**Inertial Labs INS interface for connection to ArduPilot 2023.12.01**

# Electrical interface

This is described in INS-U ICD, section "5. Electrical Interface", sub-section "5.1. INS-U (Standard RS232 Configuration)". The INS-U has two COM ports with RS-232 interface for data output and input. We propose to connect INS-U to ArduPilot using COM2 to leave COM1 for possible communication with the host computer (to send command to INS, for communication with INS GUI, INS parameters change, firmware update, output of other INS data, receiving aiding data, etc.).

# Software interface

INS can output data in binary and ASCII text form. Just binary data will be used to provide INS data to ArduPilot, namely "User Defined Data" (UDD) that allows to choose desirable INS data for output. Common structure of INS messages is shown in ICD, section "6. Software Interface", Table 6.2. For chosen UDD output format, this structure is following

***Table 1. Byte structure for INS messages (specifically for UDD)***

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Byte number** | **0** | **1** | **2** | **3** | **4, 5** | **6 .. (n+5)** | **n+6, n+7** |
| Parameter | Header 0 | Header 1 | Message type | Message identifier | Message length | Payload | Check sum |
| Length | 1 byte | 1 byte | 1 byte | 1 byte | 1 word | n bytes | 1 word |
| *Note* | 0xAA | 0x55 | 0x01 | 0x95 | n+6 |  |  |

Table 1 and all other tables denote the following:

**word** = unsigned 2-byte integer

**sword** = signed 2-byte integer

**Message type** equals to 1 for output/input data from/to INS

**Message identifier** equals to 0x95 (code of UDD messages)

**Message length** is the number of bytes in the message without header. It is equal to the payload length (n) + 6.

**Check sum** is the arithmetical sum of bytes 2…(n+5) (all bytes without header). In the check sum LSB (Least Significant Byte) is transmitted first.

**Important note:** In all multi-byte data LSB is transmitted first.

Payload length is **n=98** bytes for minimal data number necessary for ArduPilot, or **n=161** bytes for desirable data set (see discussion below). As result, the **message length** in Table 1 is 104 (0x68 hex) or 167 (0xA7 hex) accordingly.

## 2.1. UDD configuration for ArduPilot

According to email from Andrew Tridgell on Jan 22, 2021, the necessary set of INS data to using in ArduPilot is following:

 - time  
 - body acceleration  
 - body rotational rate (gyro)  
 - baro pressure  
 - body magnetic field  
 - attitude (quaternion, euler or dcm)  
 - velocity  
 - position  
 - accuracy information on the velocity and position states  
 - health status flags  
 - gps fix type  
 - gps sat count

INS can provide all these data using UDD messages configuration shown in Table 2. These data are taken from the full list in INS-U ICD, section 6.2.9, Table 6.22. Detailed description of “User Defined Data” structure.

***Table 2. List of UDD data necessary for ArduPilot***

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Data type** | **Description** | **Size, bytes** | | **Structure** | | ***Note*** | |
| 0x01 | GPS INS Time (round) | 4 | | unsigned integer | | Time of INS solution, milliseconds from the beginning of the GPS reference week, rounded to 1000/(output data rate) | |
| 0x3C | GPS week | 2 | | word | |  | |
| 0x23 | Accelerometer data HR | 12 | | integer | | Accelerometer X, g\*1.0e6 | |
| integer | | Accelerometer Y, g\*1.0e6 | |
| integer | | Accelerometer Z, g\*1.0e6 | |
| 0x21 | Gyro data HR | 12 | | integer | | Gyro X, deg/s\*1.0e5 | |
| integer | | Gyro Y, deg/s\*1.0e5 | |
| integer | | Gyro Z, deg/s\*1.0e5 | |
| 0x25 | Barometer data | 6 | | word | | Pressure, Pa/2 | |
| integer | | Baro altitude, m\*100 | |
| 0x24 | Magnetometer data | 6 | | sword | | Magnetometer X, nT/10 | |
| sword | | Magnetometer Y, nT/10 | |
| sword | | Magnetometer Z, nT/10 | |
| 0x07 | Orientation angles | | 6 | | word | | Heading, deg\*100 |
| sword | | Pitch, deg\*100 |
| sword | | Roll, deg\*100 |
| 0x12 | Velocities | 12 | | integer | | East speed, m/s\*100 | |
| integer | | North speed, m/s\*100 | |
| integer | | Vertical speed, m/s\*100 | |
| 0x10 | Position | 12 | | integer | | Latitude, deg\*1.0e7 | |
| integer | | Longitude, deg\*1.0e7 | |
| integer | | Altitude, m\*100 | |
| 0x58 | KF velocity covariance | 3 | | byte | | East speed STD, mm/s | |
| byte | | North speed STD, mm/s | |
| byte | | Vertical speed STD, mm/s | |
| 0x57 | KF position covariance HR | 6 | | word | | Latitude STD, mm | |
| word | | Longitude STD, mm | |
| word | | Altitude STD, mm | |
| 0x53 | Unit status word (USW) | 2 | | word | | see INS-U ICD, Table 6.61 | |
| 0x4A | GNSS extended info | 2 | | byte | | GPSfix: 0 – no fix; 1 – 2D fix; 2 – 3D fix; 3 – OTHER | |
| byte | | Spoofing detect:  0 – unknown or deactivated;  1 – no spoofing indicated;  2 – spoofing indicated;  3 – multiple spoofing indications | |
| 0x3B | Number of satellites used in solution | 1 | | byte | |  | |

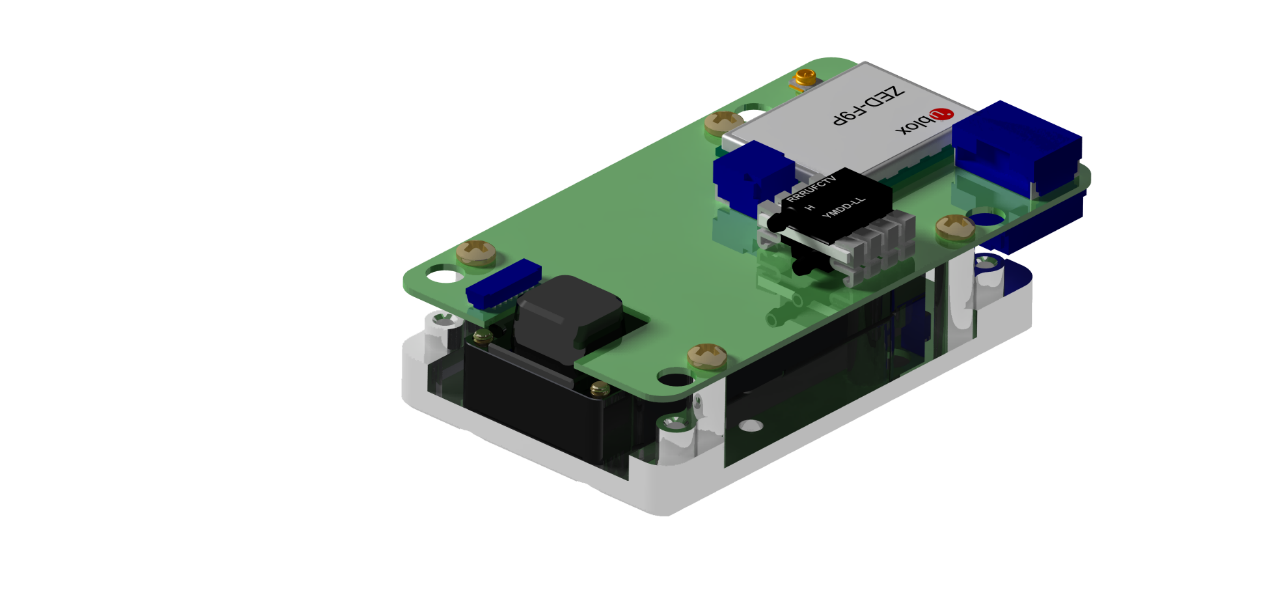
***Notes***

**1.** Take into account X,Y,Z axes orientation shown in INS-U ICD, section 2, Fig.2.3 that is copied below as Fig.1. These are axes for accelerometer, gyro and magnetometer data.

If to compare Inertial Labs INS axes to VectorNav INS ones (for example), then the following transformation is necessary for accelerometer, gyro and magnetometer data (see Table 3):

***Table3. Corresponding of sensors axes of Inertial Labs and VectorNav devices***

|  |  |
| --- | --- |
| Inertial Labs INS | VectorNav INS |
| X  Y  Z | Y  X  minus Z |



Heading

Pitch

X0 (Lateral)

Z0 (Vertical)

Y0 (Longitudinal)

Roll

***Fig.1. INS-U coordinate system***

**2.** We chose Euler angles for INS attitude presentation (see data type 0x07 “Orientation angles” in the Table 2). But it is possible (and may be better) to use quaternion (data type 0x09 “Quaternion of orientation” – see Table 6.22 in INS-U ICD). In this case we should agree possible transformation of Inertial Lab quaternion to one used in ArduPilot. Description of quaternion used in Inertial Lab devices see in INS-U ICD, Appendix C. Forms of the Orientation Presentation.

**3.** Heading is positive when rotating clockwise (see Fig.1).

**4.** We want only INS data are used in ArduPilot, to exclude any calculations of attitude, position, velocity in ArduPilot inside, even in GNSS denied, or jammed, spoofed GNSS data. To switch off all Kalman filters of ArduPilot. Therefore, if information about GPS fix type, Number of satellites used in solution can be used by ArduPilot to ignore INS data then it is necessary to perform the following substitutions:

* GPSfix = 2 (3D fix) – always;
* if “Number of satellites” == 0 then “Number of satellites” = 77 (any number > 4)

**5.** Health status flags can be set based on Unit status word (data type 0x53). See its description in INS-U ICD, section 6.4.7. The Unit Status Word Definition.

In addition to requested INS data for ArduPilot , we’d like to add more INS data for output, so we could simulate and analyze INS data using binary log saved by ArduPilot. Additional INS data are listed in Table 4. It is desirable to combine data listed in Table 2 and Table 4 in one UDD message.

***Table 4. List of UDD data desirable to add to the necessary data***

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Data type** | | **Description** | | **Size, bytes** | | **Structure** | | ***Note*** | | |
| 0x30 | GNSS Position | | 12 | | integer | | GNSS Latitude, deg\*1.0e7 | | |
| integer | | GNSS Longitude, deg\*1.0e7 | | |
| integer | | GNSS Altitude, m\*100 | | |
| 0x32 | GNSS Velocity, Track over ground | | 10 | | integer | | GNSS Horizontal speed, m/s\*100 | | |
| word | | GNSS Track over ground, deg\*100 | | |
| integer | | GNSS Vertical speed, m/s\*100 | | |
| 0x3E | GNSS Position timestamp | | 4 | | unsigned  integer | | ms | | |
| 0x36 | GNSS info short | | 2 | | byte | | GNSS\_info1 (position type, pseudo­range iono correction – see Table 6.7) | | |
| The following data byte | | GNSS\_info2 (solution status, time status, GNSS constellations in use – see Table 6.8) | | |
| 0x41 | New GPS | | 1 | | byte | | Indicator of new update of GPS data (see Table 6.9) | | |
| 0xС0 | u-blox jamming status | | 1 | | byte | | 0 - unknown or feature disabled  1 - ok (no significant jamming)  2 - warning (interference visible but fix ok)  3 - critical (interference visible and no fix) | |
| 0x28 | Differential pressure | | 4 | | integer | | Differential pressure, mbar\*1.0e4 | | |
| 0x86 | True airspeed (TAS) | | 2 | | sword | | TAS, m/s\*100 | | |
| 0x8A | Wind speed | | 2 | | sword | | East wind, m/s\*100 | | |
| 2 | | sword | | North wind, m/s\*100 | | |
| 2 | | sword | | Vertical wind, m/s\*100 | | |
| 0x8D | ADU status | | 2 | | word | | Air Data Unit status (see INS-U ICD, Table 8.12) | | |
| 0x50 | Supply voltage | | 2 | | word | | VDC\*100 | | |
| 0x52 | Temperature | | 2 | | sword | | °C\*10 | | |
| 0x5A | Unit status word (USW2) | | 2 | | word | | see INS-U ICD, Table 6.62 | | |

***Notes***

Wind speed Wind speed in three directions (eastward, northward and vertical) is estimated at available GNSS data and at receiving of external or internal air speed otherwise these estimates are frozen.

## 2.2. Payload in INS message

Configured UDD data will appear in INS message in the payload field (see Table 1) with structure described in INS-U ICD, section 6.2.9, Table 6.20. According to two variants of UDD, the payloads have structure shown in Table 5 and Table 6.

Table 5. Payload of the “User Defined Data” with necessary data list according to Table 2

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Field** | **Offset in payload, bytes** | **Size, bytes** | **Value** | **Note** |
| Pckg Number | 0 | 1 | 0x0e (14 decimal) | Number of data packages present in the payload (N=14, see Table 2) |
| Data List | 1 | N=14 | 0x01 0x3c 0x23 0x21 0x25 0x24 0x07 0x12 0x10 0x58 0x57 0x53 0x4a 0x3b | List of data types, one per byte, according to Table 2 |
| Data #1 | N+1 =15 | 4 |  | GPS INS Time (round) |
| Data #2 | N+5=19 | 2 |  | GPS week |
| … | … | … |  | … |
| Data #14 | 100 | 1 |  | Number of satellites used in solution |

Table 6. Payload of the “User Defined Data” with desirable data list according to Table 2 plus Table 4

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Field** | **Offset in payload, bytes** | **Size, bytes** | **Value** | **Note** |
| Pckg Number | 0 | 1 | 0x1b (27 decimal) | Number of data packages present in the payload (N=27, see Table 2 and Table 4) |
| Data List | 1 | N=27 | 0x01 0x3c 0x23 0x21 0x25 0x24 0x07 0x12 0x10 0x58 0x57 0x53 0x4a 0x3b 0x30 0x32 0x3e 0x36 0x41 0xc0 0x28 0x86 0x8a 0x8d 0x50 0x52 0x5a | List of data types, one per byte, according to Table 2, Table 4 |
| Data #1 | N+1 =28 | 4 |  | GPS INS Time (round) |
| Data #2 | N+5=32 | 2 |  | GPS week |
| … | … | … |  | … |
| Data #14 | 100 | 1 |  | Number of satellites used in solution |
| … | … | … |  | … |
| Data #27 | 162 | 2 |  | Unit status word (USW2) |

## 2.3. Examples of INS data output

Example of one data package with UDD configured according to Table 2:

AA 55 01 95 6B 00 0E 01 3C 23 21 25 24 07 12 10 58 57 53 4A 3B 46 3F 44 1D F2 08 61 FF FF FF 10 A4 FE FF E3 3E 0F 00 BB 10 00 00 03 02 00 00 0B F9 FF FF E6 BF 64 5A 00 00 5F FD FC F8 77 F8 48 42 00 FE 01 00 00 00 00 00 FF FF FF FF 00 00 00 00 A6 8E 0D 1E BB 2A 2B 12 49 5A 00 00 10 12 0C 3A 00 33 00 81 00 00 00 02 01 19 7D 21

Example of one data package with UDD configured according to Table 2 and Table 4:

AA 55 01 95 AA 00 1B 01 3C 23 21 25 24 07 12 10 58 57 53 4A 3B 30 32 3E 36 41 C0 28 86 8A 8D 50 52 5A 0E 24 65 1D F2 08 B6 FA FF FF 54 A0 FE FF EF 3C 0F 00 63 EE FF FF 4C 0F 00 00 99 0D 00 00 ED BF B8 59 00 00 70 FD 00 F9 83 F8 80 42 00 FE 09 00 FF FF FF FF 00 00 00 00 00 00 00 00 AD 8E 0D 1E A4 2A 2B 12 A9 59 00 00 0C 0E 02 42 00 36 00 0C 00 00 00 02 01 1A B0 8E 0D 1E A6 2A 2B 12 91 59 00 00 00 00 00 00 16 75 00 00 00 00 8C 23 65 1D 01 0C 00 02 9C 03 00 00 00 00 00 00 00 00 00 00 00 00 DE 05 16 01 00 00 9B 2D

Here are hexadecimal numbers highlighted by color, according to Table 1:

* yellow – the first 6 bytes #0 to #5 up to payload;
* cyan – the first bytes of payload that describes the main data;
* uncolored – the main INS data;
* green – check sum.

**Note:** In all multi-byte data LSB is transmitted first.

## 2.3. Maximum data rate of INS messages

Inertial Labs INS calculates all navigation data with frequency 200 Hz. This is the maximum frequency of INS data output. User can set desirable data rate for INS output that is factor of 200 (1, 2, 4, 5, 8, 10, 20, 25, 40, 50, 100, and 200 Hz). But take into account that the maximum data rate depends on length of data message and COM port baud rate (see INS-U ICD, section 6.3).

Taking into account two variants of UDD configuration, the maximum data rates are shown in Table 7.

***Table 7. INS maximum data rate of UDD messages***

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Output data format** | **Data package length, bytes** | **COM-port baud rate, bps** | | | | | |
| 9600 | 19200 | 38400 | 115200 | 230400 | 460800 |
| **Maximum data rate, Hz** | | | | | |
| UDD according to Table 2 | 109 | 8 | 10 | 25 | 50 | 100 | 200 |
| UDD according to Table 2 and Table 4 | 172 | 5 | 10 | 20 | 50 | 100 | 200 |