is actually constituted by 32 (24+8 for reserve) satellites. The constellation has been designed to provide the service to every point of the Earth. Its configuration is formed by 24 satellites distributed on six orbital planes (4 for each plane), inclined by 55° with respect to equatorial one and separated by 60° right ascension of the ascending node. Every satellite is placed in a quasi-circular orbit of radius 26600km, so its orbital period is 11h and 58min, is that, half sidereal day.

Every satellite transmits information by means of carriers L1 and L2. In particular it sends three main MSGs: codes C/A and P for the pseudo-distances and carrier phase, plus navigation MSG for ephemeris of satellite.

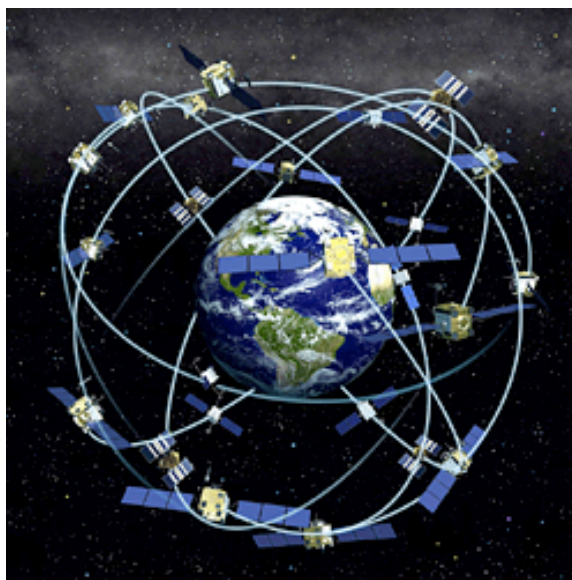


Figure 2-2 Satellite Constellation

2.2 Control segment

The GPS-System is controlled by the US Army: the master control station (Schriever Air Force Base, Colorado) and four additional monitoring stations (on Hawaii, Ascension Islands, Diego Garcia and Kwajalein) were set up for monitoring the satellites. Policy and management oversight resides with the National Space-Based Positioning, Navigation, and Timing Executive Committee cochaired by deputy secretaries of defense and transportation.



Figure 2-3 Control Segment

The passive monitor stations are GPS receivers, which track all satellites in their range and collect data of the satellite signals. The raw data are then sent to the mater control station where the data are processed. Here the data from the monitor stations are

processed 24 h a day in RT. As results, information about orbits and clocks of the satellites are obtained. Doing this, possible malfunctions can quickly be detected. Additionally, from the raw data new ephemeris data are calculated. Once to twice a day, these data and other commands are sent back to the satellites via the transmitting antennae on Ascension Islands, Diego Garcia or Kwajalein by means of a S-band signal (S-band: 2000 - 4000 MHz).

2.3 User segment

This component consists of the GPS receivers and the user community. GPS receivers convert SV signal into position, velocity and time estimates. This process requires four satellites to compute the four dimension of X, Y, Z (position) and time. With this ability, GPS system has three main functions: navigation (for aircraft, ships, etc), precise positioning (for surveying, plate tectonics, etc,) and time and frequency dissemination (for astronomical observatories, telecommunications facilities, etc.)

2.4 GPS signal

The GPS navigation MSG is the data supplied to the user from a satellite. Signals are transmitted at two L-band frequencies, L1 (1575.42 MHz) and L2 (1227.60 MHz), to permit corrections to be made for ionospheric delays in signal propagation time in dual frequency receivers. The L1 carrier is modulated with a 10.23 MHz precise (P-code) ranging signal and a 1.023 MHz clear acquisition (C/A code) ranging signal. These are pseudo random noise (PRN) codes in phase quadrature. The L2 signal is modulated with the P-code only.

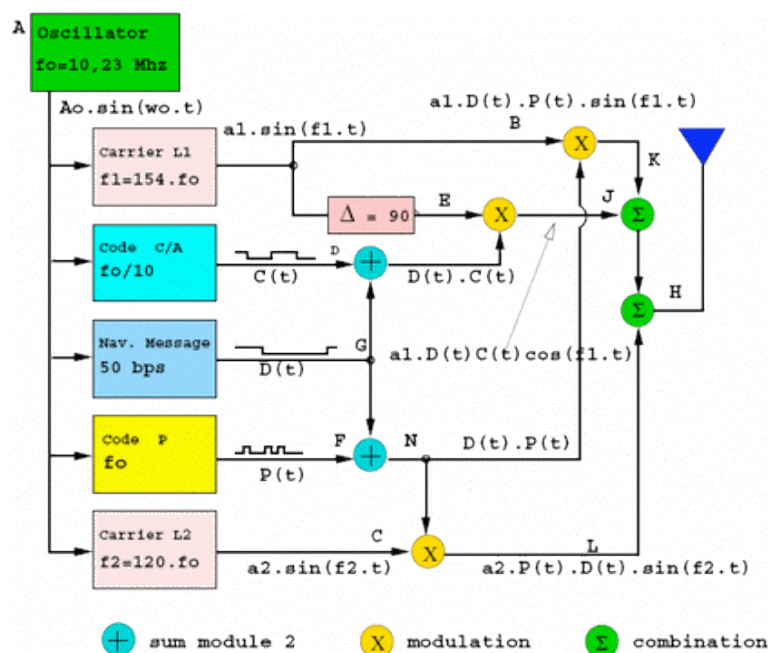


Figure 2-4 Signal structure

Both the L1 and L2 signals are also continuously modulated with a data stream at 50 bits per second. The P-code is a PRN sequence with a period of 38(+) weeks. The C/A code is a shorter PRN sequence of 1023 bits having a period of one millisecond. The P-code is intended for military use and is only available to authorized users. Access to GPS by civilian users is provided through the C/A coded signals. The navigation MSG consists of a 50 bit per second data stream containing information enabling the receiver to perform the computations required for successful navigation. Each satellite has its own unique C/A code that provides satellite identification for acquisition and tracking by the user.

Design, development, and acquisition of the GPS space, ground, and military user-equipment segments is handled by the GPS Wing (formerly NAVSTAR GPS Joint Program Office), which is part of the Space and Missile Systems Center at Los Angeles Air Force Base, California. A thorough documentation of the signals, which can be used as the basis for designing civil GPS receivers and related products, resides in the GPS Interface Specifications (formerly called Interface Control Documents or ICDs) maintained by the GPS Wing. The current GPS documentation, including IS-GPS-200 and the draft IS-GPS-800 for the new L1 civil signal (L1C).

2.5 Navigation MSG

The navigation MSG is made up of three major components. The first part contains the GPS date and time, plus the satellite's status and an indication of its health. The second part is about orbital information called ephemeris data and allows the receiver to calculate the position of the satellite. The third part, called the almanac, contains information and status concerning all the satellites, their locations and PRN numbers.

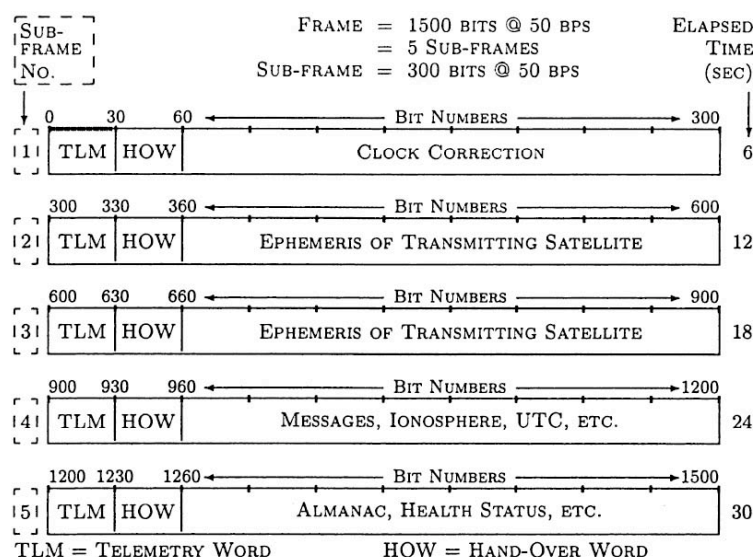


Figure 2-5 Navigation MSG

Whereas ephemeris information is highly detailed and considered valid for no more than four hours, almanac information is more general and is considered valid for up to 180 days. The almanac assists the receiver in determining which satellites to search for,

and once the receiver picks up each satellite's signal in turn, it then downloads the ephemeris data directly from that satellite. A position fix using any satellite can not be calculated until the receiver has an accurate and complete copy of that satellite's ephemeris data. If the signal from a satellite is lost while its ephemeris data is being acquired, the receiver must discard that data and start again.

The navigation MSG itself is constructed from a 1,500 bit frame, which is divided into five subframes of 300 bits each and transmitted at 50 bit/s. Each subframe, therefore, requires 6 seconds to transmit. Subframe 1 contains the GPS date and time, plus satellite status and health. Subframes 2 and 3 together contain the transmitting satellite's ephemeris data. Subframes 4 and 5 contain components of the almanac. Each frame contains only 1/25th of the total almanac; a receiver must process 25 whole frames worth of data retrieve the entire 15,000 bit almanac MSG. At this rate, 12.5 minutes are required to receive the entire almanac from a single satellite.

2.6 Position calculation

Using MSGs received from a minimum of four visible satellites, a GPS receiver is able to determine the times sent and then the satellite positions corresponding to these times sent. A satellite's position and pseudorange define a sphere, centered on the satellite with radius equal to the pseudorange. The position of the receiver is somewhere on the surface of this sphere. Thus with four satellites, the indicated position of the GPS receiver is at or near the intersection of the surfaces of four spheres. In the ideal case of no errors, the GPS receiver would be at a precise intersection of the four surfaces.

The PseudoRange measurements PR can be modelled as follows:

$$PR = \rho + c\Delta\delta + d_{ion} + d_{trop} + e \quad \text{Eq.1}$$

where ρ is the slant range between the GPS satellite and the receiver, c is the speed of light, $\Delta\delta$ contains the GPS clock error and the receiver clock error ($\Delta\delta = \Delta t - \Delta T$, where Δt refers to the navigation satellite and ΔT to the receiver), d_{ion} is the ionospheric delay, d_{trop} is the tropospheric delay and e contains the residual errors including multipath.

2.6.1 Least Square Fitting

A first estimate of position is used to create function f , which must be minimized using an appropriate algorithm as least square method.

Let y be the residuals pseudo distance differences:

$$y = PR_{obs} - PR_{calc} \quad \text{Eq. 1}$$

f can be write as:

$$f = \sum (PR_{obs} - PR_{calc})^2 \quad \text{Eq. 2}$$

We can write

$$y = Ax + \varepsilon \quad \text{Eq. 3}$$

where A is the matrix of the partials of the PseudoRange relative to the position coordinates (geocentric reference system), receiver clock bias and atmospheric delay, x is the array of the corrections to be applied to the independent variables, ε is the noise term.

It is then possible to use the Least Square Solution approach to minimize Eq. 2:

$$A^T \Sigma y = A^T \Sigma A x \quad \text{Eq. 4}$$

Where Σ , the observation correlation matrix, is equal to $\Sigma = \sigma^2 I$ assuming to have independent errors (zero mean) so it can be simplified as

$$A^T y = A^T A x \quad \text{Eq. 5}$$

So the increase to give at each variable can be determined as:

$$x = [A^T A]^{-1} A^T y \quad \text{Eq. 6}$$

3 HW/SW ARCHITECTURE

The section provide a brief numbering of all HW/SW elements used:

- GPS receiver
- Power supply / Battery;
- Receiver power supply cable
- Receiver – PC cable;
- Serial– USB adapter;
- Laptop (PC);
- MATLAB® R2009;
- GOOGLE EARTH®.

Fig. 6 shows the network between all the parts and as the single elements works.

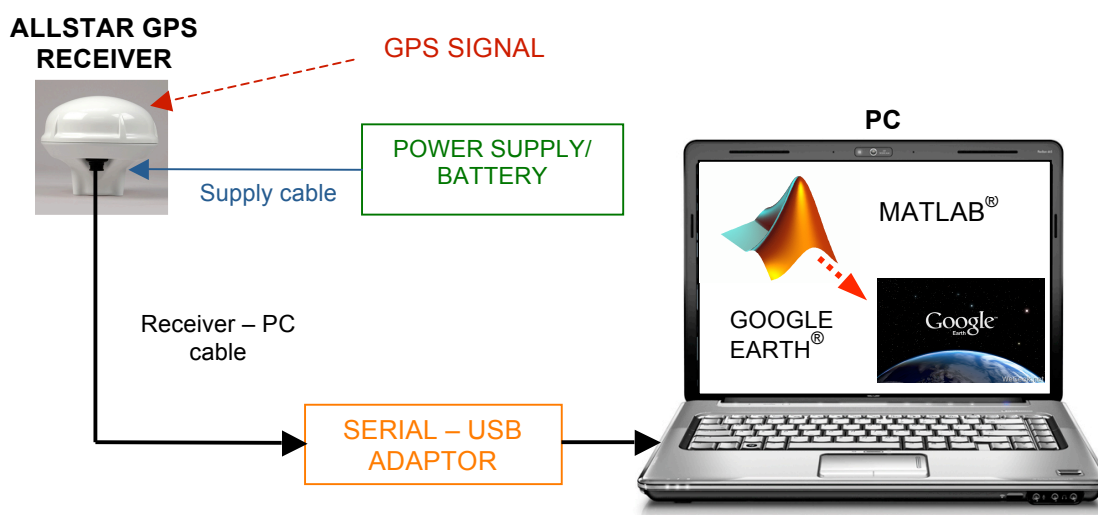


Figure 3-1 HW/SW elements

3.1 CMC Smart Antenna RS232

The CMC Electronics Inc. Smart Antenna is a Global Positioning System (GPS) Standard Positioning Service (SPS) single board twelve-channel code differential receiver for embedding in Original Equipment Manufacturer (OEM) consumer market navigation systems. This receiver is a self-contained and high-performance GPS position sensor that accepts DGPS correction signals to further enhance accuracy. The sensor provides highly accurate position and speed data for a variety of applications.

The receiver has 12 independent parallel channels each capable of simultaneously tracking a GPS satellite signal. The receiver makes provisions for external initialization of data to support faster GPS signal acquisition.



Figure 3-2 CMC Smart Antenna RS232

3.1.1 Main Features

- 12 parallel channels – “all in view” tracking
- 9-36 volt DC power (1.8 watt) rated for SAE 1455 heavy duty truck power system
- -30°C to 75°C operating temperature range standard
- <1m circular error probability (CEP), DGPS
- <16m circular error probability (CEP), no DGPS, without SA

3.1.2 Interconnections

All interconnections are made through a single 7-conductor cable

3.1.3 Data interfaces

- Output data: The Smart antenna is shipped with the following protocol: proprietary binary at 9600baud, MSG 20 at 1Hz. It can be user-programmed to output additional binary MSGs or to output NMEA0183 Version 2.0 sentence types GGA, GSA, GSV, RMC, VTG, ZDA, GLL, and proprietary MSGs. Baud rates are user-selectable from 300 to 19200.
- Input format: The default format is the binary protocol at 9600 baud. On Port1 the Smart Antenna can accept NMEA or binary MSGs for altitude, position, date and time. On Port2, it can receive RTCM DGPS MSG types 1,2,3,9 and 16 in SC-104 format.

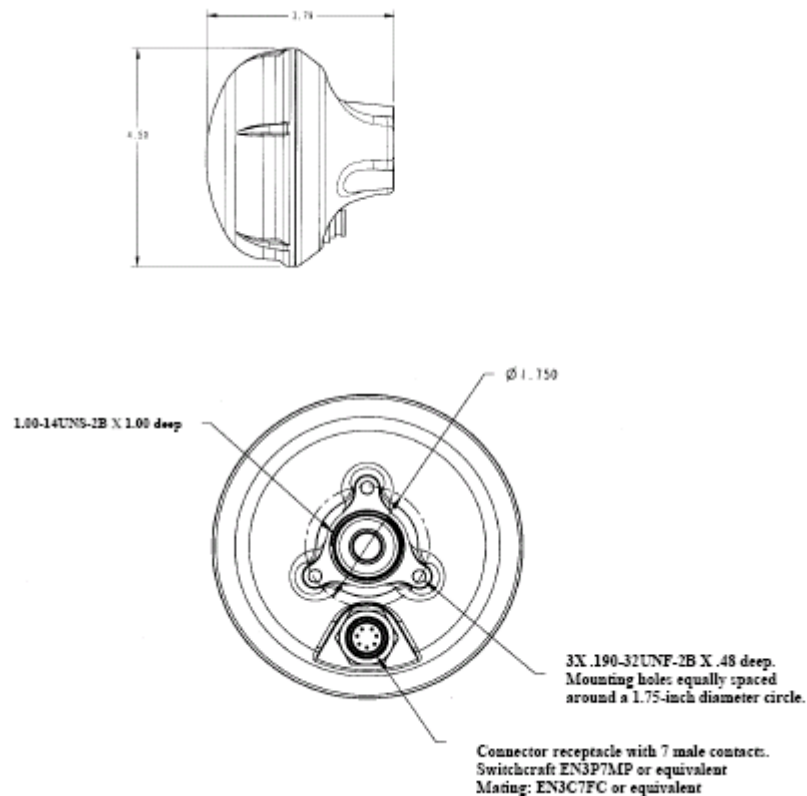


Figure 3-3 Receiver geometrical features

3.1.4 Detailed specifications

- 12-parallel tracking channels characteristics
 - L1 frequency: 1575.42MHz
 - Coarse Acquisition: C/A code (1023 MHz chip rate), code&carrier phase tracking
 - Sensitivity: -143 dBm
 - DGPS SW: standard
- Performance Characteristics:
 - Velocity: 1575.42 MHz
 - Acceleration: 39.2m/sec²
 - Position accuracy:
 - <1m circular error probability (CEP), DGPS
 - <16m circular error probability (CEP), without SA
 - <40m circular error probability (CEP), with SA imposed
 - Time to First Fix:
 - Hot start: 15 sec typical with current almanac, position, time and ephemeris
 - Warm start: 45 sec typical, with current almanac, position and time

- Cold start: 2 min typical, with no almanac, no position and no time
- Re-acquisition time
 - <1 sec typical to re-acquire (5-sec. Obscuration)
 - <3 sec typical to re-acquire (60-min. Obscuration)

3.1.5 Interface characteristics

- Prime power: 9 to 36 VDC (12V and 24V system) SAE 1455 Heavy Duty Truck Power System. 1.8 watts typical at 14V Reverse Polarity protected and SAE1455 Load Dump protected
- Serial communications: RS-232 asynchronous data ports; main port IN/OUT plus DGPS INPUT. 9600 baud standard
- Input MSGs:
 - NMEA/Binary: set altitude, position, date and time selectable output MSGs and rates
 - DGPS (RTCM SC-104): MSGs type 1,2,3,9,16
- Output MSGs
 - Tx1 (NMEA): GGA, GSA, GSV, RMC, VTG, ZDA, GLL plus proprietary MSGs
 - Tx1 (binary): all data available on NMEA MSGs plus, ephemeris, channel assignments, self-test result (BIT), plus others
 - Time mark Output: 1 pulse/sec, aligned with GPS time (± 200 ns, typical in absolute mode)

3.1.6 Physical characteristics

- Dimensions: (115mm Dia. x 90mm H)
- Weight: 0.55kg maximum not including cable
- Mounting: 1-14 UNS threads x 1" deep and/or 10-32UNF screws
- Cable: 22Ga conductors foil shielded cable, environmentally sealed
- Connectors:
 - Equipment: Weathertight, Switchcraft EN3P7MP or equivalent
 - Cable: Weathertight, switchcraft EN3C7FC or equivalent

3.1.7 Environmental characteristics

- Operating temperature: -30°C to 75°C
- Storage temperature: -55°C to 90°C
- Humidity: SAE J1455/4.2 Procedure I/II

- Waterproof: Fully sealed unit. Meets MIL-STD 810E method 512.3
- Shock: MIL-STD 810E Method 506.4, Procedure I,IV
- Vibration: MIL-STD 810E Method 514.4, category 8
- Salt spray: MIL-STD 810E Method 509.3, (48 hours)
- Chemical resistance: Antenna material is compatible with chemical encountered in heavy-duty trucks industry
- Sand and dust: MIL-STD 810E Method 510.3
- ESD: IEC 1000-4-2 level 2 (-8KV to 8KV)
- EMI: FCC Class B, European CE, 89/EEC EN55022 class B, EN50082-I
- Transient Protection: SAE J1455 4.11.2 typical vehicle transient voltage characteristics
- Ultraviolet Light Protection: ASTM G53-88
- Altitude: -3000m to 12000m

3.1.8 Receiver State

A. NON-OPERATIONAL STATES

The receiver has two non-operating modes, OFF mode and SRAM Keep-Alive mode. The maintenance of the DC power on the SRAM will determine which of the two non-operating modes will be automatically entered during the power down sequence.

B. OPERATIONAL STATES

The receiver has 6 operating modes: Self-Test, Initialization, Acquisition, Navigation, Dead-Reckoning and Fault. The receiver switches between modes automatically and reports on its host port the current operating and navigation modes.

- Self-Test Mode: the receiver enters Self-Test mode upon request from an external source (CMC Binary MSG ID #51).
- Initialization Mode: upon power-up, the receiver enters Initialization mode. During this mode hardware is initialized prior to Acquisition mode entry.
- Acquisition Mode: the receiver is in Acquisition mode when insufficient satellite data is available to produce an initial navigation solution. To acquire signals from the GPS satellites, the receiver uses:
 - a. Almanac data which describes the satellite orbits.
 - b. Time, which in conjunction with almanac data is used to estimate the present position of satellites in their orbits.
 - c. The approximate location of the receiver so a prediction can be made as to which satellites are visible. The receiver then collects ephemeris data by decoding the satellite down-link data MSG. After each satellite in view is acquired, its measurement data set is produced. When a sufficient number of satellites are

being tracked, position, velocity and time can be computed and Navigation mode entered. If the receiver cannot perform an acquisition due to an absence of valid almanac data or user position and/or time it initiates a "Search the Sky" acquisition.

- **Navigation Mode:** the receiver is in Navigation mode whenever sufficient satellite information and measurement data is available to produce a GPS fix. Navigation Mode is entered from Acquisition or Dead-Reckoning mode, and exits to Dead-Reckoning or Fault mode. In Navigation mode, a receiver configured as a roving unit operates in 2 sub-modes: Differential and Stand-Alone Nav. Sub-mode transition occurs automatically depending on satellite data availability. A receiver which is configured as a base station unit will operate in Base Station Navigation mode only. The receiver reports its current navigation sub-mode on its host port.
 - a. **Differential (Roving Unit Only) :**the receiver operates in Differential mode when data from at least 4 satellites with adequate geometry and differential corrections and/or measurements exists to compute position, velocity and time outputs.
 - b. **Stand-Alone Nav (Roving Unit Only):** the receiver operates in Stand-Alone Nav mode when data from at least 4 satellites with adequate geometry, but no differential corrections or measurements, exists to compute position, velocity and time outputs.
 - c. **Base Station Nav (Base Station Unit Only):** the receiver operates in Base Station Nav mode once the time has been initialized and at least 4 satellites with adequate geometry can be used for navigation purposes. Once in this mode, only a change of configuration (rover mode requested) or a reset will cause the unit to leave this navigation mode.
- **Dead-Reckoning Mode:** the receiver enters Dead-Reckoning mode when it cannot remain in a Navigation. The speed and direction is assumed constant to allow the receiver to provide an estimated position.
- **Fault Mode:** the receiver enters Fault mode during the period of the time in which the receiver outputs are affected by one or more critical system faults. This mode supersedes all others and remains active until the next power-down/power-up cycle. Fault mode is entered from any other mode except Initialization.

C. DATUM SUPPORT

The receiver has the ability to provide its position in one of the 62 predefined datums. Moreover, the receiver can also support two user-defined datum. These have to be defined, prior to their use, using binary MSG ID #88. Afterwards the desired datum, whether it is user-defined or predefined, can be selected using CMC Binary MSG ID #88.

4 INTERFACE CONTROL DOCUMENT (ICD)

4.1 General Description

The MATLAB program foresees the following interfaces (Fig. 9):

- IF1, allowing the communication with the GPS receivers;
- IF2, allowing the decoding of the GPS MSGs.



Figure 4-1 MATLAB program interface

4.2 Communication Protocol

4.2.1 GPS receivers (IF1)

The GPS receivers communicate with the PC via serial link, so a Serial-USB converter has been employed, because the serial input port was not available in the laptop used.

In order to establish and set a communication between GPS receiver and PC we have used the following Matlab functions:

- instrhwinfo: return information on available hardware;
- serial: construct serial port object;
- set: configure serial port object properties;
- fopen: connect serial port object to device;
- fread: read binary data from GPS device;
- fclose: disconnect serial port object from device.

4.2.1.1 CMC Allstar receiver

The GPS receiver generates a data flux towards the computer, containing the information about the C/A signals and carrier phase calculated by the receiver, ephemeris and health status of constellation satellites.

The whole communication happens using MSG blocks. Each MSG consists of a header and useful flux data, whose length is a function of MSG ID. The block starts with a header that defines the contents and size of the MSG itself, depending on the MSG ID. Every header is formed by 4-bytes:

- Start of Header character, SOH.

- Block ID, ID #: Byte containing the Block ID numeric value. The block ID number field is used uniquely to identify the format of the data portion of the block.
- Block ID Complement, Cmpl ID #: 1's complement of the ID # field. This can be calculated as (Block Compl ID #) = 255 – (Block ID #). This field, in conjunction with the SOH, helps to synchronize the MSG blocks, since the SOH character can appear within the data, the Block Cmpl ID # field validates the header contents and thus confirms the start of the block.
- MSG Data length, Msg Data Length: One byte containing the length of the data part of the MSG in bytes, excluding header and checksum.

Moreover each MSG block ends with a truncated 16-bit word containing the Checksum associated with the complete content of the block. It is appended at the end of the Data portion of the block.

The MSG Block structure is as follows:

byte 1	[SOH]
byte 2	[ID #]
byte 3	[Cmpl ID #]
byte 4	[Msg Data Length]
...	
byte n-1	[Checksum] LSB
byte n	[Checksum] MSB

The electrical signals utilized are those specified for RS-232 communication port. Only the Receive and Transmit lines are required. A baud rate of 9600 is used.

It is possible to request to the receivers only specific information, in fact the serial data communication protocol is divided in input and output MSGs. If no specific requirements are made, the receiver will provide the binary output navigation MSG (ID #20) at a rate of one per second after each power up.

4.2.2 Binary Protocol Input MSGs

The Input MSGs can be divided in three main MSG type:

- Command MSG (CM);
- Data Request (DR);
- Protocol MSG (PM).

The CM is used to set the receiver (data flow, time alignment, etc.), the DR asks for a specific information, while the PM stops the receiver waiting for a new request.

In order to communicate with the receiver and obtain in output the MSGs 20, 21, 22, 23, 33 and 63 (a brief description of them is given in Table 1), ad hoc SW has been developed with Matlab.

MSG	Byte	Description	Unit	Type
20 – Navigation data request (user coordinates)		No data bytes		
21 – Navigation data request (GPS coordinates)		No data bytes		
22 – Ephemeris (ICD-GPS-200 format) request		The GPS receiver will transmit a complete set of ephemeris and then transmit only on new ephemeris reception.		
23 – Measurement data request	5	Transmission rate: 0: 1 Hz, 1: 2 Hz, 2: 5 Hz, 3: 10 Hz		
33 – SV visibility and status request		No data bytes		
63 – Initiate link	5...12	UGPS-000: Cancels all previous data request		Char[8]

Table 4-1 CMC MSGs

When the serial port is opened and so the communication with the receiver begins, the Matlab SW sends the DR MSGs 20, 21, 22, 23 and 33 and PM MSG 63 are sent to the GPS receiver. Moreover, if not specified, MSG 23 is required with a 5Hz frequency.

4.2.3 Binary Protocol Output MSGs

There are six types of output MSGs:

- Dummy MSG (reserved);
- Initiate link;
- Acknowledge MSG;
- Link overload Error MSG;
- Data MSG;
- Status MSG.

As it has just been said the output MSGs required by Matlab SW are: 20, 21, 22, 23, and 33. These MSGs (see Table 2) contain respectively information about the user rough position, GPS receiver status and coordinates, broadcast navigation data, in view satellites and their navigation data.

MSGs 20, 21 and 33 are required and read once per second, while the satellite positions given by 22 only on power-up or new ephemeris data.

MSG	Byte	Description	Unit	Type
20 – Navigation data (user coordinates)	5 ... 14	The MSG is output once per second upon reception of a MSG ID #20 request. The latency on this MSG is less than 0.5 seconds. The latency defined here refers to the time difference between the time tag of the computed position and the time of transmission of the first MSG byte. MSG Length : 77 bytes UTC Time units: HR:MN:SC	HR:MN:SC	hour ->, minute -> byte, second -> long float
		Date	DY:MO:YR	day ->, month -> byte, year -> word
	19..26	Latitude range: -P1/2 .. P1/2	radians	long float
	27..34	Longitude range: -P1 .. P1	radians	long float
	35..38	Altitude	meters	short float
	39..42	Ground Speed	meters/sec	short float
	43..46	Track Angle range: -P1 .. P1	radians	short float
	47..50	Velocity North	meters/sec	short float
	51..54	Velocity East	meters/sec	short float
	55..58	Vertical velocity	meters/sec	short float
	59..62	HFOM	meters	short float
	63..66	VFOM	meters	short float
	67..68	HDOP resolution: 0.1 units	word	N/A
	69..70	VDOP resolution: 0.1 units	word	N/A
	71	bits 0-4: NAV Mode 0 -> Init. Required, 1 -> Initialized, 2 -> Nav 3-D, 3 -> Alt. Hold (2-D), 4 -> Diff. 3-D, 5 -> Diff. 2-D, 6 -> Dead. Reckoning	N/A	N/A

		bit 5: Solution Confidence Level 0-> Normal (NAV solution from less than 5 SVs) 1 -> High (NAV solution from at least 5 SVs) bits 6: Reserved bit 7 : GPS Time Alignment mode 1-> Enable 0-> Disable bits 0..3 : Number of SVs used to compute this solution		
	72	System Mode and Satellite tracking mode (c.f. msg #49, byte 5)	N/A	N/A
	73	bit 7: Reserved	N/A	N/A
	74	bits 4..7 : Coordinate system (lowest nibble))	N/A	N/A
	75	bits 4,5: Coordinate system (highest nibble). Datum number = B73 b5,b4, B72 b7,b6,b5,b4 (B=byte, b=bit).	N/A	N/A
	76 ... 77	Reserved		
21 – Navigation data (GPS coordinates)	5...12 13...14 15...38 39...58 59...66 67...70 71...74 75...76 77...78 79 80 81...83	GPS time Week Cartesian coordinates velocity clock drift HFOM VFOM HDOP VDOP Bits 0-4: nav mode 0: initialisation required 1: initialised 2: nav 3D 3: Alt. Hold (2D) 4: Diff. 3D 5: Diff. 2D 6: Dead. Reckoning # of SV used for the solution Reserved	sec week m m/sec sec/sec M M	Long float Word Long float Long float Long float Short float Short float word word
22 – Broadcast ephemeris data	5 6-77	Bits 0-4: SV number Bits 5-7: reserved Ephemeris sub-frame 1-	Ref.[5]	Ref.[5]

		3/words 3-10		
23 – Measurement block data	5-6	Reserved		
	7	# of measurement blocks		
	8...15	predicted GPS time	Sec	Double
	16	bits: 0...5: SV # 6: reserved 7: toggle for each trans.		
	17	SNR	0.25 dB/Hz	Unsigned char
	18...21	Code phase	1/1024 half chip	Unsigned long
	22...25	Integrated Carrier Phase (ICP): Bit 0-1: 0 – ready 1 – phase unlock 2 – cycle slip 3 – not ready		
	26	bits 2-11: carrier phase bits 12-31: Integrated cycles cycle slip counter	1/1024 cycle cycles	Unsigned char
		Measurements #2 - #N		
33 – Satellite visibility and status data	5	Bit 0...3: # of SV in view		
		Bit 4...7: reserved		
	6	Bit 0...4: SV number		
		Bit 5...6: 0 – in view 1 – tracking 2 – meas. ready 3 – used by nav.		
		Bit 7: differential corrections		
	7	elevation	Deg	Signed char
	8-9	azimuth	Deg	Word
	10	SNR	dB	byte
	11...15	2 nd SV visibility data		
	16...20	3 rd SV visibility data		
	21...25	4 th SV visibility data		
	26...30	5 th SV visibility data		
	31...35	6 th SV visibility data		
	36...40	7 th SV visibility data		
	41...45	8 th SV visibility data		
	46...50	9 th SV visibility data		
	51...55	10 th SV visibility data		
	56...60	11 th SV visibility data		
	61...65	12 th SV visibility data		

Table 4-2 CMC output MSGs

4.2.4 CMC Binary Protocol decoding (IF2)

Every time a new MSG in output from the receiver is recognized, it must be sent to decoding functions in order to be elaborated. Following the procedure reported in Table 2 for each MSG an appropriate Matlab function has been built to decode the raw data and obtain the required information. The algorithm of CMC Binary protocol decoding is more in detail described in GPS RAW DATA DECODING.

5 SW DESCRIPTION

5.1 SW OVERVIEW

The SW has been developed in Matlab language and for plotting the position in Google Earth several kml files have been created.

In particular Matlab has been used to:

- Open and initiate the communication between receiver and serial port
- Set up the receiver
- Acquire the data flow
- Decode the sent MSGs
- Process the decoded MSGs
- Start Google Earth
- Create the link file to Google Earth
- Update the position in the kml file (this represent the exchange of information between Matlab and Google Earth)

The link file is very important because it lets to update the position in the map. By means of this link Google Earth loads five times per second the kml file, where Matlab writes the coordinates of the receiver every time a new position data is available.

The network between these parts (Matlab, kml file, link file, Google Earth) can be easily schematized with the following Figure 5.1.

Google Earth is lastly used to report the user position in the map and draw the followed path.

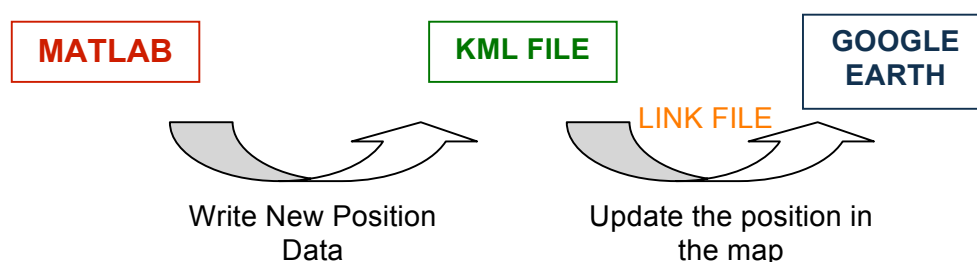


Figure 5-1 Matlab - kml file - link file - Google Earth network

5.2 SW FLOW CHART

Two Matlab programs have been written:

- The first works in RT: acquisition of data flux from receiver, saving data as binary format in log file, and representation of user RT position (latitude, longitude, height) in Google Earth;

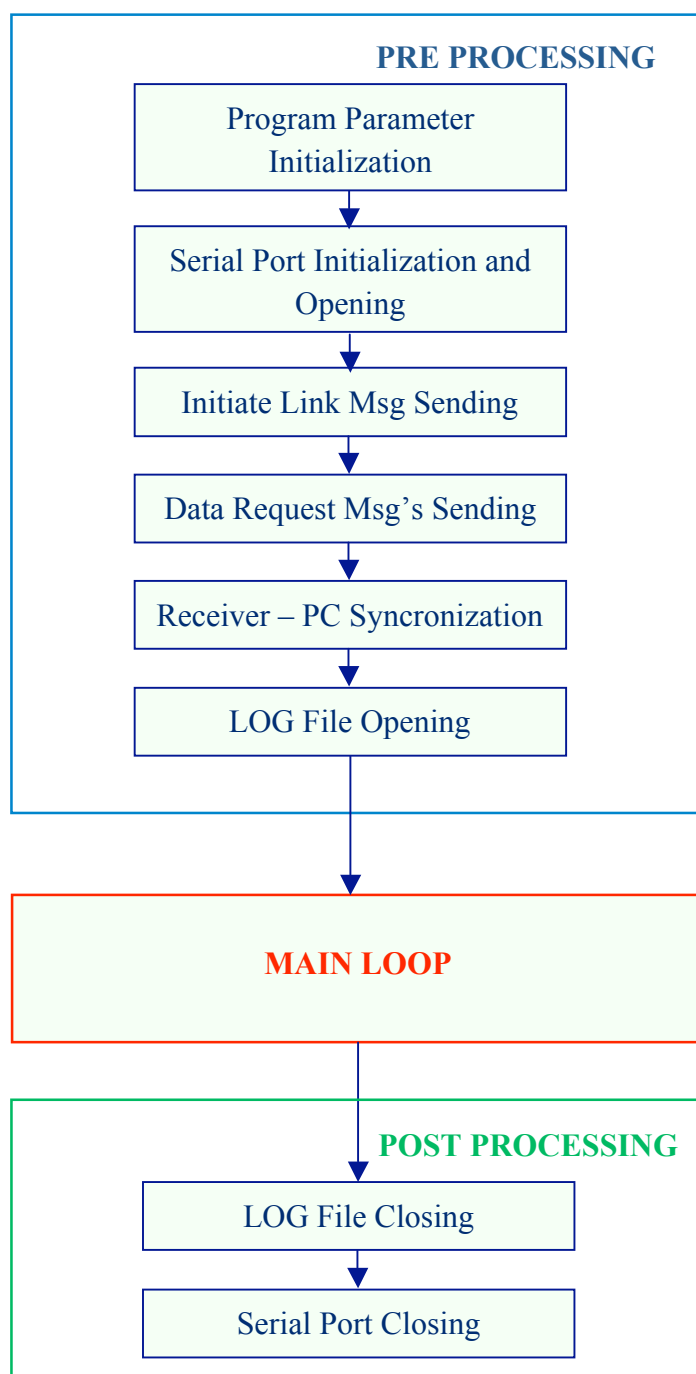


Figure 5-2 Main Program Flow Chart RT mode

- The second work in PB mode: data reading from log file and processing of raw data.

Both the Matlab programs are subdivided in three main sections:

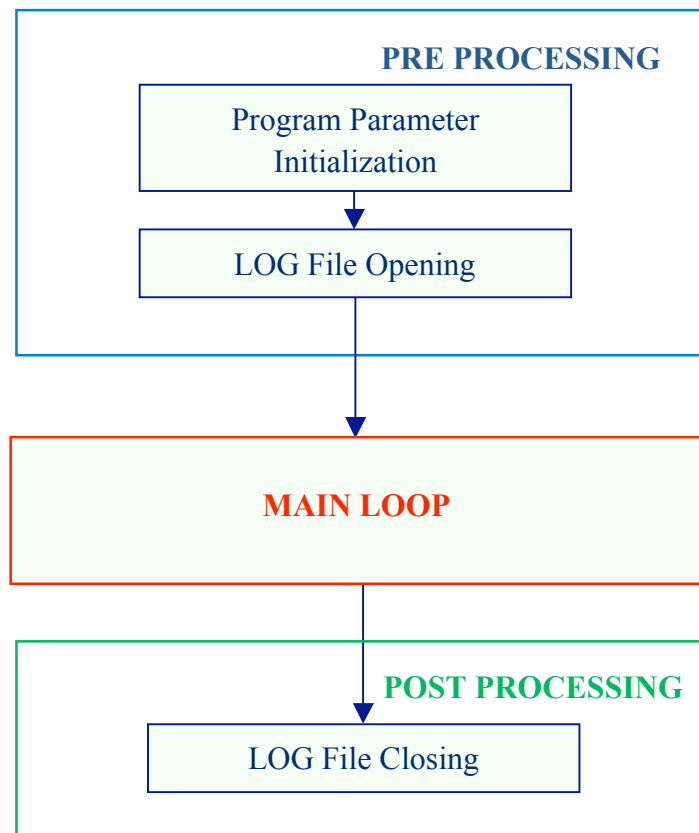


Figure 5-3 Main Program Flow Chart PB mode

1. PRE-PROCESSING: first the variables used in the whole program are initialized, then the network with the serial port / log file is opened and the receiver is initialized too (only RT mode).
2. MAIN LOOP: reading of raw data, decoding of arrived MSGs and writing of kml file for the following plotting in Google Earth
3. POST-PROCESSING: the serial port / file log must be closed

Figures 11 and 12 illustrate the block diagrams of Matlab SW structure for RT and PB modes respectively. The MAIN LOOP is common to both the modes and is reported in Figure 13.

In order to identify a MSG two type of header vectors have been employed:

- Current Header Vector: a vector updated every iteration with the last three bytes read from the serial port
- MSG Header Vector: a reference vector so defined [SOH, ID#, Compl ID#], to compare with the previous for recognizing the MSG type.

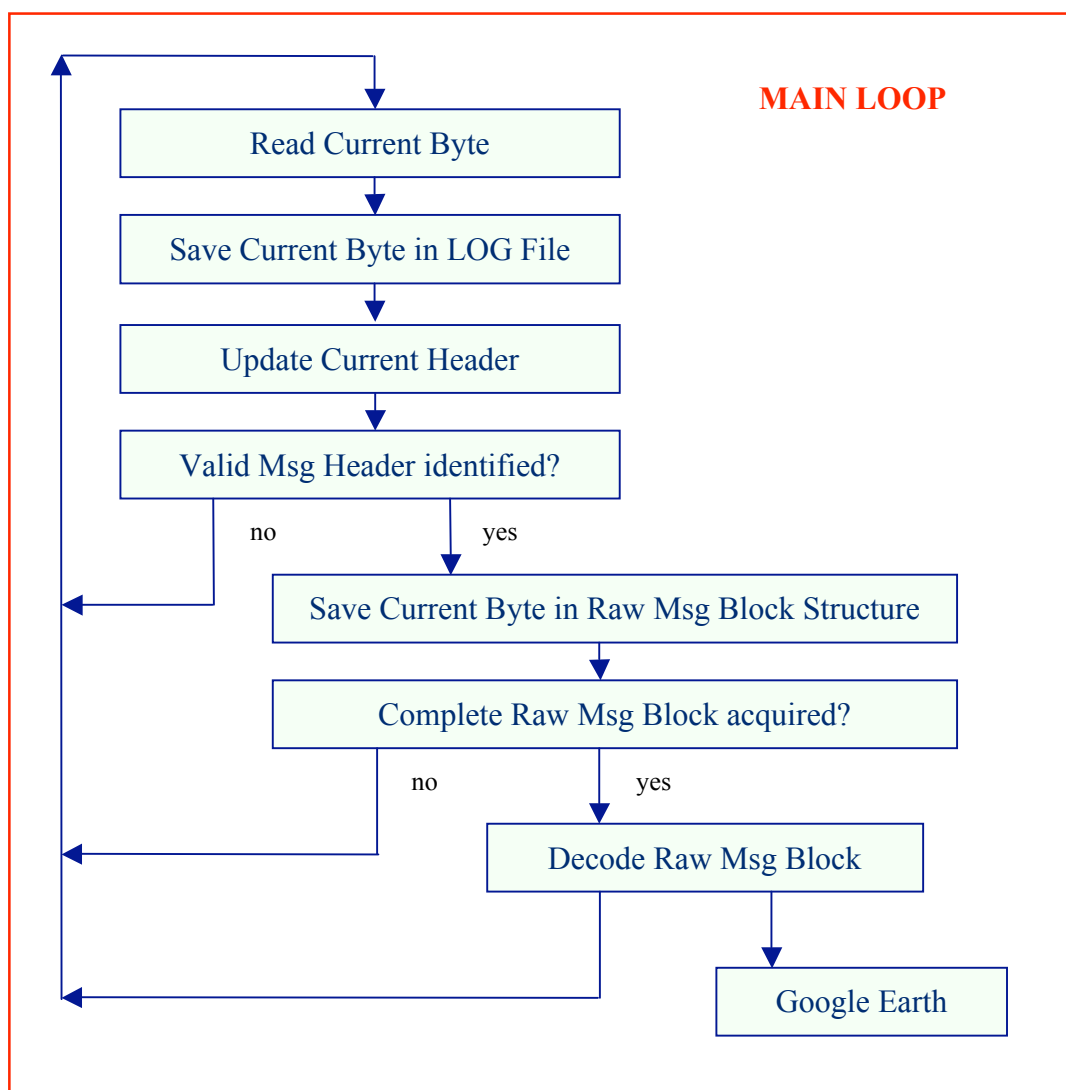


Figure 5-4 Main LOOP Flow Chart

Five MSG Header Vector have been considered (corresponding to MSGs 20-21-22-23-33) to detect and then decode (see Table 5-1). If the Current Head Vector coincides with one of the five MSG Header Vectors then it means a new MSG has been identified, and so the raw data of the MSG are saved in a vector called with the corresponding ID.

The decoding procedure starts only when the whole MSG is acquired, afterwards raw data is sent to the decoding function to be interpreted, and at last the information is saved in an equivalent MSG structure.

MSG HEADER VECTOR	VALUE
head_vect_20	[1;20;235]
head_vect_21	[1;21;234]
head_vect_22	[1;22;233]
head_vect_23	[1;23;232]
head_vect_33	[1;33;222]

Table 5-1 MSG Header Vectors

5.3 MSG STRUCTURES

During the receiver initialization the Matlab SW sends several input MSG to require the output. We have sent five input MSGs:

- MSG 20: Navigation data (user coordinates);
- MSG 21: Navigation data (GPS coordinates);
- MSG 22: Ephemeris (ICD-GPS-200 format) data;
- MSG 23: Measurement block data;
- MSG 33: Satellite visibility data and status.

A decoding procedure and data structure have been implemented for each output MSG type: once the raw MSG has been acquired, the correct function is recalled to decipher it, then the data extracted are saved in the corresponding structure.

In Table 5-2 the 20-21-22-23-33 MSG structures are reported in detail.

MSG Structure	Fields	Description	Unit
20 – Navigation data (user coordinates)	hour	Hour	
	min	Minute	
	sec	Second	
	day	Day	
	month	Mounth	
	year	Year	
	lat	Latitude	radians
	long	Longitude	radians
	alt	Altitude	meters
	GS	Ground Speed	m/sec
	TA	Track Angle	radians
	VN	Velocity North	m/sec
	VE	Velocity East	m/sec

	VV HF VF HDOP VDOP n_sat	Vertical Velocity HFOM VFOM HDOP VDOP Number of SVs used to compute this solution	m/sec meters meters word word
21 – Navigation data (GPS coordinates)	time week X Y Z Xv Yv Zv CDrift	GPS time Week X cartesian coordinate Y cartesian coordinate Z cartesian coordinate Velocity in x direction Velocity in y direction Velocity in z direction Clock drift	seconds weeks m m m m/sec m/sec m/sec sec/sec
22 – Broadcast Ephemeris data	SV TGD toc af2 af1 af0 IODE Crs Dn M0 Cuc e Cus sqrt_a toe Cic Omega0	SV ID Correction term Clock correction Polynomial coefficients Issue of data (ephemeris) Sine harmonic correction term to orbit radius Mean motion difference from computed value Mean anomaly Cosine harmonic correction term to argument of latitude Eccentricity Sine harmonic correction term to argument of latitude Square root of semimajor axis Ephemeris reference time Cosine harmonic correction term to the angle of inclination Longitude of ascending	sec sec rad semicircle/ sec semicircle rad rad m ^{1/2} sec rad semicircle

	Cis	node Sine harmonic correction term to the angle of inclination	rad
	i0	Inclination angle	semicircle
	Crc	Sine harmonic correction term to orbit radius	m
	omega	Argument of perigee	semicircle
	dOmega	rate of right ascension	semicircle/ sec
	IDOT	Rate of inclination angle	semicircle/ sec
23 – Measurement block data	nbm	Number of measurement blocks	
	GPS_TIME	Predicted GPS Time	Sec
	SV	SV ID	
	SNR	SNR	0.25 dB/Hz
	CodePhase *	Code Phase	1/1024 half
	PseudoRange	Pseudo Range	m
	CarrierPhase _State		chip
	CarrierPhase	Carrier Phase	1/1024
	NumberOfCyc le	Integrated Number of Cycles range	cycle cycles
	CycleSlip	Cycle_Slip Counter	
33 – Satellite visibility and status data	SV	Total number of Satellites in view	
	Sat	SV Number	
	Status	SV Status	
	DifCor	Differential Corrections Available	
	EI	Elevation	degree
	az	Azimuth	degree
	SNR	SNR	dB

Table 5-2 MSG Structure

Raw Code Phase measurements are punctual measurements. They can be used to derive PseudoRanges measurements using the following relation:

$$PR_i = [GPS_TIME] - CodePhase/(1023000*2048) \quad \text{Eq. 7}$$

Where the operator [] denotes taking the fraction of the predicted time. When the difference is bigger than 1 second, you must subtract 1 second. While when the difference is smaller than -1 second, you must add 1 second to the result.

5.3.1 Example

Exempla of raw output MSG:

1	20	235	71	10	54	0	0	22	31
0	0	8	64	29	9	218	7	81	170
20	64	211	92	233	63	188	96	61	150
150	146	202	63	22	11	104	66	141	20
60	63	142	209	44	64	188	15	42	191
45	170	160	62	101	225	99	62	64	105
41	64	171	205	64	64	17	0	23	0
162	7	3	12	0	189	23			

HEADER:

1	20	235	71
---	----	-----	----

1 → SOH; 20 → ID; 235 → Compl ID; 71 → Msg Length, escluso Header e CheckSum;
 $71 \text{ (Msg Length)} + 4 \text{ (Header)} + 2 \text{ (CheckSum)} = 77 \rightarrow \text{Raw MSG 20 Block Structure length.}$

CHECKSUM:

189	23
-----	----

189 → Checksum LSB; 23 → Checksum MSB.

Checksum = 6077 dec = 17BD hex;

Checksum LSB = BD hex = 189 dec.

Checksum MSB = 17 hex = 23 dec.

Example of corresponding MSG structure:

MSG 20 structure fields	Value
hour	10
min	54
sec	03
day	29
month	9
year	2010

lat	0.792581200750030
long	0.207598517760521
alt	58.010826110839844
GS	0.734688580036163
TA	2.700290203094482
VN	-0.664302587509155
VE	0.313798338174820
VV	0.222539499402046
HF	2.647048950195313
VF	3.012552976608276
HDOP	17
VDOP	23
n_sat	7

MSG 22 structure fields	Value
SV	28
TGD	1.103617250919342e-007
toc	302400
af2	0
af1	2.728484105318785e-012
af0	1.751352101564407e-006
IODE	75
Crs	1.971312500000000e003
Dn	1.971312500000000e003
M0	0.869489836506546
Cuc	1.180749386548996e-004
e	0.003842324134894
Cus	1.071579754352570e-005
Sqrt_a	5.153661672592163e+003
toe	302400
Cic	8.568167686462402e-008
Omega0	0.718159681651741
Cis	3.166496753692627e-008
i0	0.305863461457193
Crc	1.704062500000000e002
omega	1.603694882243872
dOmega	1.904784539874527e-006
IDOT	1.625153345230501e-009

5.4 GPS RAW DATA DECODING

The GPS ALLSTAR SMART ANTENNA receives and transmits 4 data types:

- Character Data
- Integer Values
- Fixed Point Values
- Floating Point Values

In the MSGs used by Matlab there are only two data types: Integer Values and Floating Point Values. The Integer Values are data formed by 16 bits (2 bytes), while Floating Point Values can be Short Float, is that 32 bits (4 bytes), or Double Float, given by 64 bits (8 bytes).

A function, named SCRAMBLE, has been created to decode these data types when found inside the raw MSG. This function receives in input the byte number and the same bytes to decode, and gives in output the data elaborated. To understand when the SCRAMBLE function is used it's sufficient to observe the Table 5-2: word, short and long float required this function to be decoded.

In Table 5-3 the Matlab functions containing the 5 decoding procedures are reported.

Raw Msg Block Structure ID	Decoding Procedure function
20	DECODING_MSG_20.m
21	DECODING_MSG_21.m
22	DECODING_MSG_22.m
23	DECODING_MSG_23.m
33	DECODING_MSG_33.m

Table 5-3 Decoding Functions

6 FEASIBILITY AND RESOURCE ESTIMATE

S/W Environments

The development S/W environment will be the following:

- The S/W will run under:
 - Windows XP, Vista, 7 Operating System;
 - Mac OS X 10.5.8 Operating System;
- MATLAB version 7.9.0.529 (R2009b);
- Google Earth version 5.1.3534.0411.

Serial Port:

- Windows XP, Vista, 7 Operating System: 'COM4';
- Mac OS X 10.5.8 Operating System: '/dev/tty.usbserial-ftDXK5P9'.

7 TEST PLAN

In this section we present the results of a kinematic test conducted on 30.09.2010 in via Venezia, Padova, in order to validate our SW and check the communication between Matlab and serial port, and so with Google Earth.

7.1 Kinematic testing

Purpose

This test aims to prove the functionality of the Matlab – Google Earth program in dynamic conditions (both RT and PB modes).

Procedure

This test case must be executed in the following way

- Hold the GPS receiver in hand or fix it on a stick, and keep it up as much as possible;
- Power up the GPS receivers;
- Connect Serial – USB adapter to the computer in which the Matlab – Google Earth program is installed;
- Connect the GPS receiver to the Serial – USB adapter port;
- On the compute launch Matlab and Google Earth;
- Set program parameters, e.g., total time of execution, output file names, visualization options;
- Execute the Matlab – Google Earth program;
- Verify from both Matlab Command Window and Google Earth that the SW is working correctly;
- If all is right, continue the program execution, walking on the sidewalk with the sky as free from obstructions as possible, until total time of execution is reached.

Results

A kinematic test was done on 30.09.2010 in via Venezia, Padova, on the sidewalk in front of CISAS (see Figure 8.1).

From an inspection of Matlab Command Window and Google Earth while the SW was running we noticed that the SW was working correctly, in accordance to the SW specifications (ref).

The results have been listed and reported in tables in the following order:

- Figure 7.1: Google Earth plot of the path we followed on via Venezia;

- Table 7-1: list of raw data obtained from the GPS receiver approximately in the first 2 seconds of the kinematic test;
- Tables 7-2,7-3,7-4 and 7-5: MSG structures 20, 21, 23 and 33 corresponding to the first raw data structures obtained from the GPS receiver at the beginning of the test.
- Table 7-6: list of 21 Pseudo Range measurements of the SV's in view, corresponding to the time interval 10:53:32 – 10:53:52;
- Table 7-7: coordinates list corresponding to initial and final part of the path we trailed.



Figure 7-1 Google Earth plot of the path along via Venezia

1	20	235	71	10	53	0	0	54	5	0	0
44	64	29	9	218	7	215	168	247	27	216	92
233	63	53	40	151	55	99	146	202	63	78	176
105	66	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	85	24
86	64	221	161	117	64	36	0	28	0	162	6
3	10	0	30	17	1	21	234	79	108	10	0
0	164	54	18	65	67	6	41	169	134	172	0
190	80	65	197	156	170	111	249	53	44	65	253
4	139	137	178	61	81	65	0	0	0	0	0
0	0	0	0	0	0	0	227	80	227	146	39

195	43	62	192	194	22	217	194	93	179	190	85
24	86	64	221	161	117	64	36	0	28	0	162
6	0	0	0	83	27	1	23	232	77	0	0
6	20	217	204	204	164	54	18	65	29	179	78
236	178	16	108	206	5	221	162	24	176	111	57
134	16	220	13	132	239	131	28	197	217	37	89
16	128	135	107	213	18	11	170	184	183	250	15
168	35	202	6	25	30	120	76	251	129	15	176
65	18	253	160	13	170	42	90	75	15	68	229
30	27	176	170	33	1	33	222	61	11	0	80
59	0	0	125	79	11	0	45	120	78	26	0
44	124	63	229	0	49	107	48	86	0	43	33
33	62	0	28	126	33	55	1	30	109	24	249
0	43	8	10	153	0	0	3	7	34	0	0
20	2	186	0	0	0	0	0	0	0	177	11
1	23	232	77	0	0	6	243	167	153	153	165
54	18	65	29	179	150	172	172	41	124	163	238
220	162	24	176	150	249	127	41	240	87	110	239
131	28	197	187	231	82	41	56	42	65	213	18
11	170	232	117	244	40	96	69	204	6	25	30
120	81	190	123	40	72	62	218	252	160	13	170
241	23	69	40	40	238	37	27	176	161	36	1
23	232	77	0	0	6	210	118	102	102	166	54
18	65	29	179	223	108	166	66	200	121	215	220
162	24	176	190	185	121	66	224	162	88	239	131
28	197	155	169	76	66	72	206	22	213	18	11
170	20	52	238	65	240	103	206	6	25	30	120
102	129	117	65	0	59	162	252	160	13	170	183
213	62	65	76	248	44	27	176	84	36	1	23
232	66	255	0	5	242	57	51	51	167	54	18
65	29	180	185	43	160	91	36	77	192	220	162
24	179	121	120	115	91	244	234	66	239	131	28
195	12	106	70	91	224	110	236	212	18	11	177
213	240	231	90	52	135	208	6	25	13	174	12
146	56	90	196	254	51	27	176	175	31	1	23
232	66	0	0	5	209	8	0	0	168	54	18
65	29	180	1	236	153	116	224	35	169	220	162
24	179	161	56	109	116	128	54	45	239	131	28
195	239	43	64	116	192	18	194	212	18	11	177
1	175	225	115	212	170	210	6	25	13	174	211
79	50	115	252	7	59	27	176	1	29	1	20
235	71	10	53	0	128	104	4	0	0	46	64
29	9	218	7	33	33	232	27	216	92	233	63
202	122	199	54	99	146	202	63	125	172	105	66
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	214	242	85	64
245	124	117	64	17	0	23	0	162	5	3	10
0	250	18	1	21	234	79	209	8	0	0	168
54	18	65	67	6	7	170	106	172	0	190	80
65	104	124	152	110	249	53	44	65	248	68	87
137	178	61	81	65	0	0	0	0	0	0	0

0	0	0	0	0	228	49	230	171	193	205	46
62	70	221	192	164	238	93	179	190	214	242	85
64	245	124	117	64	17	0	23	0	162	5	0
0	0	15	29	1	23	232	66	0	0	5	115
215	204	204	168	54	18	65	29	180	75	236	178
16	72	252	145	220	162	24	179	203	56	134	16
196	131	23	239	131	28	195	208	45	89	16	12
184	151	212	18	11	177	50	173	250	15	184	208
212	6	25	13	174	151	77	75	15	240	16	66
27	176	86	30	1	33	222	61	11	0	80	59
0	0	125	79	11	0	45	120	78	26	0	45
124	63	229	0	49	107	48	86	0	44	33	33
62	0	27	62	33	55	1	30	109	24	249	0
44	8	10	153	0	0	3	7	34	0	0	20
2	186	0	0	0	0	0	0	0	115	11	1
23	232	66	0	0	5	82	166	153	153	169	54
18	65	29	180	149	172	172	41	252	214	122	220
162	24	179	245	248	127	41	188	211	1	239	131
28	195	179	239	82	41	20	96	109	212	18	11
177	98	107	244	40	208	248	214	6	25	13	174
93	11	69	40	144	29	73	27	176	44	31	1
23	232	66	0	0	5	49	117	102	102	170	54
18	65	29	180	222	108	166	66	208	178	99	220
162	24	179	35	185	121	66	4	36	236	238	131
28	195	147	177	76	66	28	9	67	212	18	11
177	149	41	238	65	236	31	217	6	25	13	174
36	201	62	65	116	44	80	27	176	198	27	1
23	232	77	0	0	6	16	68	51	51	171	54
18	65	29	177	38	45	160	91	44	141	76	220
162	24	173	80	121	115	91	144	114	214	238	131
28	196	117	115	70	91	4	177	24	212	18	11
176	199	231	231	90	236	69	219	6	25	30	122
36	82	111	90	32	48	82	251	160	13	172	234
134	56	90	88	59	87	27	176	250	31	1	23
232	77	255	0	6	49	7	0	0	172	54	18
65	29	177	0	236	153	116	24	100	53	220	162
24	173	13	56	109	116	0	190	192	238	131	28
196	231	51	64	116	144	85	238	211	18	11	176
139	164	225	115	36	104	221	6	25	30	122	191
19	105	115	232	43	26	251	160	13	172	64	67
50	115	68	70	94	27	176	93	32	1	20	235
71	10	53	0	64	204	1	0	0	48	64	29
9	218	7	19	99	144	30	216	92	233	63	92
141	161	17	99	146	202	63	100	134	105	66	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	111	26	86	64	128
118	117	64	36	0	28	0	162	6	3	11	0
120	16	1	21	234	79	49	7	0	0	172	54

Table 7-1 Raw data flux from the GPS receiver in the first 2 seconds of the kinematic test

In Table 7-1, the distinction between the different raw data blocks is emphasized using thicker lines. Moreover the four MSG type are highlighted with different colours: red for MSG 20, yellow for MSG 21, green for MSG 23, blue for MSG 33 and black for MSG 23 after the first one of the same UTC time. Header is in bold characters.

MSG 20 structure fields	Value
hour	10
min	53
sec	14.00
day	29
month	9
year	2010
lat	0.792583517669551
long	0.207592394012239
alt	58.422172546386719
GS	5.877471754111438e-039 ¹
TA	5.877471754111438e-039
VN	5.877471754111438e-039
VE	5.877471754111438e-039
VV	5.877471754111438e-039
HF	3.345235109329224
VF	3.838004350662231
HDOP	36
VDOP	28
n_sat	6

Table 7-2 First MSG 20 structures decoded

MSG 21 structure fields	Value
time	2.9840900e+005
week	1603
X	4.388866695719042e+006
Y	9.244127180985442e+005
Z	4.519626149110076e+006
Xv	5.877471754111438e-039
Yv	5.877471754111438e-039
Zv	5.877471754111438e-039
CDrift	-1.154318713819113e-006

Table 7-3 First MSG 21 structures decoded

¹ An aproximativly zero velocity means GPS receiver not moving.

MSG 23 structure fields	Value
nbm	6
GPS_TIME	2.984088000001244e+005
SV	28
SNR	197
CodePhase	1.531339285000000e+009
PseudoRange	2.072606071685250e+007
CarrierPhase_State	0
CarrierPhase	94
NumberOfCycle	875524
CycleSlip	18

Table 7-4 First MSG 23 structures decoded

MSG 33 structure fields	Value
SV	11
Sat	0
Status	0
DifCor	0
EI	80
az	59
SNR	0

Table 7-5 First MSG 33 structure decoded

hour	10						
minute	53						
second	32	33	34	35	36	37	38
1	22575.69538	22575.89271	22576.08883	22576.28491	22576.48159	22576.67963	22576.87559
11	21618.68146	21619.06164	21619.44219	21619.8217	21620.20166	21620.58113	21620.9608
13	23265.56405	23266.0197	23266.4752	23266.93044	23267.38539	23267.8415	23268.29723
24	20303.21798	20303.23488	20303.25158	20303.26868	20303.28551	20303.30256	20303.31953
28	20720.75172	20720.45489	20720.15728	20719.85993	20719.56274	20719.26635	20718.9693
29	19883.37543	19883.37029	19883.36551	19883.36084	19883.35561	19883.35047	19883.34539
30	22736.28779	22735.78348	22735.27725	22734.77299	22734.26774	22733.76157	22733.25518
SV ID							

hour	10						
minute	53						
second	39	40	41	42	43	44	45
1	22577.07312	22577.2705	22577.4681	22577.66585	22577.86322	22578.06116	22578.25822

11	21621.34076	21621.72027	21622.0993	21622.47876	21622.85827	21623.23763	21623.61697
13	23268.75309	23269.20886	23269.66466	23270.12042	23270.57522	23271.03214	23271.48904
24	20303.3365	20303.35446	20303.37164	20303.38925	20303.40677	20303.42515	20303.44322
28	20718.67211	20718.37576	20718.07864	20717.78209	20717.48588	20717.19039	20716.89344
29	19883.34088	19883.33664	19883.33278	19883.32848	19883.32424	19883.321	19883.31701
30	22732.75122	22732.24796	22731.74593	22731.24162	22730.73477	22730.23122	22729.72621
SV ID							

hour	10						
minute	53						
second	46	47	48	49	50	51	52
1	22578.45539	22578.65397	22578.8529	22579.04948	22579.2088	22579.36716	22579.56521
11	21623.99786	21624.37857	21624.75836	21625.13751	21625.44087	21625.74472	21626.12462
13	23271.94496	23272.40167	23272.85839	23273.31373	23273.77183	23274.13683	23274.59405
24	20303.46084	20303.47928	20303.49736	20303.51552	20303.5295	20303.54722	20303.56581
28	20716.59775	20716.30189	20716.00595	20715.71096	20715.4742	20715.17777	20714.88234
29	19883.31343	19883.31025	19883.30586	19883.30283	0	19883.29529	19883.29197
30	22729.22075	22728.71869	22728.21227	0	22727.30765	22726.90228	22726.39897
SV ID							

Table 7-6 Pseudo Range measurements (km) of the SV's in view corresponding to the first 21 seconds of the kinematic test

From Table 7.6 it is possible to note that all PR measurements are correctly around the expected value of 20000 km. A zero value of PR means corresponding SV GPS signal not correctly acquired (i.e., SV not in view in that instant of time).

point #	PATH COORDINATES		
	longitude	latitude	altitude
	[deg]	[deg]	[m]
1	11.89416804	45.41169047	58.42217255
2	11.89416801	45.41169047	58.41844559
3	11.89416702	45.41169075	58.38124084
4	11.89416688	45.41169099	58.36223984
5	11.89416739	45.41169158	58.30780411
6	11.89416725	45.41169191	58.29034805
7	11.89416721	45.41169203	58.28844070
8	11.89416979	45.41169145	58.26427841
9	11.89417246	45.41168956	58.16302872
10	11.89417643	45.41168873	58.19676590
11	11.89418050	45.41168686	58.25376892
12	11.89418510	45.41168348	58.29163742
13	11.89418963	45.41167962	58.31300354
14	11.89419289	45.41167437	58.28121948
15	11.89419950	45.41166953	58.32331848
16	11.89420654	45.41166735	58.34183121
17	11.89421298	45.41166331	58.34590149
18	11.89422128	45.41166072	58.37614441
19	11.89423074	45.41165738	58.36887360
20	11.89423931	45.41165422	58.35942078
21	11.89424755	45.41165144	58.35158157
22	11.89425655	45.41164882	58.34974670
23	11.89426503	45.41164627	58.34687424
24	11.89427372	45.41164337	58.37177658
25	11.89428111	45.41164138	58.34651184
26	11.89428754	45.41163852	58.29285812
27	11.89429496	45.41163556	58.26774216
28	11.89430224	45.41163228	58.14941025
29	11.89430952	45.41162919	58.20540237
30	11.89431831	45.41162561	58.25178528
...	...	...	...
146	11.89560019	45.41117277	57.38425827
147	11.89561068	45.41116907	57.14860916
148	11.89562223	45.41116718	57.15375900

149	11.89563529	45.41116247	57.08062363	163	11.89579902	45.41109950	56.95368576
150	11.89564692	45.41115728	57.12385941	164	11.89580968	45.41109502	56.94625854
151	11.89565815	45.41115077	56.96962357	165	11.89582048	45.41109127	56.96347809
152	11.89566958	45.41114630	56.93042755	166	11.89583154	45.41108648	56.90519714
153	11.89568120	45.41114216	56.85042572	167	11.89584217	45.41108254	56.91764450
154	11.89569293	45.41113736	56.84896088	168	11.89585301	45.41107844	56.85519791
155	11.89570530	45.41113150	56.89677048	169	11.89586452	45.41107493	56.83675003
156	11.89571737	45.41112640	56.89900208	170	11.89587548	45.41107048	56.75938797
157	11.89573079	45.41112241	56.89664459	171	11.89588706	45.41106517	56.66598129
158	11.89574280	45.41111987	56.91474533	172	11.89589864	45.41106054	56.63566208
159	11.89575408	45.41111635	56.89218903	173	11.89591355	45.41105688	56.58893585
160	11.89576616	45.41111181	56.91810226	174	11.89592261	45.41105241	56.64871597
161	11.89577744	45.41110814	56.94106674	175	11.89593245	45.41104917	56.51194382
162	11.89578814	45.41110354	56.93798065	176	11.89594289	45.41104528	56.50430298

Table 7-7 Coordinates list corresponding to initial and final part of path on via Venezia.
Initial UTC time 10:53:14, finale UTC time 10:56:09

Observing Table 7-7 it is possible to note that longitude, latitude and altitude have a small variation in their values. In fact the good visibility and the short path walked lets to obtain stable coordinates that don't change steeply.

8 CONCLUSION

Smart Antenna GPS Software has been shown in order to demonstrate its usefulness as navigation or data post-processing system.

The possibility to work in Matlab environment has several advantages due to its huge library that lets to write more compact programs and easier to understand. To decode the information transmitted inside the MSGs, a large utilization of functions about number binary representation has been employed. In addition, it has been necessary to implement another important routine, called SCRAMBLE, to interpret word, short and long format expressions.

The decoded MSG is, at last, saved in a structure, as explained in section 5, in order to better organize the information obtained for next calculus operations, as ephemeris coordinates determination and position estimation.

In the last section an example, used to validate the SW, has been reported, full of results about the structures, in view SV pseudoranges data, user coordinates and path plot along via Venezia.