A Correlation Based Pulse Detection Technique for Gamma/Neutron Detectors

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Motivation

• Shielded radioactive materials
  – Low energy radiation
  – Difficult to detect
• Signal processing to detect these pulses
• Efficient online detection required (e.g. airports)

Real-Time Detection
Current State-of-the-Art

- Analog: mostly counting pulses
- Digital: Data stored for post-processing

- Threshold must be lowered to detect lower energy pulses → false detections
This Approach

• Data is analyzed prior to storage
  – Significantly less amount of data is stored
• Improve detector sensitivity
• Real-time pre-processing
Equipment

- Commercial board
  - 250MS/s, 14 bits, 4 channels
  - Connects directly to PC (e.g. laptop)
- On-board FPGA customizable for pre-processing of data

Innovative Integration’s X5-210M

Real-time detection
Extract useful information from pulses (e.g. height, time)
Normalized Cross Correlation (1/2)

- Pre-processing in real time on an FPGA
- Measure of similarity between two signals

\[ C(u) = \frac{\sum_x [f(x) - \bar{f}_u][f(x-u) - \bar{f}_u]}{\sqrt{\sum_x [f(x) - \bar{f}_u]^2 \sum_x [f(x-u) - \bar{f}_u]^2}} \]

\[ -1 \leq C(u) \leq +1 \]
Normalized Cross Correlation (2/2)

Incoming Pulses

Pulse Template

Correlator Output

Amplify Signal & Attenuate Noise
Template

- Template used in the correlator to recognize pulses

- Capture pulses
  - Bin pulse data
  - Average pulses in each bin
  - Normalize

Measured Pulses

Template

Average 1500 pulses

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Hardware Implementation (1/2)

$$C(u) = \frac{\sum_x [\text{Incoming Data}] \times [\text{Template}]}{\sqrt{\sum_x [\text{Incoming Data}]^2 \sum_x [\text{Template}]^2}}$$

- Correlator building block: Multiply and Accumulate

- Available on FPGA as hardware accelerators
Hardware Implementation (2/2)

\[ V_{pk} = \frac{N}{\sqrt{D \cdot K_t}} + C(i) + C(i+1) + C(i+2) \]

FPGA

Data

Template

ROM

M&A

Detect

\( t_{arrival} \)

\( V_{pk} \)
Simulation Results (1/2)

- Pulses detected in presence of noise
- E.g. A 5 keVee pulse in 5 keVee noise

Noise Level 5 keVee

Noise Correlation $C_{th} = 0.245 \ (3-\sigma)$

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Simulation Results (2/2)

- A 5 keVee pulse in presence of 5 keVee noise
- Probability of detection: 18% to 86%
Conclusion

• Proposing an FPGA-based approach for pulse detection
  – Real-time data processing
  – Improved sensitivity ($\approx 4x @ 5\text{keVee}$)
  – Reduced data storage
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