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Wavelet filtering for data recovery

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Abstract

In case of electrical wave measurements in space instruments, digital filtering and data compression on board can significantly enhance the signal and reduce the amount of data to be transferred to Earth. While often the instrument's transfer function is well known making the application of an optimized wavelet algorithm feasible the computational power requirements may be prohibitive as normally complex floating point operations are needed. This article presents a simplified possibility implemented in low-power 16-bit integer processors used for plasma wave measurements in the SPEDE instrument on SMART-1 and for the Permittivity Probe measurements of the SESAME/PP instrument in Rosetta's Philae Lander on its way to comet 67P/Churyumov-Gerasimenko.

1. Introduction

On September 27, 2003, The European Space Agency's satellite SMART-1 (Small Missions for Advanced Research in Technology-1) [1] was launched towards the Moon, spiraling slowly out of Earth orbit by using only solar-powered Hall effect thrusters until it was captured by the Moon's gravity and continued in a Moon orbit. Besides several other instruments for Moon science the satellite carried also the plasma instrument SPEDE (Spacecraft Potential, Electron and Dust Experiment) [2], built by the Finnish Meteorological Institute (FMI). Its main purpose was the monitoring of the plasma in the vicinity of the spacecraft to support the operation of the electrical propulsion system. In between thruster activations it could also be used for natural plasma observations, provided it could operate inside the Earth radiation belt and did not use much power. Plasma wave measurements needed a high data compression rate in order not to exceed the very limited telemetry budget. This objective was fulfilled by calculating on board a plasma wave power spectrum, reducing the measured 8000 to 16000 time series points to a vector of 10 power values.

The same algorithm was implemented in the SESAME processor of the Rosetta Lander [3] to digitally filter the AC-current and voltages measured by the FMI-built Permittivity Probe and also to calculate power spectra when the instrument operates in a passive mode to observe plasma waves generated by comet activities.

2. Implementation principles

The expected observations were sinusoidal signals or their superposition. A Daubechies D4 Wavelet algorithm [4] is adequate for this problem and straight forward to implement. The four used scaling coefficients are:

$$h_0 = \frac{1+\sqrt{3}}{4\sqrt{2}} \quad (1)$$

$$h_1 = \frac{3+\sqrt{3}}{4\sqrt{2}} \quad (2)$$

$$h_2 = \frac{3-\sqrt{3}}{4\sqrt{2}} \quad (3)$$

$$h_3 = \frac{1-\sqrt{3}}{4\sqrt{2}} \quad (4)$$

By multiplying these coefficients with four subsequent time series vector elements and correct signs and adding the products one can construct low-pass or high-pass filters and power spectra.

To implement this algorithm idea in a 16-bit integer processor environment, each of the four coefficients is multiplied by 128 and then rounded to the closest integer value before storing it as constant vector in the code. The 8-bit detector values are also multiplied by 128, which is a simple 7-bit shift operation. Using an intermediate 32-bit signed working format, the multiplication with the coefficients and subsequent addition of the four neighbor products is straight forward. The resulting value is again divided by 128 via a 7-bit right shift operation to generate the element for the new level vector of half length.

Repeating this step *n* times results in *n* vectors of decreasing length where each subsequent vector represents only the lower frequency components. By calculating the power of each vector one generates a power spectrum with *n* logarithmically spread frequency bins. To reduce the digital error the needed normalization is not done on board but is left to ground processing.

To detect sinusoidal signals of known frequency the sequential application of low-pass and high-pass filtering can extract a known frequency band and thereby suppress high frequency noise and low frequency offset variations and other EMC disturbances.

3. Power spectrum calculation

Figure 1 shows a power spectrum calculated with the wavelet algorithm while SMART-1 was orbiting the Moon. Plasma waves are generated when dust particles lifted off the Moon surface hit the satellite. This is dominant in the right third of the figure starting with a sudden increase (brown bar) at the Umbra end.

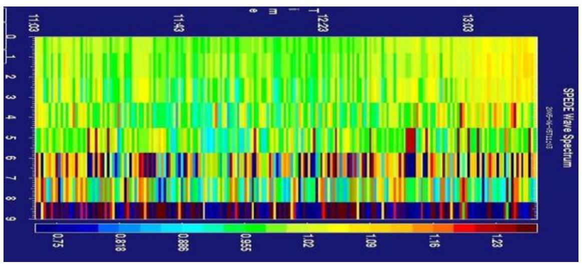

Figure 1: SPEDE power spectrum from one Moon orbit: X-axis = time, Y-axis = frequency, color code= spectral power

4. AC-signal filtering

The Rosetta Permittivity Probe injects AC-currents of known frequencies into the comet surface material, and measures the current and resulting potential variations as a function of time. Using a sampling rate optimised to the generated current frequency, the vector element index has the same meaning for all frequencies. An initial wavelet low-pass filter to remove high frequency noise followed by a low – pass filter to remove frequencies below the measurement frequency increases the SNR significantly. As the wavelet algorithm maintains the phase ratio between the current and potential vectors, the sine waves for both signals can be reconstructed after filtering. As only the amplitudes of both signals and their relative phase shift have to be determined, these three parameters are heavily over-determined. This allows the recovery of signals even in case the measured signals exceeded the dynamic range of the detector, as each sine wave of known frequency is fully defined by just 2 points.

This not only allows a significant SNR improvement and error removal but also a drastic data compression: from typically 2 x 1024 data points measured only 4 values have to be transmitted to Earth: the used frequency, the current amplitude, the potential amplitude and the phase angle between the signals.

5. Summary and Conclusions

The presented integer wavelet filtering can be used in different space instrument applications where the availability of energy and telemetry bandwidth is limited. The introduced error can be made comparable to the resolution of the detectors used.

Acknowledgements

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