

Motion Reference Unit

MRU-B, MRU-E



Interface Control Document

Revision 1.1

CHANGE STATUS LOG			
DOCUMENT: Inertial Labs™ MRU Interface Control Document			
REVISION	DATE	AFFECTED PARAGRAPHS	REMARKS
1.0	Jun.13, 2016	All	Released version.
1.1	Dec.16, 2016	5.2	1. Added $\pm 450^\circ/\text{s}$ gyro range for KG values and $\pm 8\text{g}$, $\pm 10\text{g}$, $\pm 15\text{g}$ accelerometer range for KA values (see notes to Tables 5.4, 5.5, 5.7).
		5.27	2. Added MRU TSS1+HEHDT output format.
		5.4.3	3. Added Significant Wave Height calculation description
		5.6.5	4. Added description of VG3D calibration, and appropriate command
		5.7	5. Changed description of the bits #7, 15 of USW

TABLE OF CONTENTS

1. Introduction	5
1.1. Description of the System	5
1.2. Principles of the Inertial Labs™ MRU Operation	8
1.3. True and magnetic heading	9
2. Scope and applicability	10
3. Mechanical interface	10
3.1. Mechanical mounting the Inertial Labs™ MRU	11
3.2. Where to install the Inertial Labs™ MRU for tests	12
3.3. Where to install the Inertial Labs™ MRU on the object	13
4. Electrical Interface.....	15
5. Software interface	18
5.1. Operational modes of the Inertial Labs™ MRU	20
5.2. Output Data Formats of the Inertial Labs™ MRU in the Operating Modes	20
5.2.1. The “MRU Calibrated Data” format	21
5.2.2. The “MRU Quaternion Data” format	22
5.2.3. The “MRU Full Output Data” format	24
5.2.4. The “MRU Minimal Data” format	25
5.2.5. The “NMEA Output” data format	27
5.2.6. The “TSS1 Output” data format	27
5.2.7. The “TSS1+HEHDT Output” data format	28
5.3. Control of the Inertial Labs™ MRU	29
5.3.1. MRU_ClbData, MRU_QuatData, MRU_FullData, MRU_minData, MRU_NMEA, MRU_TSS1 commands	30
5.3.2. SetOnRequestMode command – getting MRU data on request (on demand).....	32
5.3.3. Stop command.....	33
5.3.4. LoadMRUPar command	33
5.3.5. ReadMRUPar command	35
5.3.6. GetDevInfo command.....	36
5.3.7. GetBIT command.....	37
5.4. Heave calculation	38
5.4.1. Adjustment of the algorithm of heave calculation.....	38
5.4.2. Heave calculation for chosen point of the carrier object	38
5.4.3. Significant Wave Height calculation	38
5.5. Acceleration compensation at object swaying	39
5.6. Calibration of the Inertial Labs™ MRU-E on hard and soft iron.....	39

5.6.1. Start3DClb command for MRU-E 3D calibration.....	40
5.6.2. StopClbRun command	42
5.6.3. AcceptClb command.....	42
5.6.4. ExitClb command.....	43
5.6.5. StartVG3DClb command for MRU VG3D calibration	43
5.6.6. Start2D2TClb command for MRU-E 2D-2T calibration	44
5.6.7. StartClbRun command	47
5.6.8. FinishClb command for MRU-E 2D-2T calibration	48
5.6.9. Start2DClb command for MRU-E 2D calibration.....	48
5.6.10. ClearClb command	50
5.6.11. GetClbRes command	50
5.7. The Unit Status Word definition	52
5.8. MRU automatic start.....	53
5.9. Change of the MRU COM port baud rate	54
5.10. Limitation of the MRU maximum output data rate	54
APPENDIX A. The Inertial Labs™ MRU-E Calibration.....	56
APPENDIX B. Variants of the Inertial Labs™ MRU mounting relative to the object axes	57
APPENDIX C. Full list of the Inertial Labs™ MRU commands.....	59
APPENDIX D. Forms of the Inertial Labs™ MRU orientation presentation	60

1. INTRODUCTION

1.1. Description of the System

The Inertial Labs™ Motion Reference Unit (MRU) utilizes solid state 3-axes each of precision gyroscopes, accelerometers, magnetometers and barometric sensor to provide accurate Heave, Sway, Surge, Pitch and Roll of the device under measure.



Fig.1.1. The Inertial Labs™ MRU

Integration of very low noise gyroscopes output provides high frequency, real-time measurement of the Vessel, Ships, Helidecks, ROV, Marine antennas, Cranes rotation about all three rotational axes. Accelerometers and fluxgate magnetometer measure absolute Pitch, Roll and magnetic Azimuth at MRU initial alignment as well as providing ongoing corrections to gyroscopes during operation.

Note: Heading angle calculation is provided only in the Inertial Labs™ MRU-E and MRU-P products.

Fig.1.2 shows the MRU own coordinate system $Ox_0y_0z_0$. This coordinate system is body-fixed and defined as the calibrated sensors coordinate system. Non-orthogonality between the axes of the body-fixed coordinate system $Ox_0y_0z_0$ is an order of 0.01° .

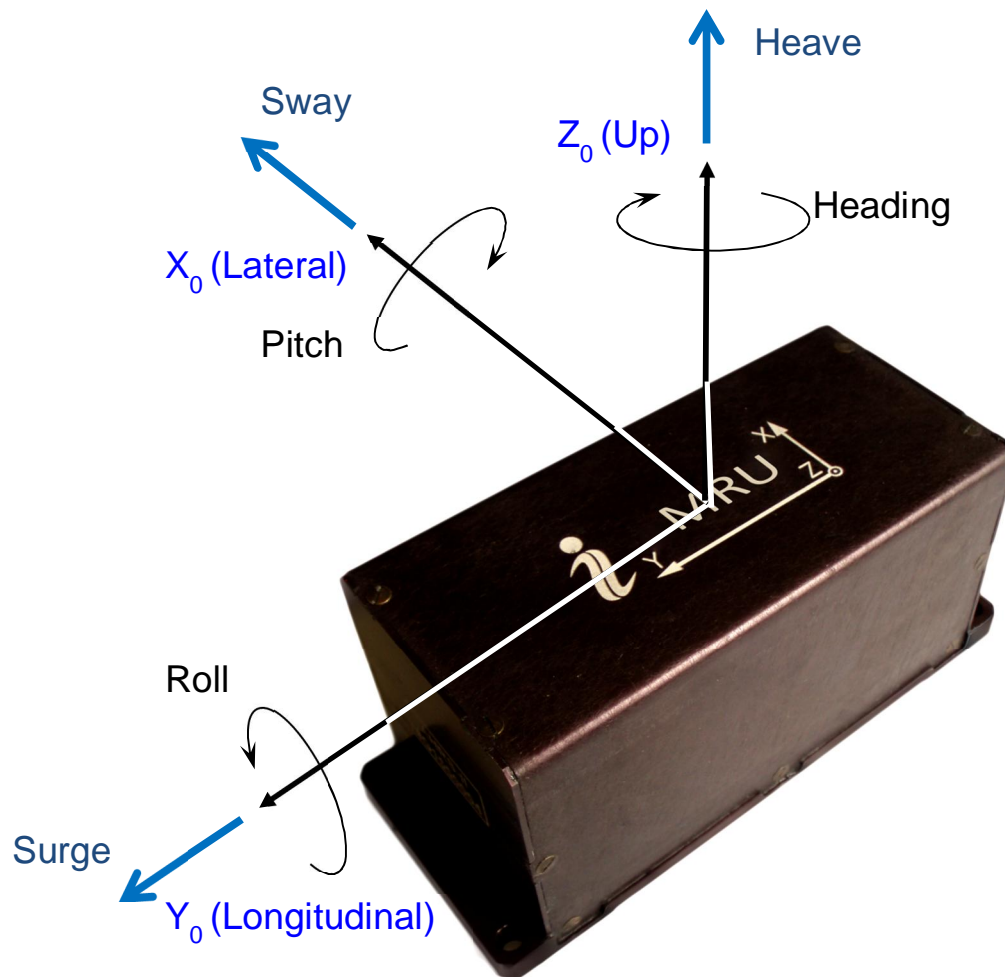


Fig.1.2. Coordinate system of the Inertial Labs™ MRU

Measured angles are the standard Euler angles of rotation from the Earth-level frame (East-North-Up) to the body frame, heading first, then pitch, and then roll.

Orientation angles, measured by the Inertial Labs™ MRU, are not limited and are within common ranges:

- Heading 0...360°;
- Pitch ±90°;
- Roll ±180°.

Also the Inertial Labs™ MRU provides orientation calculation in quaternion form. See “APPENDIX D. Forms of the Inertial Labs™ MRU orientation presentation”.

Heave is the linear vertical (up/down) motion; sway is the linear lateral (side-to-side) motion; surge is the linear longitudinal (front/back) motion.

Inertial Labs™ provides three models of MRU products:

- MRU-B (Basic) – includes gyros, accelerometers and pressure sensor;
- MRU-E (Enhanced) – includes gyros, accelerometers, magnetometers and pressure sensor;
- MRU-P (Professional) – includes gyros, accelerometers, magnetometers, pressure sensor and GNSS receiver.

Measured parameters of each MRU product are shown in the Table 1.1.

Table 1.1. Measured parameters

Parameters	MRU-B	MRU-E	MRU-P
Heave	+	+	+
Pitch & Roll	+	+	+
Heading		+	+
Linear Velocity			+
Position			+

Because MRU-B has no magnetometers and does not measure heading, some sections of this ICD are not related to MRU-B. The Table 1.2 specifies ICD sections which are associated to different MRU devices. MRU-P is described in other document.

Table 1.2. Association of ICD sections

Section	MRU-B	MRU-E
1.3. True and magnetic heading		✓
5.6. Calibration of the Inertial Labs™ MRU-E on hard and soft iron		✓
Appendix A. The Inertial Labs™ MRU-E Calibration		✓

1.2. Principles of the Inertial Labs™ MRU Operation

Fig.2.1 shows the operational diagram of the Inertial Labs™ MRU. The MRU uses gyros to measure absolute angular rate of the carrier object, then its orientation angles (heading, pitch and roll) are obtained by using special integration of gyros outputs.

Accelerometers are used to determine initial attitude of the MRU and to correct gyros bias in the tilt angles (pitch, roll) calculation. Magnetometers are used to determine initial heading of the MRU and to correct gyros bias in the heading angle calculation.

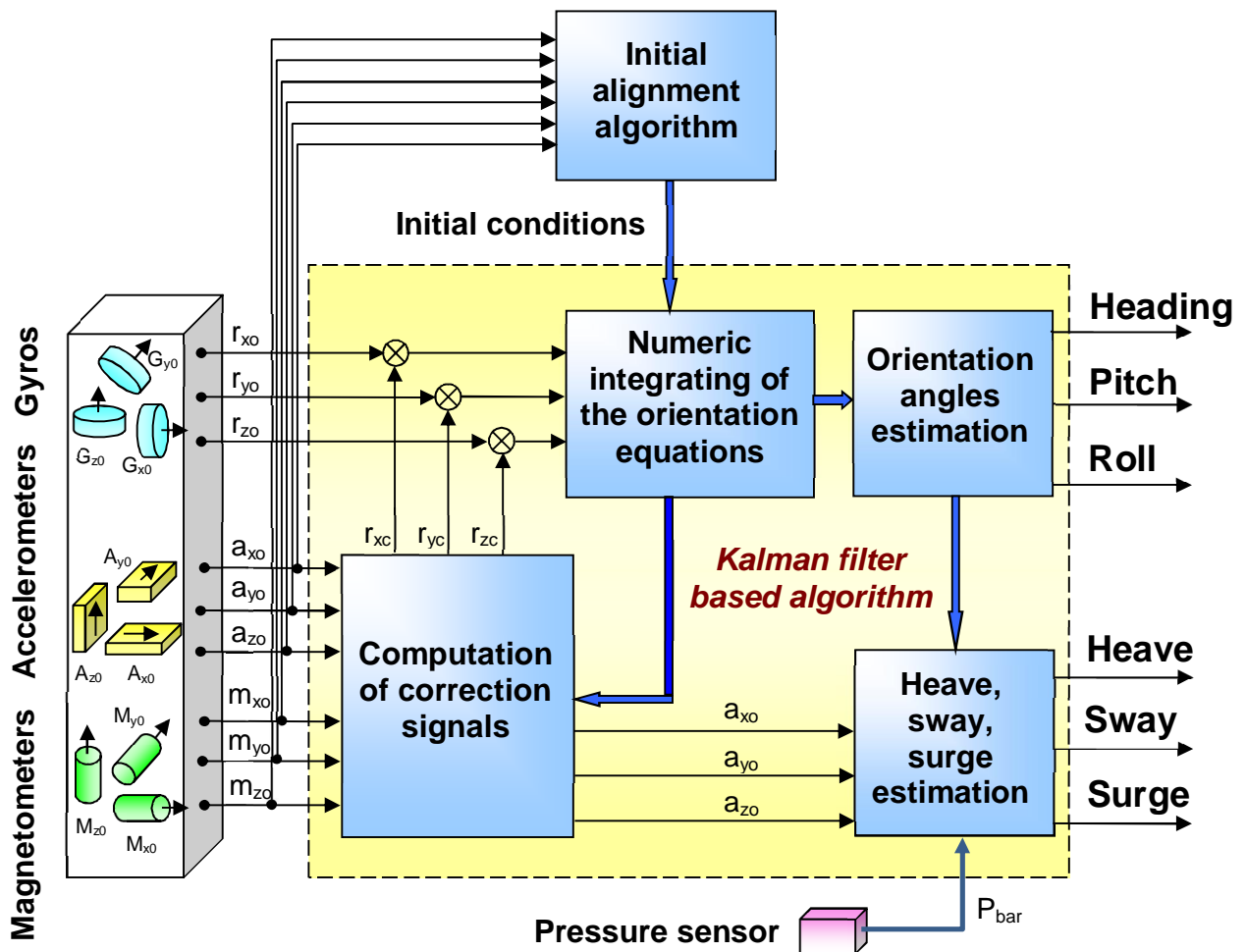


Fig.2.1. Operational Diagram of the Inertial Labs™ MRU

The base of the MRU algorithm is robust Kalman filter which is used for estimation of the gyros bias and for calculation of stabilized heading, pitch and roll angles. Then the Kalman filter calculates heave, sway and surge

as special integration of vertical and horizontal accelerations. The Kalman filter automatically adjusts for changing dynamic conditions without any external user input.

After start the Inertial Labs™ MRU it requires about 30 seconds for the initial alignment process. At this initial orientation angles are determined as initial conditions for integration of gyros outputs. Also gyros bias is estimated using Kalman filter for next compensation. Therefore don't move the MRU during initial alignment process. If this requirement is not met then large errors may be occurred in orientation angles calculation.

1.3. True and magnetic heading

Only Inertial Labs™ MRU-E product is able to calculate heading angle. As MRU-E uses magnetic sensors for heading reference, then it directly determines just magnetic heading.

The Inertial Labs™ MRU-E also provides true North heading when the current magnetic declination is set. Declination, also called magnetic variation, is the difference between true and magnetic North, relative to a point on the Earth. Declination angle vary throughout the world, and changes slowly over time. Declination angle can be entered directly to the Inertial Labs™ MRU-E memory using special command (see section 5.3.4. LoadMRUPar command) or the Inertial Labs™ MRU Demo Program. Also, the declination can be calculated by MRU-E itself based on entered latitude, longitude, altitude and date (see section “5.3.4. LoadMRUPar command” for details).

Both MRU-E unit onboard and MRU Demo Program calculate the declination using the World Magnetic Model WMM2015 produced by the U.S. National Geophysical Data Center and the British Geological Survey.
<http://www.ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml>

The World Magnetic Model is the standard model of the US Department of Defense, the UK Ministry of Defense, the North Atlantic Treaty Organization (NATO), and the World Hydrographic Office (WHO) navigation and attitude/heading referencing systems.

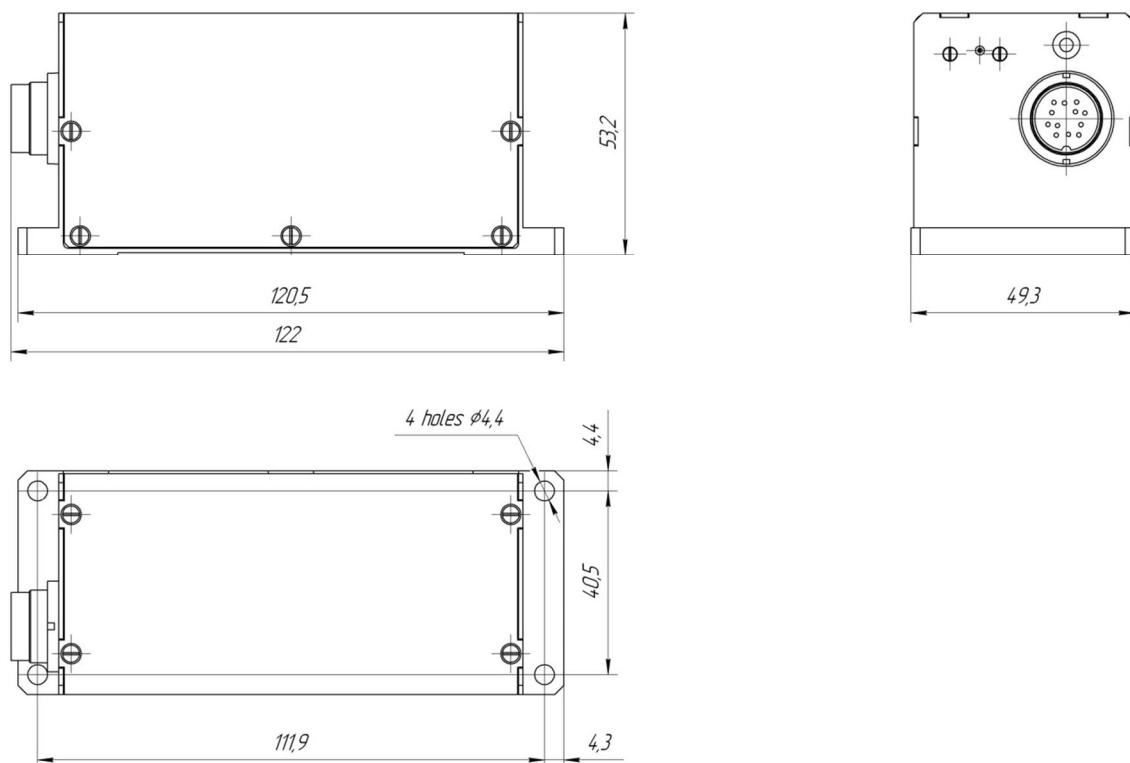
2. SCOPE AND APPLICABILITY

This Interface Control Document (ICD) provides details on mechanical mounting, the electrical connections, powering and software interface between the Inertial Labs™ MRU and host computer.

This document is intended for all parties requiring such information, including engineers and researchers responsible for implementing the interface.

3. MECHANICAL INTERFACE

Fig.3.1 shows the outline drawings of the Inertial Labs™ MRU. All dimensions are in millimetres.



**Fig.3.1. The Inertial Labs™ MRU outline drawing
(all dimensions are in millimetres)**

3.1. Mechanical mounting the Inertial Labs™ MRU

The Inertial Labs™ MRU housing has two base surfaces A and B (see Fig.3.2) that are designed for the MRU mounting during its run and testing.

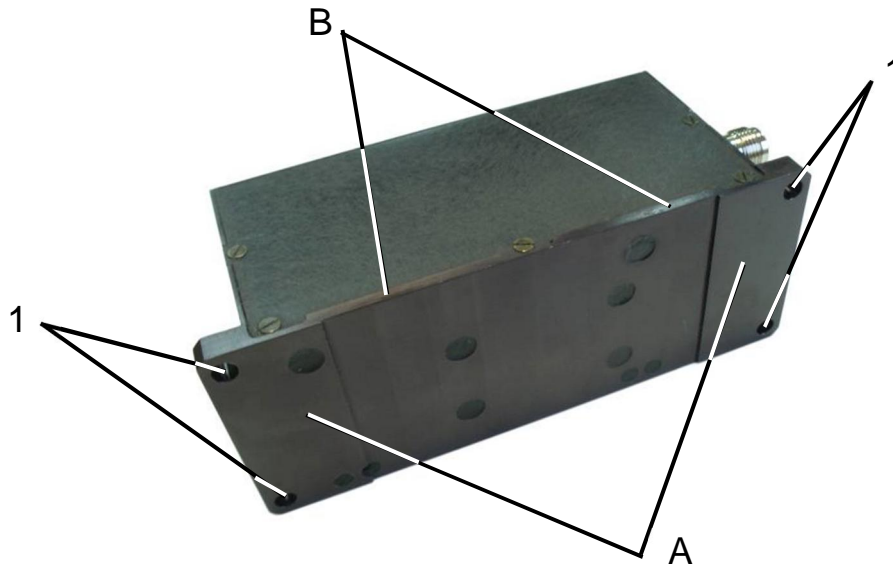


Fig.3.2. MRU mounting surfaces A, B and mounting holes 1, 2

Salient bottom base surface A has 4 holes $\varnothing 4.2$ mm (see Fig.3.2, positions 1) which are designed for the MRU mounting. Lateral base surface B is designed for the MRU alignment during mounting.

The Inertial Labs™ MRU is factory calibrated with respect to the base surfaces A and B, thus it must be aligned within the host system (carrier object) with respect to these mounting surface, not the device edges.

When mounting Inertial Labs™ MRU on your system, please pay attention to orientation of input axes "X", "Y", "Z" marked on the cover of the MRU (see Fig.1.2). During the ordinary operation on the carrier object the MRU is set on the surface A with the axis Y directed to the nose of the object.

Also the Inertial Labs™ MRU can be mounted on the object in any known position (up to upside-down, upright etc.) relative to the object axes. Such mounting doesn't change right calculation of the object orientation if angles

of the MRU mounting are correctly stored in the MRU nonvolatile memory. See Appendix B. Variants of the Inertial Labs™ MRU mounting relative to carrier object axes.

To obtain accurate attitude and heading, please remember that mounting is very important and mounting error can cause attitude and heading errors. When Inertial Labs™ MRU mounting please align it on two base surfaces A, B relative your system axes.

The Inertial Labs™ MRU should be mounted on your system using 4 holes $\varnothing 4.2$ mm (see Fig.3.2, positions 1).

Requirements to the mounting surface of the carrier object: flatness tolerance is 0.03 mm; undulation is Ra=1.25.

3.2. Where to install the Inertial Labs™ MRU for tests

- ***Locate the Inertial Labs™ MRU-E away from local sources of magnetic fields***

The place for testing must not have ferromagnetic (magneto-susceptible) materials and the lab room itself must have the level of intrinsic magnetic and electro-magnetic fields suitable for the magnetic heading system testing:

- inside and near the lab room there must be no powerful source of magnetic, electrical and electro-magnetic fields. The magnetic field intensity must not be different from the Earth magnetic field intensity at the test site more than 0.01%;
- small ferromagnetic objects must be as far as 3 meters from the test table. Large size ferromagnetic objects such as cars and trucks must be as far as 15 m from the table;
- it is necessary to conduct a regular check-up of the magnetic field uniformity inside the lab room.

It is highly recommended to degauss MRU-E before heading test to remove permanent magnetization of some components in the MRU-E (if you accidentally expose the unit to a large magnetic field). You can use a

hand-held degausser (tape eraser) to demagnetize the MRU-E. Most audio and video degaussing units can be used. Follow the instructions for your demagnetizer.

If heading accuracy is not checked and only pitch and roll accuracy are tested then there are no requirements to magnetic fields and ferromagnetic materials near place of the Inertial Labs™ MRU-E mounting.

- ***The Inertial Labs™ MRU should be mounted in a physically stable location***

Choose a location that is isolated from excessive shock, oscillation, and vibration. Special rotary table must be used for the Inertial Labs™ MRU accuracy testing which is mounted on a special testing basement which is free from the laboratory oscillations and vibrations.

Tests on vibrations and shocks are fulfilled separately from the main accuracy tests.

The Inertial Labs™ MRU-E uses magnetometers for heading calculation. The magnetometers have wide dynamic range and their sophisticated calibration algorithms allow them to operate in many environments. For optimal performance however, you should mount the Inertial Labs™ MRU-E with the following considerations in mind.

3.3. Where to install the Inertial Labs™ MRU on the object

It is necessary to follow the recommendations listed in the section 3.1 whenever it is possible, when installing the Inertial Labs™ MRU on a carrier object.

- ***Inertial Labs™ MRU-E should be installed on an object as far as possible from large ferromagnetic masses of the object and powerful sources of magnetic, electrical and electro-magnetic fields***

Inertial Labs™ MRU software allows compensation of hard and soft iron effects of the carrier object on the heading measurement accuracy. For this purpose, field calibration of the MRU-E magnetometers is provided. This

calibration does not require any additional equipment, but it requires turns of the carrier object, on which the MRU-E is mounted.

Note that the above field calibration is correct until the residual magnetic field of the object surrounding the MRU-E is changed. If this field is changed due to displacement of ferromagnetic masses of the object or magnetic field sources, the MRU-E should be re-calibrated.

Field calibration procedure of the Inertial Labs™ MRU-E can be performed by two means:

- by MRU-E itself using special commands described in the section 5.6;
- using the Inertial Labs™ MRU Demo Program.

The MRU Demo Program provides more variants of the field calibration and is more convenient for use, but it requires connection of the MRU-E to PC. Calibration of the MRU-E itself is performed without its disconnection from the host system on the carrier object.

More detailed description of the field calibration procedure is given in the section 5.6. Calibration of the Inertial Labs™ MRU-E on hard and soft iron.

- ***It is preferable to locate the Inertial Labs™ MRU as close to the centre of gravity of the object as possible***

With such location, effects of linear accelerations during oscillations on the MRU accelerometers are reduced, and therefore, orientation angle calculation errors are also reduced.

4. ELECTRICAL INTERFACE

The Inertial Labs™ MRU has the Binder Series 723 male 12 pin connector, part # 09 0131 80 12, <https://www.binder-usa.com/products/partsdetail/86929>

For electrical connection to the Inertial Labs™ MRU the host system should have a cable with mating connector – Binder Series or 423, 425 or 723 female 12 pin connector (or cordset), part # 09 0130 70 12, # 99 5130 40 12, # 79 6130 20 12.

Fig.4.1 shows the Inertial Labs™ MRU connector pinout. Table 4.1 contains pin diagram of this connector and appropriate color of wires in cable with mating Binder Series 425 Female plug, part # 79 6130 20 12.

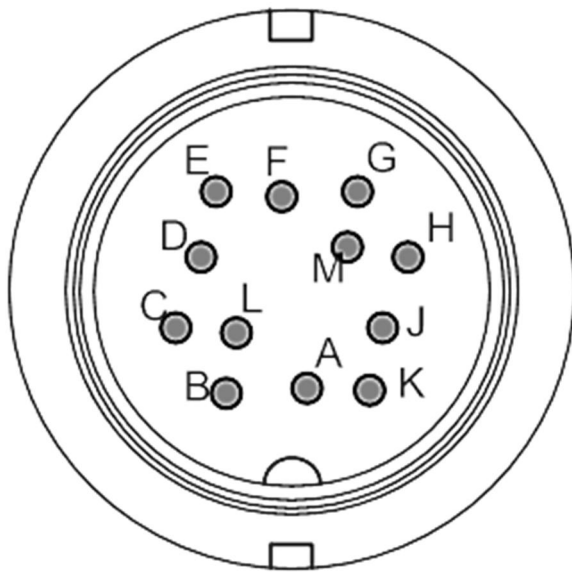


Fig.4.1. The Inertial Labs™ MRU connector pinout (mating side of the connector)

Table 4.1 Pin diagram of the Inertial Labs™ MRU connector

Pin	Wire color	Signal
A	White	RS422 – A
B	Brown	RS422 – B
C	Green	RS422 – Y
D	Yellow	RS422 – Z
E	Grey	Power
F	Pink	Ground
G	Blue	RS232 – RX
H	Red	RS232 – TX
J	Black	PPS
K	Violet	GPIO
L	Grey/pink	Do not connect
M	Red/blue	Do not connect

Notes: 1. Do not connect anything to pins #L or #M that are connected to MRU PCB for firmware updates.
2. RS-232 is the default interface. In this case pins #A to #D are not used.

Table 4.2 Electrical specifications

Parameter	Conditions	Min	Typical	Max	Units
Input Supply		+9	+12V	+36V	Volts DC
Power		1.35	1.40	1.50	W
Current	V _{DD} = +12V	100	115	125	mA

At the Inertial Labs™ MRU operations it should be connected to the host system which provides command interface described in the section 5 and the MRU powering.

For tests, the Inertial Labs™ MRU can be connected to PC by cable set as Fig.4.2 shows. At this, for the Inertial Labs™ MRU powering the AC/DC adapter can be used which receives the power from the 100...240V 50...60Hz AC power source. This AC/DC adapter is provided by the Inertial Labs and is included in the delivery set.

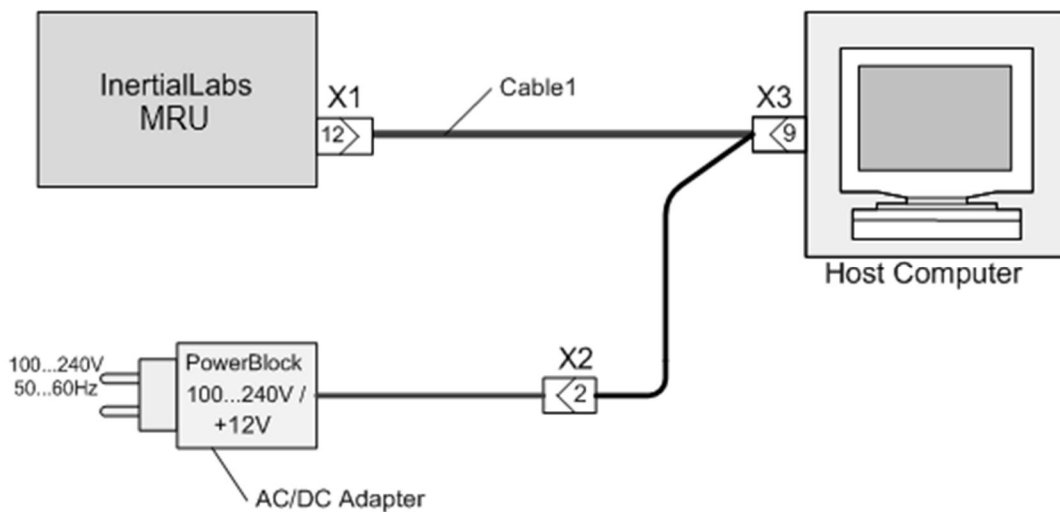


Fig.4.2. The diagram of electric connection of the Inertial Labs™ MRU to host computer (PC)

The delivery set for the MRU electrical connection to PC is provided by the Inertial Labs and includes:

- interface cable 1 for the Inertial Labs™ MRU connection to the COM-port of PC or another device, with branch wires for the Inertial Labs™ MRU DC powering;
- COM-to-USB converter for connection of the MRU to PC through the USB port;
- AC/DC adapter.

Also Inertial Labs MRU Demo software is included in the delivery set for quick evaluation of the Inertial Labs™ MRU.

Fig.4.3 shows the diagram of the interface cable 1 for the Inertial Labs™ MRU connections to the COM-port of host computer and to the DC power source.

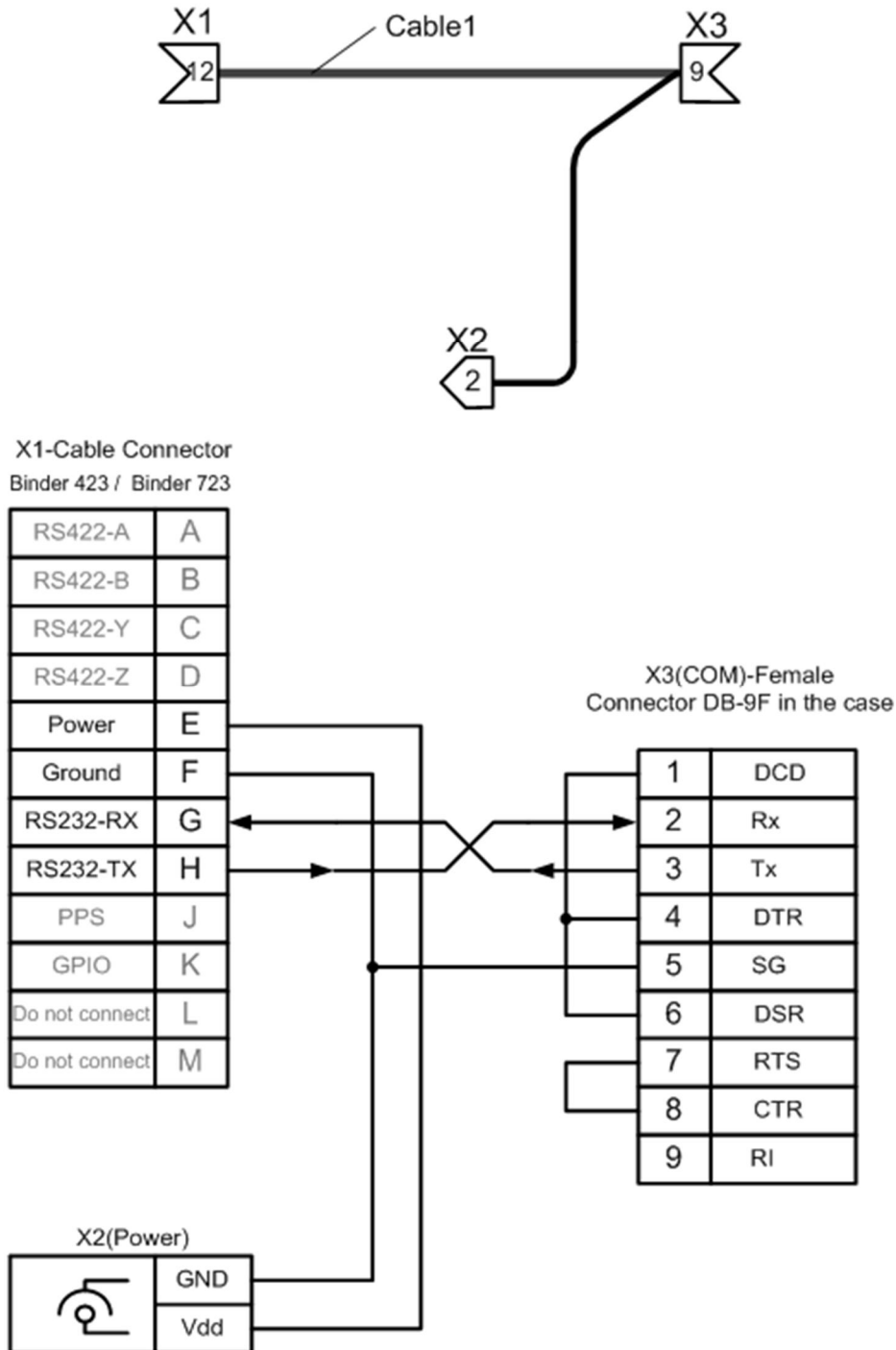


Fig.4.3. The diagram of the interface cable 1 for the Inertial Labs™ MRU connections to the COM-port of host computer and to the AC/DC adapter

5. SOFTWARE INTERFACE

After power connection the primary initialization of the Inertial Labs™ MRU microprocessor takes place and then the main program starts. The time of the device pretreatment is not more 1 second. Then the program operates in the mode of commands waiting. The MRU indicator lights red.

If the auto start option is enabled the MRU starts operation automatically after power on (see section 5.8 for more details). The MRU indicator lights green.

The commands are transmitted through the serial port according to the protocol RS-232 with baud rate 115200 bps (default settings).

Table 5.1. COM-port parameters

COM-port parameters	
Baud rate	115200
Data bits	8
Parity	none
Stop bits	1

Notes

1. Other baud rate than 115200 bps can be set for MRU with firmware version since 2.2.0.0. See section “5.9. Change of the MRU COM port baud rate” for details.
2. The Inertial Labs™ MRU with RS-422, RS-485, CAN 2.0 interfaces are also available.

All commands and messages to/from the Inertial Labs™ MRU have the byte structure shown in the Table 5.2. Exception is done for the MRU output in the NMEA, TSS1, TSS1+HEHDT text formats (see section 5.2).

Table 5.2. Byte structure for all commands and messages to / from the MRU

Byte number	0	1	2	3	4, 5	6..(n-1)	n, (n+1)
Parameter	Header 0	Header 1	Message type	MRU data identifier	Message length	Payload	Check sum
Length	1 byte	1 byte	1 byte	1 byte	1 word	Variable	1 word
<i>Note</i>	0xAA	0x55		In MRU messages	Equal to n		

In the Table 5.2 and in all other there is denoted:

word = unsigned 2 byte integer;

sword = signed 2 byte integer.

Message type is equal to:

0 – for commands;

1 – for transferring data.

All the MRU outputs are data, therefore they have Message type = 1.

MRU data identifier is used in MRU output data only. This byte is equal to code of the command from the host system which requested this MRU message. See all commands code in “APPENDIX C. Full list of the Inertial Labs™ MRU commands”.

Note byte #3 in the block of the initial alignment data is equal to set output data rate (see Table 5.11). In all other messages and commands byte #3 in the Table 5.2 is zero.

Note: in MRU with firmware version before 2.1.2.0 this byte #3 is zero in all messages.

The Message length is the number of bytes in the message without header.

The Check sum is the arithmetical sum of bytes 2...(n-1) (all bytes without header). In the check sum the low byte is transmitted first (see Table 5.3).

Table 5.3. Format of the check sum transmitting

byte0	byte1
low byte	high byte

Important note

The low byte is transmitted by first in all data denoted as word, sword, float.

5.1. Operational modes of the Inertial Labs™ MRU

The Inertial Labs™ MRU can operate in the four modes:

1. **Idle** mode. All sensors and electronics are powered. The MRU microprocessor waits any command from the host computer to start operate in one of the next modes. In the idle mode the indicator of MRU lights red.
2. **Continuous** operating mode. In this mode the MRU operates in the endless loop, providing the continuous output of calculated orientation angles and other data according to chosen output data format (see section 5.2). Data rate is set by user from 1 Hz to 200 Hz. In the Continuous operating mode indicator of the MRU lights green.
3. **“On Request”** operating mode. It is close to the Continuous operating mode, but the MRU sends only one data block after each Request command issued from host computer. In this mode indicator of the MRU lights green.
4. **Calibration** operating mode. In this mode the embedded calibration procedure is performed for compensation of hard and soft iron effects of the carrier object. For MRU-E only. See section 5.6 for more details.

5.2. Output Data Formats of the Inertial Labs™ MRU in the Operating Modes

The next output data formats are available in the “Continuous” and “On Request” operating modes:

- MRU Full Output Data;
- MRU Calibrated Data;
- MRU Quaternion Data;
- MRU Minimal Data;
- NMEA Output;
- TSS1 Output;
- TSS1+HEHDT.

5.2.1. The “MRU Calibrated Data” format

This is default data format. It provides the MRU output in the form of:

- 3 orientation angles (heading, pitch and roll);
- heave and its rate;
- surge, sway and their rate;
- calibrated outputs of the 9 sensors (gyros, accelerometers, magnetometers) that give information about current angular rate, linear acceleration of the MRU and components of outer magnetic field;
- calibrated data from pressure sensor.

Structure of the MRU data blocks at the “MRU Calibrated Data” data format corresponds to the Table 5.2 with payload shown in the Table 5.4.

Table 5.4. The message payload at MRU Calibrated Data format

Byte number	0 – 1	2 – 3	4 – 5	6 – 11	12 – 17	18 – 23	24 – 25	26 – 27	28 – 29	30 – 31	32 – 33
Parameter	Heading	Pitch	Roll	GyroX, GyroY, GyroZ	AccX, AccY, AccZ	MagX, MagY, MagZ	Reserved	Reserved	USW	Vinp	Temper
Length	2 byte word	2 byte sword	2 byte sword	3× 2 byte sword	3× 2 byte sword	3× 2 byte sword	2 byte sword	2 byte sword	2 byte word	2 byte word	2 byte sword
Note	Orientation angles, deg*100			Angular rates, deg/s *KG	Accelerations, g*KA	Magnetic fields, nT/10				Supply voltage, VDC* 100	Temperature, °C*10

Table 5.4 (continued)

Byte number	34 – 37	38 – 39	40 – 41	42 – 43	44 – 45	46 – 47	48-49	50-53
Parameter	Heave	Surge	Sway	Heave velocity	Surge velocity	Sway velocity	P_bar or Hs	H_bar
Length	4 byte integer	2 byte sword	2 byte sword	2 byte sword	2 byte sword	2 byte sword	2 byte word	4 byte integer
Note	m*100	m*100	m*100	m/s*100	m/s*100	m/s*100	Pa/2 or m*100	m*100

Notes

1. Heading is calculated in MRU-E only.
2. Values of KG, KA are scale factors depending on gyro and accelerometer range:

Gyro range, deg/sec	250 or 300	450 or 500	1000	2000
KG	100	50	20	10

Accelerometer range, g	2	6	8	10	15
KA	10000	5000	4000	2000	2000

3. Angular rates, linear accelerations and magnetic fields are in the carrier object axes (X is lateral axis, Y is longitudinal axis, Z is vertical axis). The MRU orientation relative to the carrier object axes is set by alignment angles (see Appendix D. Variants of the Inertial Labs™ MRU mounting relative to the object axes).
4. USW is unit status word (see section 5.7 for details).
5. Vinp is input voltage of the MRU.
6. Temper is averaged temperature in 3 gyros.
7. P_bar or Hs – pressure or Significant Wave Height, see section 5.4.3.
8. H_bar – barometric height.
9. The low byte is transmitted by first.

More correctly gyros, accelerometers, magnetometers output are integrated angular rate, linear acceleration (specific force), magnetic field increments. In the MRU output these increments are divided by time step of data output so they may be interpreted as average angular rates, linear acceleration and magnetic field for cycle of data output. On the other hand, incremental sensor data are good for the MRU using as IMU (inertial measurement unit) – they are delta Theta and Delta Velocity divided by time step of data output.

Maximum data rate for the MRU output at the “MRU Calibrated Data” format is limited to 160 Hz at standard COM-port baud rate 115200 bps. See Table 5.24 for maximum data rate at other baud rates.

5.2.2. The “MRU Quaternion Data” format

This is data format is near the same as the “MRU Calibrated Data” format but provides the quaternion of orientation instead of orientation angles. See “APPENDIX D. Forms of the Inertial Labs™ MRU orientation presentation” for correct relationship between orientation angles and quaternion.

The “MRU Quaternion Data” format provides output in the form of:

- Quaternion of orientation;
- heave and its rate;
- surge, sway and their rate;

- calibrated outputs of the 9 sensors (gyros, accelerometers, magnetometers) that give information about current angular rate, linear acceleration of the MRU and components of outer magnetic field;
- calibrated data from pressure sensor.

Structure of the MRU data blocks at the “MRU Quaternion Data” data format corresponds to the Table 5.2 with payload shown in Table 5.5.

Table 5.5. The message payload at MRU Quaternion Data format

Byte number	0-7	8 – 13	14 – 19	20 – 25	26 – 27	28 – 29	30-31	32 – 33	34 – 35
Parameter	Lk0, Lk1, Lk2, Lk3	GyroX, GyroY, GyroZ	AccX, AccY, AccZ	MagX, MagY, MagZ	Reserved	Reserved	USW	Vinp	Temper
Length	4× 2 byte sword	3× 2 byte sword	3× 2 byte sword	3× 2 byte sword	2 byte sword	2 byte sword	2 byte word	2 byte word	2 byte sword
Note	Quaternion of orientation *10000	Angular rates, deg/s *KG	Accelerations, g*KA	Magnetic fields, nT/10				Supply voltage, VDC* 100	Temperature, °C*10

Table 5.5 (continued)

Byte number	36 – 39	40 – 41	42 – 43	44 – 45	46 – 47	48 – 49	50 – 51	52 – 55
Parameter	Heave	Surge	Sway	Heave velocity	Surge velocity	Sway velocity	P_bar or Hs	H_bar
Length	4 byte integer	2 byte sword	2 byte sword	2 byte sword	2 byte sword	2 byte sword	2 byte word	4 byte integer
Note	m*100	m*100	m*100	m/s*100	m/s*100	m/s*100	Pa/2 or m*100	m*100

Notes

1. Heading is calculated in MRU-E only.
2. Values of KG, KA are scale factors depending on gyro and accelerometer range:

Gyro range, deg/sec	250 or 300	450 or 500	1000	2000
KG	100	50	20	10

Accelerometer range, g	2	6	8	10	15
KA	10000	5000	4000	2000	2000

3. Angular rates, linear accelerations and magnetic fields are in the carrier object axes (X is lateral axis, Y is longitudinal axis, Z is vertical axis). The MRU orientation relative to the carrier object axes is set by alignment angles (see Appendix D. Variants of the Inertial Labs™ MRU mounting relative to the object axes).
4. USW is unit status word (see section 5.7 for details).
5. Vinp is input voltage of the MRU.
6. Temper is averaged temperature in 3 gyros.
7. P_bar or Hs – pressure or Significant Wave Height, see section 5.4.3.
8. H_bar – barometric height.
9. The low byte is transmitted by first.

More correctly gyros, accelerometers, magnetometers output are integrated angular rate, linear acceleration (specific force), magnetic field increments. In the MRU output these increments are divided by time step of data output so they may be interpreted as average angular rates, linear acceleration and magnetic field for cycle of data output. On the other hand, incremental sensor data are good for the MRU using as IMU (inertial measurement unit) – they are delta Theta and Delta Velocity divided by time step of data output.

Maximum data rate for the MRU output at the “MRU Quaternion Data” format is limited to 160 Hz at standard COM-port baud rate 115200 bps. See Table 5.24 for maximum data rate at other baud rates.

5.2.3. The “MRU Full Output Data” format

This format is near the same as the “MRU Calibrated Data” format but all sensors data are in original ADC codes (raw data). Usually the “MRU Full Output Data” format is used by the MRU developers for full control of calculations in the MRU microprocessor. Also this format can be used by user at any troubles to get full data from the MRU for next sending them to developers.

Structure of the MRU data blocks at the “MRU Full Output Data” data format corresponds to the Table 5.2 with payload shown in the Table 5.6.

Table 5.6. The message payload at MRU Full Output Data format

Byte number	0 – 1	2 – 3	4 – 5	6 – 23	24 – 25	26 – 27	28 – 29	30 – 31	32 – 33
Parameter	Heading	Pitch	Roll	Ugyro, Uacc, Umag	Reser- ved	Reser- ved	USW	Vdd	Utermo
Length	2 byte word	2 byte sword	2 byte sword	9×2 byte sword	2 byte sword	2 byte sword	2 byte word	2 byte word	2 byte sword
Note	Orientation angles, deg*100			Raw sensor data (gyros, accelerometers, magnetometers)				Combi- ned voltage	Temper- ature in each sensor

Table 5.6 (continued)

Byte number	34 – 37	38 – 39	40 – 41	42 – 43	44 – 45	46 – 47	48-49	50-51
Parameter	Heave	Surge	Sway	Heave velocity	Surge velocity	Sway velocity	UP	UT
Length	4 byte integer	2 byte sword	2 byte sword	2 byte sword	2 byte sword	2 byte sword	2 byte word	2 byte word
Note	m*100	m*100	m*100	m/s*100	m/s*100	m/s*100		

Notes

1. Heading is calculated in MRU-E only.
2. USW is unit status word (see section 5.7 for details).
3. The following data are recorded in the field «Vdd» sequentially:
 - the MRU input voltage, V_{in} , $VDC*100$;
 - stabilized voltage supplied to the MRU sensors, V_{dd} , $VDC*1000$;
4. In the «Utermo» field ADC codes are recorded sequentially from 7 temperature sensors inside gyros, accelerometers and magnetometers.
5. UP and UT are raw data from the pressure sensor – pressure and temperature.
6. The low byte is transmitted by first.

Maximum data rate for the MRU output in the “MRU Full Output Data” format is limited to 160 Hz at standard COM-port baud rate 115200 bps. See Table 5.24 for maximum data rate at other baud rates.

5.2.4. The “MRU Minimal Data” format

This format specifies the minimum of MRU data that can be transferred with maximum data rate 200 Hz.

- 3 orientation angles (heading, pitch and roll);

- heave;
- calibrated outputs of the 9 sensors (gyros, accelerometers, magnetometers) that give information about current angular rate, linear acceleration of the MRU and components of outer magnetic field.

Structure of the MRU data blocks at the “MRU Minimal Data” data format corresponds to the Table 5.2 with payload shown in the Table 5.7.

Maximum data rate for the MRU output in the “MRU Minimal Data” format is 200 Hz at standard COM-port baud rate 115200 bps. See Table 5.24 for maximum data rate at other baud rates.

Table 5.7. The message payload at MRU Minimal Data format

Byte number	0 – 1	2 – 3	4 – 5	6 – 11	12 – 17	18 – 23	24–27	28 – 29	30 – 31	32 – 33
Parameter	Heading	Pitch	Roll	GyroX, GyroY, GyroZ	AccX, AccY, AccZ	MagX, MagY, MagZ	Heave	USW	Vinp	Temper
Length	2 byte word	2 byte sword	2 byte sword	3× 2 byte sword	3× 2 byte sword	3× 2 byte sword	4 byte integer	2 byte word	2 byte word	2 byte sword
Note	Orientation angles, deg*100			Angular rates, deg/s *KG	Accelerations, g*KA	Magnetic fields, nT/10	m*100		Supply voltage, VDC* 100	Temperature, °C*10

Notes

1. Heading is calculated in MRU-E only.
2. Values of KG, KA are scale factors depending on gyro and accelerometer range:

Gyro range, deg/sec	250 or 300	450 or 500	1000	2000
KG	100	50	20	10

Accelerometer range, g	2	6	8	10	15
KA	10000	5000	4000	2000	2000

3. Angular rates, linear accelerations and magnetic fields are in the carrier object axes (X is lateral axis, Y is longitudinal axis, Z is vertical axis). The MRU orientation relative to the carrier object axes is set by alignment angles (see Appendix D. Variants of the Inertial Labs™ MRU mounting relative to the object axes).
4. USW is unit status word (see section 5.7 for details).
5. Temper is averaged temperature in 3 gyros.
6. The low byte is transmitted by first.

5.2.5. The “NMEA Output” data format

At the “NMEA Output” the MRU data are transmitted in the form of sentences with printable ASCII characters like the NMEA 0183 format. Each sentence starts with a "\$" sign and ends with <CR><LF> (carriage return 0xD and line feed 0xA symbols). All data fields are separated by commas. The general form of the “NMEA Output” sentence is the next

\$PAPR,AAAA.aa,B,RRRR.rr,PPP.pp,HHH.hh,TTT.t,V.vv,SSSS*CC<CR><LF>

where PAPR is identifier and other fields are listed in the Table 5.8.

Table 5.8.The MRU message in NMEA format

Field	AAAA.aa	B	RRRR.rr	PPP.pp	HHH.hh	TTT.t	V.vv	SSSS	CC
Parameter	Heave	h	Roll	Pitch	Heading	Temperature	Vinp	USW	Check sum
<i>Note</i>	m		deg	deg	deg	°C	VDC	hex written with ASCII	

Notes

1. “B” field is always equal to ‘h’ that denotes ‘heave’ calculated in AAAA.aa field.
2. Heading is calculated in MRU-E only.
3. USW is unit status word (see section 5.7 for details).
4. Temperature is averaged value for 3 gyros.
5. Vinp is input voltage of the MRU.
6. Check sum consists of a "*" and two hex digits representing XOR of all characters between, but not including "\$" and "*".

Maximum data rate for the MRU output at the “NMEA Output” data format is limited to 180 Hz at standard COM-port baud rate 115200 bps. See Table 5.24 for maximum data rate at other baud rates.

5.2.6. The “TSS1 Output” data format

At the “TSS1 Output” the MRU provides accelerations, heave, pitch, and roll message in the commonly used TSS1 message format. The TSS1 data string consists of five data fields and contains 27 printable ASCII characters. The acceleration fields contain ASCII-coded hexadecimal values. Motion measurements include ASCII-coded decimal values.

The general form of the “TSS1” sentence is the next:

:XXAAAASMHHHQMRRRRSMPPPP<CR><LF>

Table 5.9. The MRU message in TSS1 format

Message component	Description						
:	Start character						
XX	Horizontal acceleration (hex value), in 3.83 cm/s ² , with a range of zero to 9.81 m/s ²						
AAAA	Vertical acceleration (hex value - 2's complement), in 0.0625 cm/s ² , with a range of -20.48 to +20.48 m/s ²						
S	Space character						
M	Space if positive; minus if negative						
HHHH	Heave, in centimeters, with a range of -99.99 to +99.99 meters						
Q	Status flag <table border="1" style="margin-left: 20px;"> <thead> <tr> <th>Value</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td>F</td> <td>MRU Ready Mode with valid GPS input</td> </tr> <tr> <td>H</td> <td>MRU Ready Mode without GPS input</td> </tr> </tbody> </table>	Value	Description	F	MRU Ready Mode with valid GPS input	H	MRU Ready Mode without GPS input
Value	Description						
F	MRU Ready Mode with valid GPS input						
H	MRU Ready Mode without GPS input						
M	Space if positive; minus if negative						
RRRR	Roll, in units of 0.01 degrees (ex: 1000 = 10°), with a range of -99.99° to +99.99°						
S	Space character						
M	Space if positive; minus if negative						
PPPP	Pitch, in units of 0.01 degrees (ex: 1000 = 10°), with a range of -99.99° to +99.99°						
<CR>	Carriage return						
<LF>	Line feed						

Maximum data rate for the MRU output at the TSS1 data format is 200 Hz at standard COM-port baud rate 115200 bps. See Table 5.24 for maximum data rate at other baud rates.

5.2.7. The “TSS1+HEHDT Output” data format

At the “TSS1+HEHDT” output the MRU provides the TSS1 message format supplemented with the HEHDT message format.

The general forms of the “TSS1+HEHDT” sentences are the next:

:XXAAAASMHHHQMRRRRSMPPPP<CR><LF>
\$HEHDT,XXX.XX,T*CC<CR><LF>

where first row is the MRU message in TSS1 format (see Table 5.9) and second row is NMEA HEHDT message which fields are listed in the Table 5.10.

Table 5.10 The HEHDT message in TSS1+HEHDT format

Message component	Description
\$	Start character
HEHDT	identifier
XXX.XX	heading in degrees
T	true heading indicator
CC	check sum that consists of a "*" and two hex digits representing XOR of all characters between, but not including "\$" and "*"
<CR>	Carriage return
<LF>	Line feed

Maximum data rate for the MRU output at the TSS1+HEHDT data format is 200 Hz at standard COM-port baud rate 115200 bps. See Table 5.24 for maximum data rate at other baud rates.

5.3. Control of the Inertial Labs™ MRU

After power connection the MRU is in the idle mode. Red light of the LED indicator near the connector signifies the readiness of the Inertial Labs™ MRU to receive commands from the host computer. When the MRU switches from idle to any operation mode, the light indicator changes its color from red to green.

The next commands are used to control the MRU:

- MRU_ClbData;
- MRU_QuatData;
- MRU_FullData;
- MRU_minData;
- MRU_NMEA;
- MRU_TSS1;
- MRU_TSS1HEHDT;
- SetOnRequestMode;
- Stop;
- ReadMRUPar;
- LoadMRUPar;
- GetDevInfo;
- GetBIT.

All these commands have the byte structure shown in the Table 5.2. Payload for all commands has length 1 byte and contains code of the command. See Appendix C for exact structure of these commands.

5.3.1. MRU_ClbData, MRU_QuatData, MRU_FullData, MRU_minData, MRU_NMEA, MRU_TSS1 commands

Commands MRU_ClbData, MRU_QuatData, MRU_FullData, MRU_minData, MRU_NMEA, MRU_TSS1, MRU_TSS1HEHDT are used to start the Inertial Labs™ MRU in the “Continuous” operating mode with appropriate variant of output data format as Table 5.11 shows.

Table 5.11. MRU control commands and appropriate output data format

Command	Code	Output data format
MRU_FullData	0x31	MRU Full Output Data
MRU_ClbData	0x32	MRU Calibrated Data
MRU_QuatData	0x36	MRU Quaternion Data
MRU_minData	0x33	MRU Minimal Data
MRU_NMEA	0x34	NMEA Output
MRU_TSS1	0x35	TSS1 Output
MRU_TSS1HEHDT	0x42	TSS1+HEHDT Output

All these commands have the byte structure shown in the Table 5.2. Payload for all commands has length 1 byte and contains code of the command listed in the Table 5.11.

In order to identify to the host system that MRU received one of these commands, the MRU answers back immediately on this command prior to completion of the initial alignment process. The MRU calculates the check sum of the message (without its header and check sum) and returns it for a checking. Byte structure of this message is shown in the Table 5.2 where payload is the calculated check sum (1 word). This check sum should be equal to the check sum in the message that was sent to the MRU.

After receiving of any from these commands the MRU starts process of initial alignment that takes usually 30 seconds. This process includes the MRU gyros bias estimation, therefore don't move the MRU during its initial alignment. If this requirement is not met then large errors may be occurred in orientation angles calculation.

Note: Default time 30 seconds of the initial alignment can be changed (see section 5.3.4. LoadMRUPar command) but only in agreement with developers of the Inertial Labs™ MRU.

After completing of the initial alignment the MRU gives out message with block of the initial alignment data (see Table 5.12, Table 5.13) and goes to the “Continuous” operating mode.

Table 5.12. Byte structure of the block of initial alignment data

Byte number	0	1	2	3	4, 5	6..55	56, 57
Parameter	Header 0	Header 1	Message type	Output data rate (Hz)	Message length	Payload	Check sum
Length	1 byte	1 byte	1 byte	1 byte	1 word	50 bytes	1 word
Note	0xAA	0x55	0x01	hexadecimal value	0x38 0x00	see Table 5.12	

Table 5.13. Structure of the payload of the block of initial alignment data

Byte	Parameter	Format	Length	Note
0-11	Gyros bias	float	3*4	3 numbers in ADC codes
12-23	Average acceleration	float	3*4	3 numbers in ADC codes
24-35	Average magn. field	float	3*4	3 numbers in ADC codes
36-39	Initial Heading	float	4	degrees
40-43	Initial Roll	float	4	degrees
44-47	Initial Pitch	float	4	degrees
48-49	USW (see section 5.7)	word	2	0 – successful initial alignment; ≠0 – unsuccessful

In the “Continuous” operating mode set by any of commands MRU_ClbData, MRU_QuatData, MRU_FullData, MRU_minData, MRU_NMEA, MRU_TSS1, the program in the MRU microprocessor operates in the endless loop, providing the process of data reading from ADC and orientation angles calculating.

At the **MRU_ClbData**, **MRU_QuatData**, **MRU_FullData**, **MRU_minData** commands output data blocks have binary structure according to chosen variant of output data in messages described in the Table 5.2. The message payload depends on chosen variant of output data (see Tables 5.4 – 5.7).

At the **MRU_NMEA**, **MRU_TSS1**, **MRU_TSS1HEHDT** commands output data blocks are transmitted in the form of sentences with printable ASCII characters as sections 5.2.5 and 5.2.7 describe.

The update rate of data blocks is set by the user in range (1...200) Hz, but maximum data rate depends on chosen output data format and COM port baud rate (see Table 5.24).

5.3.2. SetOnRequestMode command – getting MRU data on request (on demand)

The command SetOnRequestMode is used to start the Inertial Labs™ MRU operation in the “On Request” (on demand) operating mode. This command has the byte structure shown in the Table 5.2 where payload is one byte equal to 0xC1.

In order to identify to the host system that MRU received this command, the MRU answers back immediately on this command prior to completion of the initial alignment process. The MRU calculates the check sum of the message (without its header and check sum) and returns it for a checking. Byte structure of this message is shown in the Table 5.2 where payload is the calculated check sum (1 word). This check sum should be equal to the check sum in the message that was sent to the MRU.

After receiving of the SetOnRequestMode command the MRU starts process of initial alignment that takes usually 30 seconds. This process includes the MRU gyros bias estimation, therefore don't move the MRU during its initial alignment. If this requirement is not met then large errors may be occurred in orientation angles calculation.

Note: Default time 30 seconds of the initial alignment can be changed (see section 5.3.6. LoadMRUPar command) but only in agreement with developers of the Inertial Labs™ MRU.

After completing of the initial alignment the MRU gives out message with block of the initial alignment data (see Table 5.12, Table 5.13) and goes to the “On Request” operating mode.

In the “On Request” operating mode the MRU sends only one data block after each request. To get this data block send one of above described commands MRU_ClbData, MRU_QuatData, MRU_FullData, MRU_minData, MRU_NMEA, MRU_TSS1, MRU_TSS1HEHDT (see section 5.3.1).

If one of the **MRU_ClbData**, **MRU_QuatData**, **MRU_FullData**, **MRU_minData** commands is used for request then output data block has binary structure described in the Table 5.2 with payload depending on chosen variant of output data format (see matching Table 5.11 and detailed Tables 5.4 – 5.7).

If one of the **MRU_NMEA**, **MRU_TSS1**, **MRU_TSS1HEHDT** commands is used for request then output data block contains printable ASCII characters as sections 5.2.5 - 5.2.7 describe.

5.3.3. Stop command

At receiving the Stop command (code 0xFE in the “Payload” field) the MRU stops work in an operating mode and goes to the idle mode. The MRU LED indicator changes its color to red. The MRU is ready to receive any command from the host computer.

Important Note: Before using all other commands please send the **Stop** command to the MRU to switch device into the idle mode. Be sure that the MRU’s light indicator is red before sending of any other commands.

5.3.4. LoadMRUPar command

The LoadMRUPar command (code 0x40 in the “Payload” field) is used to load the block of the MRU parameters (which are available for changing by user) into the MRU nonvolatile memory. After sending the LoadMRUPar command, the block of the MRU parameters must be send to the MRU in the message shown in the Table 5.2 with payload shown in the Table 5.14. This message should be sent without pause after sending the LoadMRUPar command.

**Table 5.14. Payload of the message following after the LoadMRUPar command
(block of parameters for loading to the MRU)**

Byte	Parameter	Format	Length	Note
0-1	Data rate	word	2	Hz
2-3	Initial alignment time	word	2	seconds
4-7	Magnetic declination, Mdec	longint	4	degrees*100, for MRU-E only. If Mdec > 360 then MRU-E calculates it
8-11	Latitude	longint	4	degrees*1e7
12-15	Longitude	longint	4	degrees*1e7
16-19	Altitude	longint	4	meters*100
20	Date (Year from 2000)	byte	1	0 to 255
21	Date (Month)	byte	1	1 to 12
22	Date (Day)	byte	1	1 to 31
23-24	Alignment angle A1	sword	2	Angles of MRU mounting on the carrier object, degrees*100 (see Appendix B)
25-26	Alignment angle A2	sword	2	
27-28	Alignment angle A3	sword	2	
29-30	MRU mount, right	sword	2	MRU mounting lever relative to the center of the object gravity, m*100 (see section 5.5)
31-32	MRU mount, forward	sword	2	
33-34	MRU mount, up	sword	2	
35-36	Reserved	sword	2	Must be all zeros
37-38	Reserved	sword	2	
39-40	Reserved	sword	2	
41	Barometric altitude mode	byte	1	2 = Heave (see section 5.4)
42	Cutoff frequency for Heave HP filter	byte	1	Hz*100
43	Cutoff frequency for Heave LP filter	byte	1	Hz*10, must be not less than cutoff frequency for Heave HP filter, or zero
44-45	Target position, right	sword	2	Target position relative to the MRU for Heave calculation, lever, m*100
46-47	Target position, forward	sword	2	
48-49	Target position, up	sword	2	
50-57	MRU device name	char	8	only read , change is ignored
58	Baro_enabled	byte	1	0 = disabled; 1 = enabled
59	Reserved	byte	1	

The MRU calculates the check sum of received parameters and returns it for a checking. Byte structure of this message is shown in the Table 5.2 where payload is the calculated check sum (2 bytes).

Notes:

1. The most easy and sure way to change above parameters is using the Inertial Labs™ MRU Demo Program.
2. Before using **LoadMRUPar** command it is necessary to use **ReadMRUPar** command (see below) to read parameters from the MRU at first. After that user can change some parameters listed in the Table 5.13, and to send back all block of parameters to the Inertial Labs™ MRU.
3. Default time 30 seconds of the initial alignment can be changed but only in agreement with developers of the Inertial Labs™ MRU.
4. It is necessary to set current latitude, longitude, altitude, year, month, day only for MRU-E, in two cases :
 - a) if the magnetic declination is unknown so its calculation inside the MRU-E is required for current place and date;
 - b) before hard/soft iron calibration of the MRU-E magnetometers (see section 5.6)
5. Baro_enabled switch enables or disables using of the pressure sensor data for the heave correction. On default it is enabled.

5.3.5. ReadMRUPar command

The ReadMRUPar command (code 0x41 in the “Payload” field, see the Table 5.2) is used to read block of the Inertial Labs™ MRU parameters (60 bytes) from the MRU nonvolatile memory.

After receiving ReadMRUPar command, the MRU sends out the message with structure according to the Table 5.2 and payload shown in the Table 5.15.

Table 5.15. Payload of the MRU answer on the ReadMRUPar command (block of parameters read from the MRU)

Byte	Parameter	Format	Length	Note
0-1	Data rate	word	2	Hz
2-3	Initial alignment time	word	2	seconds
4-7	Magnetic declination	longint	4	degrees*100, for MRU-E only
8-11	Latitude	longint	4	degrees*1e7
12-15	Longitude	longint	4	degrees*1e7
16-19	Altitude	longint	4	meters*100
20	Date (Year from 2000)	byte	1	0 to 255
21	Date (Month)	byte	1	1 to 12
22	Date (Day)	byte	1	1 to 31
23-24	Alignment angle A1	sword	2	Angles of MRU mounting on the carrier object, degrees*100 (see Appendix B)
25-26	Alignment angle A2	sword	2	
27-28	Alignment angle A3	sword	2	
29-30	MRU mount, right	sword	2	MRU mounting lever relative

31-32	MRU mount, forward	sword	2	to the center of the object gravity, m*100 (see section 5.5)
33-34	MRU mount, up	sword	2	
35-36	Reserved	sword	2	
37-38	Reserved	sword	2	
39-40	Reserved	sword	2	
41	Barometric altitude mode	byte	1	2 = Heave (see section 5.4)
42	Cutoff frequency for Heave HP filter	byte	1	Hz*100
43	Cutoff frequency for Heave LP filter	byte	1	Hz*10
44-45	Target position, right	sword	2	Target position relative to the MRU for Heave calculation, lever, m*100
46-47	Target position, forward	sword	2	
48-49	Target position, up	sword	2	
50-57	MRU device name	char	8	
58	Baro_enabled	byte	1	0 = disabled; 1 = enabled
59	Reserved	byte	1	

See Notes to the section 5.3.4. LoadMRUPar command.

5.3.6. GetDevInfo command

The GetDevInfo command (code 0x12 in the “Payload” field) is used to get detailed information about devices installed in the MRU:

- 1) MRU processor;
- 2) IMU (MRU);
- 3) GNSS receiver (isn’t included in the MRU);
- 4) Pressure sensor.

As answer the MRU sends out the message with structure according to the Table 5.2 and payload shown in the Table 5.16.

Table 5.16. Payload of the MRU answer on the GetDevInfo command

Byte	Parameter	Format	Length	Note
0-7	ID_sn	char	8	Integrated device (MRU) s/n
8-47	ID_fw	char	40	MRU firmware version
48	Press_Sens	byte	1	Pressure sensor: 1= present, 0 = absent
49	IMU_type	byte	1	IMU type (1=MRU)
50-57	IMU_sn	char	8	IMU (MRU) s/n
58-97	IMU_fw	char	40	IMU (MRU) firmware version

98-113	GNSS_model	char	16	GNSS receiver model
114-129	GNSS_sn	char	16	GNSS receiver product s/n
130-145	GNSS_hw	char	16	GNSS receiver hardware version
146-161	GNSS_fw	char	16	GNSS receiver firmware version
162-163	GPS_week	word	2	GPS reference week number
164	GNSS_data_rate	byte	1	GNSS receiver max data rate, Hz
165	Reserved	byte	1	Reserved

Note. The Inertial Labs™ MRU-B and MRU-E do not include GNSS receiver, so fields in bytes 98 to 164 are empty. If you need in MRU with GNSS receiver please order the Inertial Labs™ MRU-P.

5.3.7. GetBIT command

The Inertial Labs™ MRU has continuous built-in monitoring of its health. In both “Continuous” and “On Request” operation modes the MRU sends out the Unit Status Word (USW) in each data block (see Table 5.4 – Table 5.7). The USW is described in the section 5.7.

The USW can be got in any time if the MRU is in Idle or “On Request” operation mode (after SetOnRequestMode command). For this the **GetBIT** command (code 0x1A in the “Payload” field) is used. In answer the MRU sends out the message with data according to the Table 5.17.

Table 5.17. Payload of the MRU answer on the GetBIT command

Byte number	0 – 1	2 – 3
Parameter	Utermo100	USW
Length	2 byte word	2 byte word

In the Table 5.17 Utermo100 is the MRU temperature in 1/100 °C increments.

5.4. Heave calculation

At its operation the MRU calculates heave for marine applications. Heave is a ship motion along the vertical axis.

5.4.1. Adjustment of the algorithm of heave calculation

To calculate the heave as the MRU vertical position with respect to its equilibrium position, the vertical acceleration is doubly integrated. However, because signals from accelerometers always contain a DC component as well as spurious low frequency components, after integration the heave error is accumulated and increases with time significantly. To avoid such error, integrated signals are filtered by High-Pass (HP) filter. Also, to decrease noise the Low-Pass (LP) filter can be applied.

The main adjustment parameter is cutoff frequency for heave HP filter, f_{HP} . It must be much less than the main frequency of a ship vertical motion. But very low value of the f_{HP} allow accelerometers' bias instability to affect the heave accuracy. The default value is $f_{HP} = 0.02$ Hz that should be enough for intensive vertical motion of a ship.

Values of HP and LP cutoff frequencies for the heave filter can be set using the LoadMRUPar command (see Table 5.14, bytes #42 and 43) or using the MRU Demo Program (that is more easy).

5.4.2. Heave calculation for chosen point of the carrier object

Usually heave is calculated for place of the MRU mounting on the carrier object. But it is possible to set desirable point on the carrier object for heave calculation. For this purpose please set coordinates of this point relative to the MRU position, in the object axes – on the right, forward and up. For this please use the LoadMRUPar command (see Table 5.14, bytes #44-49) or the MRU Demo Program (that is more easy).

5.4.3. Significant Wave Height calculation

The Inertial Labs™ MRU can calculate height of the wave during its work. For this purpose it is necessary to check **Significant Wave Height**

calculation checkbox by using MRU Demo Program (see User's Manual, section "10.2.3 Significant Wave Height calculation" for details).

5.5. Acceleration compensation at object swaying

It is possible to increase the MRU accuracy at the carrier object's swaying if to compensate linear acceleration at place of the MRU mounting. For this purpose please set coordinates of the MRU mounting relative to the center of the object swaying (usually this is object center of gravity).

These coordinates are set in meters in such sequence of the object directions: right, forward, up. For this please use the LoadMRUPar command (see Table 5.14, bytes #29-34) or the MRU Demo Program (that is more easy).

5.6. Calibration of the Inertial Labs™ MRU-E on hard and soft iron

The Inertial Labs™ MRU-E uses magnetometers™ for heading calculation. The Inertial Labs™ MRU software allows compensation of hard and soft iron effects of the carrier object on the heading calculation accuracy. For this purpose, field calibration of the MRU-E magnetometers is provided (see Appendix A, The MRU-E calibration). Inertial Labs utilizes several types of field calibration depending on the carrier object type.

The next types of the calibration are realized in the Inertial Labs™ MRU-E firmware:

- 3D calibration;
- 2D-2T calibration;
- 2D calibration;
- VG3D calibration.

The next commands are used for the MRU-E calibration:

Start3DCIb;	FinishCIb;
StartVG3DCIb;	AcceptCIb;
Start2D2TCIb;	ClearCIb;
Start2DCIb;	ExitCIb;
StartCIbRun;	GetCIbRes.
StopCIbRun;	

All these commands have the byte structure shown in the Table 5.2. Payload for all commands has length 1 byte and contains code of the command. See Appendix C for examples of these commands.

5.6.1. Start3DCIb command for MRU-E 3D calibration

The **3D calibration** is designed for carrier objects that can operate in full heading, pitch and roll ranges. At this calibration the carrier object should be rotated in all these ranges.

To start the 3D calibration the host computer sends to the MRU-E the Start3DCIb command (code 0x23 in the “Payload” field) followed by message with block of parameters listed in the Table 5.18. This message have the byte structure shown in the Table 5.2, and should be sent without pause after sending the Start3DCIb command.

Table 5.18. Payload of the message following after the Start3DCIb, Start2D2TCIb, Start2DCIb and StartVG3DCIb commands (the block of parameters loaded to the MRU-E)

Byte	Parameter	Format	Length	Note
0-3	Reserved	byte	4	
4-5	Time of data accumulation in one run	word	2	Seconds
6-9	Latitude	float	4	Degrees
10-13	Longitude	float	4	Degrees
14-17	Altitude	float	4	Meters
18-21	Date (Year, Month, Day)	float	4	Year + (Month -1)/12 + Day/365

The MRU-E calculates the check sum of received parameters and returns it for a checking. Byte structure of this message is shown in the Table 5.2 where payload is the calculated check sum (1 word).

Then the MRU-E starts process of initial alignment. This process includes the MRU gyros bias estimation, therefore don't move the MRU during its initial alignment. Default time of the initial alignment is 30 seconds and can be changed (see section 5.3.4. LoadMRUPar command) but only in agreement with developers of the Inertial Labs™ MRU.

After completing of the initial alignment the MRU gives out the block of the initial alignment data (see Table 5.12, Table 5.13) and starts data accumulation during time specified in message sent after the Start3DCIb command (see the Table 5.18).

During the MRU data accumulation the object should be rotated in full azimuth, pitch and roll ranges. For example the object is rotated in the horizon plane (the Z-axis is up) with periodical stops about each 90 degrees for tilting in pitch and roll. After full 360° rotation the object with the MRU is turned over (the Z-axis is down) and the procedure described above should be repeated. During this calibration the range of pitch and roll angles changing must be as much as possible.

Note: there is estimation of 3D calibration quality in terms of possible MRU-E heading accuracy. To allow this possibility it is necessary to include additional rotation of the MRU-E with the carrier object in the horizon plane on about 360 degrees or more with pitch and roll near the level. Acceptable pitch and roll change can be set using MRU Demo Software by the “Pitch/Roll threshold” parameter in the “Magnetometers calibration options”.

After set accumulation time is reached or StopCIBRun command is sent to the MRU-E (see section 5.6.2 for details) the MRU-E finishes data accumulation and calculates the calibration parameters.

After calculation of the calibration parameters that takes <0.5 seconds, the MRU-E gives out message with the calibration results (see the Table 5.19) and it waits one of the next commands:

- the AcceptCIB command (see section 5.6.3) to accept and save the calibration parameters (usually if the “Calibration success” byte in the MRU-E message is nonzero and corresponds to satisfactory MRU-E heading accuracy (see the Table 5.19 and Note below it));
- or the ExitCIB command (see section 5.6.4) to exit from calibration procedure without accepting and saving its results (usually if the “Calibration success” byte in the MRU-E message is equal to 0 or corresponds to not satisfactory MRU-E heading accuracy (see the Table 5.19 and Note below it)).

The MRU-E answers on these commands with checksum and goes to idle mode.

Table 5.19. Payload of the MRU-E message after calibration completed

Byte	Parameter	Format	Length	Note
0	Type of calibration	byte	1	1 for 2D calibration; 2 for 2D-2T calibration; 3 for 3D calibration; 4 for VG3D calibration.
1	Number of used calibration runs	byte	1	
2	Percent of used data points	byte	1	for 2D and 3D calibrations only
3	Calibration success	byte	1	0 – calibration is not successful >0 – calibration is successful (see Note below)
4-39	Matrix for soft iron correction	float	9*4	Matrix Tm_c (3×3) by rows
39-51	Matrix for hard iron correction	float	3*4	Matrix Hm_0 (3×1)

Note: there is estimation of the calibration quality as predicted MRU-E heading accuracy. So nonzero value of byte #3 “Calibration success” is predicted maximum (3 sigma) heading error of the MRU-E after calibration, in degrees*10. For example, byte #3 equal to 5 corresponds to the MRU-E accuracy ± 0.5 deg. If calibration is successful but MRU-E cannot estimate predicted accuracy it returns byte #3 equal to 255.

5.6.2. StopClbRun command

After receiving the StopClbRun command (code 0x20 in the “Payload” field) the MRU-E early stops data accumulation in the calibration run before set accumulation time is reached.

Then the calibration procedure continues in the same way as after set accumulation time was reached.

5.6.3. AcceptClb command

The AcceptClb command (code 0x2E in the “Payload” field) is applied to accept the calibration parameters and to save them to the MRU-E nonvolatile memory. This command can be used in the end of the calibration procedure.

The MRU-E answers on this command. The MRU-E calculates the check sum of the message (without its header and check sum) and returns it for a checking. Byte structure of this message is shown in the Table 5.2 where payload is the calculated check sum (1 word).

5.6.4. ExitCib command

The ExitCib command (code 0xFE in the “Payload” field) is used to exit from the calibration without any calculations in the MRU-E and without saving any calibration parameters. The MRU-E stops work in operating mode and goes into the idle mode.

The MRU-E answers on this command. The MRU-E calculates the check sum of the message (without its header and check sum) and returns it for a checking. Byte structure of this message is shown in the Table 5.2 where payload is the calculated check sum (1 word).

5.6.5. StartVG3DCib command for MRU VG3D calibration

Since firmware version 2.6.2.2 the MRU provides **VG3D calibration**. The **VG3D calibration** is designed for carrier objects that can operate in full heading, pitch and roll ranges. VG3D calibration is similar to 3D calibration but allows performing simpler rotation than is necessary for 3D calibration.

Note: VG3D calibration is at the testing stage. Please contact Inertial Labs about the possibility of using the VG3D calibration.

To start the VG3D calibration the host computer sends to the MRU the StartVG3DCib command (code 0x25 in the “Payload” field) followed by message with block of parameters listed in the Table 5.18. This message have the byte structure shown in the Table 5.2, and should be sent without pause after sending the StartVG3DCib command.

The MRU calculates the check sum of received parameters and returns it for a checking. Byte structure of this message is shown in the Table 5.2 where payload is the calculated check sum (1 word).

Then the MRU starts process of initial alignment. This process includes the MRU gyros bias estimation, therefore don't move the MRU during its initial alignment. Default time of the initial alignment is 30 seconds and can be changed (see section 5.3.4. LoadINSpar command) but only in agreement with developers of the Inertial Labs™ MRU.

After completing of the initial alignment the MRU gives out the block of the initial alignment data (see the Table 5.12, Table 5.13) and starts data

accumulation during time specified in message sent after the StartVG3DCIb command (see the Table 5.18).

During the MRU data accumulation the object should be rotated in full azimuth range and maximum possible pitch and roll ranges. Allowed object motion should be agreed with Inertial Labs.

After set accumulation time is reached or StopClbRun command is sent to the MRU (see section 5.6.2 for details) the MRU finishes data accumulation and calculates the calibration parameters.

After calculation of the calibration parameters that takes <0.5 seconds, the MRU gives out message with the calibration results (see the Table 5.19) and it waits one of the next commands:

- the AcceptClb command (see section 5.6.3) to accept and save the calibration parameters (usually if the “Calibration success” byte in the MRU message is nonzero and corresponds to satisfactory MRU heading accuracy (see the Table 5.18 and Note below it));
- or the ExitClb command (see section 5.6.4) to exit from calibration procedure without accepting and saving its results (usually if the “Calibration success” byte in the MRU message is equal to 0 or corresponds to not satisfactory MRU heading accuracy (see the Table 5.18 and Note below it)).

The MRU answers on these commands with checksum and goes to idle mode.

5.6.6. Start2D2TCIb command for MRU-E 2D-2T calibration

The **2D-2T calibration** is designed for objects that operate in full azimuth range but with limited range of pitch and roll angles. This calibration procedure involves a few full 360° rotations of the object in azimuth with different pitch angles.

To start the 2D-2T calibration the host computer sends to the MRU-E the Start2D2TCIb command (code 0x22 in the “Payload” field) followed by message with block of parameters listed in the Table 5.18. This message have the byte structure shown in the Table 5.2, and should be sent without pause after sending the Start2D2TCIb command.

The MRU-E calculates the check sum of received parameters and returns it for a checking. Byte structure of this message is shown in the Table 5.2 where payload is the calculated check sum (1 word).

The 2D-2T calibration procedure involves a few runs with full 360° rotations of the object with installed MRU-E in heading with different pitch angles.

Set the object to the first pitch angle (usually the minimum pitch angle is set first). Then send the StartClbRun command followed by message (see section 5.6.7) to start the first run of the calibration.

After receiving the StartClbRun command with its message, the MRU-E calculates the check sum of received block of parameters and returns it for checking. This check sum should be equal to the check sum in the StartClbRun command message that was sent to the MRU-E. Byte structure of this message is shown in the Table 5.2 where payload is the calculated check sum (1 word).

Then the MRU-E starts process of initial alignment. This process includes the MRU-E gyros bias estimation, therefore don't move the MRU-E during its initial alignment. Default time of the initial alignment is 30 seconds and can be changed (see section 5.3.6. LoadMRUPar command) but only in agreement with developers of the Inertial Labs™ MRU-E.

After completing of the initial alignment the MRU-E gives out the block of the initial alignment data (see Table 5.12, Table 5.13) and starts data accumulation during time specified in message sent after the Start2D2TClb command (see the Table 5.18). Rotate object in azimuth with approximately constant pitch and roll. This rotation must include one or more full 360 deg turns. Please, correct the time required for such rotation in the «Time of data accumulation» field of the message (Table 5.18) to provide necessary rotation.

After set accumulation time is reached or StopClbRun command is sent to the MRU-E (see section 5.6.2 for details) the MRU-E gives out message with result of the calibration run (see the Table 5.20).

Table 5.20. Payload of the MRU-E message after each calibration run of the 2D-2T calibration

Byte	Parameter	Format	Length	Note
0	Type of calibration	byte	1	2 for 2D-2T calibration
1	Calibration run	byte	1	1, 2, ...
2	Percent of used data points	byte	1	
3	Calibration success	byte	1	0 – unsuccessful; >0 – successful (see Note below)
4-7	Reserved	float	4	
8-11	Average pitch, deg	float	4	
12-15	Average roll, deg	float	4	
16-27	Reserved	float	3*4	
28-29	USW	word	2	See section 5.7

If the “Calibration success” byte is zero (calibration run is not successful) in the MRU-E answer Table 5.20 then this run will be excluded from calculations in the 2D-2T calibration procedure. To complete this procedure, it is necessary to perform at least two successful runs with essentially different pitch angles.

Note: there is estimation of the calibration quality as predicted MRU-E heading accuracy. So nonzero value of byte #3 “Calibration success” is predicted maximum (3 sigma) heading error of the MRU-E after calibration, in degrees*10. For example, byte #3 equal to 5 corresponds to the MRU-E accuracy ± 0.5 deg. If calibration is successful but MRU-E cannot estimate predicted accuracy it returns byte #3 equal to 255.

After each calibration run completed the MRU-E sends message with payload shown in the Table 5.20, and it waits one of the next three commands from the host computer:

1. StartClbRun command followed by its message (see section 5.6.7) to start new calibration run. Before send this command the object should be turned to the next pitch angle. After sending this command the above described procedure of the calibration run with object rotation in heading should be performed.
2. FinishClb command (see section 5.6.8 for details) to finish the calibration procedure and to calculate calibration parameters. After

that the MRU-E gives out message with the calibration results (see the Table 5.19) and waits one of the two commands:

- a. the `AcceptClb` command (see section 5.6.3) to accept and save the calibration parameters (usually if the “Calibration success” byte in the MRU-E message is nonzero and corresponds to satisfactory MRU-E heading accuracy (see the Table 5.18 and Note below it));
- b. or the `ExitClb` command (see section 5.6.4) to exit from calibration procedure without accepting and saving its results (usually if the “Calibration success” byte in the MRU-E message is equal to 0 or corresponds to not satisfactory MRU-E heading accuracy (see the Table 5.19 and Note below it)).

The MRU-E answers on these commands with checksum and goes to idle mode.

3. `ExitClb` command (see section 5.6.4) In this case the calibration finishes without any calculations in the MRU-E and without saving any calibration parameters. The MRU-E answers on this command with checksum and goes into the idle mode.

Notes:

1. Rotation of the object with the MRU-E in heading must include one or more full 360° turns. Please, correct the time required for saving data in the «**Accumulation time**» window to attain necessary rotations.
2. During calibration run pitch and roll angles should be approximately constant.
3. If place of the MRU-E mounting on the object is changed, or if the object is changed, then the MRU-E should be re-calibrated on the hard and soft iron of this object.

5.6.7. StartClbRun command

If calibration procedure includes more than one run (like 2D-2T calibration) then the `StartClbRun` command (code 0x2B in the “Payload” field) is used to start each run.

For unification with the `StartClbRun` command for some other calibration types, this command must be followed by message with block of parameters listed in the Table 5.21. But for the 2D-2T calibration the values of those 6 bytes don't influence, so these 6 bytes may be any, for example zeros. Only requirement is that this message should have the byte

structure shown in the Table 5.2, and should be sent without pause after sending the StartClbRun command.

Table 5.21. Payload of the message following after the StartClbRun command (block of parameters loaded to the MRU-E)

Byte	Parameter	Format	Length	Note
0-3	Reserved	float	4	
4-5	Reserved	word	2	

After receiving the StartClbRun command the MRU-E calculates the check sum of received parameters and returns it for a checking. This check sum should be equal to the check sum in the StartClbRun command message that was sent to the MRU-E. Byte structure of this message is shown in the Table 5.2 where payload is the calculated check sum (1 word).

5.6.8. FinishClb command for MRU-E 2D-2T calibration

After receiving the FinishClb command (code 0x2C in the “Payload” field) the MRU-E finishes the calibration procedure with multiple runs (like 2D-2T) and calculates the calibration parameters. After that the MRU-E gives out message with the calibration results (see the Table 5.19).

Then the MRU-E waits one of the next commands:

- the AcceptClb command (see section 5.6.3) to accept and save the calibration parameters;
- or the ExitClb command (see section 5.6.4) to exit from calibration procedure without accepting and saving its results.

5.6.9. Start2DClb command for MRU-E 2D calibration

The **2D calibration** is designed for carrier objects that operate in full azimuth range but with small pitch and roll angles (not more than a few degrees). This calibration procedure involves full 360° rotation of the carrier object in azimuth. During this rotation pitch and roll angles must be as close to zero as possible.

To start the 2D calibration the host computer sends to the MRU-E the Start2DClb command (code 0x21 in the “Payload” field) followed by message with block of parameters listed in the Table 5.18. This message have the byte structure shown in the Table 5.2, and should be sent without

pause after sending the Start2DCIb command. Note that first 4 bytes in the payload (Reference azimuth) do not influence on the 2D calibration as it is noted in the Table 5.18.

The MRU-E calculates the check sum of received parameters and returns it for a checking. Byte structure of this message is shown in the Table 5.2 where payload is the calculated check sum (1 word).

Then the MRU-E starts process of initial alignment. This process includes the MRU-E gyros bias estimation, therefore don't move the MRU-E during its initial alignment. Default time of the initial alignment is 30 seconds and can be changed (see section 5.3.4. LoadMRUPar command) but only in agreement with developers of the Inertial Labs™ MRU-E.

After completing of the initial alignment the MRU-E gives out the block of the initial alignment data (see Table 5.12, Table 5.13) and starts data accumulation during time specified in message sent after the Start2DCIb command (see the Table 5.18). Rotate the carrier object in azimuth with pitch and roll angles close to zero as possible. This rotation must include one or more full 360 deg turns. Please, correct the time required for such rotation in the «Time of data accumulation» field of the message (Table 5.18) to provide necessary rotation.

After set accumulation time is reached or StopClbRun command is sent to the MRU-E (see section 5.6.2 for details) the MRU-E finishes data accumulation and calculates the calibration parameters.

After calculation of the calibration parameters that takes <0.5 seconds, the MRU-E gives out message with the calibration results (see the Table 5.19) and it waits one of the next commands:

- the AcceptClb command (see section 5.6.3) to accept and save the calibration parameters (usually if the “Calibration success” byte in the MRU-E message is nonzero and corresponds to satisfactory MRU-E heading accuracy (see the Table 5.19 and Note below it));
- or the ExitClb command (see section 5.6.4) to exit from calibration procedure without accepting and saving its results (usually if the “Calibration success” byte in the MRU-E message is equal to 0 or corresponds to not satisfactory MRU-E heading accuracy (see the Table 5.19 and Note below it)).

The MRU-E answers on these commands with checksum and goes to idle mode.

5.6.10. ClearClb command

The ClearClb command (code 0x2F in the “Payload” field) is used to clear parameters of the hard and soft iron calibration from the MRU-E nonvolatile memory.

The MRU-E answers on this command. The MRU-E calculates the check sum of the message (without its header and check sum) and returns it for a checking. Byte structure of this message is shown in the Table 5.2 where payload is the calculated check sum (1 word).

You should clear parameters of the soft and hard iron calibration if you uninstall the MRU-E from object to avoid incorrect azimuth calculation with standalone MRU-E.

5.6.11. GetClbRes command

The GetClbRes command (code 0x2A in the “Payload” field) can be send from the host computer to check the last calibration results of the MRU-E. As answer on this command the MRU-E sends out the message with the data block near the same as after completing calibration, see Table 5.22.

Table 5.22. Payload of the MRU-E answer on request GetClbRes about calibration results

Byte	Parameter	Format	Length	Note
0	Type of calibration performed	byte	1	0 – MRU-E is not calibrated; 1 – 2D calibration; 2 – 2D-2T calibration; 3 – 3D calibration; >0x80 – MRU-E is calibrated by loading calibration parameters from other software (e.g. Demo software).
1	Number of used calibration runs	byte	1	
2	Reserved	byte	1	
3	Calibration success	byte	1	0 – calibration is not

				successful >0 – calibration is successful (see Note below)
4-39	Matrix for soft iron correction	float	9*4	Matrix Tm_c (3×3) by rows
39-51	Matrix for hard iron correction	float	3*4	Matrix Hm_0 (3×1)

Note: There is estimation of the calibration quality as predicted MRU-E heading accuracy. So nonzero value of byte #3 “Calibration success” is predicted maximum (3 sigma) heading error of the MRU-E after calibration, in degrees*10. For example, byte #3 equal to 5 corresponds to the MRU-E accuracy ±0.5 deg. If calibration is successful but MRU-E cannot estimate predicted accuracy it returns byte #3 equal to 255.

5.7. The Unit Status Word definition

The Unit Status Word (USW) provides the MRU state information. The low byte (bits 0-7) of USW indicates failure of the MRU. If this byte is 0, the MRU operates correctly, if it is not 0, see the Table 5.23 for type of failure. The high byte (bits 8-15) contains a warning or is informative for the user. Status of each bit of the USW warning byte is specified in the Table 5.23.

Table 5.23. The Unit Status Word description

	Bit	Parameter	Description
Low (failure) byte	0	Initial Alignment	0 – Successful initial alignment 1 – Unsuccessful initial alignment due to MRU moving or large changing of outer magnetic field
	1	MRU Parameters	0 – Parameters are correct 1 – Parameters are incorrect
	2	Gyroscope Unit	0 – No failure 1 – Failure detected
	3	Accelerometer Unit	0 – No failure 1 – Failure detected
	4	Magnetometer Unit	0 – No failure 1 – Failure detected (for MRU-E only)
	5	Electronics	0 – No failure 1 – Failure detected
	6	Software	0 – No failure 1 – Failure detected
	7	Reserved	–
High (warning) byte	8	Incorrect Power Supply	0 – Supply voltage is not less than minimum level 1 – Low supply voltage detected
	9		0 – Supply voltage is not higher than maximum level 1 – High supply voltage detected
	10	Angular Rate Exceeding Detect	0 – X-angular rate is within the range 1 – X-angular rate is outrange
	11		0 – Y-angular rate is within the range 1 – Y-angular rate is outrange
	12		0 – Z-angular rate is within the range 1 – Z-angular rate is outrange
	13	Large Magnetic Field Detect	0 – Total magnetic field is within the normal range 1 – Total magnetic field limit is exceeded
	14	Environmental Temperature	0 – Temperature is within the operating range 1 – Temperature is out of the operating range
	15	Reserved	–

5.8. MRU automatic start

Since firmware version 1.0.1.8 the Inertial Labs™ MRU auto start is implemented that allows start of its operation and data output after power on without any command from the host computer. Since firmware version 1.0.2.0 it is possible to choose desirable output data format for auto start (see section 5.2.4).

The auto start option can be enabled or disabled using the MRU Demo Program, in the “Options / Device options” menu. There is drop-down list “Auto start” where auto start with desirable output data format can be chosen. See MRU Demo Program User’s Manual, section “10.5. MRU automatic start” for details.

If the auto start option is enabled then after the MRU power on the next operations take place:

- The primary initialization of the MRU microprocessor that takes not more than 1 second. The MRU LED indicator lights yellow.
- The MRU automatically starts operation from sending out the message AA 55 01 00 08 00 00 00 09 00 (in hexadecimal format) that indicates MRU started without any external command. The MRU LED indicator changes color to green.
- Then the initial alignment procedure starts when initial orientation angles are calculated and gyros bias is estimated for its next compensation. Therefore don’t move the MRU during initial alignment process. If this requirement is not met then large errors may be occurred in orientation angles calculation.
Note: Default time of the initial alignment is 30 seconds. It can be changed (see section 5.3.4) but only in agreement with developers of the Inertial Labs™ MRU.
- After completing of the initial alignment the MRU gives out message with block of the initial alignment data (see Table 5.12, Table 5.13) and starts data output according to the chosen data format. The MRU LED indicator lights green.

To stop the MRU please send the Stop command (see section 5.3.3). After receiving the Stop command the MRU stops data calculation and goes to the idle mode. The MRU LED indicator changes its color to red. The MRU is ready to receive any command from the host computer.

5.9. Change of the MRU COM port baud rate

The default baud rate for MRU COM port is set to 115200 bps (maximum for the standard COM-port). Since firmware version 2.2.0.0 the MRU supports different baud rates: 4800, 9600, 14400, 19200, 38400, 57600, 115200, 230400, 460800 bps.

Change of the MRU COM port baud rate can be done using MRU Demo Program since version 2.0.19.78 from 03/18/2016. See MRU Demo Program User's Manual, section "4.2.3. Change of the COM port baud rate" for details.

Note the same baud rate must be set for COM port of the host computer.

5.10. Limitation of the MRU maximum output data rate

When setting of the output data rate for the MRU unit using LoadMRUPar command (see section 5.3.4) or using the Inertial Labs™ MRU Demo Program it is essential to ensure the chosen COM port baud rate is capable of handling the data throughput with desirable data rate. The maximum data rate (Hz) can be calculated using the baud rate and data package length:

$$\text{max_data_rate} = \frac{\text{COM_baud_rate}}{\text{bits_per_byte} * \text{package_length}}, \quad (5.1)$$

where COM_baud_rate is COM port baud rate (bits/s); bits_per_byte = 11 bits per one transferred byte of data; package_length for binary data = payload length plus 8 bytes of overhead. See Table 5.4 to Table 5.7 for payload length of binary output data formats. The package_length of the text output data formats correspond to their structure shown in Table 5.8, Table 5.9.

Below Table 5.24 contains data package length for each output data format and also maximum data rate calculated using formula (5.1), with some spare. Note the maximum measurement rate of MRU data is limited by 200 Hz.

Table 5.24. MRU maximum data rate for different output data formats

Output data format	Data package length, bytes	COM-port baud rate, bps				
		9600	19200	38400	115200	230400
		Maximum data rate, Hz				
MRU Full Output Data	52+8	10	20	50	160	200
MRU Calibrated Data	54+8	10	20	50	160	200
MRU Quaternion Data	56+8	10	20	50	160	200
MRU Minimal Data	34+8	20	40	80	200	200
NMEA Output	58	10	30	60	180	200
TSS1 Output	27	30	60	120	200	200

Note MRU unit controls correctness of the data rate setting. If user sets data rate which exceeds limit shown in Table 5.24, then its value is corrected. True data rate is given out in the byte #3 of MRU message after completing of the initial alignment procedure (see Table 5.12).

APPENDIX A. The Inertial Labs™ MRU-E Calibration

The Inertial Labs MRU software allows to take into account influence of the carrier object soft and hard iron on the heading calculation. For this purpose, field calibration of the MRU-E magnetometers on hard and soft iron is provided. This calibration does not require any additional equipment, but it requires setting of the carrier object, where the MRU-E is mounted, in specified positions.

There are several types of the calibration realized onboard the MRU-E:

- 3D calibration;
- 2D-2T calibration;
- 2D calibration.

Other types of hard/soft iron calibration can be fulfilled with Inertial Labs MRU-E Demo software.

3D calibration is designed for carrier objects that can operate in full heading, pitch and roll ranges. For this calibration the carrier object is rotated in the horizon plane (the Z-axis is up) with periodical stops about each 90 degrees for tilting in pitch and roll. After full 360° rotation the carrier object with the MRU-E is turned over (the Z-axis is down) and the procedure described above should be repeated. During this calibration the range of pitch and roll angles changing must be as much as possible.

2D-2T calibration is designed for carrier objects that operate in full heading range but with limited range of pitch and roll angles. This calibration procedure involves a few full 360° rotations of the carrier object with installed MRU-E in heading with different pitch angles. During each rotation, pitch and roll angles should be as constant as possible.

2D calibration is designed for carrier objects that operate in full azimuth range but with small pitch and roll angles (not more than a few degrees). This calibration procedure involves full 360° rotation of the carrier object with installed MRU-E in the horizon plane. During this rotation pitch and roll angles must be as close to zero as possible.

If place of the MRU-E mounting on the carrier object is changed, or if the

carrier object is changed, then the MRU-E should be re-calibrated on the hard and soft iron of the carrier object.

APPENDIX B.

Variants of the Inertial Labs™ MRU mounting relative to the object axes

The Inertial Labs™ MRU can be mounted on the object in any known position (up to upside-down, upright etc.) relative to the object axes. Such mounting doesn't change right calculation of the object orientation if angles of the MRU mounting are correctly stored in the MRU nonvolatile memory.

To store angles of mounting in the MRU please use the Inertial Labs™ MRU Demo Program (item «Device option ...» from the «Options» menu) or send LoadMRUPar command to the MRU directly (see structure of the message following after the LoadMRUPar command in the Table 5.13).

Angles of the MRU position (alignment angles) are set in next order (like heading, pitch and roll setting):

- first alignment angle sets position of the MRU longitudinal axis Y relative to longitudinal axes of the object measured in the horizontal plane of the object. Clockwise rotation is positive;
- second alignment angle is equal to angle of inclination of the MRU longitudinal axis Y relative to the horizontal plane of the object. Positive direction is up;
- third alignment angle is equal to inclination angle of the MRU lateral axis X measured around MRU' longitudinal axis. Positive rotation is X axis moving down.

All angles are set in degrees.

Some examples of the Inertial Labs MRU mounting relative the carrier object are shown on Fig.B.1.

To check correctness of the alignment angles please run the MRU using the Inertial Labs MRU Demo program.

Default values of the MRU alignment angles are all zero.

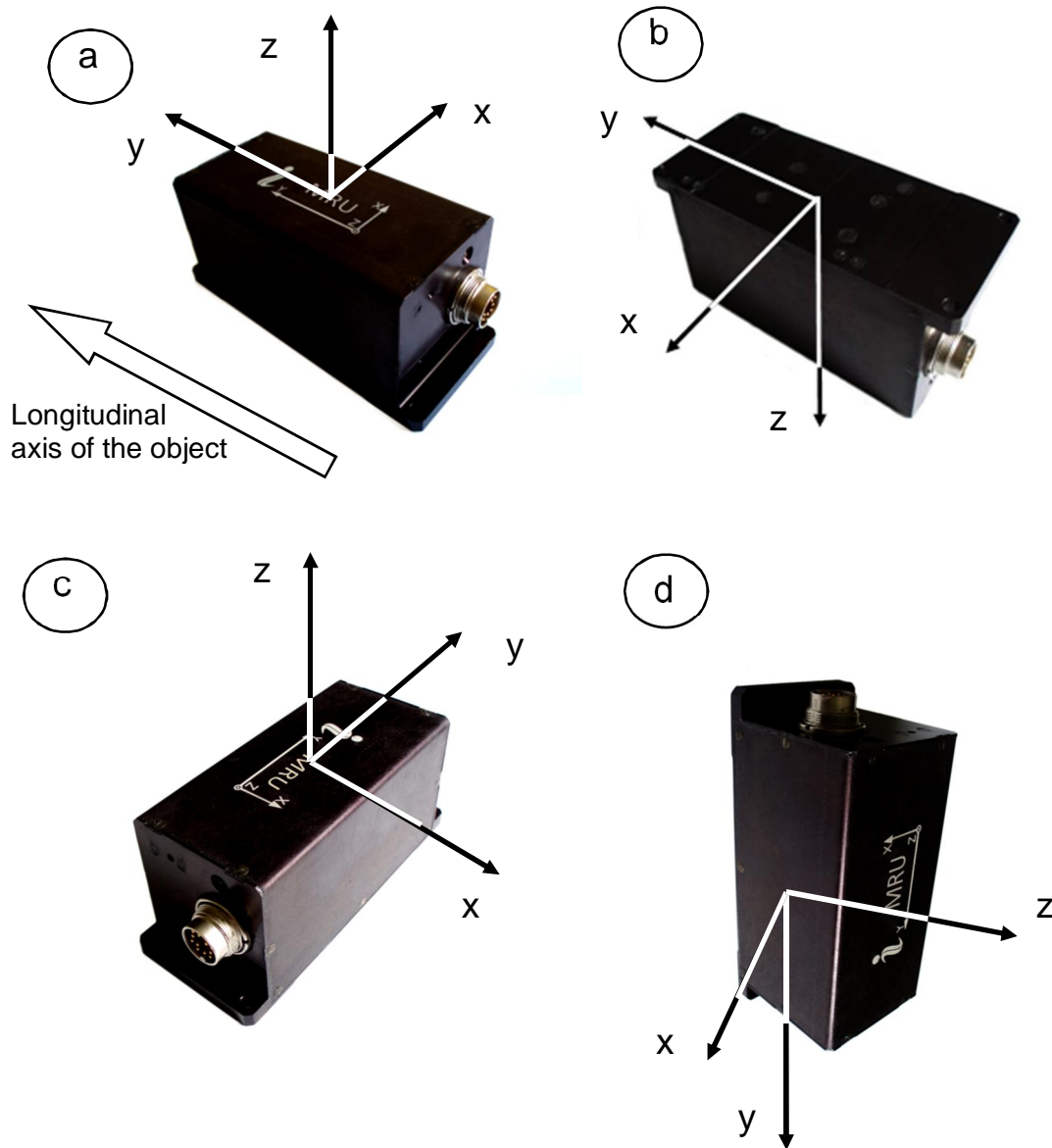


Fig.B.1. Examples of the Inertial Labs™ MRU mounting on the carrier object

- a – alignment angles are 0, 0, 0 (degrees);
- b – alignment angles are 0, 0, 180 (degrees);
- c – alignment angles are 90, 0, 0 (degrees);
- d – alignment angles are 180, -90, 0 (degrees);

APPENDIX C. Full list of the Inertial Labs™ MRU commands

All the MRU commands have the byte structure shown in the Table 5.2. Payload for all commands has length 1 byte and contains code of the command. Below Table C.1 lists all commands with their exact structure in hexadecimal numbers.

Table C.1. List of the MRU commands with exact structure

Command name	Code	Exact structure (hex)
Commands for Inertial Labs™ MRU control		
MRU_FullData	0x31	AA 55 00 00 07 00 31 38 00
MRU_ClbData	0x32	AA 55 00 00 07 00 32 39 00
MRU_minData	0x33	AA 55 00 00 07 00 33 3A 00
MRU_NMEA	0x34	AA 55 00 00 07 00 34 3B 00
MRU_TSS1	0x35	AA 55 00 00 07 00 35 3C 00
MRU_TSS1HEHDT	0x42	AA 55 00 00 07 00 42 49 00
MRU_QuatData	0x36	AA 55 00 00 07 00 36 3D 00
SetOnRequestMode	0xC1	AA 55 00 00 07 00 C1 C8 00
Stop	0xFE	AA 55 00 00 07 00 FE 05 01
LoadMRUPar	0x40	AA 55 00 00 07 00 40 47 00
ReadMRUPar	0x41	AA 55 00 00 07 00 41 48 00
GetDevInfo	0x12	AA 55 00 00 07 00 12 19 00
GetBIT	0x1A	AA 55 00 00 07 00 1A 21 00
Commands for Inertial Labs™ MRU calibration		
Start2DClb	0x21	AA 55 00 00 07 00 21 28 00
Start2D2TClb	0x22	AA 55 00 00 07 00 22 29 00
Start3DClb	0x23	AA 55 00 00 07 00 23 2A 00
StartVG3DClb	0x25	AA 55 00 00 07 00 25 2C 00
StartClbRun	0x2B	AA 55 00 00 07 00 2B 32 00
StopClbRun	0x20	AA 55 00 00 07 00 20 27 00
FinishClb	0x2C	AA 55 00 00 07 00 2C 33 00
AcceptClb	0x2E	AA 55 00 00 07 00 2E 35 00
ExitClb	0xFE	AA 55 00 00 07 00 FE 05 01
ClearClb	0x2F	AA 55 00 00 07 00 2F 36 00
GetClbRes	0x2A	AA 55 00 00 07 00 2A 31 00

APPENDIX D. Forms of the Inertial Labs™ MRU orientation presentation

Define coordinate system $Ox_0y_0z_0$ to be fixed to the carrier object where Ox_0 axis is lateral and directed to the right, Oy_0 axis is longitudinal and directed forward, Oz_0 axis is normal and directed vertical. At usual installation of the MRU on carrier object the MRU appropriate axes should be parallel to the axes as above Fig.1.2 shows. Also, it is possible to install the MRU in any known position relative to the object with known alignment angles (see APPENDIX B for details).

The Inertial Labs™ MRU calculates orientation of the coordinate system $Ox_0y_0z_0$ fixed to the carrier object with respect to Cartesian geographical reference frame $Oxyz$ where axes Ox and Oy are in the level and directed to the East and North, and Oz axis is directed up. Such reference frame is also known as ENU (East-North-Up) Earth-level frame.

Measured angles are the standard Euler angles of rotation from the Earth-level frame to the object frame: heading K is first, then pitch θ , and then roll γ -- see Fig.D.1.

Notes:

1. Positive direction of heading is clock-wise. So heading K is shown with minus sign on Fig.D.1.
2. In different applications “heading” is also known as “azimuth” or “yaw”; “pitch” is also known as “elevation” or “tilt”; “roll” is also known as “bank”.

Due to the definition of Euler angles there is a mathematical singularity when the object longitudinal y_0 -axis is pointed up or down (i.e. pitch approaches $\pm 90^\circ$). This singularity is not present in the quaternion or directional cosine matrix (rotation matrix) presentation.

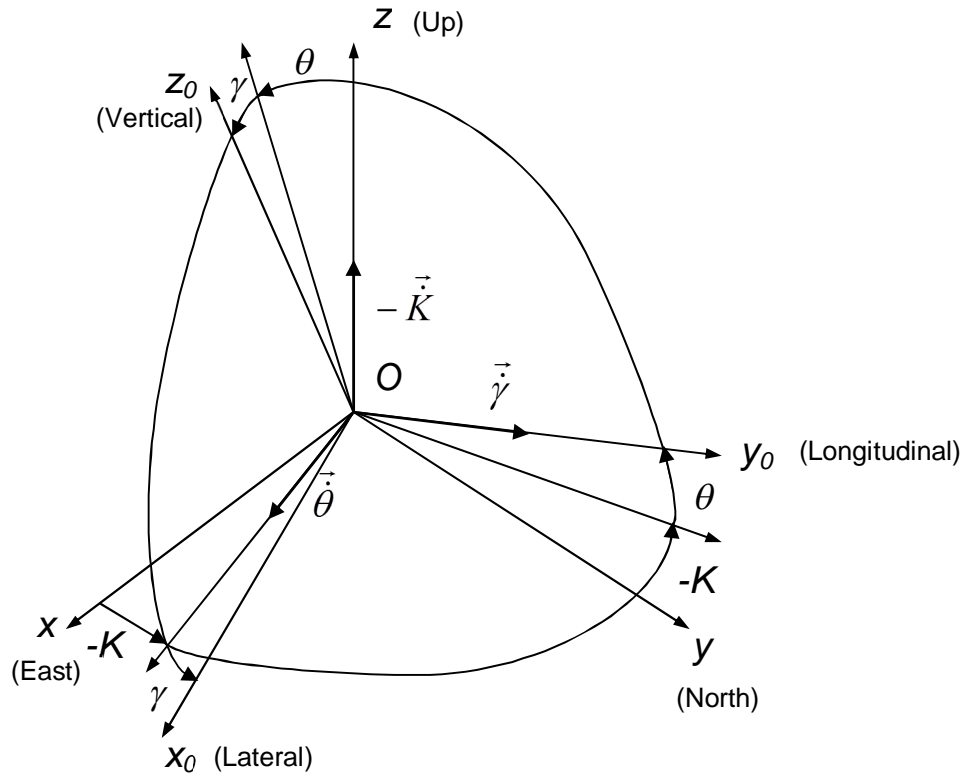


Fig.D.1. Transformation of coordinate systems

Directional cosine matrix (DCM) is the rotation matrix \mathbf{C} from the object body reference frame $Ox_0y_0z_0$ to the geographical reference frame $Oxyz$. According to Fig.D.1, DCM can be represented through Euler angles as

$$\mathbf{C} = \begin{bmatrix} \cos K \cos \gamma + \sin K \sin \gamma \sin \theta & \sin K \cos \theta & \cos K \sin \gamma - \sin K \cos \gamma \sin \theta \\ -\sin K \cos \gamma + \cos K \sin \gamma \sin \theta & \cos K \cos \theta & -\sin K \sin \gamma - \cos K \cos \gamma \sin \theta \\ -\cos \theta \sin \gamma & \sin \theta & \cos \theta \cos \gamma \end{bmatrix}. \quad (\text{D.1})$$

Or, Euler angles can be calculated from elements c_{ij} of directional cosine matrix \mathbf{C} :

$$K = \arctan \frac{c_{12}}{c_{22}}; \theta = \arcsin c_{32}; \gamma = -\arctan \frac{c_{31}}{c_{33}}. \quad (\text{D.2})$$

Also the Inertial Labs™ MRU provides orientation output in quaternion \mathbf{Q} form which is a hyper-complex number with four components

$$\mathbf{Q} = (q_0, q_1, q_2, q_3), \quad (\text{D.3})$$

where q_0 is real part, q_1, q_2, q_3 are vector part. In other words, q_0 represents the magnitude of the rotation, and the other three components represent the axis about which that rotation takes place.

With only four components, quaternion representation of orientation is computationally efficient. However, manipulation of quaternions is not intuitive, so their use in place of directional cosine matrices may increase the chances of mistakes being made.

Quaternion \mathbf{Q} is converted to directional cosine matrix \mathbf{C} using the next expressions:

$$\mathbf{C} = \begin{bmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2(q_1q_2 - q_0q_3) & 2(q_1q_3 + q_0q_2) \\ 2(q_1q_2 + q_0q_3) & q_0^2 + q_2^2 - q_1^2 - q_3^2 & 2(q_2q_3 - q_0q_1) \\ 2(q_1q_3 - q_0q_2) & 2(q_2q_3 + q_0q_1) & q_0^2 + q_3^2 - q_1^2 - q_2^2 \end{bmatrix}. \quad (\text{D.4})$$

The reverse conversation from directional cosine matrix \mathbf{C} to quaternion \mathbf{Q} is following:

$$q_0 = \frac{1}{2} \sqrt{1 + c_{11} + c_{22} + c_{33}}; \quad (\text{D.5})$$

$$q_1 = \frac{c_{32} - c_{23}}{4q_0}; \quad q_2 = \frac{c_{13} - c_{31}}{4q_0}; \quad q_3 = \frac{c_{21} - c_{12}}{4q_0}.$$

Expressions (D.5) are wide used but they have singularity at $q_0 = 0$. Therefore the Inertial Labs™ MRU uses other expressions that have no singularity:

$$q_0 = \frac{1}{2} \sqrt{1 + c_{11} + c_{22} + c_{33}}; \quad q_1 = \frac{1}{2} \sqrt{1 + c_{11} - c_{22} - c_{33}} \cdot \text{sign}(c_{32} - c_{23}); \quad (\text{D.6})$$

$$q_2 = \frac{1}{2} \sqrt{1 - c_{11} + c_{22} - c_{33}} \cdot \text{sign}(c_{13} - c_{31}); \quad q_3 = \frac{1}{2} \sqrt{1 - c_{11} - c_{22} + c_{33}} \cdot \text{sign}(c_{21} - c_{12}).$$

At necessity to calculate Euler angles from quaternion, calculate elements C_{12} , C_{22} , C_{31} , C_{32} , C_{33} , according to (D.6), and then use formulas (D.2):

$$K = \arctan \frac{2(q_1q_2 - q_0q_3)}{q_0^2 + q_2^2 - q_1^2 - q_3^2}; \quad \theta = \arcsin(2q_2q_3 + 2q_0q_1); \quad (D.7)$$

$$\gamma = -\arctan \frac{2(q_1q_3 - q_0q_2)}{q_0^2 + q_3^2 - q_1^2 - q_2^2},$$

where arctan is four-quadrant inverse tangent.