Olsonet Communications

CMA3000 accelerometer

driver

April 2012

Introduction

CMA3000 is an accelerometer sensor manufactured by VTI Technologies. Documentation available from the manufacturer (data sheet + specification) covers all the technical intricacies. That documentation is not required to understand how to use the driver and what you can expect from the sensor.

Summary of the sensor's functionality

The sensor has three configurable modes of operation:

1. motion detection
2. free fall detection
3. perpetual measurement

The first two modes are inherently event-oriented, meaning that the sensor uses the acceleration data internally to decide when to trigger an interrupt signaling the respective event. The last mode is intended for high-speed readouts of raw acceleration data. The maximum accuracy/resolution of the acceleration data is only available in measurement mode.

The sensor measures acceleration along three axes (X, Y, Z). The readings are 8-bit signed integers. The resolution is determined by the range (in g) which is approximately evenly spread over the discrete range of values represented by a signed byte. There are two ranges, roughly:

8 g (resolution = 67 mg), note that it is (-8 g, +8 g)
2 g (resolution = 17 mg)

Motion detection mode

In the motion detection mode, a motion event is triggered when the delta of acceleration measurements, sampled at 10 Hz, exceeds a configurable threshold for a configurable amount of time. Only 8g range (67 mg resolution) is available in this mode.

The acceleration data is passed through a band pass filter whose purpose is to ignore high and low frequency changes (like some external vibrations). The document says that the –3dB cutoffs of the filter are at 1.3Hz and 3.8Hz. The exact meaning of the threshold and time parameters is not immediately clear. The threshold is probably applied against the absolute delta after the signal has passed through the filter. The time should be probably interpreted as the amount of time (in $1/10^{th}$ of a second) for which the filtered signal should exceed the threshold to trigger the event (this is what the document basically says).

From my very rough experiments, the most sensitive setting of time is 3 (this is also the default). If you wonder why not 0 or 1, then my explanation would be that the time must fall in the range where the filter passes a significant portion of the signal, and the center of the band is at 2.55 Hz. This would also mean that using values larger than 5 is pointless, except that they work (!) although the sensitivity is significantly lower for time > 3. So there is something there I don't quite understand.

The best (and useless) sensitivity is at threshold = 0, time = 3. Useless, because with this setting the sensor generates spurious events when completely stationary. You can manipulate either parameter to reduce the sensitivity. For example, the spurious events cease when time becomes 0 (on the low end) or 8 (on the high). The maximum settable

value of time is 15. For threshold it is formally up to 255, but I couldn't get any triggers with 20, so perhaps 15 is a good practical limit for both (the driver cuts it at 31).

The most reliable kind of extra information returned along with a motion event is the axis, i.e., X, Y, or Z on which the threshold has been reached/exceeded. At one point in the document they say that the acceleration registers read in the motion detection mode show the filtered acceleration data, i.e., the current deltas on the three axes (according to my understanding). However, some other part (under the “known issues” header) says that *“Interrupt (INT-pin) based acceleration data reading can be used only in measurement mode”*. The driver does return this data also in the motion detection mode (as described below) and you can decide for yourself how much sense it makes.

Motion detection mode is the most frugal mode in terms of energy usage (the current drawn by the sensor is below 11 uA).

Free fall detection mode

A free fall event is triggered when all three acceleration values (sampled at 400 Hz) remain below a configurable threshold (are close to zero) for a configurable amount of time. Formally, the device offers two options for the sampling frequency: 100 Hz and 400 Hz, as well as the two range/resolution options (8 g versus 2 g). I have noticed no significant power advantages of the 100 Hz option – the sensor draws about 70 uA in both cases), so the driver only implements the 400 Hz option at 2 g range (high resolution).

The threshold and time parameters are similar to the two parameters of the motion detection mode (although their interpretation may be simpler, because there is no mention of any filters in the documentation). I haven't tested the fall detection mode at all, because I couldn't trigger any free-fall event within the confines of my simplistic lab.

About the only useful information returned by the event is the event itself. The document says that you can read the acceleration data after the event (and it is the actual acceleration data); then again, the same qualifier (known issues) applies. The driver does give you access to the acceleration data as read at the time of the event, and you can do with it whatever you please.

Measurement mode

In this mode, raw acceleration data is available sampled at 10 Hz, 100 Hz, 400 Hz, within the range of 2 g or 8 g (the former not available at 10 Hz). The driver only implements 400 Hz and 2 g range. No events are triggered.

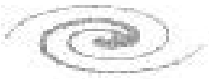
The driver doesn't implement the measurement mode directly, but reading the sensor without accepting an event amounts to switching it to measurement mode. This happens in a transparent way, as explained below.

Driver interface

The driver uses the new (as of April 2012) sensor API function *wait_sensor* to await events, in addition to reading sensor values with (the old function) *read_sensor*.

Switching the sensor on and off

Before it can deliver events and values, the sensor must be explicitly switched on with this function:



```
void cma3000_on (byte mode, byte threshold, byte time);
```

where *mode* is 0 for motion detection and 1 for free-fall detection, and the remaining two values are the two parameters of the respective mode, as described above. Note that *time* is forcibly bounded to 15 (any larger value will translate into 15) and *threshold* is forcibly bounded to 31.

This function:

```
void cma3000_off ();
```

powers the sensor down.

The operation of switching the sensor on is relatively fast (normally taking about 300us); however, I have noticed that writing to the sensor's registers is not 100% reliable, so the operations are retried until the read-back value matches the one that has been written. This happens on both specimens of CHRONOS that I have. On initialization, I sometimes have to write the reset/mode registers up to 5 or 6 times before the sensor catches on. In any case, the maximum delay incurred by the function is of order millisecond, so there's little penalty for switching the sensor on and off.

Calling *cma3000_on* always resets the sensor, so you don't have to insert *cma3000_off* between two calls to *cma3000_on*. In other words, if the sensor happens to be on, *cma3000_on* will act as if the sensor has been powered off first.

Receiving events

Note that *wait_sensor* is a void-type function invoked like this:

```
wait_sensor (CMA3000_SENSOR, TARGET_STATE);
```

and it always forces *release*, so it should be the last statement in the current state.[1] The issuing FSM is suspended and will be resumed in *TARGET_STATE* when the event (motion, free fall) occurs. Needless to say, the FSM can issue other wait requests before calling *wait_sensor*.

Reading values

The generalized “value” returned by the sensor (*read_sensor*) is a sequence of 4 single-byte signed integer numbers, i.e., a 4-element *char* array, e.g.,

```
char acc_data [4];
…
read_sensor (RETRY_STATE, CMA3000_SENSOR, (address)acc_data);
```

The values returned in the array depend a bit on the context. If the function is being invoked after an event (motion, free fall) was triggered and there was an FSM waiting for it (the event was expected), then the first (pilot) item in the array will be nonzero. The remaining three items will be the readings of the acceleration registers (X, Y, Z) obtained in the original mode immediately after receiving the event interrupt.

In the motion detection mode, the pilot value will be 1, 2, or 3, depending on whether the trigger occurred on the X, Y, or Z axis. In the free-fall detection mode, the value can only be 4 (indicating a free-fall event).

[1] It has to do so because of race conditions with interrupts.

The idea is that following the reception of an (expected) event, the driver remembers that fact until the nearest *read_sensor* (or until the sensor is reset) and will return the event data to the first invocation of *read_sensor*. Then the event data is erased. Subsequent calls to *read_sensor* will be returning raw acceleration data updated at 400Hz and ranged to 2 g. The first (pilot) value will then be zero, so the program can easily tell which is the case, even if it doesn't know whether an event has been just received or not.

Note that the event-related reading of *read_sensor* is only produced if the event was in fact expected, i.e., awaited by some FSM (there was a pending *wait_sensor* for that event). If an event occurs and no FSM is expecting it, the event is completely ignored.

If you invoke *read_sensor* with no event data outstanding (e.g., there was no event to begin with it, or it has been cleared by a previous call to *read_sensor*), the driver will switch the sensor to measurement mode. The sensor will remain in that mode until the nearest call to *wait_sensor* (which will resume the previous event mode, i.e., motion or free-fall detection) or until the sensor is reset (re-powered). The first call to *read_sensor* in a possible series of measurement calls does the extra job of switching the sensor to the measurement mode, so it will take more time than any of the subsequent measurement calls. The extra delay is about 120 msec and does involve the scheduler (the state specified as the first argument to *read_sensor* is actually used). Subsequent measurement calls return immediately in no more than 200 usec each.

The operation of reverting the sensor to event mode (by a call to *wait_sensor*) from measurement mode (forced by a previous call to *read_sensor*) is much faster than in the opposite direction. This is because the waiting time for the transition is determined by the current sampling frequency of the sensor.

Note that you can ignore the event modes altogether and use the sensor exclusively in the measurement mode. If you never issue a *wait_sensor* request, then all invocations of read_sensor will be “measurement” calls.

Also note that event-related acceleration values obtained in motion-detection mode (whatever sense they make) refer to the range of 8 g (the granularity is 67 mg), while the readings obtained in measurement mode (when the pilot value is zero) always refer to the range of 2 g (at 17 mg granularity).

Test praxis for CHRONOS

There is a test praxis for CHRONOS, especially tailored for CMA3000, which you can use to experiment with the sensor. It is called CMATEST and has been derived from RFTEST. It does involve the same AP (access point) setup as RFTEST to pass commands to (and receive feedback from) the CHRONOS.

Commands

a mode threshold time

Starts the report FSM. The three numbers directly translate into the arguments of *cma3000_on* invoked in the first step of the resulting action. A missing number defaults to zero. The FSM's behavior (described below) is controlled by three parameters settable with this command:

s tmout nrds rintv

where *tmout* is a timeout in seconds (60 max), *nrds* is the number of required readouts after an event, and *rintv* is the interval between two consecutive readouts in PicOS milliseconds. The default setting of the three parameters (before the first use of the command) is all zeros. A missing number in the command defaults to zero as well.

q

Stops the report FSM and powers the sensor down. Note: you have to execute *q* between two *a*'s.

h n

Switches off the radio for *n* seconds (60 max) or until the nearest sensor event or report, whichever comes first. Used to measure the current drawn by the node. If the argument is absent, it defaults to zero meaning “no timeout”, i.e., just wait for a sensor event.

d m

Switches the LCD off (*m* = 0) or on (*m* != 0). Intended for current measurements.

p m

Switches between the powerdown (*m* = 0) or powerup (*m* != 0) modes of the CPU. The initial mode is powerdown.

The following commands are directly inherited from RFTEST:

r year month day dow hour minute second

Sets or reads the real-time clock. The *year* should be written modulo 100 (only the LS byte of the specified integer number is used); *dow* is the day of the week, e.g., 0 meaning Sunday, 1 for Monday, and so on.

If the number of arguments is less than 7 (e.g., zero), the command ignores them and instead displays the current reading of the real-time clock.

b time

Activates the buzzer for the specified number of milliseconds.

fr a

Reads FIM word number *a* (specified as unsigned decimal).

fw a b

Writes word value *b* at FIM location *a* (both unsigned decimals).

fe a

Erases FIM block containing location *a*.

The praxis also responds to push buttons reporting them to the access point.

The report FSM

Here is the action carried out by the report FSM. Its main loop commences by issuing a *wait_sensor* request to the accelerometer. If *tmout* is nonzero, the FSM also issues a *delay* request for that many seconds. The idea is to force a sensor reading every *tmout* seconds even if there are no events.

Whenever an event occurs, the FSM looks at the value of *nrds*. If *nrds* is zero, it means that we don't care about any acceleration values, only about the event's occurrence. In such a case, the FSM sends the text “E!” to the access point and resumes the main loop (i.e., issues another *wait_sensor* request).

If *nrds* is nonzero (following an event reception), the FSM will read the sensor that many times before returning to the main loop (to issue another call to *wait_sensor*). The first readout is made right away. Note that it will return the event data (the pilot value in the returned 4-tuple will be nonzero). If *nrds* is equal 1, there will be no more readings and the sensor will never switch to the measurement mode. Otherwise, the FSM doesn't return to the main loop (doesn't call *wait_sensor*), but *rintv* milliseconds after the first readout, calls *read_sensor* again, this time producing the raw acceleration data in measurement mode. As we said earlier, there is a 120 msec time penalty for that call. Any subsequent calls to *read_sensor* (the case *nrds* > 1), issued at *rintv* millisecond intervals, will return quickly (without dropping the measurement mode). At the end (after all *nrdv* readouts have been made), the FSM will return to the main loop invoking *wait_sensor,* which will put the sensor back into the event mode.

If *tmout* is nonzero and there has been no event for that many seconds since the last call to *wait_sensor*, the FSM will force a readout and then get back to the main loop. Note that that readout will be done in measurement mode.

The readout format, as presented to the access point, is:

```
u: [p] <x,y,z>
```

where *u* is “E”, if the readout has been caused by an event, or “P”, if it is a forced readout after a timeout; *p* is the “pilot” value, i.e., the first of the four numbers returned by *read_sensor*, shown in hexadecimal, and *x*, *y*, *z*, are the three acceleration values shown as signed integers. Note that *p* equal zero indicates a readout performed in measurement mode.