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Accelerometer

An accelerometer is a primary sensor responsible for measuring inertial acceleration, also known as specific force, acting on its input axis direction. As also mentioned before, to provide a three-dimensional solution, 3 accelerometers are needed, one for each orthogonal axis. The 3 accelerometers mounts together in an almost orthogonal cluster (due imperfections), also known as triad. The perfect orthogonal reference frame defined by the accelerometers ideal orthogonal input directions is defined as the platform reference frame.

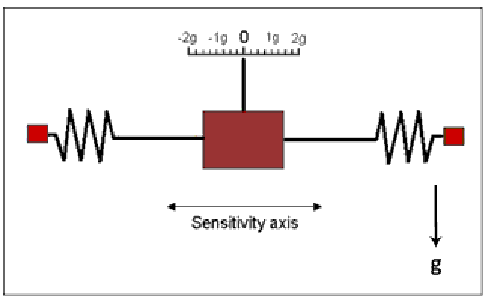
There are several of types of accelerometers, the mechanical accelerometer is here given as a model example. From physics we know that velocity is the change in position over time.

$$\bar{\mathbf{v}} = \frac{\Delta\mathbf{x}}{\Delta t}$$

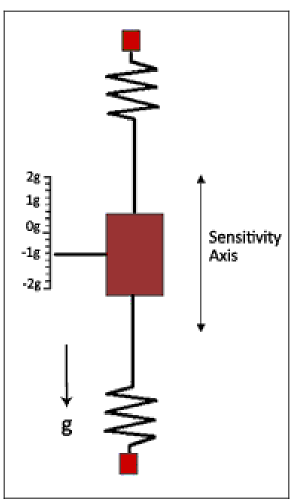
Acceleration is the change in velocity over time. Based upon classical mechanics we know that the acceleration a body is subjected to is proportional to the force acting upon it. This is also known as Newton's second law.

$$\mathbf{F} = m\mathbf{a} \quad \rightarrow \quad \mathbf{a} = \mathbf{F}/m$$

An accelerometer can be thought of as a weight suspended on two sides with springs. The weight is known as the "proof mass" and the direction that the mass is allowed to move is known as the sensitivity axis.



If the accelerometer was subjected to a linear acceleration, the proof mass would attempt to remain at rest, in accordance with Newton's first law, which states that an object at rest tends to remain at rest. As you can imagine an acceleration would cause the proof mass to shift to one side compressing one of the springs. The amount of deflection in this spring is proportional to the net acceleration. Now consider rotating the above accelerometer so that the sensitivity axis is aligned with gravity.



In this case gravity would act on the proof mass causing a the bottom spring to compress. As such an accelerometer measures both the linear acceleration due to motion and the pseudo-acceleration caused by gravity. It is called a pseudo-acceleration since this acceleration due to gravity doesn't necessarily result in a change in velocity or position. Because of this it isn't completely accurate to even call it an acceleration, and this is why many refer to this more accurately as a specific force. The deflection of the springs is proportional to the force acting on the proof mass, which is equivalent to the linear acceleration of the accelerometer package plus the gravitational acceleration due to gravity. Simply put just remember that an the output of an accelerometer is affected by both linear acceleration and gravity.
Note that the accelerometer is only capable to react to specific forces and unable to measure directly field forces (the gravitational component). The gravitational component is only detectable when there is a reaction specific force to it (the Normal for example). The sensor output is a displacement related to the input and not properly an inertial acceleration.

Accelerometer Sensor Model

A sensor model is used to mathematically correct for errors in scale factor, misalignment, and bias. The accelerometers used in VectorNav inertial sensors unless otherwise stated use a linear sensor model.

$$A = \begin{bmatrix} x \\ y \\ z \end{bmatrix}_I = \begin{bmatrix} 1 & M_{XY} & M_{XZ} \\ M_{YX} & 1 & M_{YZ} \\ M_{ZX} & M_{ZY} & 1 \end{bmatrix} * \begin{bmatrix} \frac{1}{S_X} & 0 & 0 \\ 0 & \frac{1}{S_Y} & 0 \\ 0 & 0 & \frac{1}{S_Z} \end{bmatrix} \left(B_D + \begin{bmatrix} B_X \\ B_Y \\ B_Z \end{bmatrix} - \begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix} \right)$$

This written as algebraic equations gives the following:

$$A_X = \frac{B_D + B_X - V_X}{S_X} + \frac{M_{XY}(B_D + B_Y - V_Y)}{S_Y} + \frac{M_{XZ}(B_D + B_Z - V_Z)}{S_Z}$$

$$A_Y = \frac{M_{YX}(B_D + B_X - V_X)}{S_X} + \frac{B_D + B_Y - V_Y}{S_Y} + \frac{M_{YZ}(B_D + B_Z - V_Z)}{S_Z}$$

$$A_Z = \frac{M_{ZX}(B_D + B_X - V_X)}{S_X} + \frac{M_{ZY}(B_D + B_Y - V_Y)}{S_Y} + \frac{B_D + B_Z - V_Z}{S_Z}$$

Temperature calibration

To above calibration parameters will vary with changing temperature. To account for this all VectorNav sensors utilize a third order algebraic polynomial for each calibration coefficient as a function of temperature. Each calibration coefficient can be calculated as follows:

$$C_n = C_{n_0} + C_{n_1}\Delta T + C_{n_2}\Delta T^2 + C_{n_3}\Delta T^3$$

$$where\ \Delta T = [Temperature - 25]\ °C$$

How to measure linear acceleration with an accelerometer

Linear acceleration is the time rate of change of linear velocity. For it to have any meaning it must be given in reference to a specific coordinate frame. For navigation acceleration is measured with the intent of determining an object's velocity and position. In order to accomplish this we will need to integrate acceleration to get velocity, and integrate velocity to get position. It is very important to remember that any integration of either acceleration or velocity needs to be done in an inertial coordinate frame. An inertial coordinate frame is one that is not moving or rotating. The inertial coordinate frame used for a project depends upon several factors, however for this example we will assume that a North East Down (NED) inertial coordinate frame is used. In this case the measured acceleration measured by the accelerometer needs to be converted from the sensor coordinate frame to the inertial coordinate frame. This is accomplished by performing a coordinate transformation. The measured acceleration is multiplied by the transpose of the orientation matrix to get the equivalent measured acceleration in the inertial coordinate frame.

Once you have the measured acceleration in the inertial coordinate frame you can then subtract out the static acceleration due to gravity. The resulting acceleration will be the equivalent acceleration linear acceleration due to motion.

The quantity that results from the above calculation is a measure of the inertial acceleration. It can numerically integrated once to get velocity, or twice to get position. There are various means available to perform numerical integration. One of the simplest methods uses the trapezoidal rule. Using this method the position and velocity would be calculated as follows:

$$V_t = V_{t-1} + \Delta t\left(\frac{A_t + A_{t-1}}{2}\right)$$

$$P_t = P_{t-1} + \Delta t\left(\frac{V_t + V_{t-1}}{2}\right)$$

In the above equation A is the inertial acceleration, V is the inertial velocity, and P is the inertial position. The subscript t means the measurement at the current time step, while the subscript (t-1) means the measurement at the previous time step. Delta t is the measurement sample time, which for the case of the VN-100 that samples at 200Hz this would be 0.005 s.

the latest miniature MEMS inertial sensor technology.

Dual Antenna GPS Aided INS

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