Table of Contents

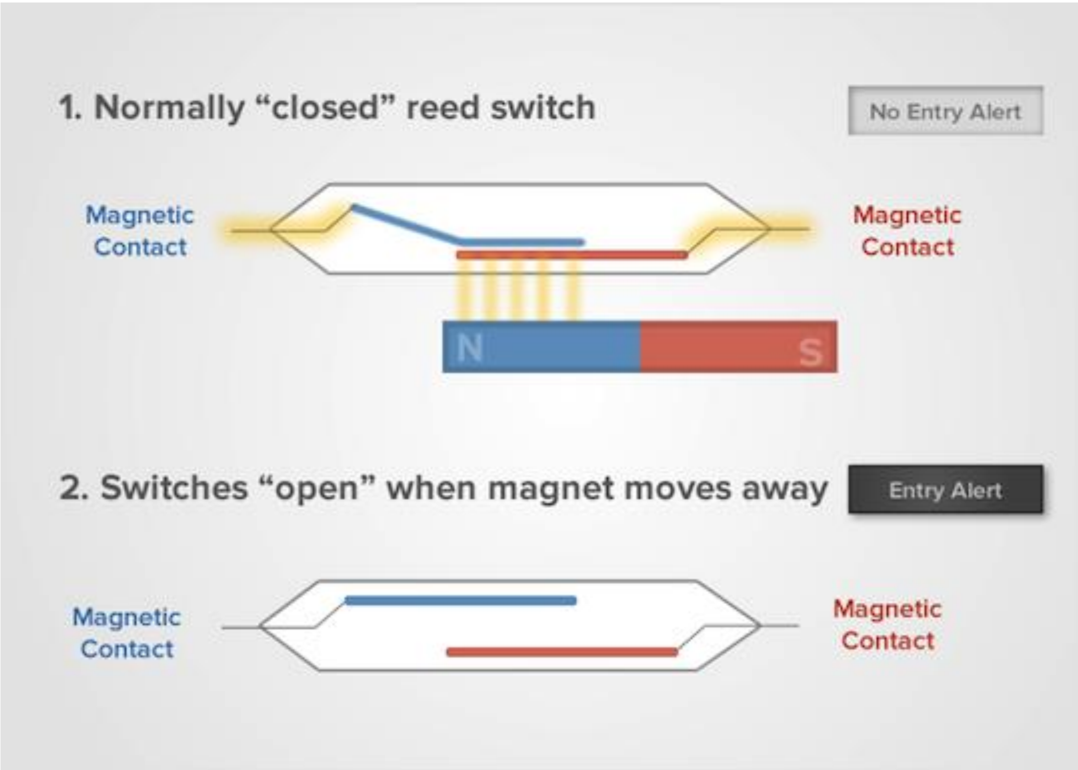
Project Purpose

Background

Entrances and exits are your home's weakest points—and to a burglar, an unsecured door or window is like a big "WELCOME" sign. That's why door sensors—also known as "entry sensors" or "window sensors"— are some of the most popular home security devices. Before technology evolved, home security systems were entirely made up of door sensors—when someone opened a door or window, it triggered a big vibrating bell in a central part of the home. Nowadays, technology has improved the market offers different choices. Here is a short description of the most popular entry sensor today.

Magnetic Sensors

Most of the door and window sensors use a "reed switch" to determine when a monitored entrance has been breached. A reed switch consists of a set of electrical connectors placed slightly apart. When a magnetic field is placed parallel to the electrical connectors, it pulls them together, closing the circuit.



Door sensors have one reed switch and one magnet, creating a closed circuit. If someone opens the door or window, the magnet is pulled away from the switch, which breaks the circuit and triggers an alarm.

A system made of reed switch and a magnet has some disadvantages. One of them is that for some doors and windows the system may not fit, such as doors and windows with very deep frames. Another disadvantage is that metal objects can affect the sensors performance and may cause false-positive events or even miss true events. The biggest disadvantage of the magnet operated sensor is that a burglar can use a special magnet and trick the system, an unlikely event, but still possible.

Project Description

A window opening detector is a sensor used in electronic burglar alarms that detects if a window or door is opened. There are different products in the market which detect window opening. Most of them, work with magnets. In our project, we'll use an accelerometer to detect movements of the window or door. Our product uses a micro-controller and an accelerometer from ST product catalog.

A window opening is detected when the position or angle calculated from the accelerometer's data is above the threshold value. An accelerometer sensor can identify the acceleration and return the value to the micro-controller for analyzing process.

//TODO (it's old, rewrite and stuff)
The product will work as following:

1. The accelerometer analyzes the vibrations on the glass constantly.
2. The micro-controller contains an algorithm.
3. The algorithm checks the output values from the accelerometer.
    a. If the value is above the threshold value-
        i. The glass is broken!

For making this program work, we need to identify the threshold accelerate when a glass breaks. Therefore, when we get a value equal or higher from the threshold value, a breaking is detected.

According to the products available today in the market, they use a 3-axis accelerometer that detects $\pm 2g$. Therefore, the threshold value if lower than 2g. We will know exactly the threshold value after testing few glass breakings.

There is an accelerometer that satisfies this purpose (at least for now) in ST catalog- AIS328DQ.

Some of the feature:

- Wide supply voltage range: 2.4 V to 3.6 V
- Low voltage compatible IOs: 1.8 V
- Ultra low-power mode consumption: down to 10 μA
- ±2g/±4g/±8g dynamically selectable full-scale
- output data rates from 0.5 Hz to 1 kHz

Our micro-controller, STM32F411, works with 100MHz, so it's able to analyze all the output rates from the accelerometer.

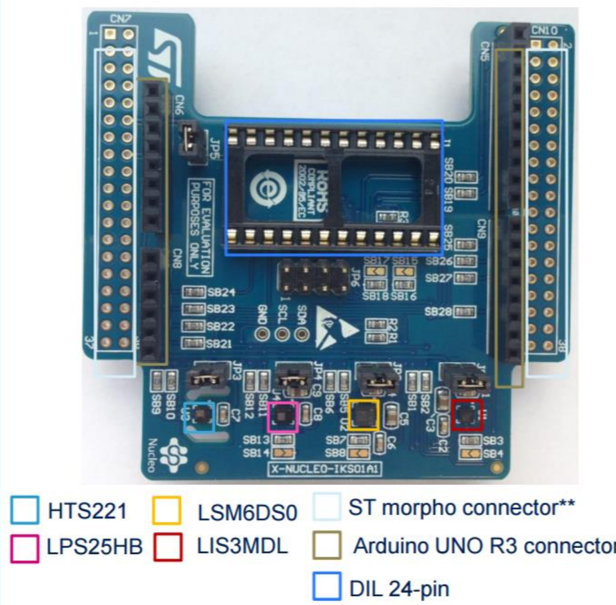
Hardware Description

X-NUCLEO-IKS01A1 - motion MEMS and environmental sensor

The X-NUCLEO-IKS01A1 is a motion MEMS and environmental sensor evaluation board system. It is compatible with the Arduino UNO R3 connector layout, and is designed around STMicroelectronics' LSM6DS0 3-axis accelerometer + 3-axis gyroscope, the LIS3MDL 3-axis magnetometer, the HTS221 humidity and temperature sensor and the LPS25HB* pressure sensor. The X-NUCLEO-IKS01A1 interfaces with the STM32 microcontroller via the I²C pin, and it is possible to change the default I²C port.

<u>Features:</u>

- LSM6DS0: MEMS 3D accelerometer (±2/±4/±8 g) + 3D gyroscope (±245/±500/±2000 dps)
- LIS3MDL: MEMS 3D magnetometer (±4/ ±8/ ±12/ 16 gauss)
- LPS25HB*: MEMS pressure sensor, 260-1260 hPa absolute digital output barometer
- HTS221: capacitive digital relative humidity and temperature
- DIL 24-pin socket available for additional MEMS adapters and other sensors (UV index)
- Free comprehensive development firmware library and example for all sensors compatible with STM32Cube firmware
- Compatible with STM32 Nucleo boards
- Equipped with Arduino UNO R3 connector
- RoHS compliant



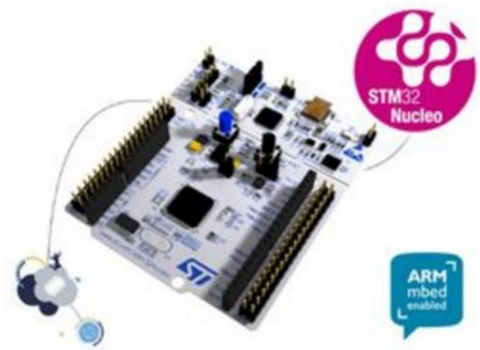
NUCLEO-F411RE - Microcontroller

A platform to ease prototyping using a STM32F411RET6 microcontroller. The STM32 Nucleo board provides an affordable and flexible way for users to try out new ideas and build prototypes with any STM32 microcontroller line, choosing from the various combinations of performance, power consumption and features.

The Arduino™ connectivity support and ST Morpho headers make it easy to expand the functionality of the STM32 Nucleo open development platform with a wide choice of specialized shields.

The STM32 Nucleo board does not require any separate probe as it integrates the ST-LINK/V2-1 debugger/programmer.

<u>Microcontroller features</u>



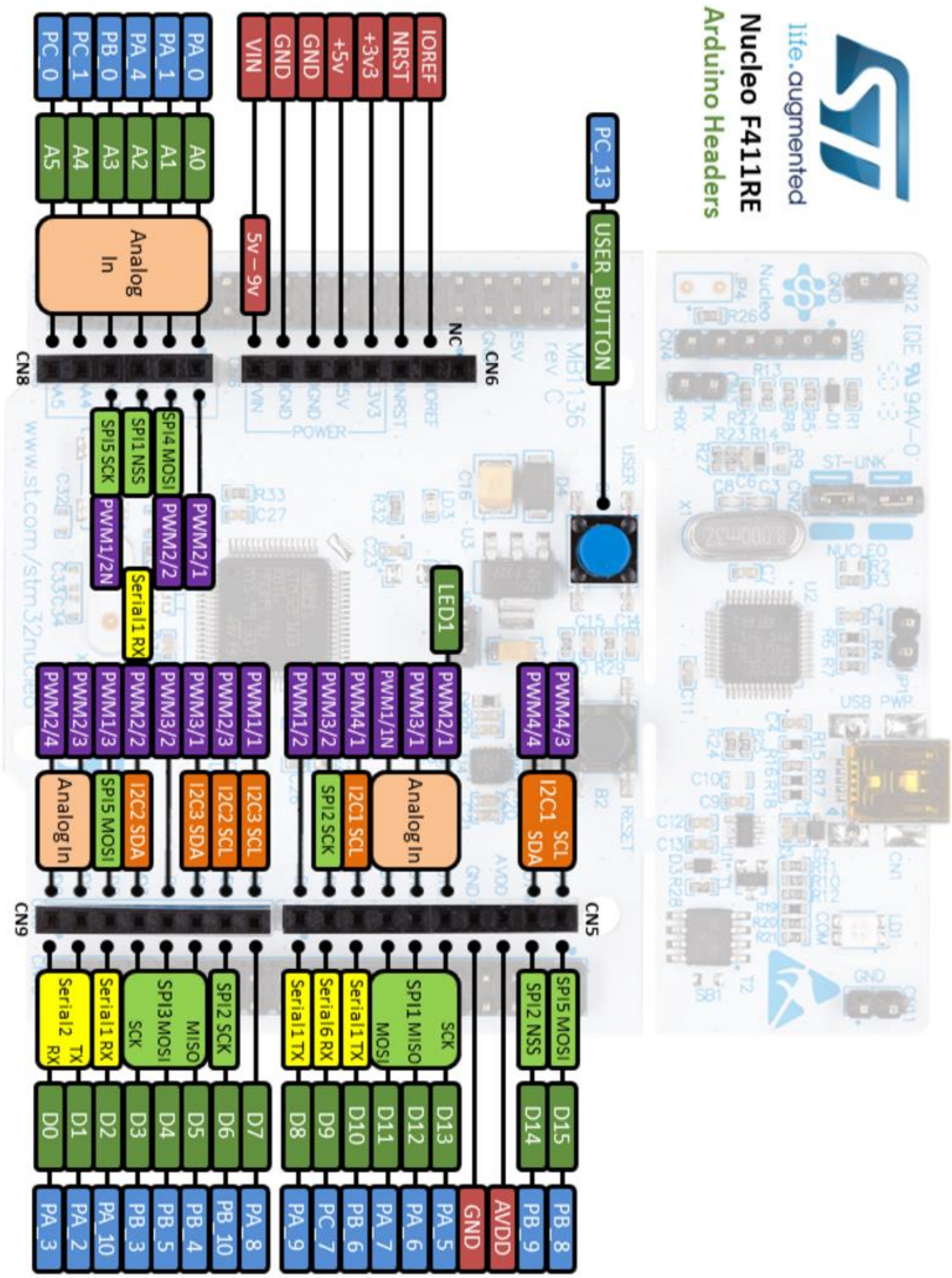
- STM32F411RET6 in LQFP64 package
- ARM®32-bit Cortex®-M4 CPU with FPU
- 100 MHz max CPU frequency
- VDD from 1.7 V to 3.6 V
- 512 KB Flash
- 128 KB SRAM
- GPIO (50) with external interrupt capability
- 12-bit ADC with 16 channels
- RTC
- Timers (8)
- I2C (3)
- USART (3)
- SPI (5)
- USB OTG Full Speed
- SDIO

<u>Nucleo features</u>

- Two types of extension resources
- Arduino Uno Revision 3 connectivity
- STMicroelectronics Morpho extension pin headers for full access to all STM32 I/Os
- On-board ST-LINK/V2-1 debugger/programmer with SWD connector
- Selection-mode switch to use the kit as a standalone ST-LINK/V2-1
- Flexible board power supply
- USB VBUS or external source (3.3 V, 5 V, 7 - 12 V)
- Power management access point
- User LED (LD2)
- Two push buttons: USER and RESET
- USB re-enumeration capability: three different interfaces supported on USB
- Virtual Com port
- Mass storage (USB Disk drive) for drag'n'drop programming
- Debug port

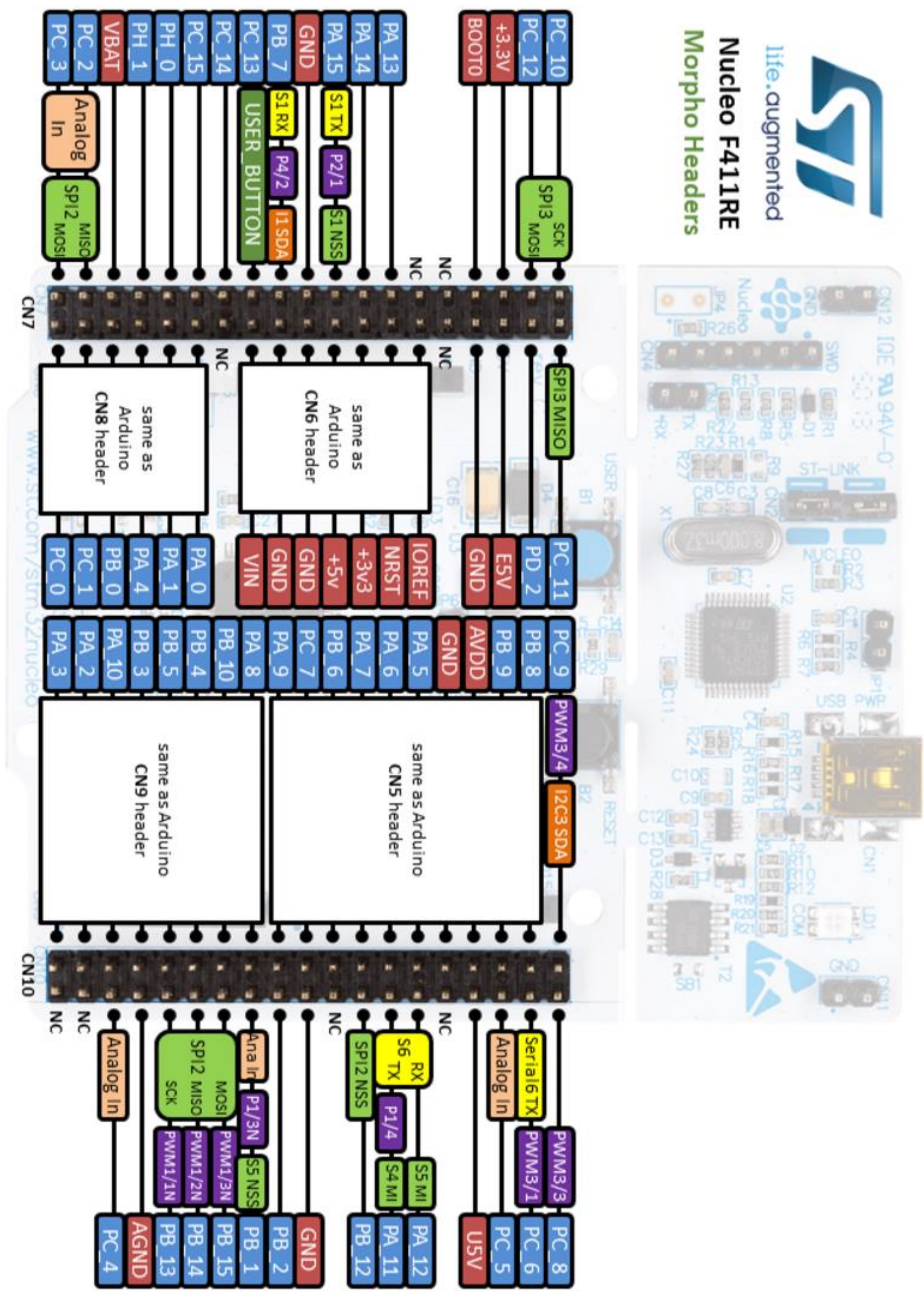
Nucleo pinout

Arduino-compatible headers



Morpho headers

These headers give access to all STM32 pins.

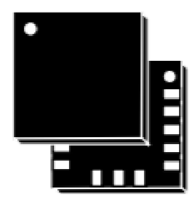


LSM6DS0 Sensor - 3D accelerometer and 3D gyroscope

The LSM6DS0 is a system-in-package featuring a 3D digital accelerometer and a 3D digital gyroscope. ST's family of MEMS sensor modules leverages the robust and mature manufacturing processes already used for the production of micromachined accelerometers and gyroscopes. The various sensing elements are manufactured using specialized micromachining processes, while the IC interfaces are developed using CMOS technology that allows the design of a dedicated circuit which is trimmed to better match the sensing element characteristics. The LSM6DS0 has a full-scale acceleration range of ±2/±4/±8/±16 g and an angular rate range of ±245/±500/±2000 dps. The LSM6DS0 has two operating modes in that the accelerometer and gyroscope sensors can be either activated at the same ODR or the accelerometer can be enabled while the gyroscope is in power-down. The LSM6DS0 is available in a plastic land grid array (LGA) package.

Features

- Analog supply voltage: 1.71 V to 3.6 V
- Independent IOs supply (1.71 V)
- "Always on" eco power mode down to 1.8 mA
- 3 independent acceleration channels and 3 angular rate channels
- ±2/±4/±8/±16 g full scale
- ±245/±500/±2000 dps full scale
- SPI/I2C serial interface
- Embedded temperature sensor
- Embedded FIFO
- ECOPACK®, RoHS and "Green" compliant



LGA-16L (3x3x0.86 mm)

Applications

- GPS navigation systems
- Impact recognition and logging
- Gaming and virtual reality input devices
- Motion-activated functions
- Intelligent power saving for handheld devices
- Vibration monitoring and compensation
- Free-fall detection
- 6D orientation detection

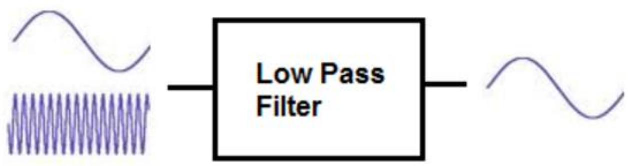
Table 1. Device summary

Part number	Temp. range [°C]	Package	Packing
LSM6DS0	-40 to +85	LGA-16L (3x3x0.86 mm)	Tray
LSM6DS0TR	-40 to +85		Tape and reel

TODO: ADD MORE

Low Pass Filter

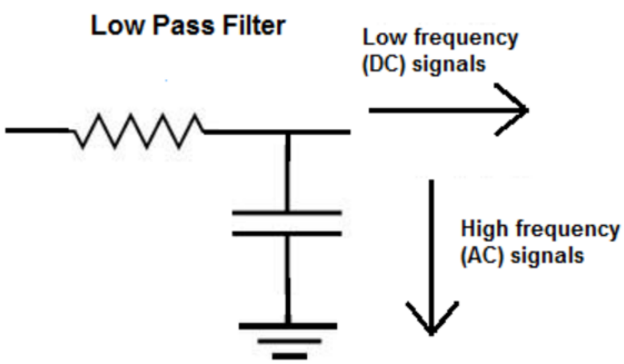
Theory – how low pass filter works



A low pass filter is a filter which passes low-frequency signals and blocks, or impedes, high-frequency signals.

Low-frequency signals go through much easier and with less resistance while high-frequency signals have a much harder getting through, which is why it's a low pass filter. Low pass filters can be constructed using resistors with either capacitors or inductors. A low pass filter composed of a resistor and a capacitor is called a low pass RC filter. A low pass filter composed of a resistor and an inductor is called a low pass RL filter. Both circuits have the effect of passing through low frequency signals while impeding high-frequency ones.

Low pass RC filter:

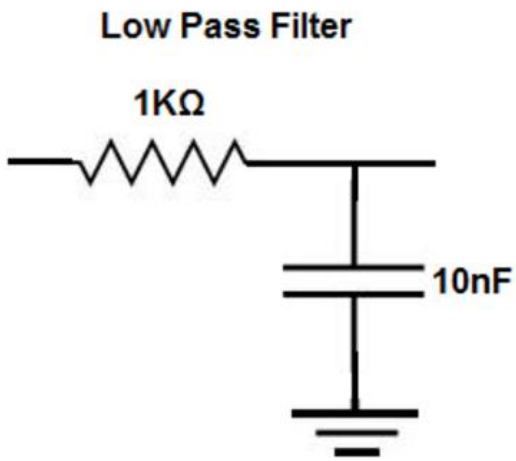


To create a low pass RC filter, the resistor is placed in series to the input signal and the capacitor is placed in parallel to the input signal, such as shown in the circuit below:

So, with this setup, the above circuit is a low pass filter. As a capacitor is a reactive device, it offers differing resistance to signals of different frequencies entering through it. A capacitor is a reactive device which offers very high resistance to low-frequency or DC signals. And it offers low resistance to high-frequency signals. As it offers very high resistance to DC signals, in this circuit, it will block DC from entering and pass them off to an alternative part in the circuit, which is shown to the right by the arrow. High-frequency signals will go through the capacitor, since the capacitor offers them a very low-resistance path. Remember that current always takes the path of least resistance. Being that a capacitor represents a low resistance in a circuit for high-frequency signals, they will take the path through the capacitor, while low-frequency signals will take an alternative, lower-resistance path.

How to Build a Low Pass RC Filter

Now that we've gone through what a low pass RC filter is, let's go over a practical example of building one.



To build a low pass filter, the components we will use are a function generator, a 10nF ceramic capacitor, and a 1KΩ resistor.

This is the schematic of the circuit we will build, shown below:

The formula to find the frequency cutoff point of an RC circuit is, frequency= 1/2πRC. Doing the math, with the values shown above, we get a frequency of, frequency= 1/2πRC = 1/2(3.14)(1KΩ)(10nF)= 15,923 Hz, which is approximately 15.9KHz.

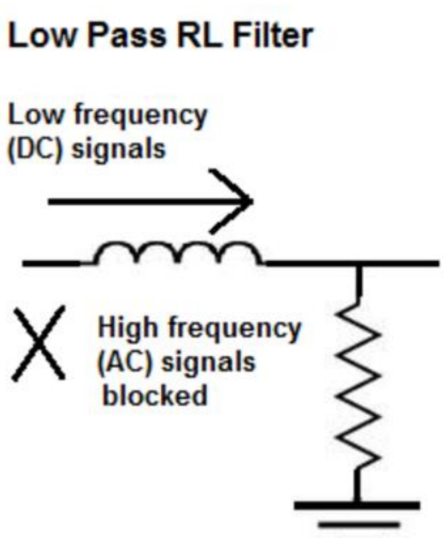
This means that all frequencies above 15.9KHz are attenuated. And as you get further (higher) from the 15.9KHz region, the attenuation becomes greater and greater.

Frequencies below 15.9KHz are passed through without attenuation.

So if we input an AC signal into the circuit from the function generator and make the signal a low frequency such as 10Hz, the circuit will pass this signal to output almost completely unattenuated. This is because low frequency signals do not take the path of the capacitor. You can check this if you have an oscilloscope. If you now increase the frequency of the signal to 30KHz, the signal will pass through to output with great attenuation. This is because high-frequency signals go through the capacitor and not to output, because capacitor is low resistance to them.

Low Pass RL Filter

A low pass RL filter, again, is a filter circuit composed of a resistor and inductor which passes through low-frequency signals, while blocking high-frequency signals.



To create a low pass RL filter, the inductor is placed in series with the input signal and the resistor is placed in parallel to the input signal, such as shown in the circuit below:

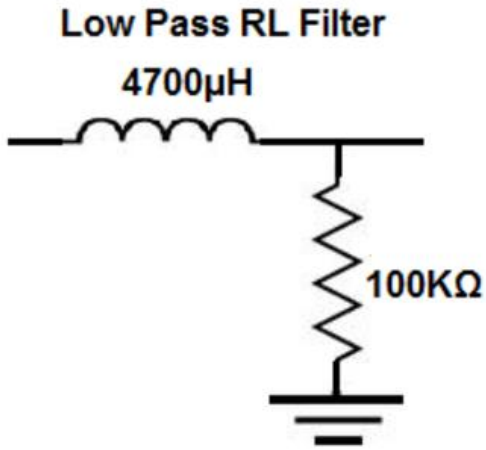
This circuit above is a low pass RL filter. How it works is based on the principle of inductive reactance. Inductive reactance is how the impedance, or resistance, of the inductor changes based on the frequency of the signal passing through the inductor. Unlike a resistor, which is a nonreactive device, an inductor offers differing impedance values to signals of differing frequencies, just as capacitors do. However, unlike capacitors, inductors offer very high resistance to high-frequency signals and offers low resistance to low-frequency signals. So it's the opposite of a capacitor. Therefore, the placement of the resistors are switched in RC and RL filter circuits. So, based on this, the above RL circuit works effectively as a low pass filter. It blocks high-frequency signals from entering and allows low-frequency signals to pass through unimpeded.

How to Build a Low Pass RL Filter

So, now that RL filters have been summarized, let's go over a practical example of building one.

To build a low pass filter, the components we will use are a function generator, a 4700µH inductor, and a 100KΩ resistor.

This is the schematic of the circuit we will build, shown below:



The formula to find the frequency cutoff point of an RL circuit is, frequency= 2πRL. Doing the math, with the values shown above, we get a frequency of, frequency= 2πRL = 2(3.14)(100KΩ)(4700µH)= 2,951 Hz, which is approximately 2.9KHz.

This means that all frequencies above 2.9KHz are attenuated. And as you get further (higher) from the 2.9KHz region, the attenuation becomes greater and greater.

Frequencies below 2.9KHz are passed through without attenuation.

So, again, you can check this on an oscilloscope to see that very low-frequency signals are passed through to output unattenuated, while high-frequency signals undergo attenuation.

Formula

For vector x of size n, time between samples dt and frequency ws, LPF is computed as the following:

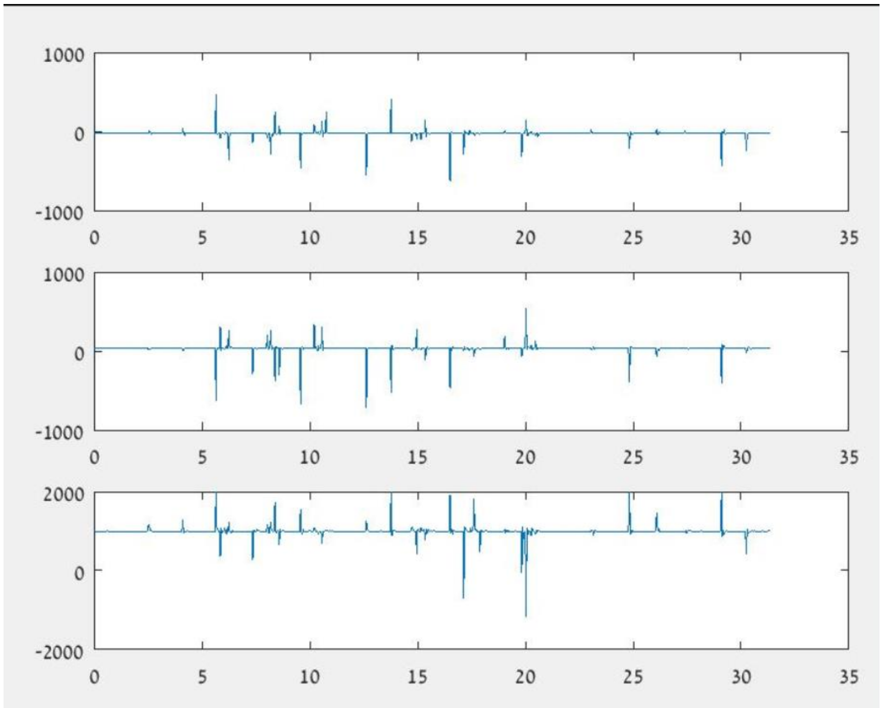
```
function y = lowpass(x, dt, ws)
n = size(x,2);
RC = dt * ws;
y = zeros(1,n);
a = dt / (RC + dt);
y(1) = x(1) * a;
for i = 2:n
  y(i) = a * x(i) + (1-a) * y(i-1);
end
```

We get the filtered vector y of size n.

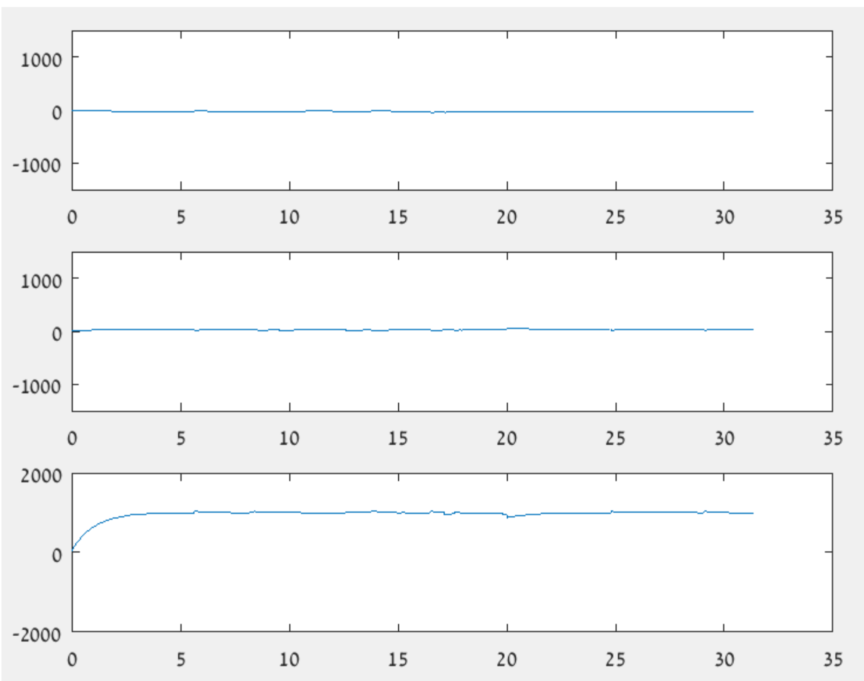
Low Pass Filter experiment:

In order to record data for this experiment we tapped the sensor to create high frequency peaks. We analyzed the data from the accelerometer for each of the 3 axes. The expected results are that the data without the lowpass filter will contain many peaks and will be unstable, while the filtered data will be stable.

Unfiltered Data:

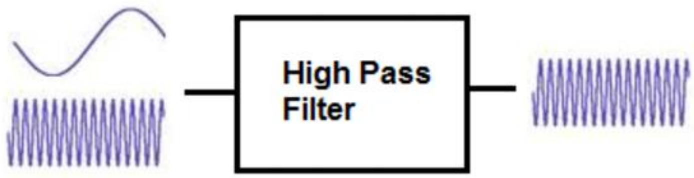


Filtered data:



High Pass Filter

Theory – how high pass filter works



A high pass filter is a filter which passes high-frequency signals and blocks, or impedes, low-frequency signals.

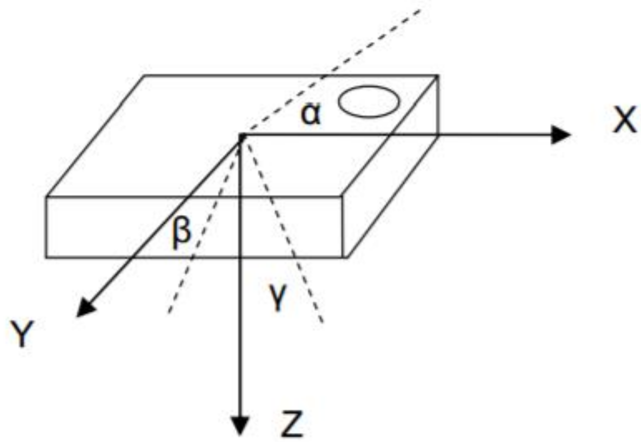
In other words, high-frequency signals go through much easier and low-frequency signals have a much harder getting through, which is why it's a high pass filter.

High pass filters can be constructed using resistors with either capacitors or inductors. A high pass filter composed of a resistor and a capacitor is called a high pass RC filter. And a high pass filter with a resistor and an inductor is called a high pass RL filter.

Calculating Pitch & Roll angles

Tri-axis tilt sensing:

With a 3-axis accelerometer, the user can use the Z-axis to combine with the X and Y axes for tilt sensing in order to improve tilt sensitivity and accuracy as shown in the next figure. We use trigonometric equations to calculate pitch and roll tilt angle, which produces constant sensitivity over 360° of rotation.

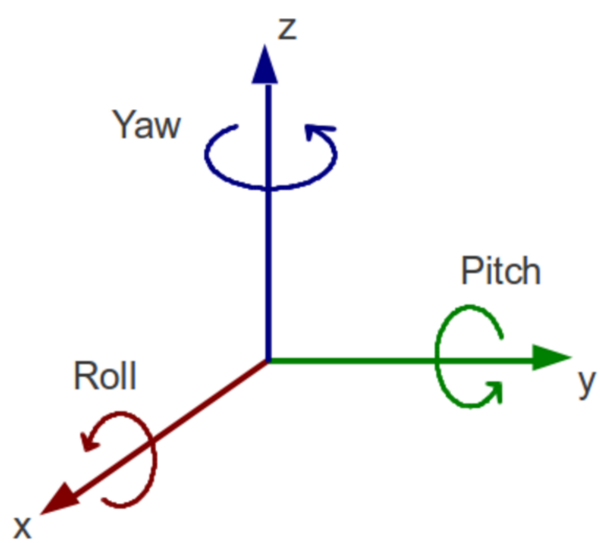


$$Pitch = \alpha = arctan\left(\frac{x}{\sqrt{y^2 + z^2}}\right)$$

$$Roll = \beta = arctan\left(\frac{y}{\sqrt{x^2 + z^2}}\right)$$

$$Yaw = \ \gamma = \arctan\left(\frac{\sqrt{x^2 + y^2}}{z}\right)$$

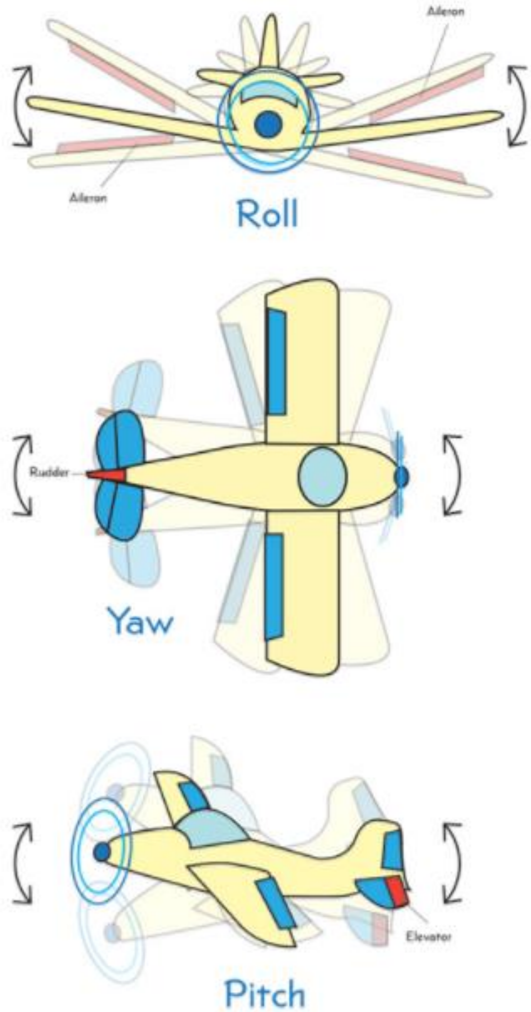
When pitch, roll and yaw angles are as following:



Those angles are usually used in airplanes, submarines and even cars.

For example, demonstrating the angle movements on an airplane help to understand each angle's position.

Vehicles that are free to operate in three dimensions, such as aircraft and submarines, can change their attitude and rotation about the three orthogonal axes centered on the vehicle's center of gravity — the longitudinal, vertical, and horizontal axes. Motion about the longitudinal axis is termed roll and in aircraft determines how much the wings are banked. Motion about the perpendicular axes is called yaw and for aircraft it determines which way the nose is pointed. Motion about the lateral axis is called pitch and it's a measure of how far an airplane's nose is tilted up or down.



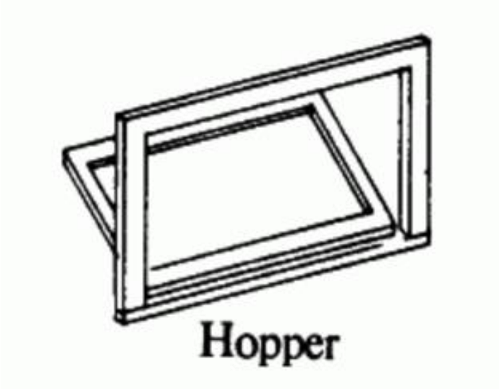
Cars also experience pitch, roll, and yaw, but the amounts are relatively small and are usually the result of the suspension reacting to turns, accelerations, and road conditions.

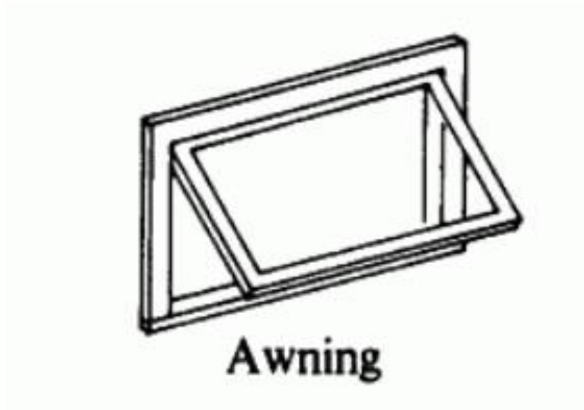
Opening Hopper and Awning windows

Theory

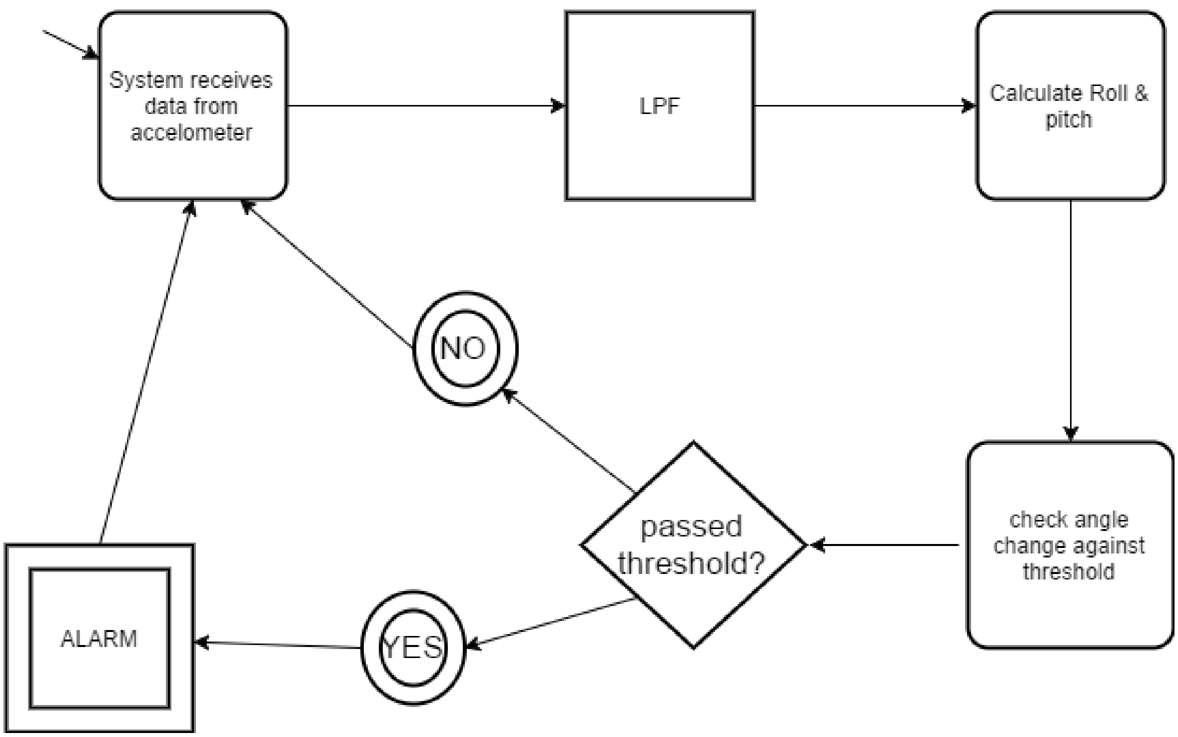
This window’s opening can be detected by calculating the change in the angle.

The system is attached to the window \ door. The accelerometer records 25 samples per second. The data is passed through LPF. Then, the angle is calculated from the new data.





General Diagram:



Hopper and Awning windows opening detection uses only the Roll angle. We assume the system starts when the window is closed.

<u>Threshold:</u>

Opening is detected as following:

$$Current_{Angle} \leq Start_{Angle} - threshold$$

Closing is detected as following:

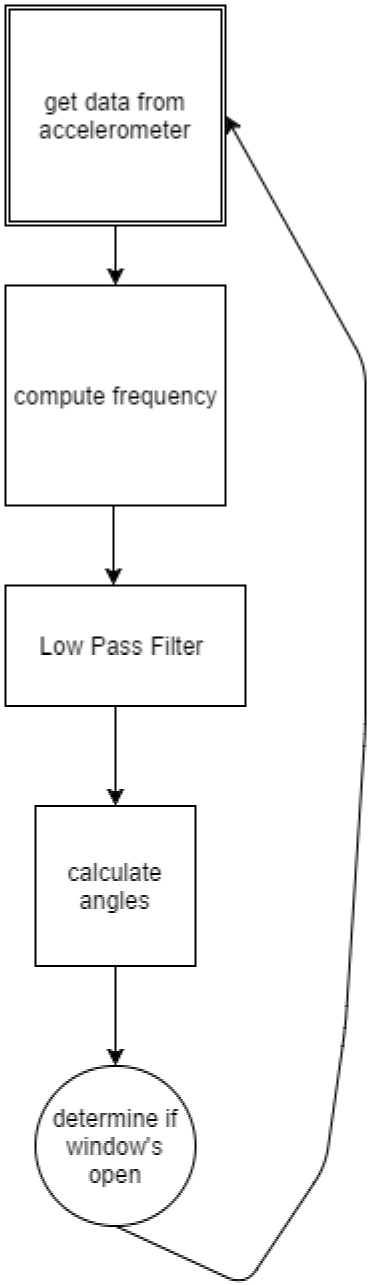
$$Current_{Angle} \geq Start_{Angle} - \frac{threshold}{2}$$

when

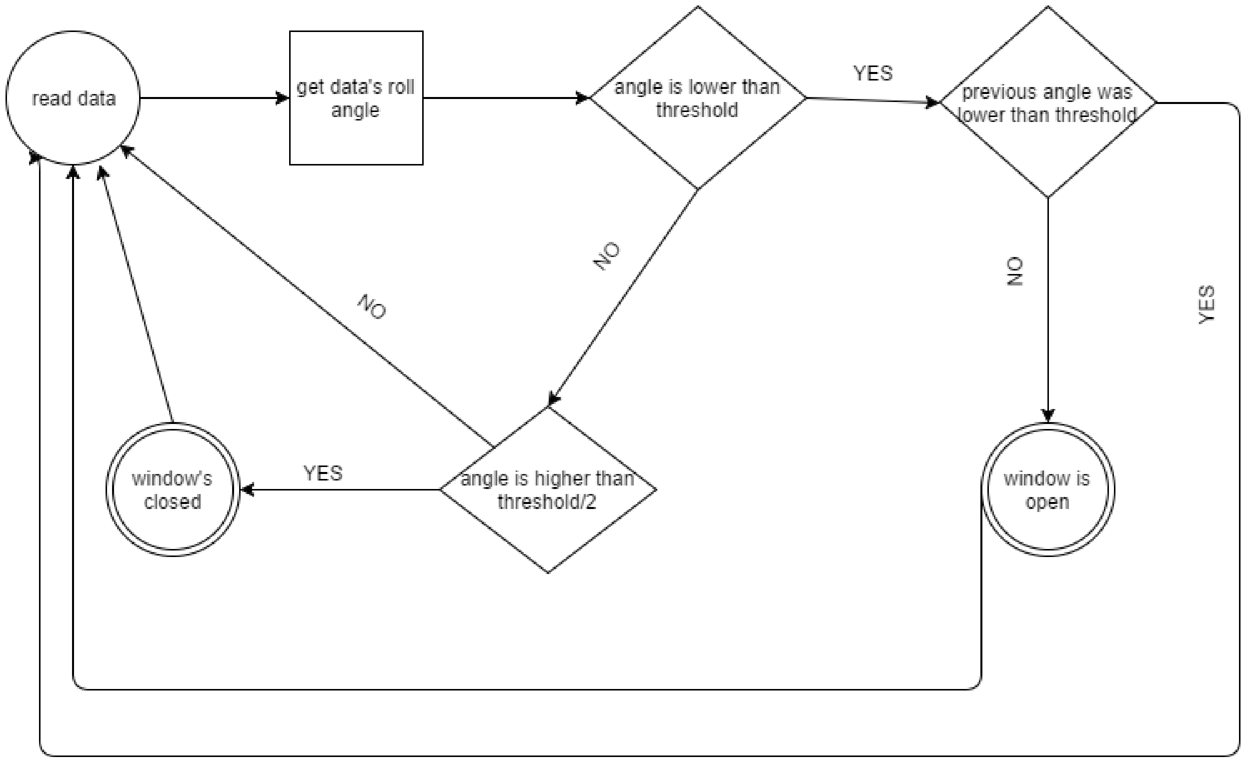
$$threshold = 0.4$$

The threshold was found after an initial experiment. We found that the window is completely closed at angle of 1.6 (aprox.). When angle reaches 0.4 below the starting angle it is absolutely opened, considering building angle and window straightness.

Detailed diagram of the code for hopper and awning window:



The following diagram expands and explains the “determine if window’s open” circle:



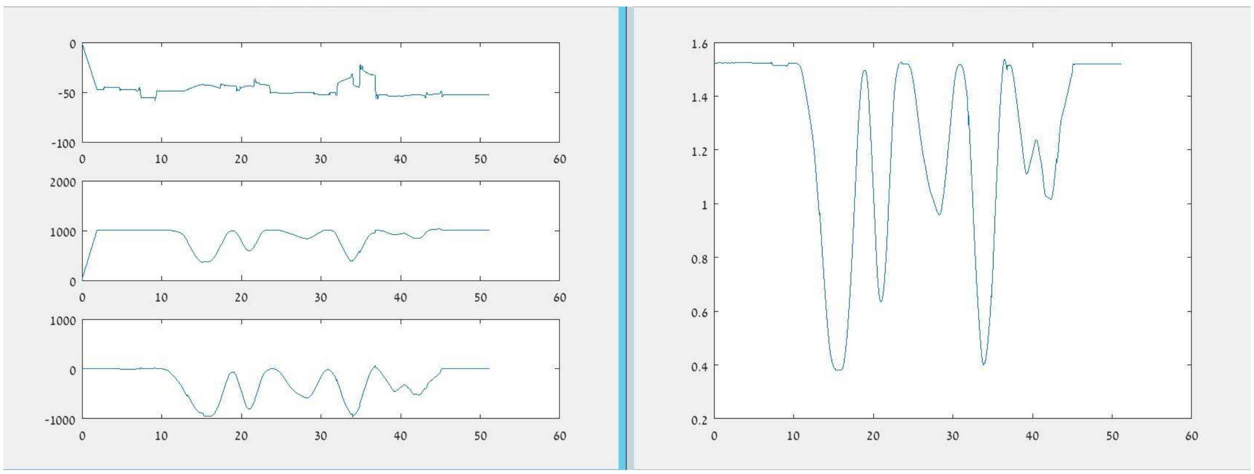
Experiments Data: (move to nispahim)

Example data for opening event:

time stamp	X	Y	Z
19610294	-95	903	430
19648835	-96	888	507
19687377	-71	853	491
19725919	-81	838	528
19764460	-59	837	614
19803002	-51	798	503
19841544	-73	792	529
19880085	-57	756	578
19918627	-58	736	629
19957169	-53	698	654
19995710	-68	663	635
20034252	-66	650	756
20072794	-97	589	778
20111335	-75	573	762

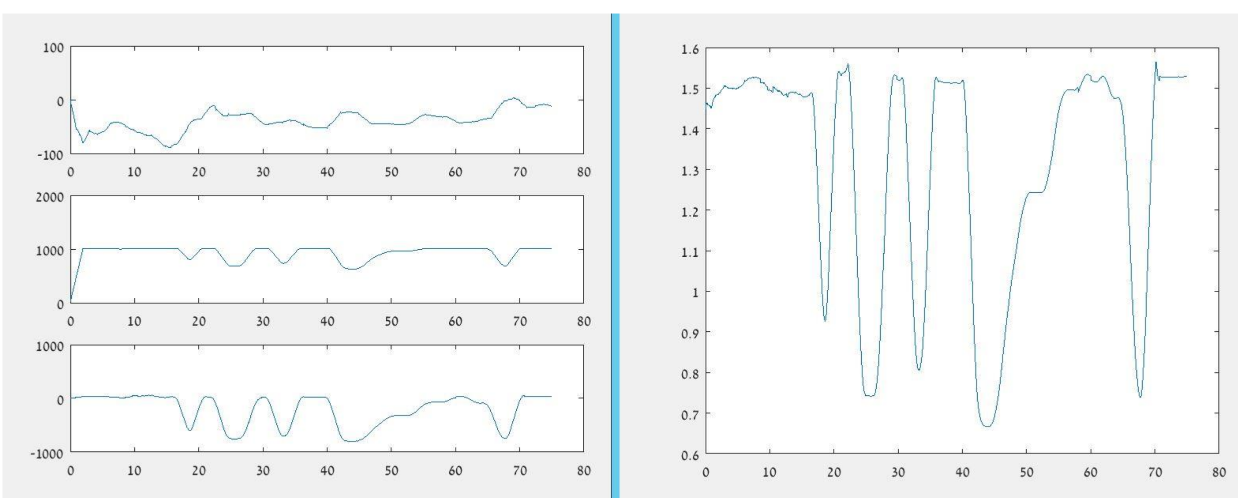
20149877	-77	573	938
20188419	**-143**	**524**	**874**
20226960	**-119**	**528**	**1001**
20265502	**-128**	**510**	**1031**
20304044	**-131**	**496**	**1034**
20342585	-99	488	1034
20381127	-89	474	949

The following graphs are produced from the hopper experiment:



The left 3 graphs represent the acceleration changes after LPF.
The right graph represents the Roll angle. We can see that the hopper window was opened and closed completely 5 times and one mock closing. The program detected 5 openings and ignored the mock as expected.

The following graphs are produced from the awning experiment:



The left 3 graphs represent the acceleration changes after LPF.
The right graph represents the Roll angle. We can see that the awning window was opened and closed completely 5 times and one mock closing. The program detected 5 openings and ignored the mock as expected.