TN-I0029
MicroStrain Technical Note

3DM-GX3® -25 Up and North Compensation

Introduction

Up and North refer to the counter-gravitational vector and polar magnetic vector respectively. Up and North *compensation* refers to the continual incremental rotation applied to the orientation matrix (derived from the inertial orientation solution) to realign the matrix with the Up and North vectors.

When you first turn on an orientation sensor, it doesn't really know what its orientation is relative to anything around it. It needs some sort of starting reference point to know if it is upside down, sideways, pointing north, south, east, or west. The magnetometer allows the device to get a fix on magnetic north (or south) and the accelerometers allow it to get a fix on earth's gravity (if it is motionless when it is powered on). This gives the orientation sensor a starting reference point. In fact, if the gyros and accelerometers on the device were perfect, all that the sensor would need is this initial fix and from there, it could run forever and always know how it was oriented relative to the starting reference. Unfortunately, all orientation devices are imperfect and the environment they work in is imperfect. The devices themselves tend to have offset and gain imperfections such as drift and hysteresis over time and temperature. The surrounding environment also contributes error sources such as the Coriolis effect, geographic magnetic anomalies, changes in declination and even changes in gravity due to earth surface features such as mountains. Most of the sensors internal factors can be calibrated out but some stubborn problems, particularly long term drift and hysteresis, cannot. External factors such as magnetic declination can be accounted for but need an outside source of information to supply the correction.

Beyond calibrating out as many of the problems as possible at the factory, the only way to compensate for the remaining weaknesses in the sensors is to continuously correct them using known measurable references. The earth's gravity vector and magnetic vector are the two references that are available to the 3DM-GX3® -25 and they are referred to as the Up and North vectors. These references themselves are imperfect and controls have been provided to allow the user to tune the correction "gain" from these references depending on his or her application. Knowing exactly how imperfect the device is and how imperfect the references are, and knowing the application that the device is to be used for is key to understanding how to use Up and North compensation effectively.

North Compensation

The Earth's magnetic field is a good reference for polar north as long as you know the declination (difference between polar north and magnetic north) at your location. There are several reference maps available to determine your declination or you can take a simple compass reading on the North Star. Since the gyros on the 3DM-GX3® -25 drift typically at the rate of ~½ degree/minute, utilizing the magnetic field as a reference can greatly enhance the accuracy of the heading reading.

For an outdoor navigation application this may be desirable, but for other applications where you are trying to measure accurate rotation, you may not want to rely on the magnetometers so much. This is because it is very difficult to maintain a uniform magnetic field throughout a rotation due to the magnetic effects of local items such as steel mounting hardware, etc. This can be improved a great deal through hard and soft iron calibration, however good magnetometer field calibration is not always possible as it requires 3 dimensional (ideally) or 2 dimensional rotation of the entire system that the sensor is installed in. Many installations also involve parts that move relative to the sensor (robotic arms for example) which alter the magnetic field and cannot be calibrated out. An easy demonstration of this is to run the 3D display of the sensor in the 3DM-GX3® -25 Monitor software and bring a piece of steel near the sensor. Try this for different settings of North compensation and you can see how dramatically a magnetic disturbance can affect the yaw. The gyros provide a much more uniform reading of rotation. If you warm-up the sensor and capture the gyro bias you can get very good absolute and relative rotation measurements with higher settings of North compensation. The default value of 10 seconds for North compensation seems to provide a good balance of uniformity vs. drift plus a reasonably comfortable resistance to momentary magnetic disturbances. It is a good starting value for optimizing the setting in your own application.

Note: If you have a zero heading reference of your own such as a “home” location, you can turn the magnetometer off and do your own “tare” of the heading to compensate for the drift of the gyros.

Up Compensation

The Earth’s gravitational field is a very good reference for “up” as long as you are not moving the sensor from side to side when you take a reading. A good demonstration of how the Up compensation setting affects pitch and roll readings is to run the 3D display of the sensor in the 3DM-GX3® -25 Monitor software and move the sensor back and forth on a flat surface. At lower Up compensation time constants, the 3D sensor rocks back and forth. At higher time constants, it does not. This is because the Up vector swings like a pendulum when you move the sensor from side to side and the Up correction tries to align the sensor to this swinging vector. In most applications, motion applied to the sensor averages out such that the Up reading over time accurately represents the pure gravitational vector. It is intuitive that for stationary platforms, the side to side acceleration must average out to zero. For moving vehicles that start and stop, it is also intuitive that the sideways acceleration ultimately averages out to zero from start to stop.

It is very important to note that in applications that have extended periods where the sensor undergoes a constant acceleration in one direction, the Up correction will eventually realign the Up vector to the constant acceleration vector. This can cause a pitch and roll readings to become erroneous. For aircraft, this situation can occur in a prolonged “coordinated turn”. In these situations, you can turn the time constant for the Up compensation to a higher value. As with North compensation, 10 seconds seems to be a good starting value for optimizing the setting in your own application. Also, if you have a good neutral attitude reference of your own (the equivalent of “caging” gyros in aircraft), you can turn off the Up compensation and “tare” the pitch and roll readings on your own when you are in an neutral attitude.

What does it mean to "Realign" Up and North?

The 3DM-GX3® -25 provides a way of short cutting the correction gain so that the reference frame can be aligned with the magnetic and gravitational vectors independently from the correction gain settings. At first this seems simple – just read the magnetic vectors and gravitational vectors and rotate the reference frame. In practice however, this can be catastrophic if a feed back system were to attempt to instantly apply a correction – for example a camera stabilization platform. For this reason, you can apply a variable rate of correction to make a "soft" realignment. This consists of essentially boosting the compensation gains momentarily until they are almost aligned and returning to the programmed compensation gains. You can use this ability to realign to reduce the drift of the sensors if you know when your sensor is absolutely stationary. This is also referred to a "zero update" or "ZUP" and is commonly used to counter sensor drift. It requires accurate outside information to determine when to apply the zero update and can be very disruptive if the sensor is not motionless. The realignment is also useful for instances where the sensor's signals are saturated by device motion beyond the range of the sensors. This can cause significant offset errors in the orientation which will take a long time to correct if the Up and North compensation values are high. This can be demonstrated in the 3DM-GX3® -25 Monitor software by running the 3D view and moving the sensor quickly enough to saturate the sensors. Watch as the Up and North compensation gradually corrects the orientation of the device. Sending an Up or North realignment command will accelerate that correction after a saturation event.

What happens on Startup?

On startup, the 3DM-GX3® -25 always takes a quick magnetometer and accelerometer reading (if the Up and North correction is turned on in the sampling settings) to determine a starting reference frame. If the Up and/or North correction is not turned on, these vectors are simply set to [0,0,-1] and 0 degrees respectively. If the sensor is moving on startup, the Up and North vectors will realign according to the Up and North compensation settings.

What happens when sampling settings are changed?

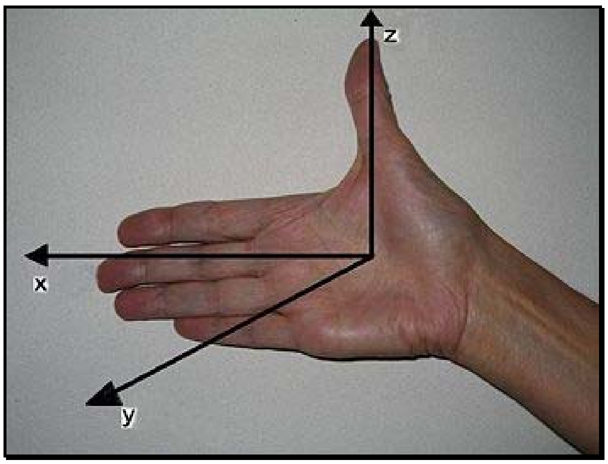
When the sampling settings are changed, the sensor sampling is stopped and restarted in an orderly fashion such that the new sampling values take effect without a glitch in the output values. This can result in a short gap of data at higher data rates while the sensors are shut down and restarted. The Up and North vectors are *not* reset. If it is desirable to reset Up and North after changing sampling settings, the Realign call should be made explicitly. For example, if the magnetometer has been off for a while, the yaw will slowly drift. When you turn the magnetometer back on, the heading vector will be corrected according to the North compensation time value. If you want to accelerate the realignment of the heading to the magnetic vector after you turn the magnetometer back on, you can send Realign command and the vector will align itself according to the accelerated realign time parameter.

What does the compensation time value mean?

The Up and North compensation settings are given in units of seconds, but this does not mean that the correction takes exactly that amount of time to correct the orientation. In general, it represents the amount of time it takes to get within approximately 90% of the Up and North vectors. The actual amount of time is really infinity as the correction function is asymptotic.

What does "NED" mean and why is the Z reading negative?

The reference frame of the sensor is "North-East-Down" or "NED" and the "Handedness" is right handed. What does all this mean? NED means that in a 3D Cartesian coordinate system, the North vector is the X axis and the East vector is the Y axis. Because this is a right handed system, in order to determine the Z axis, you point the fingers of your right hand in the direction of the X axis. If you then bend your fingers to a right angle in the direction of the Y axis, your thumb is pointing in the direction of the Z axis. You will notice on the sensor label there is a reference frame graphic indicating that the X vector is pointing toward the connector (North), the Y vector is pointing to the right (East) and the Z vector is pointing toward the bottom of the sensor (Down).



Now that you know how the sensor sees the world in terms of North, East, and Down, you may ask yourself why, when the sensor is at rest on a level surface, does the Z accelerometer read negative? The down reference frame vector is in the positive direction but the accelerometer reads negative. This seems counter intuitive. This is a common misconception when dealing with acceleration. The earth's gravitational field is exerting a constant downward force on the sensor. It wants to accelerate the sensor downward. If the sensor were allowed to fall, then it would indeed undergo this acceleration towards the earth's center. However, because there is a constant "up" acceleration, or force, acting against the earth's gravitation, it does not accelerate downward. It is this "up" force that the accelerometers are actually measuring. Since "up" is the opposite of "down", the measured vector is negative in our northeast down reference frame.

Support

MicroStrain support engineers are always available to expand on this subject and support you in any way we can.

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