# IMU & AHRS algorithms

Francois

## IMU & AHRS algorithms

The objective of this document is to provide a quick start to anyone interested in using IMUs.

Even though the code is simple and short, it is not a *plug and play* library. This document was created so you can understand what your code.

## Hardware

You will need:

- Computer
- Arduino Uno R3
- IMU

I used IMU MinIMU-9 v3 from Polulu found here: https://www.pololu.com/product/2468



Follow tutorials and connect computer, Arduino and IMU

## Software

You will need:

- Arduino IDE
- Arduino libraries for IMU sensors

https://www.pololu.com/product/2468/resources

- Excel
- PLX-DAQ add-in for Excel

http://www.parallax.com/downloads/plx-daq

# IMU

#### Lets start with a reference



## This is the most important step



# Make sure your reference is clear



## Now, lets get some data

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sketch_feb18b	
<pre>#include <wire.h> #include <l3g.h> #include <lsm303.h></lsm303.h></l3g.h></wire.h></pre>	// load libraries
L3G gyro; LSM303 compass;	
<pre>float A[4]; float G[4]; float M[4];</pre>	// declare variables A for accelerometer, G for gyro and M for magnetometer
void setup()	
<pre>Serial.begin(9600); Wire begin();</pre>	// start talking
<pre>gyro.init(); gyro.enableDefault();</pre>	// start gyro
<pre>compass.init(); compass.enableDefault( }</pre>	// start accelerometer and magnetometer );
woid loop()	
{	
<pre>gyro.read(); compass.read();</pre>	// get data from sensors
<pre>A[1] = compass.a.x; A[2] = compass.a.y; A[3] = compass.a.z; G[1] = gyro.g.x; G[2] = gyro.g.y; G[3] = gyro.g.z; G[1] = gyro.g.x; G[2] = gyro.g.y; G[3] = gyro.g.z;</pre>	// record data
<pre>Serial.print(A[1]); Se Serial.print(G[1]); Se Serial.print(M[1]); Se Serial.println(); delay(20);</pre>	rial.print(","); Serial.print(A[2]); Serial.print(","); Serial.print (A[3]); Serial.print(","); // print all data rial.print(","); Serial.print(G[2]); Serial.print(","); Serial.print (G[3]); Serial.print(","); rial.print(","); Serial.print(M[2]); Serial.print(","); Serial.print (M[3]); Serial.print(",");
}	
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28	Arduino Unio en COM6

# Click upload and here it is: raw data streaming to the serial port.

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re.begin();	// Start taiking	604.00,243.00,16826.00,88.00,-462.00,36.00,-33.00,148.00,-1542.00,	
ro.init();	// start gyro	591.00,247.00,16791.00,81.00,-469.00,43.00,-30.00,142.00,-1537.00,	
ro.enableDefault();		592.00,274.00,16795.00,75.00,-475.00,36.00,-30.00,142.00,-1537.00,	
<pre>apass.init();</pre>	// start accelerometer and magnetometer	566.00,262.00,16775.00,84.00,-467.00,43.00,-29.00,150.00,-1552.00,	
pass.enableDefault	();	568.00,284.00,16824.00,73.00,-461.00,48.00,-29.00,150.00,-1552.00,	
		583.00,294.00,16816.00,75.00,-450.00,65.00,-35.00,143.00,-1533.00,	
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		569.00,233.00,16828.00,79.00,-463.00,46.00,-26.00,146.00,-1544.00,	
ro. <mark>read</mark> ();	// get data from sensors	577.00,275.00,16808.00,94.00,-476.00,47.00,-26.00,146.00,-1544.00,	2
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2] = compass.a.y;	// prace notaer for data conversion	4 m	
3] = compass.a.z;			10
] = gyro.g.x;		V Autoscroll	
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rial print(M[1]); S	erial.print(","); Serial.print(G[2]); Serial.print(","); Serial.print(G[3])	); Serial print(",");	
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# Lets upload the raw data to Excel. It is not necessary but so useful

First install PLX-DAQ add-in for Excel

#### Add a row variable

int row = 0;

#### Add these commands to setup() function

Serial.println("CLEARDATA"); Serial.println("LABEL,time,dt in ms,acce x,acce y,acce z,gyro x,gyro y,gyro z,mag x,mag y,mag z,roll,pitch,yaw");

#### Replace print block in loop() function, by this one

```
Serial.print("DATA,TIME,");
Serial.print(","); Serial.print(",");
Serial.print(A[1]); Serial.print(","); Serial.print(A[2]); Serial.print(","); Serial.print (A[3]); Serial.print(","); // print all data
Serial.print(G[1]); Serial.print(","); Serial.print(G[2]); Serial.print(","); Serial.print (G[3]); Serial.print(",");
Serial.print(M[1]); Serial.print(","); Serial.print(M[2]); Serial.print(","); Serial.print (M[3]); Serial.print(",");
Serial.println();
row++;
if (row > 500) {row=0; Serial.println("ROW,SET,2"); }
```

For a complete explanation, see: http://robottini.altervista.org/arduino-and-real-time-charts-in-excel

# Open PLX add-in for Excel, choose the right serial port and click connect

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4 0.59107639 3.78 -4.28 -99.22 0 -0.01 0 34.37 3.33 99.92
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15 0.59108796
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29 0.59109954 4.15 -4.74 -106.95 -0.01 0 0.03 6.42 -24.5 103.37
30 0.59109954 -4.41 -3.05 -93 0.02 0 0.6 2.86 -30.08 120 11
31 0.59109954 0.2 -10.25 -99.33 0 0.02 26.54 1
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41 0.5911111 0.95 -3.17 -100.13 0.01 -0.05 0.05 -39.89 -14.92 96.29
42 0.59111111 0.68 -3.15 -98.97 0 0.01 0.02 -33.39 -10.67 100.08

#### Note: I had troubles with PLX add-in.

So if PLX add-in works you are lucky, if it does not work, do not panic: click *debug* or press *Alt+F11* to open VBA

Then find the line that bugs (it will be shown in yellow) and comment this line.



# Now that you can plot the data in real time in Excel, we can start calibrating the accelerometer

The accelerometer measure the acceleration, however like any sensor it is not perfect and the accelerometer has an offset.

The best way to calibrate the offset of the accelerometer would be to go in space and measure the output of the sensor under no acceleration and no gravity, but this is not going to happen. So lets point the accelerometer down to measure gravity then point the sensor up to measure gravity again. The mean between the 2 values is the sensor's offset.

Then repeat the experiment for all three axis.

# Now that you can plot the data in real time in Excel, we can start calibrating the accelerometer

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# Now that you can plot the data in real time in Excel, we can start calibrating the accelerometer

I added the calibration factors as definitions before the setup() function like this:

#define ACCEL\_X\_MIN ((float) -16340) // Add Min an Max values from calibration #define ACCEL\_X\_MAX ((float) 16975) #define ACCEL\_Y\_MIN ((float) -15830) #define ACCEL\_Y\_MAX ((float) 16380) #define ACCEL Z MIN ((float) -16570) #define ACCEL\_Z\_MAX ((float) 16910) #define ACCEL\_X\_DIR ((int) 1 ) // If up and down are reversed then the direction of the sensor is negative #define ACCEL Y DIR ((int) -1 #define ACCEL\_Z\_DIR ((int) -1 #define ACCEL\_X\_OFFSET ((ACCEL\_X\_MIN + ACCEL\_X\_MAX) / 2.0f) // The Offset is the average of the Min and MAX values #define ACCEL\_Y\_OFFSET ((ACCEL\_Y\_MIN + ACCEL\_Y\_MAX) / 2.0f) #define ACCEL\_Z\_OFFSET ((ACCEL\_Z\_MIN + ACCEL\_Z\_MAX) / 2.0f) #define ACCEL\_X\_SCALE (100.0f / (ACCEL\_X\_MAX - ACCEL\_X\_OFFSET) ) // Scale all accelerometers between -100 and 100 #define ACCEL\_Y\_SCALE (100.0f / (ACCEL\_Y\_MAX - ACCEL\_Y\_OFFSET) ) #define ACCEL Z SCALE (100.0f / (ACCEL Z MAX - ACCEL Z OFFSET) )

Note: scaling all accelerometer's value between -100 and 100 is arbitrary, most people like to scale the accelerometer between -9.8 and 9.8 because gravity was used during calibration. In the end accelerometers data will be used to calculate angles so the scale factor does not change anything.

A good tutorial for calibration is found here: http://www.starlino.com/imu\_guide.html

# Now, process raw accelerometer data into calibrated accelerometer data

#### **Replace this**

A[1] = compass.a.x; // place holder for data conversion
A[2] = compass.a.y;
A[3] = compass.a.z;

#### Into this

A[1] = (compass.a.x - ACCEL\_X\_OFFSET) \* ACCEL\_X\_SCALE \* ACCEL\_X\_DIR; // accelerometer' values are now between -100 and 100
A[2] = (compass.a.y - ACCEL\_Y\_OFFSET) \* ACCEL\_Y\_SCALE \* ACCEL\_Y\_DIR;
A[3] = (compass.a.z - ACCEL\_Z\_OFFSET) \* ACCEL\_Z\_SCALE \* ACCEL\_Z\_DIR;

#### Final results! Accelerometer values as a function of time



All values are fixed between -100 and 100 and value are negative when sensor is down and positive when sensor is up

### Now let's calibrate the gyro's offset

Getting the offset of the gyro is easy, leave the sensor alone (not moving) and look at the gyro's values for x y and z.

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### Now let's calibrate the gyro's direction

Let's check the direction of the sensor, by rolling 90° positive, pitching 90° positive and yawing 90° positive.

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#### We can start calibrating the gyro's data

#### Add offset and directions of the gyro as definitions

define GYRO\_OFFSET\_X ((float) 122.0 )
#define GYRO\_OFFSET\_Y ((float) -496.0 )
#define GYRO\_OFFSET\_Z ((float) 48.0 )
#define GYRO\_X\_DIR ((int) 1 )
#define GYRO\_Y\_DIR ((int) -1 )
#define GYRO\_Z\_DIR ((int) -1 )

#### Then, replace this block

G[1] = gyro.g.x; G[2] = gyro.g.y; G[3] = gyro.g.z;

#### By this one

G[1] = (gyro.g.x - GYRO\_OFFSET\_X) \* GYRO\_X\_DIR; // This take into account the offset of the gyro and the direction
G[2] = (gyro.g.y - GYRO\_OFFSET\_Y) \* GYRO\_Y\_DIR; // scale factor is still missing
G[3] = (gyro.g.z - GYRO\_OFFSET\_Z) \* GYRO\_Z\_DIR;

# Now the gyro's data is 0 when the gyro is not moving and direction correct, but data has no units

### Let's calibrate the gyro's scale factor.



### We need to find out the units of the gyro

The gyro provides a rate of change, not the change itself, so we need take time into account

#### First declare time variables

float dt; // time between gyro readings in milliseconds
float t = millis(); // time = now in milliseconds

#### Then right after reading the gyro data add

dt = millis() - t; t = millis();

#### Add the time between readings into excel

```
Serial.print("DTA,TIME,");
Serial.print("dt) Serial.print(","); // dt is added here nothing else change
Serial.print(A[1]); Serial.print(","); Serial.print(A[2]); Serial.print(","); Serial.print (A[3]); Serial.print(",");
Serial.print(G[1]); Serial.print(","); Serial.print(G[2]); Serial.print(","); Serial.print (G[3]); Serial.print(",");
Serial.print(M[1]); Serial.print(","); Serial.print(M[2]); Serial.print(","); Serial.print (M[3]); Serial.print(",");
Serial.println();
```

Now the gyro's data is 0 when the gyro is not moving and directions are correct.

Next, we need to convert the gyro arbitrary scale to something useful. In order to do that we move the gyro by 90 degrees and record the data:

## Add in Excel a column with the eq. Gyro x dt

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#### Final gyro's calibration

#### Add offset and directions of the gyro as definitions

define (	GYRO_OFFSET_X	((float)	122.0	)
#define	GYRO_OFFSET_	Y ((float)	-496.0	)
#define	GYRO_OFFSET_	Z ((float)	48.0	)
#define	GYRO_SCALE (	(float)	0.000	0090)
#define	GYRO_X_DIR (	(int)	1	)
#define	GYRO_Y_DIR (	(int)	-1	)
#define	GYRO_Z_DIR (	(int)	-1	)

#### Then, replace this block

G[1] = (gyro.g.x - GYRO\_OFFSET\_X) \* GYRO\_X\_DIR; // This take into account the offset of the gyro and the direction
G[2] = (gyro.g.y - GYRO\_OFFSET\_Y) \* GYRO\_Y\_DIR;
G[3] = (gyro.g.z - GYRO\_OFFSET\_Z) \* GYRO\_Z\_DIR;

#### By this one

G[1] = (gyro.g.x - GYRO\_OFFSET\_X) \* GYRO\_SCALE \* GYRO\_X\_DIR; // now the gyro's data is fully calibrated [degrees / ms / gyro unit]
G[2] = (gyro.g.y - GYRO\_OFFSET\_Y) \* GYRO\_SCALE \* GYRO\_Y\_DIR;
G[3] = (gyro.g.z - GYRO\_OFFSET\_Z) \* GYRO\_SCALE \* GYRO\_Z\_DIR;

# Gyro is now calibrated !

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### Calibration of the magnetometer can be tricky...

A good tutorial can be found here: https://github.com/ptrbrtz/razor-9dof-ahrs/wiki/Tutorial

I used a simple calibration using min and max similar to the accelerometer's calibration with good results. The tricky part is that it is not easy to get the min and max values because you need to orientate the accelerometer exactly in the direction of the earth's magnetic field.

One solution can be to take lots and lots of points and hope to be lucky. That works, but I prefer to see the data in a graph in order to make sure I am at the right place. This was done in Excel (Matlab would be much easier).

# Lets find magnetometer's mins and maxs

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#### Magnetometer calibration

Visualisation of the data in 3D is not necessary, but useful to make sure nothing strange is happening (for example, magnetometer's data is messed up by your computer's screen magnetic field). Once min and max have been identified add calibration parameters as definitions

#define MAGN\_X\_MIN ((float) -1643)
#define MAGN\_X\_MAX ((float) 3251)
#define MAGN\_Y\_MIN ((float) -2071)
#define MAGN\_Y\_MAX ((float) 2729)
#define MAGN\_Z\_MIN ((float) -1550)
#define MAGN\_Z\_MAX ((float) 3198)
#define MAGN\_Z\_MAX ((float) 3198)
#define MAGN\_X\_OFFSET ((MAGN\_X\_MIN + MAGN\_X\_MAX) / 2.0f)
#define MAGN\_Y\_OFFSET ((MAGN\_Y\_MIN + MAGN\_Y\_MAX) / 2.0f)
#define MAGN\_Z\_OFFSET ((MAGN\_Z\_MIN + MAGN\_Z\_MAX) / 2.0f)
#define MAGN\_X\_SCALE (100.0f / (MAGN\_X\_MAX - MAGN\_X\_OFFSET)) // again magnetometer is calibrated to be set between -100 and 100
#define MAGN\_Z\_SCALE (100.0f / (MAGN\_Y\_MAX - MAGN\_Y\_OFFSET))
#define MAGN\_Z\_SCALE (100.0f / (MAGN\_Z\_MAX - MAGN\_Y\_OFFSET))

#### Change the magnetometer values from

M[1] = (compass.m.x); M[2] = (compass.m.y); M[3] = (compass.m.z);

#### То

```
M[1] = (compass.m.x - MAGN_X_OFFSET) * MAGN_X_SCALE * ACCEL_X_DIR; // note the directions of the magnetometer are the same as the
M[2] = (compass.m.y - MAGN_Y_OFFSET) * MAGN_Y_SCALE * ACCEL_Y_DIR; // accelerometer in my IMU
M[3] = (compass.m.z - MAGN_Z_OFFSET) * MAGN_Z_SCALE * ACCEL_Z_DIR;
```

# Magnetometer is now calibrated

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# Magnetometer is now calibrated

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8 #########	95	-37.7	3 0.0	)3 -92.11	0.01	-0.11	0	-18.19	2.33	103.33																		
9 #########	95	-51.4	8 -1.3	-81.82	0	-0.1	0	11.24	2.75	105.18																		
10 #########	98	-69.	3 -2.7	-69.96	0.01	-0.09	-0.01	40.17	3.83	98.1																		
11 #########	94	-80.9	6 -1	.4 -56.87	-0.01	-0.12	0	40.17	3.83	98.1										1								
12 #########	95	-	150 <sub>T</sub>		e e e e e e e e e e e e e e e e e e e	Construction of		C. Strongers																	1	57		
13 #########	95																					Data Ac	quisition for E	xcel		25		
14 #########	96	-1	100 -	-	~	-	~										_	-				1	A	Control	1			
15 #########	93	-	c				1	-			1											PI	X-DA0	C Downlo	oad Data			
16 ########	96		80 50 -			1		1														Set	tings	Clear S	tored Data			
17 #########	97	-	E		F														mag	; x		Port:	6 -	User1				
18 #########	95	-	- ted		/													•	—— m ag	s y		Baud	9600 -	Reset Ti	mer			
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20 #########	95		₩ -50 -				<u> </u>		-+			_						·					Connect	Clear Coli	umns			
21 <del>*********</del>	95		U U					~	>	≺												- F	Reset on Connect					
22 <b>********</b>	93		-100 -					<u> </u>		<u> </u>													Contro	ller Messages	-			
24 #########	91																						Dis	sconnected		-		
25 #########	90		-150																									
26 ########	91	26.2	1 7.0	93.75	0.01	-0.04	-0.01	19.25	-4.92	-101.22																		
27 #########	94	22.	5 6.5	68 105.08	0.01	-0.05	0.01	9.89	-7.92	-102.86																		
28 #########	93	35.2	5 9.4	14 98.24	0	-0.06	0	9.89	-7.92	-102.86																		
29 #########	96	43.3	2 7.0	90.26	-0.01	-0.07	0	-8.75	-6.13	-102.19																		
30 #########	95	59.0	7 6.6	53 <b>85.5</b> 8	-0.01	-0.12	0	-8.75	-6.13	-102.19																		
31 #########	97	81.8	6 9.5	66.14	0.01	-0.14	0	-36	-3.38	-95.96																		
32 #########	95	46.	7 7.1	.3 3.59	0.14	-0.19	-0.08	-74.42	-15.75	-68.58																		
33 #########	97	110.5	6 21	.2 22.75	0.01	-0.17	0.03	-74.42	-15.75	-68.58				N/ a	aσna	ton	nete	r va	alue	s fo	r 26	ናበ°	nite	•h				
34 #########	96	102.	3 5.0	8.75	-0.03	-0.13	0.03	-95.26	-12.46	-35.97				IVIC	18110		icie		nuc	510	1 3	00	pitt					
35 #########	95	97.8	2 5.4	-27.65	-0.02	-0.08	0.02	-95.26	-12.46	-35.97																		
36 #########	97	89.7	3 1.4	42 -34.18	-0.01	-0.1	0.02	-103.43	-5.17	-3.12																		
3/ <del>#########</del>	97	84.3	/ 3.6	08 -54./3	0	-0.08	0.01	-100.69	-1	22.96																		
30 ####################################	9/	73.2	0 1.7 8 _2 ?	-00.15	0.01	-0.07	0.01	-100.09	-1	22.96																		
10 #########	50	75.2	0 -3.2 1 _2.4	-72.3 -79.27	0.01	-0.09	0.02	- 24.77	2.5	40.14																		
41 ########	96	50.1	4 -6.8	31 -90 17	-0.01	-0.08	0.01	-34.77	6.42	61.92																		
42 #########	96	35.6	. 0.0 8 -2.6	57 -94.84	-0.01	-0.08	0,01	-64.98	6,58	80,33																		
II I I I She	et1 / She	et2 / Sh	eet3 🏑 🔁	/		2.50		250	2.00			1	1															•
Ready 🔚																										100% 😑	)	

All 9 sensors a now calibrated.

We need to use them to calculate roll pitch and yaw. I am going to use a complementary filter.

# More info about it and why we would use a complementary filter found here:

https://b94be14129454da9cf7f056f5f8b89a9b17da0be.googledrive.com/host/0B0ZbiLZrqVa6Y2d3UjFVWDhNZms/filter.pdf

# AHRS

# AHRS

Step 1 Calculate roll pitch yaw using accelerometer and magnetometer

### More definitions

 roll is defined in the [-180, 180] range and pitch is defined in the [-90, 90] range, therefore you can not use same equation to calculate both roll and pitch as it is shown in many tutorials



## few equations



$$roll_a = atan2(a_y, a_z)$$

$$pitch_a = \operatorname{atan}\left(\frac{a_x}{\sqrt{a_y^2 + a_z^2}}\right)$$

$$yaw_m = atan2(Y_h, X_h)$$





Where, X<sub>M</sub>, Y<sub>M</sub>, and Z<sub>M</sub> are magnetic sensor measurements.

https://www.pololu.com/file/download/...?file\_id=0J434

#### First calculate roll pitch and yaw

#### Add 2 definitions

#define TO\_RAD(x) (x \* 0.01745329252) // \*pi/180
#define TO\_DEG(x) (x \* 57.2957795131) // \*180/pi

#### Then after data conversion in loop() function add

roll\_A = TO\_DEG( atan2(A[2], A[3]));

pitch\_A = TO\_DEG( atan(A[1]/sqrt(A[2]\*A[2]+A[3]\*A[3])));

```
Xh = M[1] * cos(TO_RAD(pitch)) + M[3] * sin(TO_RAD(pitch));
Yh = M[1] * sin(TO_RAD(roll)) * sin(TO_RAD(pitch)) + M[2] * cos(TO_RAD(roll)) - M[3] * sin(TO_RAD(roll)) * cos(TO_RAD(pitch));
yaw_M = TO_DEG(atan2(Yh,Xh));
```

# This is a good beginning but these equations assumes that the IMU is flat (roll = pitch = 0) and pointing in the right direction (yaw = 0)

These equations take into account that the IMU might not be exactly flat and pointing in the right direction:

roll\_A = T0\_DEG( atan2(A[2], A[3])) - roll\_init ; pitch\_A = T0\_DEG( atan(A[1]/sqrt(A[2]\*A[2]+A[3]\*A[3])) ) - pitch\_init ; Xh = M[1] \* cos(T0\_RAD(pitch)) + M[3] \* sin(T0\_RAD(pitch)); Yh = M[1] \* sin(T0\_RAD(roll)) \* sin(T0\_RAD(pitch)) + M[2] \* cos(T0\_RAD(roll)) - M[3] \* sin(T0\_RAD(roll)) \* cos(T0\_RAD(pitch)); yaw\_M = T0\_DEG(atan2(Yh,Xh)) - Heading ;

// roll\_init, pitch\_init and Heading are the original roll pitch and yaw when the code started

# But the equations gives results outside of the [-180, 180] or [-90, 90] ranges

#### So I created a function to set all angles in the right ranges:

#### The Final roll pitch yaw corected equations are:

```
roll_A = Correction( 180 , TO_DEG( atan2(A[2], A[3])) - roll_init );
pitch_A = Correction( 90 , TO_DEG( atan(A[1]/sqrt(A[2]*A[2]+A[3]*A[3])) ) - pitch_init );
Xh = M[1] * cos(TO_RAD(pitch)) + M[3] * sin(TO_RAD(pitch));
Yh = M[1] * sin(TO_RAD(roll)) * sin(TO_RAD(pitch)) + M[2] * cos(TO_RAD(roll)) - M[3] * sin(TO_RAD(roll)) * cos(TO_RAD(pitch));
yaw_M = Correction( 180 , TO_DEG(atan2(Yh,Xh)) - Heading );
```

#### Add the data into Excel

#### Just to check that everything is OK

#### Replace print block by this one:

#### Serial.print("DATA,TIME,");

```
Serial.print(dt);
                       Serial.print(",");
Serial.print(A[1]);
                       Serial.print(","); Serial.print(A[2]); Serial.print(","); Serial.print(A[3]); Serial.print(",");
                       Serial.print(","); Serial.print(G[2]); Serial.print(","); Serial.print (G[3]); Serial.print(",");
Serial.print(G[1]);
Serial.print(M[1]);
                       Serial.print(","); Serial.print(M[2]); Serial.print(","); Serial.print (M[3]); Serial.print(",");
Serial.print(roll_A); Serial.print(","); // roll calculated using accelerometer's data
Serial.print(roll);
                       Serial.print(","); // final roll, will be used in step 2, not used for now
Serial.print(pitch_A); Serial.print(","); // pitch calculated using accelerometer's data
Serial.print(pitch);
                       Serial.print(","); // final pitch, will be used in step 2 , not used for now
Serial.print(yaw_M);
                       Serial.print(","); // yaw calculated using magnetometer's data
Serial.print(yaw);
                       Serial.print(","); // final yaw, will be used in step 2 , not used for now
Serial.println();
```

#### Add the data into Excel



# AHRS

Step 2 Calculate roll pitch yaw using gyro

# Using gyro

#### If IMU is flat it is simple

roll\_G = roll + dt \* G[1] ;
pitch\_G = pitch + dt \* G[2] ;
yaw\_G = yaw + dt \* G[3] ;

#### If IMU is not flat it is not simple, we must correct the angular rates of the gyro to Euler's angular rates first

The resulting transformation matrix for converting body-frame angular rates to Euler angular rates is given by

 $D(\phi, \theta, \psi) = \begin{pmatrix} 1 & \sin(\phi) \tan(\theta) & \cos(\phi) \tan(\theta) \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi) / \cos(\theta) & \cos(\phi) / \cos(\theta) \end{pmatrix}.$  Source: http://www.chrobotics.com/library/understanding-euler-angles

#### Final gyro's equations:

roll\_G = roll + dt \* (G[1]+sin(TO\_RAD(roll))\*tan(TO\_RAD(pitch))\*G[2]+cos(TO\_RAD(roll))\*tan(TO\_RAD(pitch))\*G[3]); pitch\_G = pitch + dt \* (cos(TO\_RAD(roll))\*G[2]-sin(TO\_RAD(roll))\*G[3]); yaw\_G = yaw + dt \* (sin(TO\_RAD(roll))/cos(TO\_RAD(pitch))\*G[2]+cos(TO\_RAD(roll))/cos(TO\_RAD(pitch))\*G[3]);

# AHRS

Step 3 Combine step 1 and 2



Source: https://b94be14129454da9cf7f056f5f8b89a9b17da0be.googledrive.com/host/0B0ZbiLZrqVa6Y2d3UjFVWDhNZms/filter.pdf

If roll pitch and yaw are small, then it is easy to code:

roll = 0.02 \* roll\_A + 0.98 \* roll\_G ; pitch = 0.02 \* pitch\_A + 0.98 \* pitch\_G ; yaw = 0.02 \* yaw\_M + 0.98 \* yaw\_G ;

But this does not work when angles are large



Roll oscillations around 180 IMU is flipped

#### If roll pitch and yaw are large we have to take into account that the arithmetic mean is not the same as the mean used on angles

```
roll = CompFilter( 180, roll_A, roll_G );
pitch = CompFilter( 90, pitch_A, pitch_G );
yaw = CompFilter( 180, yaw_M, yaw_G );
```

# I created a function that convert the angles before calculating the mean:



roll

calculated roll

# The CompFilter function could have been avoided using the mean of circular quantities like this

roll = atan2(0.02\*sin(roll\_A) +0.98\*sin(roll\_G) , 0.02\*cos(roll\_A) +0.98\*cos(roll\_G)); pitch = atan2(0.02\*sin(pitch\_A)+0.98\*sin(pitch\_G) , 0.02\*cos(pitch\_A)+0.98\*cos(pitch\_G)); yaw = atan2(0.02\*sin(yaw\_M) +0.98\*sin(yaw\_G) , 0.02\*cos(yaw\_M) +0.98\*cos(yaw\_G));

# This code is more elegant, does not require the CompFilter function but it is slightly slower.

More info here: http://en.wikipedia.org/wiki/Mean\_of\_circular\_quantities

# IMU and AHRS are working

#### Data visualization Excel



#### **Data visualization Processing**

Looking at the data in Excel is good for calibration, a processing sketch is better for visualization

IMU_Processing   Processing 1.2.1			
File Edit Sketch Tools Help			
IMU_Processing			+
Serial fd;		MU_Processing	
int nitch - 0.			
int roll = 0;			
<pre>int yaw = 0;</pre>			
void setup ()			
(			
<pre>size(640, 640, P3D); fd = new Serial(this, Serial, list()[1].</pre>	96001: // Connect to the corresponding serial port		
fd.bufferUntil('\n');	// Defer callback until new line		
) )			
void draw ()			
( · · · · · · · · · · · · · · · · · · ·			
<pre>background(0.5);</pre>	// Set background		
pushMatrix();			
translate(width/2, height/2, -30);			
<pre>rotateZ(((float)pitch)*PI/180.0); rotateZ(((float)roll )*PI/180.0);</pre>	// Rotate		
<pre>rotateY(((float)yaw) *PI/180.0);</pre>			
<pre>print("Pitch: "); print(pitch);</pre>	// Print data		
<pre>print(", Roll: "); print(roll);</pre>			
<pre>print(", Yaw: "); println(yaw);</pre>			
scale(90); heginShane(OUADS);			
		L	
fill(0, 255, 0); vertex(-1, 0.1, 1);			-
			•
Pitch: 2, Roll: 5, Yaw: 39 Ditch: 2, Roll: 5, Yaw: 39			
Ditch: 2 Doll: 5 Yaw: 39			

# Final note

# Simpler algorithm

You might not need a full AHRS algorithm, for example in a balancing robot or hovering quadcopter where the IMU is flat

sin(x) = x

if x is small, typically x < 20°

This means that you do not have to use any trigonometry, this lead to much faster algorithms

Also, you do not have to convert the gyro's body frame to Euler's angles, because they are almost the same. This lead to even faster algorithms

#### Example balancing robot

Declarations and Setup function are the same as previously

```
void loop() {
 // GET DATA ------
 compass.read();
 qyro.read();
 dt = millis()-t;
 t = millis();
 // CALIBRATE DATA ------
 A[2] = (compass.a.y - ACCEL_Y_OFFSET) * ACCEL_Y_SCALE * ACCEL_Y_DIR; // Gather only necessary data
 A[3] = (compass.a.z - ACCEL_Z_OFFSET) * ACCEL_Z_SCALE * ACCEL_Z_DIR;
 G[1] = (gyro.g.x - GYRO_OFFSET_X) * GYRO_SCALE * GYRO_X_DIR ;
 // CALCULATE ROLL ONLY ------
 roll_A = TO_DEG(A[2]/A[3]) - roll_init; // no trigonometry here, accurate for angles bellow 30 degrees
 roll_G = roll + dt * G[1]; // no body frame to Euler conversion here
 roll = 0.04 * roll_A + 0.96 * roll_G; // simple complementary filter here
 // PID -----
 error = Setpoint - roll;
 integral = integral + error * dt;
 derivative = (error - previous_error) / dt;
 previous_error = error;
 Output = Kp*error + Ki*integral + Kd*derivative;
 // MOTORS ------
  motorGo(0, Output); // function that turn on the motor's to a specific speed
  motorGo(1, Output);
```

The simplifications make the code short and simple

}

# GL HF