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Application Note

AL10X as a Tilt Sensor

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INTRODUCTION: This application note discusses how an ORE AL100 or AL101 accelerometer can be used as a tilt sensor. In particular, issues of angular resolution and temperature drift are considered.

General Considerations for Tilt Sensing

The idea of using a gravity-sensing accelerometer to measure tilt is quite intuitive. But, actually doing it involves a lot of mathematics. A computer program to analyze the accelerometer data in terms of tilt will be available; the computer program eliminates the need for a user to apply an mathematics, or even to directly inspect the data. But to understand what the accelerometer limits are in this application, it is necessary to dig into that same mathematics.

Our first task is to resolve the gap between intuition and the formality of geometry. This gap is immediately apparent when we ask "what is the angle of this object with respect to vertical?" The first useful observation is that the question of angle with respect to vertical is essentially the same as asking about "tilt" where the emphasis is on an object's orientation with respect to horizontal. This is useful because there is a lot of literature about tilt sensing and very little about vertical sensing. In fact, the manufacturer of the the sensor used in the AL10x accelerometers has an application note on tilt sensing. It can be found at

https://www.st.com/content/ccc/resource/technical/document/application_note/d2/d6/22/4f/b9/8f/45/59/DM00119046.pdf/files/DM00119046.pdf/jcr:content/translations/en.DM00119046.pdf

Tilt Sensitivity

In the document referenced by the preceding URL, it is shown that using a 3-axis accelerometer as a tilt sensor has a sensitivity of about 17.5mg per degree (document Figure 6). This is inherent in the geometry and independent of the sensor element.

Thus, to achieve a sensitivity of 0.1 degrees, it is necessary to be able measure, accurately, 1.75mg. In some applications, accuracy may not be an issue; these applications typically occur when one is looking for changes in tilt. This will be the assumption for the remainder of this report: the primary interest is in incremental change in tilt. In this case, the concern is then about resolution (rather than accuracy) and temperature stability.

AL10X Resolution

The ability of an accelerometer to resolve changes in tilt is primarily limited by noise. The term "noise" refers to random variation of a reading from one sample to the next when the sensor acceleration is fixed in space. In actuality, it is very difficult to separate out noise generated randomly inside the accelerometer and external vibration. Vibration at the level of a few mg is not readily perceivable by human observers so it is very difficult to separate the two noise sources.

Further, measurements have shown that trees and building structures commonly have a few 10s of mg inherent "vibration" of their own, over and above the noise of the sensor. Even under what appears to be "very calm" wind conditions, a tree will "shake and sway" in the range of 10-20mg. With even a slight wind, this can increase by a factor of 2 to 4; for stronger winds, a factor of 10 or more is easily observed . This, however, depends strongly on where the accelerometer is placed on the tree or structure.

Please note that the noise level depends on the sample rate. The figure, used above, is for a sample rate of `10 times per second. Slowing the sample rate to once a second reduces the noise to the range of about 3mg to 7mg.

Based on these numbers and the conversion factor of 17.5mg per degree, it would appear that it is very difficult to achieve better than 1 degree tilt resolution, with ANY sensor on a tree, with a practical resolution closer to 2 degrees! Further, if observing trees, some method of separating the effects of wind from the effects of other disturbances is needed; separating these two sources will involve techniques significantly more challenging than geometry and trigonometry.

AL10X Temperature Stability

Putting aside the issues of resolution, we also need to ask about stability. That is, how certain can we be that an observed change is due to an actual orientation change of the object being observed? What about changes inside the instrument that are not caused by orientation changes? The major cause of such changes inside the instrument is temperature.

The specification for the sensor element is a MAXIMUM zero offset temperature sensitivity of +/-0,5mg/C relative to 25C. This specification means that typically, the temperature sensitivity will NOT be this high, but the only guarantee that the manufacturer will provide is that it will be no worse than this. That is, if the temperature is 0C, then the temperature change relative to 25C is -25 and the zero reading COULD change by (+/-0.5mg/C) * -25C or any amount between +12.5mg and -12.5mg.

From the “Tilt Sensitivity” section, it was noted that the relationship between tilt angle and acceleration change is about 17.5mg per angle degree. If we use this number in combination with the maximum temperature sensitivity of 0.5mg/C, we find that a potential error in angle reading due to temperature to be about 1 angle degree per 35C or 0.029 angle degrees per C. This does not sound like much but where a warm season high to cool season low might exceed 50C, this represents close to 1.5 angle degrees! Recall, however, that this is MAXUM and typical might be half that or less.

Physical Meaning of “Tilt Angle”

In the light of the findings, above, it may be useful to consider what tilt angle represents.

If we have an object that has a length of L, and the position of one end moves by d (in a direction at right angles to the length of the object) while the other end remains fixed, the relationship between the movement and the angle change is given by

$$\text{tangent(angle change)} = d/L$$

For 1 degree, the tangent is about 0.0175. That is, for an object 1m long, a movement of one end at right angles to the length of the object relative to the other end by 17.5mm represents 1 degree. Then 0.1 degree change results from a position change of 1.75mm.

Thus, using a tree as an example, a shift in position of some reference point at the top of a 10m tree of 17,5mm is equivalent to a change in the angle of the tree trunk of 0.1 degree.

Summary

From the document referenced by the URL in the “General Considerations for Tilt Sensing” section, it was found from basic geometry that 1 degree of tilt is equivalent to about 17.5mg of gravity shift between the sensor axes.

Typical internal sensor noise levels appear to be in the vicinity of 10mg to 20mg at as sample rate of 10Hz (10 per second). Observed random “vibration” of several trees, even on calm days, was similar, rising to higher levels, even in slight winds. A practical resolution of 2 degrees tilt is suggested.

Worst case temperature sensitivity of the sensor used in the AL100/101 accelerometers is specified by the manufacturer to be equivalent to about 0.03 degrees/C in tilt sense applications. Typical units might be half as sensitive to temperature, or better.

A tilt angle change of 1 degree is the same as a shift in position of one end of 1m long object by 17.5mm. Proportionately, 0.1 degree is equivalent to a position shift of 1.75mm.