MTLT3xxD Best Practices Guide - Rev 1.1

Application Note

MTLT3xxD Best Practices Guide

Introduction

The MTLT3xxD is an advanced dynamic 2D inclination (pitch and roll) and 3D accelerometer sensing system. Each unit is calibrated over temperature to provide accuracy over the entire operating temperature range.

Pitch and Roll (θ, φ) are determined by an advanced Extended Kalman Filter (EKF) algorithm using information from rate sensors, linear acceleration sensors and a temperature sensor. Angular Rate data from the pitch and roll rate sensors (MEMS gyroscopes) are integrated with respect to time to determine change in pitch and roll with time. New pitch and roll values are calculated and updated at 10 ms intervals. However, integration errors and bias drift errors of the gyroscopes will accumulate, increasing the error in the estimated pitch and roll angles as time passes when using just data from the rate sensors.

The EKF corrects for these errors using pitch and roll angles calculated from the linear acceleration sensors (MEMS Accelerometers). The linear acceleration data is used to determine pitch and roll angles by applying geometry and Euler Angle rotations to determine its orientation with respect to the earth's gravity vector.

When correcting for the integration and rate bias errors the EKF algorithm weights the pitch and roll angles calculated from the acceleration data heavily when $(x^2 + y^2 + z^2)$ is very close to 1, indicating the only acceleration present is from gravity. Conversely, the EKF algorithm discounts the pitch and roll angle calculated from the acceleration when $(x^2 + y^2 + z^2)$ is not very close to 1, indicating the there is significant linear acceleration other than gravity present (vibration or vehicle movement) and geometry will not provide accurate pitch and roll estimation.

Orientation Settings

The axis orientation settings inside the MTLT300D series are user configurable. It is best to set them so the largest angle of rotation in the application is about the x-axis (roll angle) with the z axis normal to the earth and the y axis parallel to the earth. If the unit is mounted such that both pitch and roll are constrained below ±70 degrees in the application, no change to orientation is needed. FIGURE 1 shows the MTLT300D Series default axes configuration.
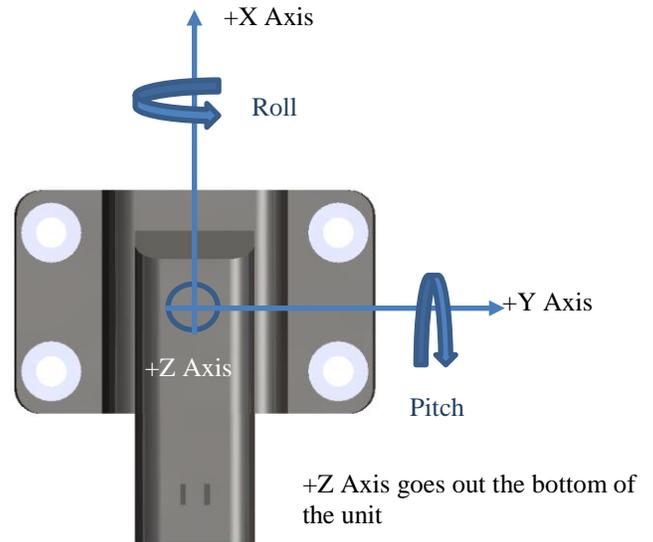

FIGURE 1

Positive Roll (+φ) is defined using the right hand rule. With your thumb aligned along the x-axis and pointing in the positive x direction, positive roll is in the direction of the rotation of your fingers are they wrap around the x-axis. The range of roll angle is 0 ± 180 degrees ($0 \pm \pi$ radians). Accuracy is maintained over the entire range. This angle of rotation should be matched to the largest angle of rotation in the application either by mounting or reconfiguring the axes orientations.

Positive pitch (θ) is defined similarly. With your thumb aligned along the y-axis and pointing in the positive y direction, positive pitch is in the direction of the rotation of your fingers are they wrap around the y-axis. Theoretically the range is limited to 0 ± 90 degrees. However, accuracy degrades at angles above +70 degrees or below -70 degrees for this axis of rotation. The accuracy is maintained in the range 0 ± 70 degrees range. See FIGURE 1 for default positive pitch and roll orientation.

To help explain why roll can operate over the entire -180 to +180 degree range and pitch is limited to -70 to +70 degree range, it is useful to look at how the correction angles used by the EKF algorithm are derived from the accelerometers.

The roll angle is calculated as the arctangent of (y/z) using an ATAN2 function, where y is the acceleration measured on the y-axis and z is the acceleration measured on the z-axis. As such the correction for roll errors applied in the EKF range from -180 to +180 degrees. Accuracy is nearly consistent over the entire range so rate sensor bias estimation and

accumulated integration errors can be effectively corrected over the entire range.

The pitch angle is calculated as the arcsine (x) where x is the amount of acceleration measured on the x-axis. The ASin function is limited to -90 to +90 degrees and only yields values in that range because the sine of 89 degrees is the same as the sine of 91 degrees and the sine of -89 degrees is the same as the sine of -91 degrees. This is the theoretical limit of the function. Furthermore, if we look at the sine function we see that near 0 degrees the value changes the most with a change in angle, and near 90 degrees the value changes very little. See TABLE 1 for some numerical examples of a 1 degree change in angle from different starting angles.

Angle	Change in Acceleration
0 to 1 degree	17.6 mg
70 to 71 degree	5.82 mg
89 to 90 degree	0.15 mg

TABLE 1

Because the sine function becomes less sensitive as it moves away from 0 degrees, a consistent level of noise in the sensor becomes much more significant as the angles get further away from 0 degrees. If the noise becomes too big in relation to the change in acceleration due to a change in angle, the rate bias estimation and integration errors cannot be effectively corrected. Pitch angle estimation accuracy degrades outside the -70 to 70 degree range and at some point the EKF algorithm may become unstable. It is necessary to restrict the pitch angle to the -70 to + 70 degree range.

Acceleration Filter Settings

Vibration energy can cause the EKF algorithm to think there is linear acceleration present and cause it to continually discount the pitch and roll angles generated from the acceleration data. Low pass filtering the acceleration data can help remove high frequency vibration energy and allow the EKF to operate as intended and weight the data correctly.

The MTLT300D is equipped with a user configurable low pass filter (LPF) for filtering the data from the accelerometers before is it applied to the EFK for gyro bias estimation and integration error correction. The default setting is 5 Hz. This does not adversely affect the response time of the inclinometer. The response time of the inclinometer is limited by the full scale range of the gyros. The gyro full scale range is 400 degrees per second. The LPF can be set lower for higher vibration environments or it can be set higher for low vibration environments. It is NOT recommended it be set higher than 25 Hz.

Gyro Filter Settings

Internal to the MTLT300D there is a user configurable low pass filter for filtering the data from the gyros before it is applied to the EFK for pitch and roll estimation. The default setting is 25 Hz.

In general, we do not recommend changing the default filter setting for gyros. If you have a specific application where you believe it makes sense to change the gyro filter setting, please first contact Aceinna for guidance.

Orientation Settings Examples

In the following examples X, Y and Z denote the physical axes of the device as shown in FIGURE 1. Ux, Uy, and Uz are configurable and define the axis as used in the application. They define pitch (rotation about Uy) and roll (rotation about Ux).

Example 1: Cab Orientation Monitoring with mounting as depicted in FIGURE 2.

Device Axis	X Axis	Y Axis	Z Axis
Assignment	+Ux	+Uy	+Uz

TABLE 2

Note: this is the default assignment and no change is necessary.
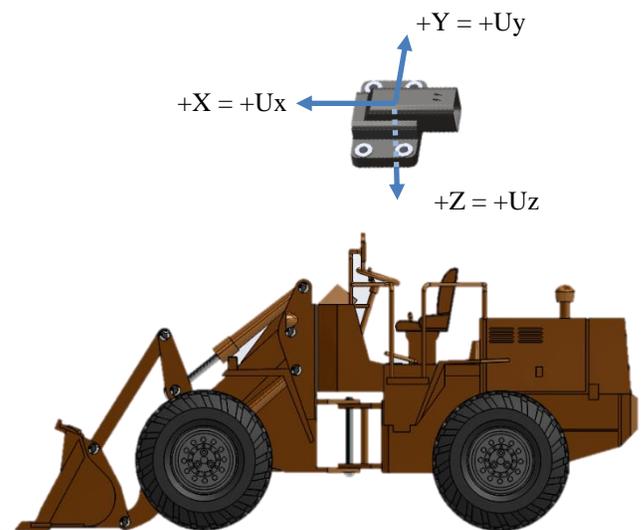

FIGURE 2

Example 2: Boom Orientation Monitoring with mounting as depicted in FIGURE 3.

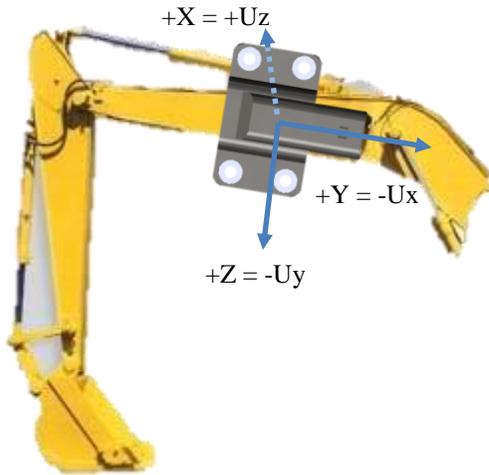| Device Axis	Field Setting	X Axis	Y Axis	Z Axis
Assignment	0x016C	+Uz	-Ux	-Uy

TABLE 3

FIGURE 3

Example 3: Bucket Orientation Monitoring with mounting as depicted in FIGURE 4

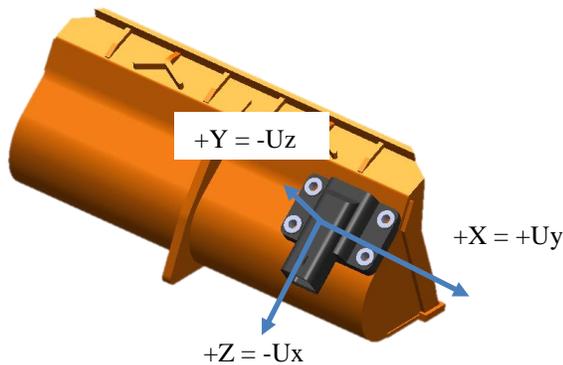| Device Axis	Field Setting	X Axis	Y Axis	Z Axis
Assignment	0x00DA	+Uy	-Uz	-Ux

TABLE 4

FIGURE 4

Changing Orientation Settings

To change orientation via CAN bus, follow the three steps below:

Step 1: Select New Orientation

Step 2: Send Orientation Command PGN

Step 3: Send Save Configuration PGN

Step 1: Select New Orientation
The orientation field defines the rotation from the factory to user axis sets. This in turn defines which axis is roll and which axis is pitch. The default factory setting is 0x0000 as shown in bold in Table 5.

Use the examples provided earlier to determine the best orientation for your application. Then select the orientation field setting that matches your requirements using TABLE 5.

Orientation Field Value	X Axis	Y Axis	Z Axis
0x0000	**+Ux**	**+Uy**	**+Uz**
0x0009	-Ux	-Uy	+Uz
0x0023	-Uy	+Ux	+Uz
0x002A	+Uy	-Ux	+Uz
0x0041	-Ux	+Uy	-Uz
0x0048	+Ux	-Uy	-Uz
0x0062	+Uy	+Ux	-Uz
0x006B	-Uy	-Ux	-Uz
0x0085	-Uz	+Uy	+Ux
0x008C	+Uz	-Uy	+Ux
0x0092	+Uy	+Uz	+Ux
0x009B	-Uy	-Uz	+Ux
0x00C4	+Uz	+Uy	-Ux
0x00CD	-Uz	-Uy	-Ux
0x00D3	-Uy	+Uz	-Ux
0x00DA	+Uy	-Uz	-Ux
0x0111	-Ux	+Uz	+Uy
0x0118	+Ux	-Uz	+Uy
0x0124	+Uz	+Ux	+Uy
0x012D	-Uz	-Ux	+Uy
0x0150	+Ux	+Uz	-Uy
0x0159	-Ux	-Uz	-Uy
0x0165	-Uz	+Ux	-Uy
0x016C	+Uz	-Ux	-Uy

TABLE 5

Step 2: Send Orientation Command Message

Create a CAN bus packet with PGN 65368. The full packet format is show below:

Priority	Base PGN	PDU Format	PDU Specific	Source Address	Data Field
6	65368	255	88	128 - 247	3 bytes

The data field is the Destination Address followed by the Orientation Field. Destination address refers to the address of the device whose orientation is to be changed. For example, if the device destination address is 0x80 and the desired Orientation Field is 0x0009, then the data field is set:

0x80, 0x00, 0x09

After formatting the packet, transmit the packet over CAN bus. The orientation change will take effect immediately, but until Step 3 is complete the change will not be maintained across a power cycle of the device.

Step 3: Save the Setting Permanently

One command is used to save all the devices settings that can be permanently changed.

Create a CAN bus packet with PGN 65361. The full packet format is show below:

Priority	Base PGN	PDU Format	PDU Specific	Source Address	Data Field
6	65361	255	81	128 - 247	3 bytes

Data Field Definition

Byte	Description	Value
1	Request or Response	0x00 = Request (Host) 0x01 = Response (Unit)
2	Address of unit	128 – 247
3	Success or Failure	0x00 = Failure 0x01 = Success

TABLE 6

For example, in order to save the setting to a device with address 0x80, the data field is set as follows: 0x00, 0x80, 0x00 as indicated in TABLE 6 above.

The first byte indicates the message is a request to save the settings, the 2nd byte the destination address (i.e., the address of the device to be set), and the 3rd byte is blank in the request phase.

If the setting is successfully save, the addressed device will echo back the same message with data packet 0x01, 0x80, 0x01

Note: this command will save all the device's current settings. If other settings have been changed besides the orientation, those changes will also be saved permanently.

FIGURE 5 shows actual command and response on the CAN bus to change the orientation settings and save them permanently.

Send: Orientation	PRI = 6	PGN = 0xff58	SRC = 0x00	128 00 09
Send: Save Request	PRI = 6	PGN = 0xff51	SRC = 0x00	00 128
Recv: Save Success	PRI = 6	PGN = 0xff51	SRC = 0x80	01 00 01

FIGURE 5

Changing Accelerometer and Rate Sensor Filter Settings

The accelerometer and rate sensors low pass filter (LPF) settings are set with the same command. However, they can be set independently They are temporary settings and must be configured each time power is cycled if they are changed over the CAN interface. To change the rate sensor and accelerometer LPF cutoff frequencies via CAN bus, follow the two steps below:

Step 1: Select Rate and Acceleration LPF Frequencies

Step 2: Send LPF Frequencies Setting Command PGN

Step 1: Select Low Pass Filter (LPF) Frequencies

The MTLT30xD rate sensor and accelerometer LPF bandwidth can be each be independently set to 2, 5, 10, 20, 25, or 50 Hz. Select the desired value for each.

Step 2: Send Filter Frequency Setting Command Message

Create a CAN bus packet with PGN 65367. The full packet format is show below:

Priority	Base PGN	PDU Format	PDU Specific	Source Address	Data Field
6	65367	255	87	128 - 247	3 bytes

The data field is a three-byte sequence including, the Destination Address followed by the two filter settings - rate sensors and accelerometer sensors.

2nd byte is to set rate sensor LPF frequency.

3rd byte is to set the accelerometer LPF frequency.

For example, to set a device at source address 0x80 to have 25Hz LPF on the rate sensor and 2Hz LPF on the acceleration sensor, the following three bytes are used for the data fields:

0x80, 0x19, 0x02

After formatting the packet, transmit the packet over CAN bus. The filter settings change will take effect immediately but will not be maintained across a power cycle.

FIGURE 6 and FIGURE 7 show the accelerometer output using a 50 Hz and 2 Hz LPF setting respectively while the unit is exposed to the same sinusoidal vibration.
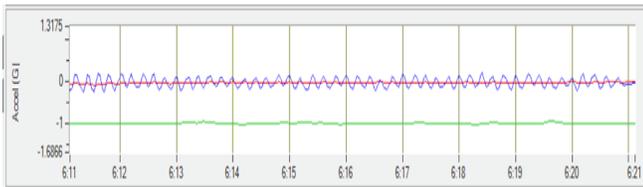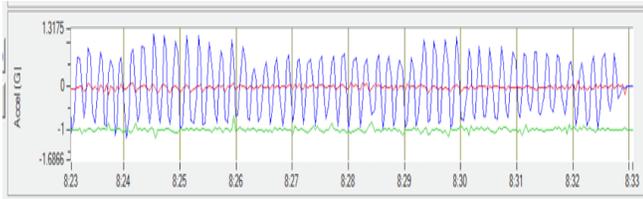

FIGURE 6: Accelerometer LPF Setting at 50 Hz

FIGURE 7: Accelerometer LPF Setting at 2 Hz

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