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Manual V2: Execution of motion measurements with multiple sensor modules connected with a Data Capturing Unit

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Contents

1 Introduction

This manual provides an overview of the usage of the Inertial Measurement Unit (IMU) module. The IMU module is designed to be non-interfering with the treatment, it transmits its orientation data wirelessly via Bluetooth Low Energy (BLE), can be wirelessly charged, and features a smooth installation and operation procedure.

Section 2 provides a list of all the needed components. Section 4 provides a quick start guide to get started. Section 5 gives options for interpreting the data. Section 6 describes the charging procedure. Section 7 explains the use of the different menu commands. Section 9 lists some safety precautions.

2 Accessories

2.1 Hardware components

- DCU board (Fig. 1)
- One of more IMU sensor modules (Fig. 2)
- Micro USB cable (COMM to PC) (Fig. 3)
- Micro-SD card
- Computer
- Qi Charger (Fig. 4)

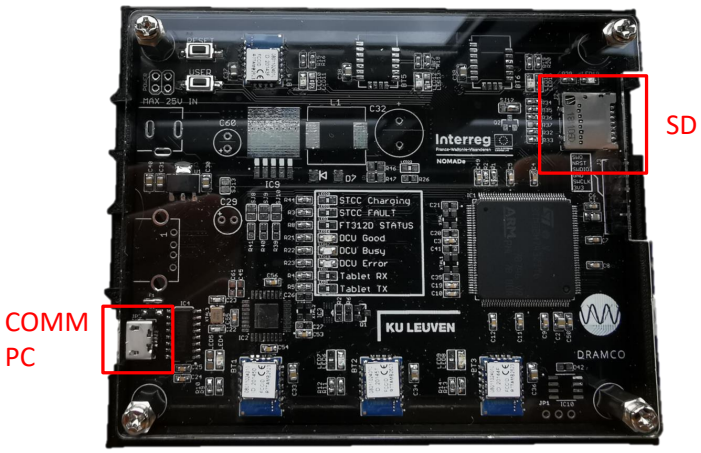

Figure 1: DCU Overview

Figure 2: IMU module

Figure 3: Micro-USB cable

Figure 4: Qi charger

2.2 Software programs

To interact with the DCU, a serial monitor like Termite or the Arduino Serial monitor is used. You can choose freely which program to use. The installation instructions for the two options are described in Section 2.2.1 and Section 2.2.2.

2.2.1 Installing Termite

- Go to: `https://www.compuphase.com/software_termite.htm`
- Click on "Termite version 3.4 - complete setup (332 KiB)" (see Fig. 5)
- Follow the installation instructions by clicking "Next" a couple of times and "Finish"

- A screen as shown in Fig. 6 will pop up.

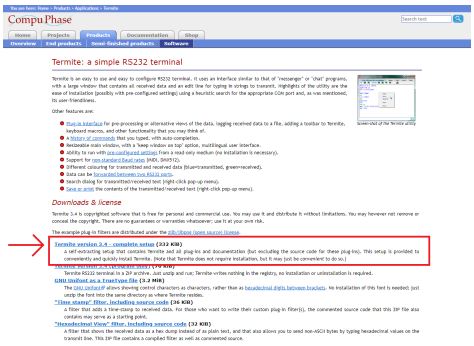

Figure 5: Termite download page

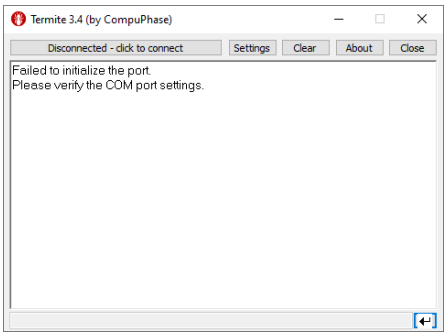

Figure 6: Termite after installation

2.2.2 Installing Arduino Serial monitor

- Go to: `https://www.arduino.cc/en/Main/Software`
- Click on "Windows Installer, for Windows 7 and up" (see Fig. 7)
- Click "I agree", "next", and "Install"
- Open the Arduino IDE (see Fig. 8)

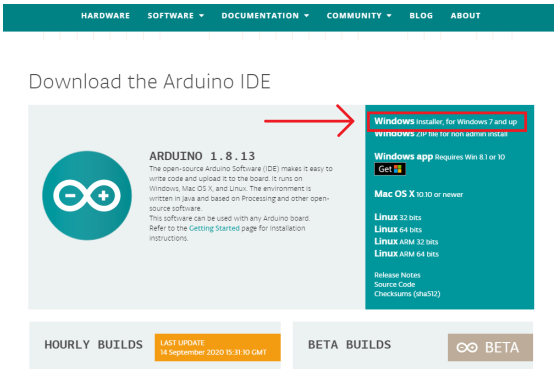

Figure 7: Arduino IDE download page

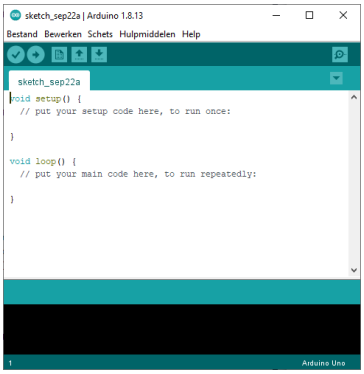

Figure 8: Arduino IDE

2.2.3 Set up a connection

To establish a connection with the Data Capturing Unit (DCU), you need to know the baudrate and COM port. The baudrate is fixed for the connected board and is here 2 000 000 bps. The COM port is determined by the PC and can be found as follows:

Press the 'Window' key and type 'Device Manager'. Look in the subdivision 'Ports (COM & LPT)' and search for 'USB-SERIAL CH340 (COMx)'. The x represents the COM port number. The Device Manager is shown in Fig. 9.

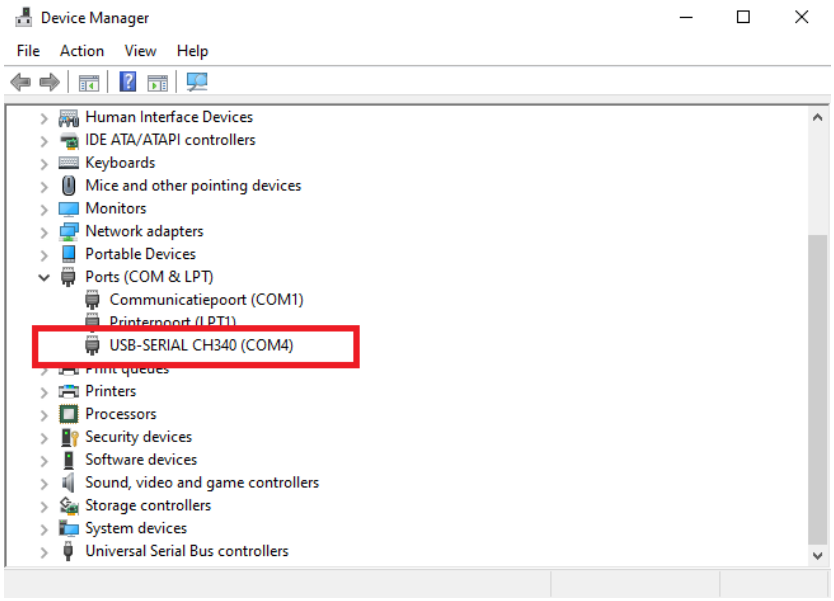

Figure 9: Device manager

- Setting the COM port in **Arduino**: Go to 'Tools' and select the serial port under 'Port'.
- Setting the COM port in **Termite**: Go to 'Settings' and select the serial port under 'Port configuration - Port'.

3 Specifications

IMU sensor module

- MEMS IMU (MPU6050) with max. 100 Hz sampling frequency
- On-board 6 axis sensor fusion on internal Digital Motion Processor (DMP)
- 20 hours autonomy[1]
- 208 days stand-by time
- 250 mAh battery

[1] Autonomy in this context means that the fully charged IMU sensor can operate for 20 hours consecutively without the need for recharging.

- $\approx$ 2 hours charging time (Wireless charging)
- Wireless data transfer via BLE

The IMU is equipped with a 19.2MHz external clock with a high frequency stability of 10ppm. This results in a negligible frequency drift during the measurements. The synchronisation is done before the measurements by means of a Beacon message that is received by all sensor modules simultaneously.

DCU receiver module

- Up to 6 simultaneous sensor connections
- Internal data processing
- USB type A output to communicate with a tablet or smartphone
- Micro USB for interfacing with a PC
- SD card slot for data storage
- On board status LEDs

3.1 Firmware version

These manual has been updated to match with the new firmware versions of the DCU and the IMU sensor module.

Device	Firmware version
Data Capturing Unit	V3.1
IMU sensor module	V3.2

Table 1: Firmware versions

4 Quick start guide

This section describes the complete process of how to start the DCU and IMU modules and start and save measurements to a SD card. An overview of the system is presented in Fig. 10.

4.1 Start communication with the DCU

- Plug in the micro USB cable into the port of the DCU

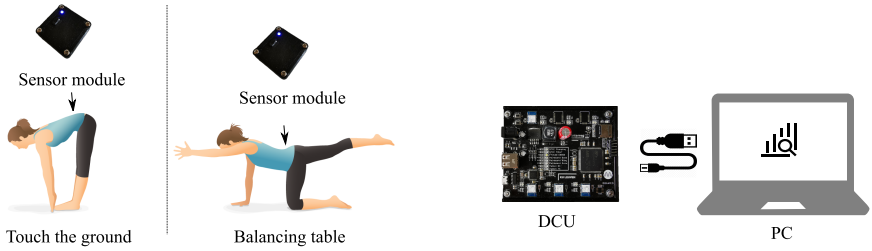

Figure 10: Representation of the motion sensor module fitted to a patient's lower back. The patient performs the exercise in the neighbourhood (can be a few meters) of the DCU, which is connected with a USB cable to a PC.

- Plug the other end (USB) into a computer
- Open a terminal (Termite or Arduino IDE)
- Set the baudrate to 2 Mbps (2 000 000)
- Search COM port (See section 2.2.3)

4.2 Connect IMU sensor modules

The connection with the IMU sensor is established by an entry in the terminal consisting of two numbers. An entry is logically followed with Enter. The first number is the command, the second number is the slot on the DCU to which the module connects to. The list of the MAC addresses (to which the DCU can connect) can be queried (see section 7 under 6). The MAC addresses of the four sensor modules are currently hard-coded in the DCU and should match with the mac addresses on the 4 modules.

Enter e.g. 11 to connect a IMU module to slot 1 on the DCU. Enter e.g. 14 to connect a IMU module to slot 4 on the DCU. When a quick connection to all IMUs is needed, type:

1 1 1 2 1 3 1 4

Press Enter. This command connects all IMU modules to their respective receivers on the DCU. If a connection failed, try to reconnect again.

4.3 Execute a calibration

For optimal performance, a calibration of the IMU sensors is strongly advised. Press c and enter. All the connected modules enter calibration mode. For calibration, the connected modules need to be on a level surface and not moving. The calibration only takes a few seconds.

```
11121314
IMU number:
IMU number:
IMU number:
IMU number:
BLE slot 1: Request received, try to connect
BLE slot 2: Request received, try to connect
BLE slot 3: Request received, try to connect
BLE slot 4: Request received, try to connect
BLE slot 4: Connection established
BLE slot 3: Connection established
BLE slot 1: Connection established
BLE slot 2: Connection established
BLE slot 4: Channel open, data transmission possible
BLE slot 1: Channel open, data transmission possible
BLE slot 3: Channel open, data transmission possible
BLE slot 2: Channel open, data transmission possible
```

Figure 11: Connecting four modules with the DCU

```
c
BLE slot 4: Calibration started
BLE slot 3: Calibration started
BLE slot 1: Calibration started
BLE slot 2: Calibration started
BLE slot 1: Calibration done
BLE slot 4: Calibration done
BLE slot 3: Calibration done
BLE slot 2: Calibration done
```

Figure 12: Calibrate all connected modules

4.4 Execute a synchronisation

The synchronisation algorithm is not working optimally at this moment. It is currently better to not perform a synchronisation and start the measurements without synchronisation.

Press s to start the synchronisation. The IMU modules will synchronise, wait a couple of seconds. Do not execute new commands during synchronisation and wait until **Synchronisation done** is printed.

4.5 Set sampling frequency

Enter e.g. f 5 to set the sampling frequencies of all connected IMU sensor modules to 100 Hz. More info on sampling frequencies, see Section 7

4.6 Determine data output format

Enter e.g. g to store only quaternion data on the SD card. More info on data formats, see Section 7.

```
s
BLE slot 1: Beacon content changed
BLE slot 4: Synchronised started
BLE slot 2: Synchronised started
BLE slot 3: Synchronised started
BLE slot 1: Synchronised started
BLE slot 4: Disconnected
BLE slot 2: Disconnected
BLE slot 3: Disconnected
BLE slot 1: Disconnected
BLE slot 1: Beacon content changed
BLE slot 3: Request received, try to connect
BLE slot 4: Request received, try to connect
BLE slot 1: Request received, try to connect
BLE slot 2: Request received, try to connect
BLE slot 1: Connection established
BLE slot 4: Connection established
BLE slot 2: Connection established
BLE slot 3: Connection established
BLE slot 1: Disconnected
BLE slot 4: Channel open, data transmission possible
BLE slot 2: Channel open, data transmission possible
BLE slot 3: Channel open, data transmission possible
BLE slot 1: Request received, try to connect
BLE slot 1: Connection established
BLE slot 1: Disconnected
BLE slot 1: Request received, try to connect
BLE slot 1: Connection established
BLE slot 1: Channel open, data transmission possible
BLE slot 4: DCU Syst Tick: 90028
BLE slot 2: DCU Syst Tick: 90048
BLE slot 1: DCU Syst Tick: 90119
BLE slot 3: DCU Syst Tick: 90126
Synchronisation done
```

Figure 13: Synchronise all connected modules

```
g
BLE slot 1: Dataformat changed
BLE slot 1: Dataformat QUAT
h
BLE slot 1: Dataformat changed
BLE slot 1: Dataformat GYRO
j
BLE slot 1: Dataformat changed
BLE slot 1: Dataformat ACC
k
BLE slot 1: Dataformat changed
BLE slot 1: Dataformat GYRO + ACC
l
BLE slot 1: Dataformat changed
BLE slot 1: Dataformat QUAT + GYRO + ACC
```

Figure 14: Data format

4.7 Mount SD card

Insert an SD card into the SD card slot on the DCU. Press m to mount the SD card. This is necessary before any data can be written to it. The SD card should be formatted to the 'FAT32' format.

4.8 Create new file

After mounting the SD card, a new file, where the measurement data will be stored, can be created. Press n to make a new file. The serial monitor shows the new name of the new file.

4.9 Start measurements

4.9.1 With synchronisation

To start the measurements, press [r]. All connected IMU sensor nodes will start measuring. This command will only work after a calibration and a synchronisation.

```
r
Start measurement
BLE slot 4: Measurement started
BLE slot 1: Measurement started
BLE slot 2: Measurement started
BLE slot 3: Measurement started
```

Figure 15: Start measurements

4.9.2 Without synchronisation

To start the measurements without synchronisation, press [t]. All connected IMU sensor nodes will start measuring. This command will only work after a calibration.

```
t
Start measurement
BLE slot 4: Measurement started without synchronisation
BLE slot 1: Measurement started without synchronisation
BLE slot 3: Measurement started without synchronisation
BLE slot 2: Measurement started without synchronisation
```

Figure 16: Start measurements without synchronisation

4.10 Stop measurements

When the measurements are done, press [e] to stop measuring. All connected sensor modules will stop measuring.

```
e
Stop measurement
BLE slot 1: Measurement stopped
BLE slot 3: Measurement stopped
BLE slot 2: Measurement stopped
BLE slot 4: Measurement stopped
```

Figure 17: Stop measurements

4.11 Put IMU sensor modules to sleep mode

Press [3]. All the connected sensor modules will go into sleep mode.

4.12 Retrieving measurement data

Unmount (with [u]) and disconnect the SD card from the DCU. Insert the card in a PC and a ".txt" file can be found in the main directory. Section 5 explains in detail how to interpret the measurement data.

5 Interpreting the data

5.1 Explanation about the data storage on the SD card

The data can be further processed in Python or Excel. The data formats are represented in Fig. 18, Fig. 19, Fig. 20, Fig. 21 and Fig. 22. An example with a number of samples stored on the SD card is shown in Fig. 23.

- BLE Slot number: The number of the slot to which the BLE module was connected.
- Packet number: A packet is considered here as a collection of ten samples. This packet number increases with every data transmission. E.g. receiving 284 packets, corresponds to 2850 stored samples. (Packet number counts from zero)
- IMU Sensor Module Timestamp: The system ticks value of the IMU module in milliseconds.
- Quaternion q_0, q_1, q_2 and q_3
  Quaternion formula: $q = q_0 + q_1 \cdot i + q_2 \cdot j + q_3 \cdot k$
- Gyroscope x, y, z
- Accelerometer x, y, z

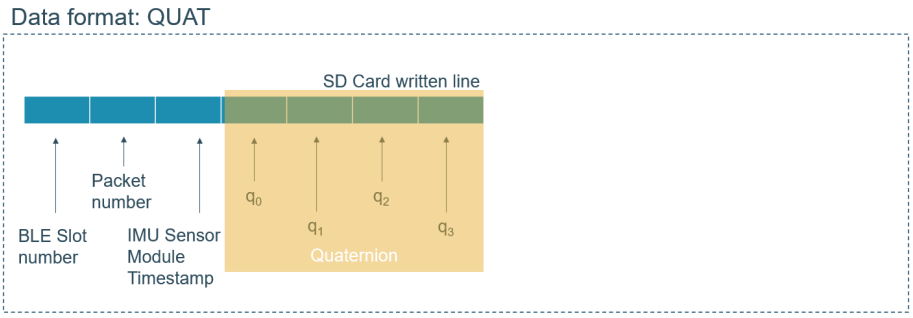

Figure 18: Data format "Quaternion data only"

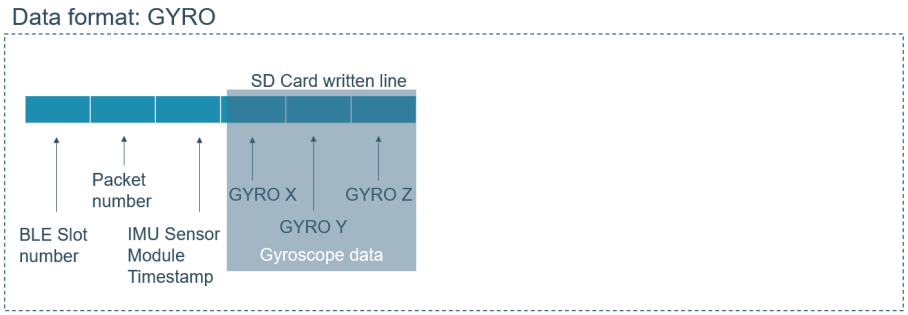

Figure 19: Data format "Gyroscope data only"

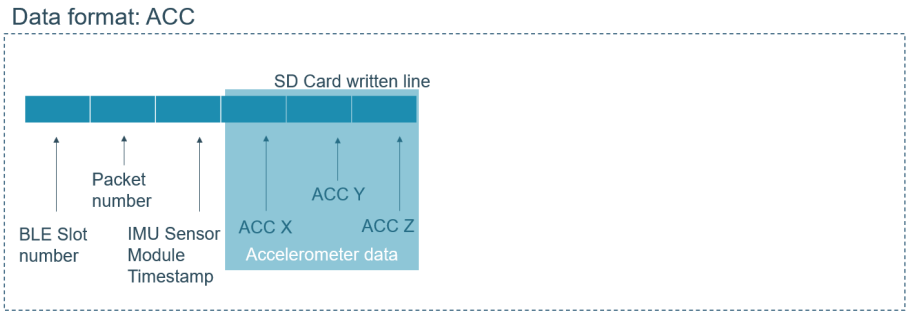

Figure 20: Data format "Accelerometer data only"

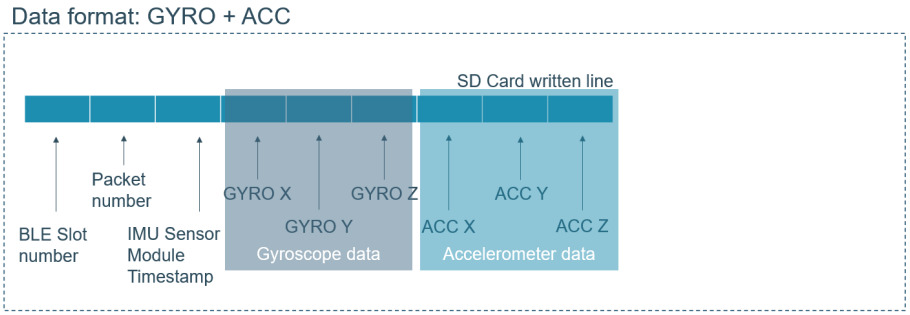

Figure 21: Data format "Gyroscope and accelerometer data"

5.2 Python script

A python script is written to visualize the data measured with the sensor modules. This script is currently written for the data format with only quaternion data. (See `https://github.com/DRAMCO/Interreg-NOMADe`)

Enter the number of the file in the script settings in 'main.py' see Fig. 24. After running the script, two graphs should be created **GRAF_X.pdf** and **GRAF_X_ypr.pdf**. X represents the measurement or file number. GRAF_X.pdf contains a plot of the quaternion data of all connected sensors. GRAF_X_ypr.pdf

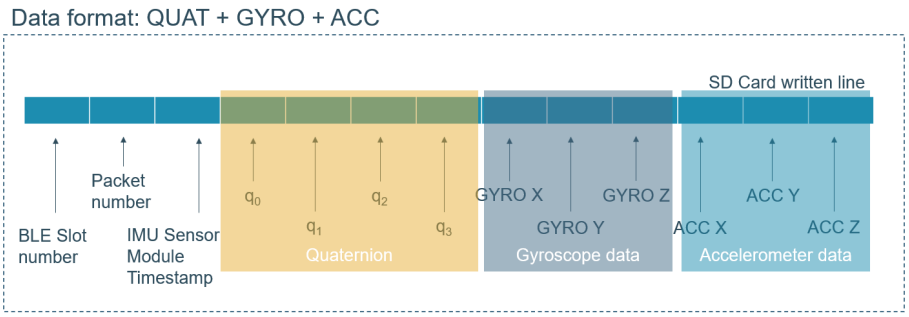

Figure 22: Data format "Quaternion, gyroscope and accelerometer data"

```
109038   1,2726,14675945,16383,2,-7,180
109039   1,2726,14675945,16383,2,-7,180
109040   1,2726,14675945,16383,2,-7,180
109041   3,2726,18714426,16383,2,-8,110
109042   3,2726,18714426,16383,2,-7,110
```

Figure 23: Example: Data output from DCU to SD card (Data format "Quaternion data only")

```
# --------------------SETTINGS------------------#
measurement_number          = 1
sampling_frequency          = 100
enable_limited_plot_range   = 0
lower_lim                   = 0
upper_lim                   = 0
# ----------------------------------------------#
```

Figure 24: Python script settings

contains a plot of the rotations in degrees (Yaw, Pitch, Roll). Examples of these graphs are shown in Fig. 29 and Fig. 30.

Angle between sensors

With the Python script, it is possible to plot the angle between sensors. In Figure 25 the sensors between which the angles will be plotted can be set. A plot will be generated with name "**GRAF_X_diff.pdf**" by the command:

plot_relative_angle_sensors(connected_sensors, sampling_frequency, sample_list, plot_name_diff, first_sensor, second_sensor)

Figure 31 and Figure 32 show an example measurement.

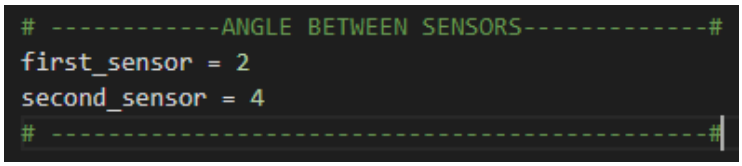

Figure 25: Python angle between sensor modules settings

6 Battery management

6.1 Charging the IMU Module

Charging the sensor module can only on a wirelessly way. Therefore a Qi compliant wireless power pad is necessary.

- Place the IMU module in the middle of the wireless charging pad
- Wait for the blue or white LED goes on and stays on. After the light goes off, the battery is fully charged.
- Charging takes about 2 hours

6.2 Battery low message

The IMU module batteries can run out of energy during measurements. A message is printed when the battery voltage reach a value under 3.5 V.

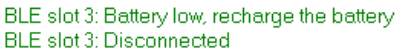

Figure 26: Example Battery Low Message

We recommend for longer measurements a battery voltage of at least 3.7 V. The battery voltages can be queried at any time (also during measurements), see section 7 under 4.

7 Explanation of the menu

Print MENU: 0
This command prints all the menu options to the terminal. An overview of the menu is shown in Appendix A.

Connect: 1
This command connects an IMU module to the DCU. The DCU will ask with

BLE slot you want to connect to the corresponding IMU sensor module. To do this, the IMU sensor module to be connected must be switched on. Since there are 6 slots, you must enter a number from 1 to 6.

Disconnect: **2**
This command disconnects an IMU module from the DCU. Enter a number between 1 to 6. The module will stay on.

Sleep: **3**
This command puts all the connected IMU modules to sleep.

Battery: **4**
This command prints out the battery voltages of all connected modules.

System ticks: **5**
This command prints out the system ticks of all connected modules.

MAC address: **6**
This command prints out the MAC addresses of the IMU modules to which the BLE modules on the DCU will connect.

Check synchronisation: **7**
This command is executed automatically during a synchronisation. If the printed times match, the synchronisation was successful.

Adjust synchronisation: **8**
This command is executed automatically during a synchronisation. Execute first command 7 before entering 8. This combination of commands solves a sync error if one is detected.

Change MAC address: **9**
This command changes the MAC address of a BLE slot. This slot can now connect to the new module whose mac address was entered. The mac address can by changed by consecutively typing 9 + BLE slot number + the new mac address. An example 9 + 3 + 0018DA201435 is shown in Fig. 27.

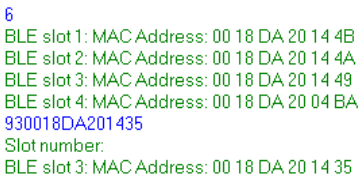

Figure 27: Change MAC Address example

Remark: The new mac address is not remembered during a power cycle.

Mount SD: **m**
This command mounts the SD card. Mounting the SD card needs to be done

before any data can be written to it.

New file: **n**
This command creates a new file on the SD card. Attention: the SD card needs to be mounted first.

Calibrate: **c**
This command calibrates all connected modules. When calibrating, the IMU modules need to be positioned on a flat surface for a short while.

Synchronisation: **s**
This command starts the synchronisation between all the connected IMU modules. A one-time synchronisation packet is send to all the IMU modules to make sure measurements from different modules can be merged.

Note: The sensor nodes only stay in sync for a couple of minutes. If strict timing requirements are necessary, please synchronise the IMUs again before measuring.

Start measurement: **r**
This command starts the measurements. It is necessary to calibrate and synchronise the IMU modules before starting the measurements.

Start measurement without synchronisation: **t**
This command starts the measurements. It is necessary to calibrate the IMU modules before starting the measurements.

Stop measurement: **e**
This command ends the measurements and writes the result to a files on the SD card.

Frequency: **f**
This command changes the sampling frequency. Possible values are:

1. Sampling frequency of 10 Hz
2. Sampling frequency of 20 Hz
3. Sampling frequency of 25 Hz
4. Sampling frequency of 50 Hz
5. Sampling frequency of 100 Hz

Enter a number between 1 to 5.

Data format: **g/h/j/k/l**
This commands determines how the data is stored on the sd card. Possible values are:

1. [g] Only quaternion data
2. [h] Only accelerometer data
3. [i] Only gyroscope data
4. [j] Accelerometer and gyroscope data
5. [k] Quaternion, accelerometer and gyroscope data

Firmware version: **[a]**
This command prints IMU module status. In most cases the module is in IDLE or MEASURING mode.

Firmware version: **[z]**
This command prints the firmware version of each connected IMU module.

8 Remarks and limitations

1. Measuring at the maximum sample rate can lead to loss of data packets. The loss of data depends on the data format. The chance of data losses increases, if both accelerometer data, gyroscope data and quaterion data is required for a measurement.
2. The synchronisation algorithm appears not to function properly yet. It is currently better to start the measurements without synchronisation.

These limitations needs to be resolved in future software releases.

9 Safety precautions

- This IMU uses Lithium Polymer (LIPO) batteries. Please handle with care. Incorrect usage of these batteries can cause fire!
- Never charge the IMU unattended.
- Always use the supplied charger.
- Never charge a deformed, swollen or ballooned battery.
- Store the IMU in a cool, dry place between 5°- 25°.
- Never store Li-ion/LiPo batteries in any locations that can exceed these temperatures such as a vehicle, garage, or in the sun.

A Appendix A

Fig. 28 shows the menu including the different commands to perform measurements and communicate with the IMU sensor modules.

```
##########################################################################
                              Command list
--------------------------------------------------------------------------
Command "0": Print MENU
--------------------------------------------------------------------------
                           General functions
--------------------------------------------------------------------------
Command "1": Connect
Command "2": Disconnect
Command "3": Go to sleep
Command "6": Print MAC addresses to which the BLE slots should connect
Command "9": Change MAC address of a BLE slot
--------------------------------------------------------------------------
                           IMU communication (sended to all connected modules)
--------------------------------------------------------------------------
Command "c": Start calibration
Command "s": Start synchronization
Command "r": Start the measurement with synchronisation
Command "t": Start the measurement without synchronisation
Command "e": End the measurement
Command "f": Change sampling frequency
Command "4": Get the battery voltage
Command "5": Get the system tick
Command "a": Get the IMU module status
Command "z": Get the IMU module sftware version
--------------------------------------------------------------------------
                           SD Card functions
--------------------------------------------------------------------------
Command "m": Mount SD card
Command "u": Unmount SD card
Command "n": Create new file
--------------------------------------------------------------------------
                           Change dataformat
--------------------------------------------------------------------------
Command "g": Only Quaternion data
Command "h": Only Gyroscope data
Command "j": Only Accelerometer data
Command "k": Gyroscope + Accelerometer data
Command "l": Quaternion + Gyroscope + Accelerometer data
##########################################################################
```

Figure 28: Menu commands

B Appendix B

B.1 Graph example

This graphs are created with the python script. (See section 5.2) Data format QUAT was chosen with a sampling frequency of 100 Hz and four connected IMU sensor modules.

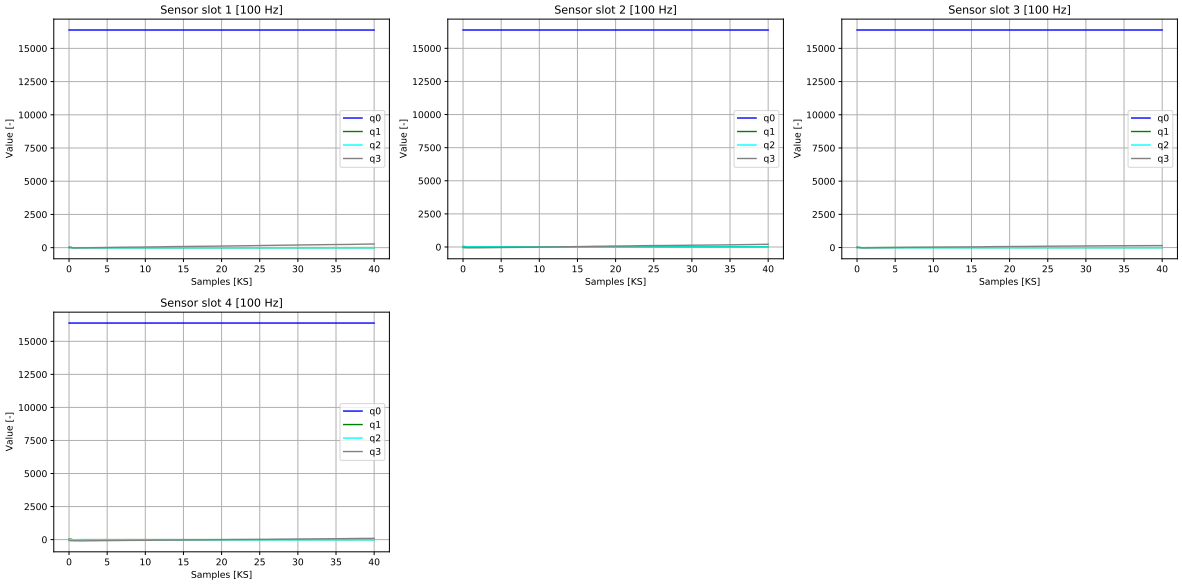

Figure 29: Example graph GRAF_X.pdf

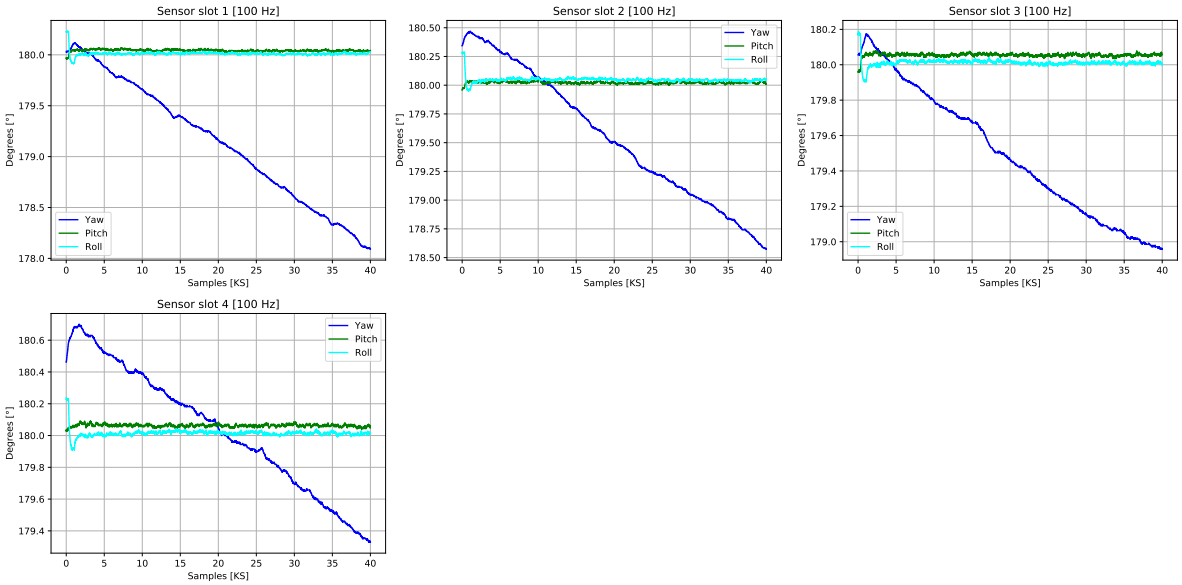

Figure 30: Example graph GRAF_X_ypr.pdf

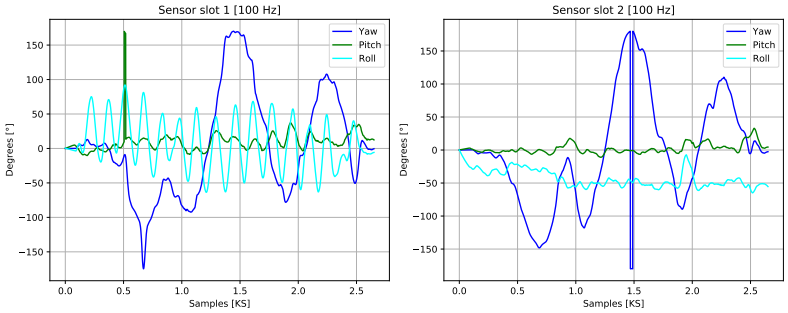

Figure 31: Example graph angle between sensors GRAF_X_ypr.pdf

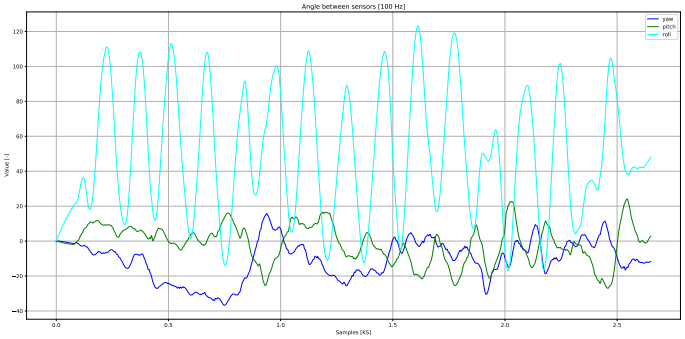

Figure 32: Example graph difference angle between sensors GRAF_X_ypr.pdf