MTLT3xxD Best Practices Guide - Rev 1.4

Application Note

MTLT3xxD Best Practices Guide

Introduction

The MTLT3xxD are advanced dynamic 2D inclination (pitch and roll), 3D rotation rate, and 3D linear acceleration 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, if rate integration alone were used, integration errors and bias drift errors of the gyroscopes will accumulate, increasing the error in the estimated pitch and roll angles as time passes.

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.

Correcting for 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.

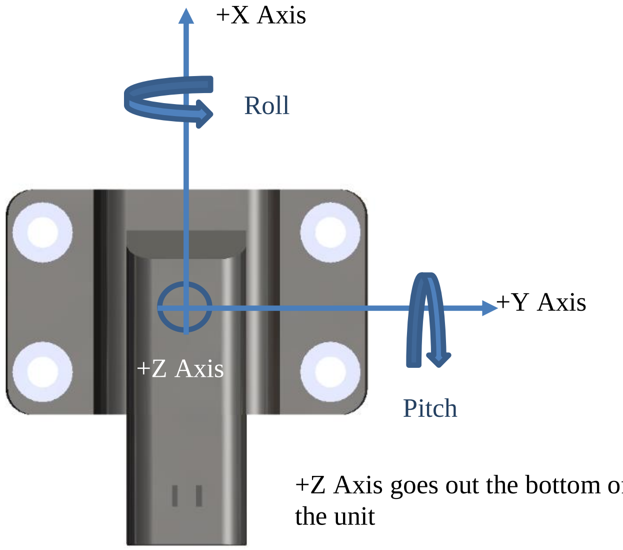

Figure 1: Physical Axis Orientation

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 as they wrap around the x-axis. The range of roll angle is 0 ± 180 degrees (0 ± π 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 orientation.

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 as 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.

Table 1: Acceleration Change with Angle

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

Because the sine function becomes less sensitive as it moves away from 0 degrees, a consistent level of noise in the sensor becomes 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. At ±90 of pitch both Y an Z are orthogonal to gravity and Roll becomes undefined. It is necessary to restrict the pitch angle to the -70 to + 70 degree range in order to get maintain good accuracy.

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 in the MTLT305D and 10 Hz in the MTLT335D. 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 Ux, Uy, and Uz denote the physical axes of the device as shown in Figure 1. Logical axis are denoted with X, Y and Z are configurable. They define the axis as used in the application. They define pitch (rotation about Y) and roll (rotation about X).

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

Table 2: Cab Mount Orientation Setting

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

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

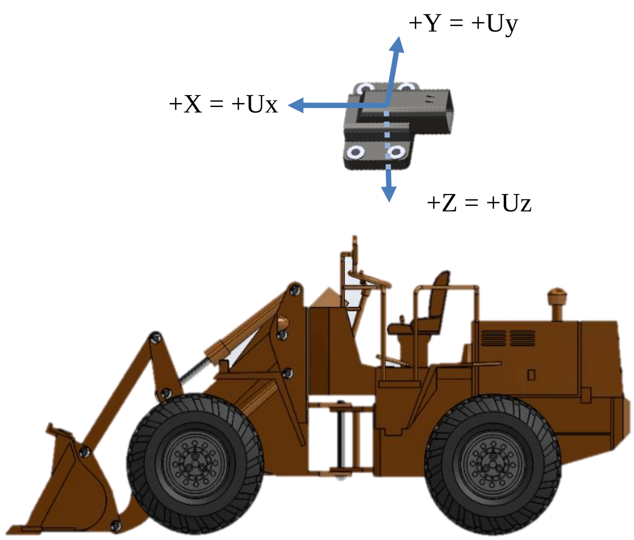

Figure 2: Cab Mounting Application

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

Table 3: Boom Mount Orientation Setting

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

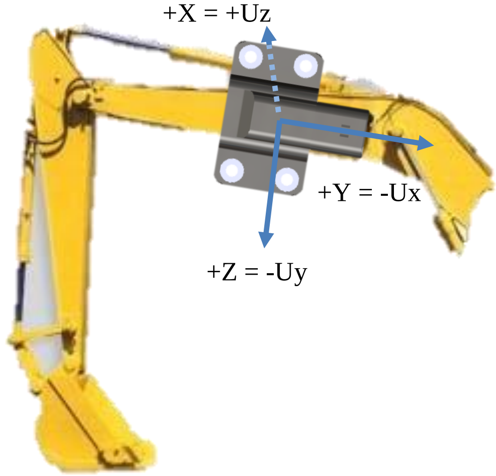

Figure 3: Boom Mounting Application

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

Table 4: Bucket Mount Orientation Setting

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

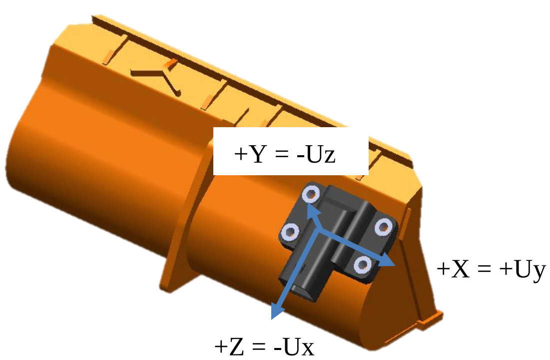

Figure 4: Loader Bucket Mounting Application

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 with Reset

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.

Table 5: Orientation Settings

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

Step 2: Send Orientation Command Message

Create a CAN bus message 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 setting. 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 the 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 or reset of the device.

Step 3: Save the Setting Permanently and Reset

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

Table 6: PGN 65361 Data Field Definition

Byte	Description	Value
1	Save Mode	0x00 = No reset after save 0x02 = Reset after save
2	Address of unit	0x80 -
3	Success or Failure (response)	0x00 = Failure 0x01 = Success

For example, in order to save the setting to a device with address 0x80 and reset the device following the save, the data field is set as follows: 0x02, 0x80 as indicated in Table 6 above.

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

The device will acknowledge by responding with PGN 65361 and data 0x02, 0x80, 0x01.

The device will then save the configuration and reset itself after the save is complete. This process takes ~1s.

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.

Action	PRI	PGN	SRC	Data
Send Oreintation	0x6	0xff58	0x00	0x 80 00 09
Send Save Request	0x6	0xff51	0x00	0x 02 89
Recv Save Aknowledge	0x6	0xff51	0x80	0x 02 00 01

Figure 5: CAN Orientation Change Command and Response

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 either be saved or be configured each time power is cycled or reset is performed. Please refer to the user manual for more information. 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 25 Hz LPF on the rate sensor and 5 Hz LPF on the acceleration sensor, the following three bytes are used for the data field:

0x80, 0x19, 0x05

After formatting the packet, transmit the packet over the CAN bus. The filter settings change will take effect immediately but will not be maintained across a power cycle unless followed by a save configuration command. It is recommended to use save configuration with reset as described earlier.

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.

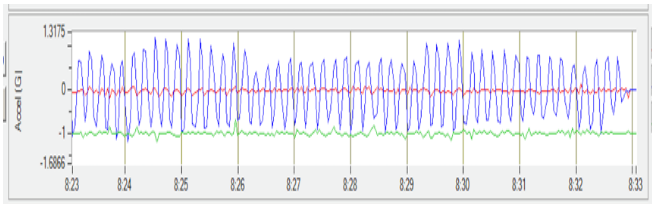

Figure 6: Accelerometer LPF Setting at 50 Hz

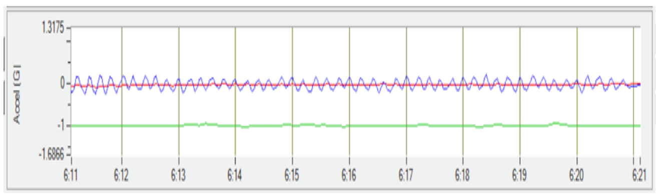

Figure 7: Accelerometer LPF Setting at 2 Hz

Modes of Operation (MTLT335D)

The MTLT335D has a choice of two modes of operation which are configurable.

General Purpose mode: This mode of operation is used for vehicles which normally do not rotate in place, such as passenger vehicles, trucks, tractors etc… Motion detected and the gain of the Extended Kalman Filter (EKF) is adjusted based primarily using linear acceleration. A lower filter setting is used on the acceleration signals. Refer to Table 7.

Excavator Mode (Default): This mode of operation is used for vehicles or applications which can rotate in place. Different from normal vehicle, an excavator primarily is in one place while doing work. The boom, stick and bucket are used to dig and swing to dump while the vehicle is not moving.

For this type of vehicle and operation, the EKF and some settings are chosen to provide better results. The rate sensors are used to detect motion and adjust the gain of the acceleration feedback. Additionally a wider filter setting is used on the acceleration sensor to reduce delay and attenuation so Euler angles more quickly converge when quasi static conditions are detected. Motion detection and the gain of the EKF is adjusted based primarily using rotational rate.

Table 7: Recommended Excavator Mode versus General Mode Filter Settings

Parameter	Excavator Mode	General Purpose Mode
Acceleration LPF	10 Hz	5 Hz

General Purpose Mode Setting Example

Excavator mode is the default setting as shipped from the factory for FW 06.02 and later. Below is a summary of the steps necessary to change a unit to General Purpose mode.

Step 1: Send Unit Behavior Setting Command Message to enable General Purpose mode.

Step 2: Send Filter Frequency Setting Command Message to set the acceleration filter to 5 or 10 Hz.

Step 3: Send save configuration and reset command

Details of these steps are provide below.

Step 1: Send Unit Behavior Setting Command Message:

Create a CAN bus packet with PGN 65369. The full packet format is show below:

Table 8: CAN Packet for Changing Mode of Operation

Priority	Base PGN	PDU Format	PDU Specific	Source Address	Data Field
6	65369	255	89	128 - 247	6 bytes

The data field is a six-byte sequence. The first payload byte is destination address, the next 4 payload bytes used to enable/disable specific unit behavior settings. To enable a specific behavior, the corresponding bit in byte 1 or 2 should be set to 1. To disable a specific behavior, the corresponding bit in byte 3 or 4 should be set to 1. The “disable” bits will override any “enable” bits if sent in the same message. This method allows individual behaviors to be turned on or off, without the need to “remember” the other settings (a zero in any bit location will leave that setting unchanged).

Table 9: Unit Behavior Switches

Byte Number	Selected Unit Behavior type
0	Destination Address
1	Enable behavior bitmask: Bit 0 – enable restart on over range (default=0) Bit 1 – enable dynamic motion (default=1) Bit 2 – use uncorrected rates in ARI message (default=0) Bit 3 – Change sequence of ARI and ACCS messages from X, Y, Z (like MTLT305) to Y, X, Z (J1939) (default=1) Bit 4 – enable autobaud detection mode (default=1) Bit 5 – Reserved Bit 6 – enable NWU (north-west-up) frame (accelerometer messages only) (default=1) Bit 7 – use raw (unfiltered) acceleration signal to detect linear acceleration in EKF (default=1). Setting this bit to 0 uses filtered acceleration, which can improve EKF performance in high vibration environments)
2	Bit 0 – Use raw (uncorrected) angular rate to predict acceleration in EKF (default=0). When this bit is 0, bias-corrected angular rate is used. Bit 1 – Swap Byte 2 and Byte 0 in a GET Message Request payload for backward compatibility with MTLT305, see Section **Error! Reference source not found.** (default=0) Bits 2:3 – Vehicle Type: 00 – Normal 01 – Excavator 10, 11 - reserved Bits 4:6 – Reserved Bit 7 – Enable VG algorithm (default=1)
3	Disable behavior bitmask (turns off the selected behavior from Byte 1 if corresponding bit is set to 1): Bit 0 – disable restart on over range Bit 1 – disable dynamic motion Bit 2 – disable usage of uncorrected rates in ARI message Bit 3 – disable swap X and Y axes in ARI and ACCS messages Bit 4 – disable auto baud detection mode Bit 5 – Reserved Bit 6 – disable NWU accelerometer frame (use NED frame) Bit 7 – disable use of raw acceleration signal to detect linear acceleration in EKF (use filtered acceleration signal instead)
4	Disable behavior bitmask (turns off the selected behavior from Byte 2 if corresponding bit is set to 1) Bit 0 – disable use of raw rate (use corrected rate instead) to predict acceleration in EKF Bit 1 – disable "Swap Byte 2 and Byte 0 in a GET Message Request payload" for backward compatibility with MTLT305 Bits 2:3 – Vehicle Type: 00 – Normal 01 – Excavator 10, 11 - reserved Bits 4:6 – Reserved Bit 7 – Disable VG algorithm–
5	New Unit address (valid address from 128 to 247). Will become active after save command issued and unit will go through reset/power cycle.

For example, to set a device at source address 0x80 to General Purpose mode, set byte 4 (fifth byte) to 0x0C. If data is being logged for analysis at Aceinna, it is recommended to set byte 1 (2nd byte) to 0x84, which enables bit 2 and bit 7 of byte 1. This sets the device to use uncorrected rates in ARI message and use raw (unfiltered) acceleration signal to detect linear acceleration in EKF. The following six bytes are used for the data fields:

0x80, 0x84, 0x00, 0x00, 0x0C, 0x80

Step 2: Send Filter Frequency Setting Command Message:
Detailed filter Settings are described earlier in the guide. For General Purpose mode a 10 Hz or 5 Hz setting is recommended. Set the acceleration filter to 5 Hz if the vibration is heavy. Set to 10 Hz if vibration is not expected to be heavy. Create a CAN bus packet with PGN 65367, with the following three bytes used for the data fields: 0x80 as source address, 25 Hz rate and 5 Hz acceleration LPF. Data packet example is below:

0x80, 0x19, 0x05

Step 3: Save the Setting Permanently and Reset:
Create a CAN bus packet with PGN 65361. The following two bytes are used for the data fields:

0x02, 0x80 (0x80 is the target unit address we want to set).

Detailed save command Settings are described earlier in the guide.

Mounting Considerations

In general purpose mode it is best to mount the device near the centerline of the vehicle. This keeps centripetal acceleration symmetry during left and right turns. Ideally near the center of gravity if this falls on the centerline.

In excavator applications it is further recommended to locate the devices as close to the body as possible. This minimizes centripetal acceleration during swings and rotations.

Feedback

We would love to hear your feedback. This helps ensure that future products are optimized to your satisfaction. Please visit following link.
http://www.aceinna.com/support/contact-us.cfm