Application Report

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Derivative Integration Algorithm for Proximity Sensing

David Wang

ABSTRACT

Proximity sensing applications requires the detection of small changes in capacitance (typically on the order of a few femtofarads) around the noise floor. There are many ways to process the data to determine whether a target was detected or not. So how do you choose? This application note describes a simple algorithm that can be used for proximity sensing or capacitive touch button applications that does not require significant processing overhead.

1 Basic Concept

To detect a change in capacitance for proximity sensing applications, a baseline measurement (no target in the sensing area) and a detection threshold above/below the baseline measurement is required to determine whether a target is within close proximity to the sensor. The minimum system sensitivity is set by the noise floor of the sensor and any external interference. The detection threshold must be set at or above this noise floor. Figure 1 illustrates the operation of the detection threshold concept.

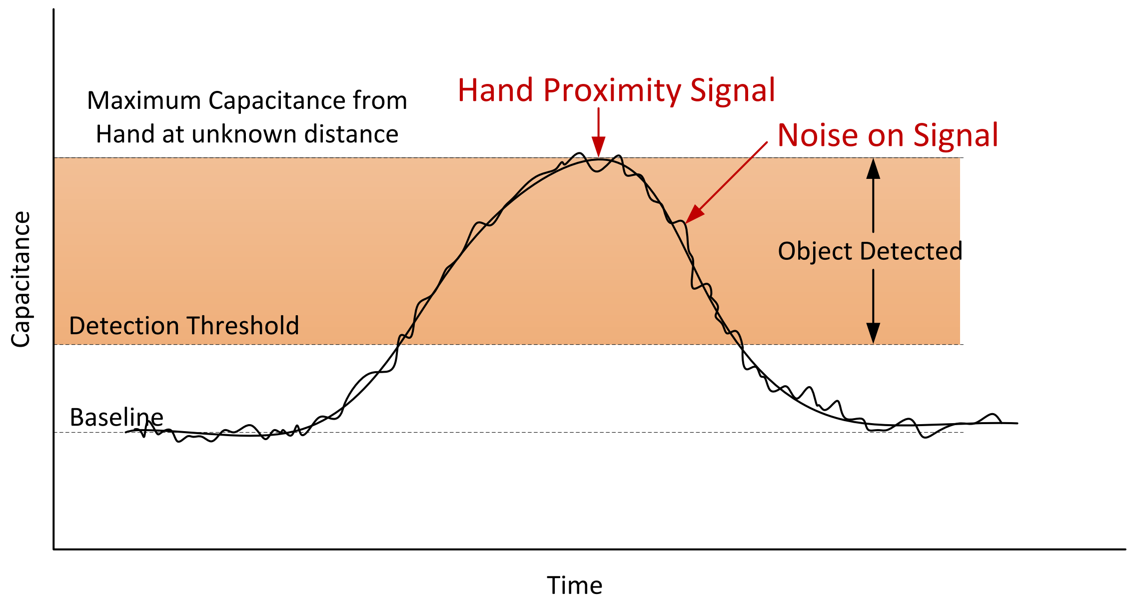

Figure 1. Signal and Noise Consideration for Determining Detection Threshold

There are several issues that arise with this basic idea. For example, if the baseline is not inherently stable or constant and a capacitance drift becomes noticeable, the algorithm will need to track a slow moving average of the baseline and compare that to the actual signal. This can be robust but not efficient. A more efficient and effective way to process the data is to look at the rate of change with a derivative integration algorithm.

2 Derivative Integration Algorithm

A derivative integration algorithm (pseudo code shown in Figure 2) is a simple and robust way to process the data. It can be used for both proximity sensing and capacitive touch buttons; the only difference between the two would be the derivative and integration thresholds for each sensor to obtain a robust and highly sensitive response.

This algorithm tracks the rate of change or derivative (D[i]) between the current measurement (X[i]) and previous measurement (X[i-1]). Proximity sensing applications require the detection of small capacitance changes (on the order of fF). This requires the derivative threshold (DT) to be very low. As the derivative value passes the threshold, a variable that tracks the integral or sum of the derivative differences accumulate until it passes an integral threshold (IT). Once IT is reached, an object has been officially detected. Changes in capacitance due to noise can be a severe problem, especially if the DT is very low. The integral of the derivative (I[i]) can start to accumulate and falsely trigger as aa detection. Random noise should stabilize the integral value so that the mean is zero (no capacitance drift occurs), but a high integration threshold (IT) can allow enough noise margin for non-random noise.

The leakage factor (L) is a value between 0 (instant dissipation) and 1 (no dissipation). It is typically set at 0.99 to represent that the algorithm has some memory and information on past values to determine where the detection boundary occurs. Various leakage factors can be used for a faster recovery time if the integral swings too far positive. This causes temporary sensitivity reduction until the integral can stabilize near zero.

```
X[i-1] = X[0]
I[i-1] = 0

Loop1:
D[i] = X[i] - X[i-1]
Is (ABS(D[i]) greater than DT)?
        true:
              I[i] = I[i-1] + D[i]
        else:
              I[i] = I[i-1]
Is (I[i] ≥ IT)
        true:
              Object detected
              I[i-1] = I[i]
        else:
              Object not detected
              I[i-1] = I[i]*L
```

Parameters
IT = Integration threshold
DT = Derivative threshold
L = Leakage factor
X[i] = Current sample point
X[i-1] = Previous sample point
D[i] = Derivative
I[i] = Integral of derivative
I[i-1] = Previous integral of derivative

Figure 2. Pseudo Code for the Derivative Integration Algorithm

As a visual example, once the human hand approaches the sensing area, the integration value starts to accumulate as along as the derivative of the measurements hit the derivative threshold. If the hand has been "detected" by the device (integral value goes above IT) and stops in the sensing area, the derivative flattens out and the integral stops accumulating. As the hand moves away from the sensor, the integral recedes until it goes below the threshold. This indicates the target object is outside of the intended sensing range.

For capacitive touch button applications, a low derivative threshold is not required. The integration threshold can be optimized based on the desired button response. Multiple derivative and integration thresholds can be implemented to filter out any high frequency noise seen in the sampled measurements and increase the sensitivity response.

Figure 3 shows an example of the raw code waveform with a target in proximity to the sensor using the FDC2214. Figure 4 corresponds to the derivative of the raw code and Figure 5 corresponds to the integral count. As the derivative becomes more negative (object approaching closer to the proximity sensor), the integral count matches the raw code signal as expected. The thresholds can also be optimized to be robust against any slow moving drift that occurs. Figure 6 shows how a drift in the raw code is compensated in the integral count. The signal is preserved without any distortions due to the slow upward drift.

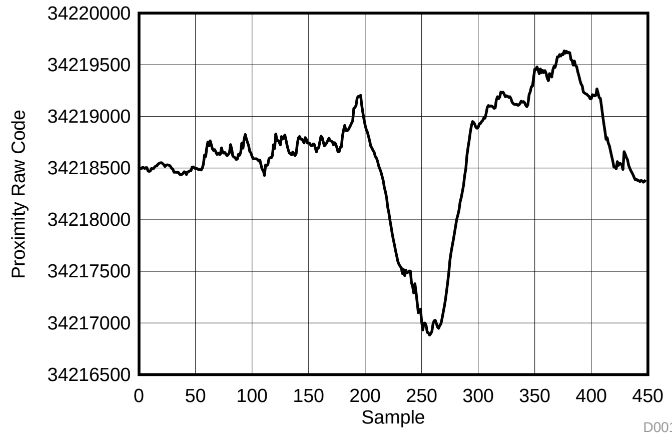

Figure 3. Proximity Raw Code Example 1

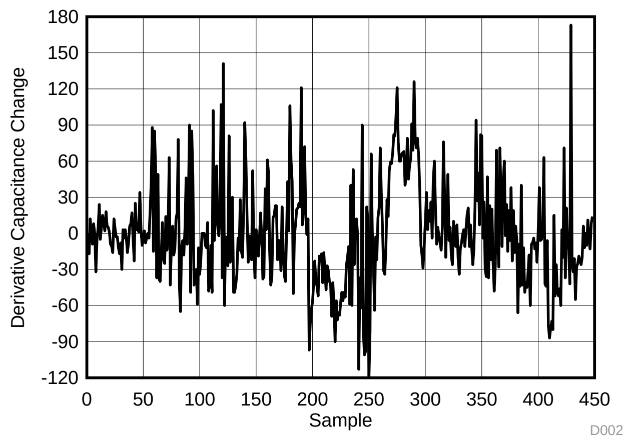

Figure 4. Proximity Derivative Code Example 1

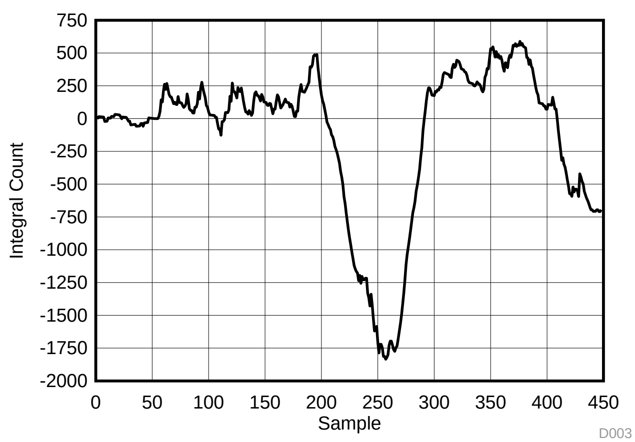

Figure 5. Proximity Integral Example 1

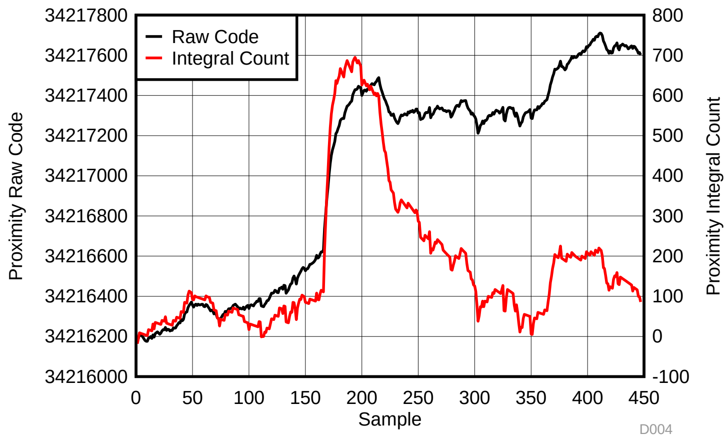

Figure 6. Raw Code and Integral Count Example 2

3 IIR Filter Implementation

To improve the signal-to-noise ratio in the measurements, an IIR filter can be implemented to process the data and obtain a smooth measurement prior to sending it through the derivative integration algorithm. The IIR filter implementation is similar to a moving average except that previous values do not have to be stored and shifted out of the summing order. This process saves memory and computational time at the expense of slight accuracy degradation.

Making N a power of 2 allows bit shifting instead of actually dividing, thus saving computational cycles.

$$\mathrm{Avg}[i] = \frac{(\mathrm{Avg}[i-1] \times N) - \mathrm{Avg}[i-1] + \mathrm{val}[i]}{N} \tag{1}$$

Figure 7 shows how the IIR filter with a 16-point moving average can reduce the amount of peak to peak noise on the signal. For applications that require high sampling rates, resolution is compromised and SNR decreases. The IIR filter can distinguish the signal from the noise.

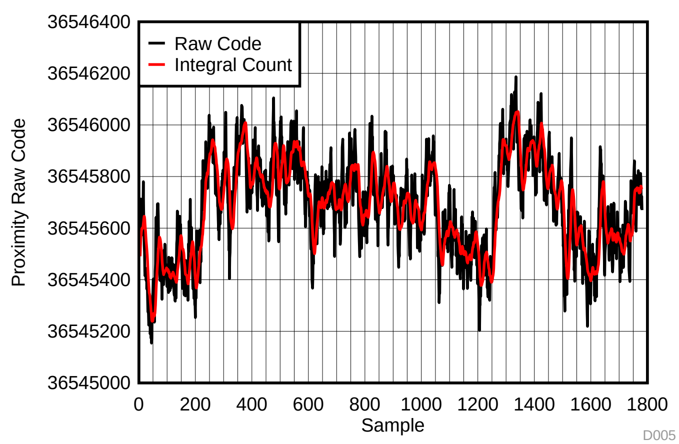

Figure 7. 16-Point Moving Average on Raw Code Output

4 Summary

Overall the derivative integration algorithm is a simple way for processing data for proximity sensing and capacitive touch button applications. This solution is a foundation that other sophisticated processing algorithms can be integrated within to be more robust for various system conditions. Depending on the system requirements, the processing must be optimized, but the derivation integration algorithm is a great start to get up and running for quick prototypes.

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