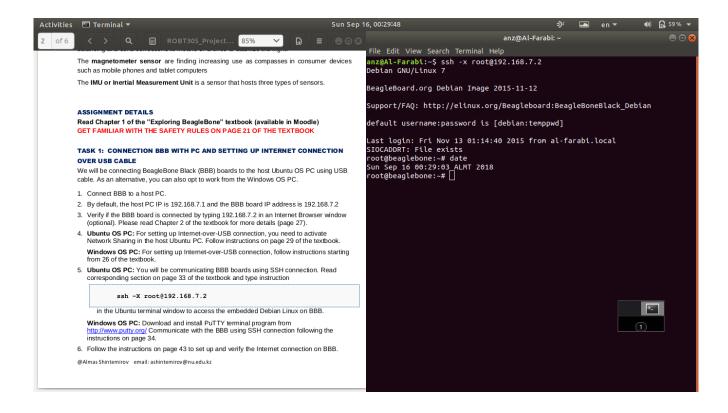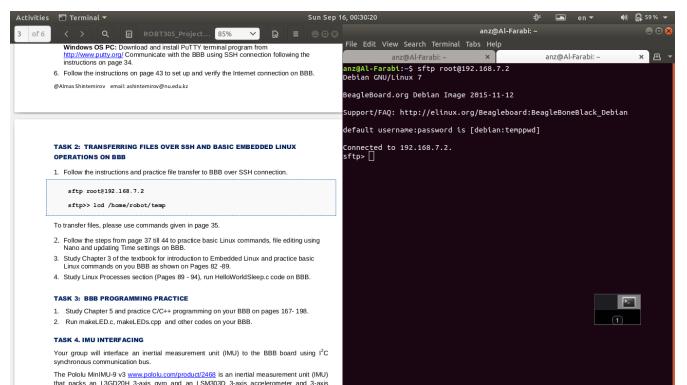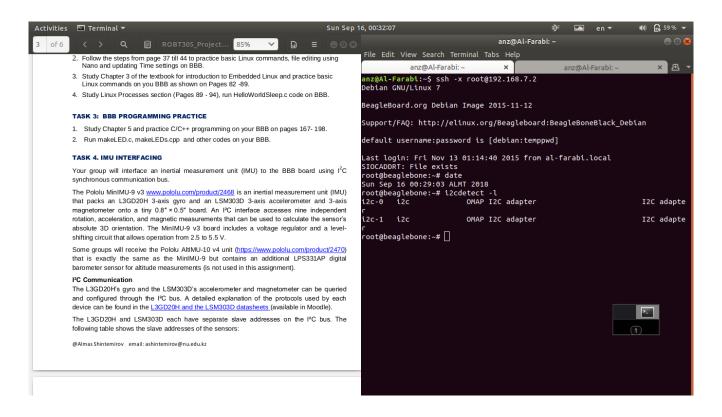# Embedded Systems

Nazarbayev University, Astana

Project 1

Al-Farabi Nagashbayev, Timur Issayev

2. Follow the steps from page 37 till 44 to practice basic Linux commands, file editing using Nano and updating Time settings on BBB.

3. Study Chapter 3 of the textbook for introduction to Embedded Linux and practice basic Linux commands on you BBB as shown on Pages 82 -89.

4. Study Linux Processes section (Pages 89 - 94), run HelloWorldSleep.c code on BBB.

TASK 3: BBB PROGRAMMING PRACTICE

1. Study Chapter 5 and practice C/C++ programming on your BBB on pages 167- 198.

2. Run makeLED.c, makeLEDs.cpp and other codes on your BBB.

TASK 4. IMU INTERFACING

Your group will interface an inertial measurement unit (IMU) to the BBB board using I²C synchronous communication bus.

The Pololu MinIMU-9 v3 www.pololu.com/product/2468 is an inertial measurement unit (IMU) that packs an L3GD20H 3-axis gyro and an LSM303D 3-axis accelerometer and 3-axis magnetometer onto a tiny 0.8" × 0.5" board. An I²C interface accesses nine independent rotation, acceleration, and magnetic measurements that can be used to calculate the sensor's absolute 3D orientation. The MinIMU-9 v3 board includes a voltage regulator and a level-shifting circuit that allows operation from 2.5 to 5.5 V.

Some groups will receive the Pololu AltIMU-10 v4 unit (https://www.pololu.com/product/2470) that is exactly the same as the MinIMU-9 but contains an additional LPS331AP digital barometer sensor for altitude measurements (is not used in this assignment).

I²C Communication

The L3GD20H's gyro and the LSM303D's accelerometer and magnetometer can be queried and configured through the I²C bus. A detailed explanation of the protocols used by each device can be found in the L3GD20H and the LSM303D datasheets (available in Moodle).

The L3GD20H and LSM303D each have separate slave addresses on the I²C bus. The following table shows the slave addresses of the sensors:

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Sensor	Slave Address (default)
L3GD20H (gyro)	1101011b (0x6B)
LSM303D (accelerometer and magnetometer)	0011101b (0x1D)

To connect the sensor to the BBB:

1. Study principles of general purpose input/output (GPIO) interfacing to BBB in **Chapter 6 of the textbook (pp. 201 - 203).**

2. Study relevant section of **Chapter 8 of the textbook (pp. 275 - 290)** and connect the IMU to the BBB board similar way as in Figure 8-1b (p. 277) using the following connections:

> IMU pin / BBB input/output
> SCL – 19
> SDA – 20
> GND – 1
> VDD – 3
> VIN – disconnected.

3. Follow the textbook and test i2c-tools: **i2cdetect**, **i2cdump** and **12cget**, in the BBB terminal.

4. Observe that the IMU gyro, accelerometer and magnetometer sensors are all off by default and do not provide orientation measurements. Use sensor datasheets to learn correct data register addresses, e.g. 8-bit registers **OUT_X_L (0x28)** and **OUT_X_H (0x29)** provide 16-bit X-axis gyro measurement data (L3GD20H sensor). The register reading commands examples are **i2cget 0x6B 0x28** and **i2cget 0x6B 0x29**.

5. In order to turn the IMU on, sensor configuration registers have to be set to the normal mode of operation. This can be done by sending, for example, the following control worlds to the corresponding configuration registers as given in the table below using **i2cset** command, e.g. **i2cset 0x6b 0x20 0x0F**

L3GD20H		LSM303D	
Register (address)	Control word	Register	Control word

Sensor	Slave Address (default)
L3GD20H (gyro)	1101011b (0x6B)
LSM303D (accelerometer and magnetometer)	0011101b (0x1D)

To connect the sensor to the BBB:
1. Study principles of general purpose input/output (GPIO) interfacing to BBB in **Chapter 6 of the textbook (pp. 201 - 203).**
2. Study relevant section of **Chapter 8 of the textbook (pp. 275 - 290)** and connect the IMU to the BBB board similar way as in Figure 8-1b (p. 277) using the following connections:

    IMU pin / BBB input/output
    SCL – 19
    SDA – 20
    GND – 1
    VDD – 3
    VIN – disconnected.

3. Follow the textbook and test i2c-tools: **i2cdetect**, **i2cdump** and **12cget**, in the BBB terminal.

4. Observe that the IMU gyro, accelerometer and magnetometer sensors are all off by default and do not provide orientation measurements. Use sensor datasheets to learn correct data register addresses, e.g. 8-bit registers **OUT_X_L (0x28)** and **OUT_X_H (0x29)** provide 16-bit X-axis gyro measurement data (L3GD20H sensor). The register reading commands examples are **i2cget 0x6B 0x28** and **i2cget 0x6B 0x29.**

5. In order to turn the IMU on, sensor configuration registers have to be set to the normal mode of operation. This can be done by sending, for example, the following control worlds to the corresponding configuration registers as given in the table below using **i2cset** command, e.g. **i2cset 0x6b 0x20 0x0F**

L3GD20H		LSM303D	
Register (address)	Control word	Register	Control word

```
root@beaglebone:~# i2cdump -y 1 0x6b
No size specified (using byte-data access)
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f    0123456789abcdef
00: a0 c6 7c 01 65 a9 a4 bf c2 fe 00 00 00 00 00 d7    ??|?e?????.....?
10: 43 a0 dc 40 85 04 1e 0a a2 86 fc 85 88 18 36 09    C??@?????????6?
20: 0f 20 00 00 00 00 02 ff f5 ff ba fe 5d 00 00 20    ? ....?.?.??]..
30: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
40: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
50: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
60: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
70: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
80: a0 c6 7c 01 65 a9 a4 bf c2 fe 00 00 00 00 00 d7    ??|?e?????.....?
90: 43 a0 dc 40 85 04 1e 0a a2 86 fc 85 88 18 36 09    C??@?????????6?
a0: 0f 20 00 00 00 00 02 ff cf ff cc fe 5e 00 00 20    ? ....?.?.??^..
b0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
c0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
d0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
e0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
f0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
root@beaglebone:~#
```

```
00: a0 c6 7c 01 65 a9 a4 bf c2 fe 00 00 00 00 00 d7    ??|?e?????.....?
10: 43 a0 dc 40 85 04 1e 0a a2 86 fc 85 88 18 36 09    C??@?????????6?
20: 0f 20 00 00 00 00 02 ff f5 ff ba fe 5d 00 00 20    ? ....?.?.??]..
30: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
40: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
50: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
60: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
70: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
80: a0 c6 7c 01 65 a9 a4 bf c2 fe 00 00 00 00 00 d7    ??|?e?????.....?
90: 43 a0 dc 40 85 04 1e 0a a2 86 fc 85 88 18 36 09    C??@?????????6?
a0: 0f 20 00 00 00 00 02 ff cf ff cc fe 5e 00 00 20    ? ....?.?.??^..
b0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
c0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
d0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
e0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
f0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
root@beaglebone:~# i2cdump -y 1 0x1d
No size specified (using byte-data access)
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f    0123456789abcdef
00: 00 00 00 00 00 00 00 ff 18 ff 4d fd 1f f7 00 49    ........?.M???.I
10: 00 00 e8 00 00 00 00 00 00 00 00 00 00 00 00 00    ..?.............
20: 57 18 00 00 64 20 00 ff 3e f6 9b 02 0d 0d 00 20    W?..d ..>?????.
30: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
40: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
50: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
60: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
70: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ..        ?.I
80: 00 00 00 00 00 00 00 18 ff 4d fd 1f f7 00 49    ..        ?.I
90: 00 00 e8 00 00 00 00 00 00 00 00 00 00 00 00 00    ..          ?.
a0: 57 18 00 00 64 20 00 ff 5f f6 aa 02 0a 0d 00 20    W?          ?.
b0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
c0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
d0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
e0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
f0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00    ................
root@beaglebone:~#
```

SDA – 20
GND – 1
VDD – 3
VIN – disconnected.

3. Follow the textbook and test i2c-tools: **i2cdetect**, **i2cdump** and **12cget**, in the BBB terminal.

4. Observe that the IMU gyro, accelerometer and magnetometer sensors are all off by default and do not provide orientation measurements. Use sensor datasheets to learn correct data register addresses, e.g. 8-bit registers **OUT_X_L (0x28)** and **OUT_X_H (0x29)** provide 16-bit X-axis gyro measurement data (L3GD20H sensor). The register reading commands examples are **i2cget 0x6B 0x28** and **i2cget 0x6B 0x29**.

5. In order to turn the IMU on, sensor configuration registers have to be set to the normal mode of operation. This can be done by sending, for example, the following control worlds to the corresponding configuration registers as given in the table below using **i2cset** command, e.g. **i2cset 0x6b 0x20 0x0F**

L3GD20H		LSM303D	
Register (address)	Control word	Register	Control word
CTRL1 (0x20)	0x0F	CTRL1	0x57
CTRL2 (0x21)	0x20	CTRL2	0x18
		CTRL5	0x64
		CTRL6	0x20
		CTRL7	0x00

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6. Learn the meaning of the control words using sensor datasheets and modify if necessary

```
#!/bin/bash

i2cset -y 1 0x6b 0x20 0x0F
i2cset -y 1 0x6b 0x21 0x20


i2cset -y 1 0x1d 0x20 0x57
i2cset -y 1 0x1d 0x21 0x18
i2cset -y 1 0x1d 0x24 0x64
i2cset -y 1 0x1d 0x25 0x20
i2cset -y 1 0x1d 0x26 0x00
```

"control.sh" 11L, 204C   1,1   All

6. Learn the meaning of the control words using sensor datasheets and modify if necessary the corresponding accelerometer, magnetometer and gyroscope sensor control registers and set the sensors to following settings:

	L3GD20H	LSM303D	
	Gyroscope	Accelerometer	Magnetometer
Data output frequency	50Hz	50Hz	6.25Hz
Range of output frequency	±245 deg/sec	±2g (2 x 9.81m/s^2)	±4 $gauss$ (2x10$^{-4}Tesla$)

Provide your modified control words in the report.

7. Use the program example from Listing 8-1 on page 286 of the textbook (the code is available in Moodle) and write a program for setting the configuration registers and reading measurement data from x, y and z axes of all of the IMU onboard sensors. Note that the 16-bit data word for each measurement axis is obtained by combining readings from two 8-bit data registers (low and high).

8. Using the IMU sensor datasheets you are required to prepare a register map similar to Table 8-2 on page 283 of the textbook containing information about configuration and data registers. Please be able to explain the meaning of the sensor control words during the class presentation.

TASK 5. IMU SIGNAL PROCESSING

1. Study, download, and implement an open-source IMU sensor measurement fusion algorithm in C code developed by Sebastian Madgwick from
http://www.x-io.co.uk/open-source-imu-and-ahrs-algorithms/

2. Interface your IMU sensor measurement data program with the algorithm code and obtain orientation estimations in the terminal window when running on the BBB (**no need** for threaded implementation and graphical user interface at this point)

```
#!/bin/bash



i2cset -y 1 0x6b 0x39 0x01
i2cset -y 1 0x6b 0x20 0x8F

i2cset -y 1 0x1d 0x20 0x57
i2cset -y 1 0x1d 0x21 0x00
i2cset -y 1 0x1d 0x24 0x64
i2cset -y 1 0x1d 0x25 0x20
i2cset -y 1 0x1d 0x26 0x00
```

"changemode.sh" 11L, 204C   1,1   All

First terminal window (top screenshot):

```bash
1 #!/bin/bash
2
3
4 g++ ggMD.cpp -std=c++0x
```

`"buildMD" 4L, 39C                    1,1          All`

Second terminal window (bottom screenshot):

```cpp
341
342    mag_x = ~mag_x +1 ;
343    mag_y = ~mag_y + ;
344    mag_z = ~mag_z + ;
345
346    magmag = sqrt(mag_x*mag_x + mag_y*mag_y +mag_z*mag_z);
347
348    mag_xd =(double) mag_x/magmag;
349    mag_yd =(double) mag_y/magmag;
350    mag_zd =(double) mag_z/magmag;
351
352
353
354    gyro_x = stoi(get(gyrADDR, GYRO_OUT_X_H), nullptr, 16) << 8 | stoi(get(gyrADDR, GYRO_OUT_X_L), nullptr, 16);
355    gyro_y = stoi(get(gyrADDR, GYRO_OUT_Y_H), nullptr, 16) << 8 | stoi(get(gyrADDR, GYRO_OUT_Y_L), nullptr, 16);
356    gyro_z = stoi(get(gyrADDR, GYRO_OUT_Z_H), nullptr, 16) << 8 | stoi(get(gyrADDR, GYRO_OUT_Z_L), nullptr, 16);
357    gyro_x = ~gyro_x+1 ;
358    gyro_y = ~gyro_y+1 ;
359    gyro_z = ~gyro_z+1 ;
360    maggy = sqrt(gyro_x*gyro_x + gyro_y*gyro_y +gyro_z*gyro_z);
361    gyro_xd =(double)- (gyro_x)/32768;
362    gyro_yd =(double)- (gyro_y)/32768;
363    gyro_zd =(double)- (gyro_z)/32768;
364
365
366
367
368    cout << "X-acc: " << accel_xd << " Y-acc: " << accel_yd << " Z-acc: " << accel_zd << endl;
369    cout << "X-gyro: " << gyro_xd << " Y-gyro: " << gyro_yd << " Z-gyro: " << gyro_zd << endl;
370    cout << "X-mag: " << mag_xd << " Y-mag: " << mag_yd << " Z-mag: " << mag_zd << endl;
371    MadgwickAHRSupdate(gyro_xd, gyro_yd,gyro_zd,accel_xd,accel_yd,accel_zd,mag_xd,mag_yd,mag_zd);
372
373    }
374    return 0;
375 }
```

`375,1          Bot`

anz@Al-Farabi: ~

File   Edit   View   Search   Terminal   Tabs   Help

anz@Al-Farabi: ~   anz@Al-Farabi: ~

```
root@beaglebone:~/last# ./buildMD
root@beaglebone:~/last# ls
a.out   build   builddgg   buildMD   changemode.sh   control.sh   default.sh   gg.cpp   ggMD.cpp   MD.cpp   rr.cpp   sensor.c   testADXL345.c
root@beaglebone:~/last#
```

anz@Al-Farabi: ~

File   Edit   View   Search   Terminal   Tabs   Help

anz@Al-Farabi: ~   anz@Al-Farabi: ~

```
root@beaglebone:~/last# ./buildMD
root@beaglebone:~/last# ls
a.out   build   builddgg   buildMD   changemode.sh   control.sh   default.sh   gg.cpp   ggMD.cpp   MD.cpp   rr.cpp   sensor.c   testADXL345.c
root@beaglebone:~/last# ./a.out
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998307     Q1:  -1.13762e-05     Q2:  -0.000203187     Q3:  -1.40965e-05
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998312     Q1:  -2.29523e-05     Q2:  -0.000406702     Q3:  -2.81412e-05
```

```
root@beaglebone:~/last# ./buildMD
root@beaglebone:~/last# ls
a.out  build  buildgg  buildMD  changemode.sh  control.sh  default.sh  gg.cpp  ggMD.cpp  MD.cpp  rr.cpp  sensor.c  testADXL345.c
root@beaglebone:~/last# ./a.out
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998307    Q1:  -1.13762e-05    Q2:  -0.000203187    Q3:  -1.40965e-05
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998312    Q1:  -2.29523e-05    Q2:  -0.000406702    Q3:  -2.81412e-05
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998312    Q1:  -3.45341e-05    Q2:  -0.000610216    Q3:  -4.21754e-05
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998312    Q1:  -4.61223e-05    Q2:  -0.000813731    Q3:  -5.61993e-05
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998312    Q1:  -5.77168e-05    Q2:  -0.00101725    Q3:  -7.02129e-05
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998312    Q1:  -6.93177e-05    Q2:  -0.00122076    Q3:  -8.42162e-05
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998311    Q1:  -8.09249e-05    Q2:  -0.00142428    Q3:  -9.82093e-05
```

```
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.99831    Q1:  -0.000127418    Q2:  -0.00223834    Q3:  -0.00015408
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998309    Q1:  -0.000139057    Q2:  -0.00244186    Q3:  -0.000168022
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998309    Q1:  -0.000150702    Q2:  -0.00264538    Q3:  -0.000181955
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998308    Q1:  -0.000162354    Q2:  -0.0028489    Q3:  -0.000195877
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998308    Q1:  -0.000174012    Q2:  -0.00305241    Q3:  -0.00020979
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998307    Q1:  -0.000185677    Q2:  -0.00325593    Q3:  -0.000223693
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998306    Q1:  -0.000197348    Q2:  -0.00345945    Q3:  -0.000237585
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998306    Q1:  -0.000209025    Q2:  -0.00366296    Q3:  -0.000251468
X-acc: 0.590187 Y-acc: -0.162124 Z-acc: -0.790946
X-gyro: -0.0017395 Y-gyro: -0.00979614 Z-gyro: 0.00335693
X-mag: 0.0949153 Y-mag: 0.289407 Z-mag: 0.952542
Q0:  0.998305    Q1:  -0.000220709    Q2:  -0.00386648    Q3:  -0.000265342
```