Radioactive mineral identification based on FFT Radix-2 algorithm

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A fast Fourier transform (FFT) Radix-2 based approach using a gamma-ray spectrometer for the identification of radioactive mineral is presented. The proposed method reduces the complexity of diagnosis associated with the spectrometer by transferring time-domain analysis to frequency-domain analysis. The operation of PDA/DSP is discussed pragmatically.

Introduction: The gamma-ray spectrometer is a device for identifying radioactive mineral deposits in rock formations. It offers virtually unlimited options for configuring a solution to a wide variety of measurement problems. The device consists of a hand-held probe coupled to a personal digital assistant (PDA) via a serial link. The hand-held probe includes a photomultiplier as a transducer to convert gamma rays to an electronic signature. The signature represented in the time domain as a pulse is sent to an analogue-to-digital (A/D) converter. The pulse obtained by a spectrometer is approximately 5 µs in duration. The amplitude of the pulse is proportional to the concentration of radioactive material. The A/D converter digitises the pulse before it is processed by a digital signal processor (DSP). The DSP converts the digitised pulse from time to frequency domain. The DSP transfers time and frequency domain information to the PDA via one of its two serial ports. The electronic signatures are converted from the analogue domain to the digital domain, and they are processed and reconstructed in a PDA. The fast Fourier transform (FFT) Radix-2 [1, 2] approach enables the conversion of the time domain information to the frequency domain. In the frequency domain the spectra of the pulses are realised. The spectra allow radioactive elements to be readily identified. This identification would be more difficult to perform in the time domain because the pulses of different radioactive elements have similar shape and amplitude.

Device specification: The spectrometer and the PDA described here have the following specifications:

- An acquisition begins when the user activates a switch on the probe. The acquisition ends when the user presses the 'end' button on the PDA.
- Up to 256 channels of radioactive isotopes are registered. During an acquisition the pulse count for each channel is accumulated and stored.
- Time domain and frequency domain representations of the peak pulse for each channel are found and stored.
- Channel boundaries defining an isotope energy band allow the probe to be dynamically reconfigured during operation. These energy bands are uploaded to the probe from the PDA.

Operation of PDA-DSP: A block diagram of the data capture system is illustrated in Fig. 1. Data packets are sent and received by the PDA and the DSP. An asynchronous binary protocol between the PDA and DSP is adopted. Packets are constructed using start of text (STX), message length, identification, data, cyclic redundancy check (CRC) and end of text (ETX) bytes.

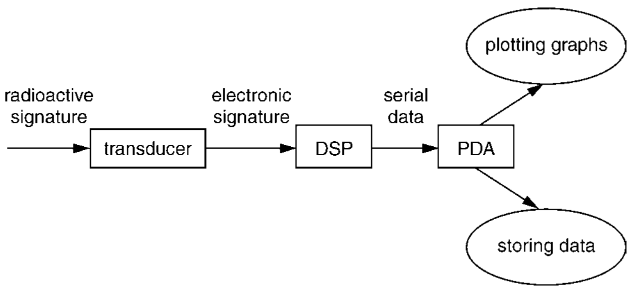

Fig. 1 *Block diagram of data capture system*

For each packet sent a 16-bit CRC is computed and included in the packet. When a packet is received the CRC is recomputed and compared with the CRC found in the packet. If the computed and received CRC are the same the message is validated by transmission of an acknowledge (ACK) character. If the computed and received CRC are not the same the packet is determined to be corrupted and a negative acknowledge (NAK) character is sent. Receipt of a NAK character prompts the transmitter to resend its last transmission.

When the PDA sends a start packet the DSP enters its acquisition state. When the PDA sends a stop packet the DSP enters its processing state. At the end of this state the DSP sends a pulse count packet to the PDA. The pulse count packet contains the pulse count for each channel accumulated in the acquisition state. The PDA extracts each channel's pulse count displaying it on the PDA. The PDA can also request a channel's FFT values and time-domain values. The data returned to the PDA is plotted on the PDA pad frame.

DSP software operation: The DSP code incorporates a state machine for the acquisition, processing and storage of sample pulses. The DSP is initialised into an idle state and the data loaded into memory. The DSP is also configured with a default set of 256 energy bands in this state. (The A/D converter resolution is 12 bits giving 4096 quantisation steps. If the analogue input ranges between 0 and 5 V, each energy band is $4096/256 = 16$ quantisation steps. A quantisation step $= 5/2^{12} = 1.22$ mV.) Finally 256 data structures representing the channel number, peak pulse amplitude, pulse count time and frequency domain data for each channel are declared and initialised to zero. In this state the DSP is waiting for commands from the PDA to begin acquiring pulses. On receipt of a start packet the DSP advances to its acquisition state. The data previously opened and stored in memory are now examined. A field of the file is retrieved and converted to a floating-point number. If this number exceeds a preset threshold the state machine advances to its storage state. The threshold is chosen to suit the sample pulse set. In the hardware DSP implementation its value has to be adjusted to suit actual pulses. The next 32 fields are retrieved and saved to another block of memory. (The A/D converter is clocked at 6 MHz, a 166 ns conversion time. For 32 conversions this allows us to characterise a $32*166$ ns $= 5.3$ µs pulse. 32 is also a power of 2, a requirement for an FFT Radix-2 algorithm.) After 32 pulses are captured the state machine advances to its processing state.

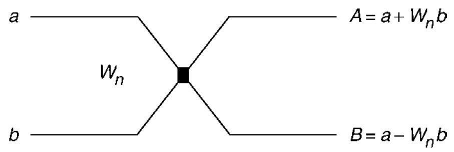

Fig. 2 *Basic computation in the decimation-in-time FFT algorithm*

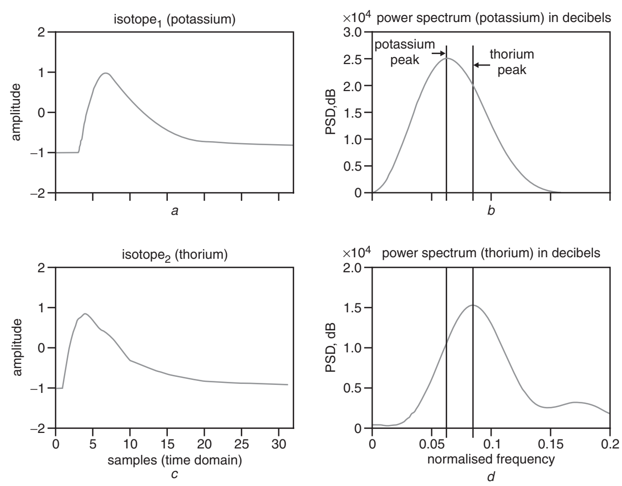

Fig. 3 *Signal analysis*

a Potassium isotope electronic signature in time domain
b Power spectrum density of potassium isotope
c Thorium isotope electronic signature in time domain
d Power spectrum density of thorium isotope

The basic computation in FFT computation performed at every stage of discrete Fourier transform (DFT), which takes two complex number (a,b), multiplies b by W_N^r $(= e^{-j2\pi r/N}$, where N is the number of data points and $r = 0, 1, \ldots, \log_2 N$), and then adds and subtracts the product from a to form two new complex numbers (A,B). The basic computation is shown in Fig. 2 [2, 3].

FFT and time domain analysis: In the simulation, two gamma-ray pulses of potassium and thorium were used. Both pulses were processed through the FFT Radix-2 algorithm. It can be seen from Figs. 3*a* and *c* that the electronic signatures of different radioactive elements exhibit similar behaviour, which complicates the decision of classification. After processing these signatures through the FFT Radix-2 algorithm, it is evident that the peaks of signatures have attained two different locations (Figs. 3*b* and *d*, two straight lines represent different location of peaks), which enables the classification of different radioactive materials. In general, the FFT algorithm helps to identify the elements.

Conclusions: The FFT Radix-2 algorithm was basically utilised to reduce the complexity involved in the identification of radioactive electronic signatures. The process involved in the algorithm allocates a unique location for each peak that makes it very easy to understand and analyse the difference in the radioactive materials. The implementation process of the data acquisition system has been discussed, which enables easy distribution of data capture from the real world. It also allows the collection and reconstruction of data with fewer errors, and the probability of information loss is minimised. The system was utilised in storage and display of the energy band counts and in plotting the graph of electronic signatures in the time domain as well as in the frequency domain.

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