Evaluation of Arduino-based Signal Readout for Low-cost Mobile Radiation Detection System

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INTRODUCTION

Low-cost Mobile Radiation Detection System

- In-situ gamma spectroscopy is important in order to evaluate type and activity of radionuclides that exist around environment.
- Conventional gamma detection system includes portable HPGe and NaI(Tl) scintillator coupled with PMT, but requires high cost and has bulky geometry, heavy weight, and high power consumption. Hence, it is necessary to develop low-cost and low-power mobile gamma detection system.

Strategy

- Use compact photo sensor (silicon photomultiplier (SiPM) or avalanche photodiode (APD))
- Use simple and compact signal processing and data acquisition electronics (ASIC or FPGA or single-board computing device)

Arduino

- An open-source platform consists of a single board microcontroller (MCU) [1]
- Offers low-cost/-power operation, easy programming
- Relatively low processing power compared to ASIC or FPGA and limited memory

Goal of this study

- Develop low-cost mobile gamma detection system using SiPM and Arduino
- Performance comparison using two different commercial Arduino MCUs
- Detector performance evaluation

MATERIALS & METHODS

Low-cost time-based signal readout system

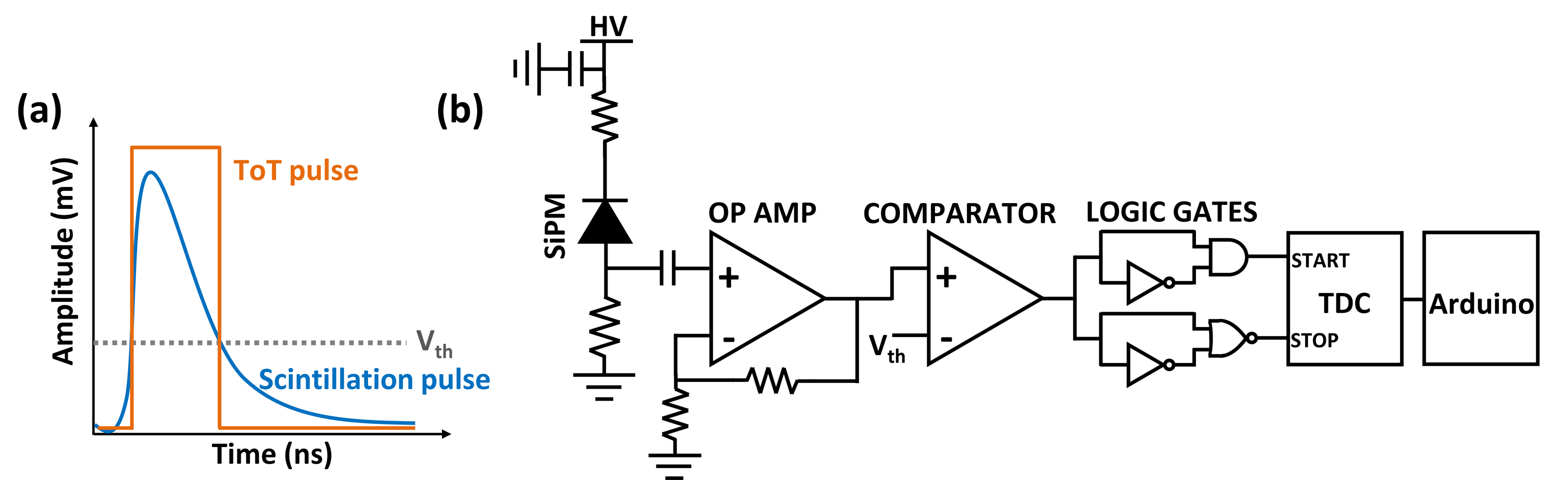

Figure 1. (a) Concept of time-over-threshold (ToT) where scintillation pulse is converted into ToT pulse by using a comparator with a fixed threshold (V_{th}). (b) Circuit diagram for the time-based readout system.

Time-over-threshold(ToT) technique [2]

- Converts a scintillation pulse into a digital ToT pulse
- ToT pulse width ∝ charge of scintillation pulse (energy)
- Provides low-cost/power system due to simplified circuitry with fewer electronic components
- Non-linear relationship between pulse width and charge [3]

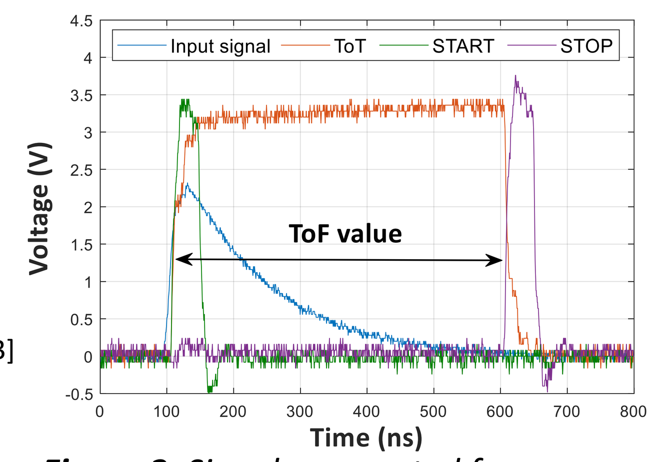

Figure 2. Signals generated from time-based readout circuit. (V_{th} = 20 mV, each signal has different voltage scale)

Time-based signal readout

- ToT signal fed into gates to generate START & STOP signal
- A low-cost/power time-to-digital converter (TDC) receives START & STOP signal and measures time-of-flight (ToF) values of a ToT signal

Low-cost data acquisition using Arduino

Table 1. Comparison between two commercial Arduino boards.

Specification	Nano	Due
MCU	ATmega328P	AT91SAM3X8E (Coretex-M3)
Architecture	AVR	ARM
Bit	8	32
Clock Speed (MHz)	16	84
Analog I/O	8	12
Digital I/O	22	54
Size (mm²)	18×45	53.3×101.52
Power consumption	19 mA	Not provided
Price ($)	20.70	40.30

- Two Arduino processors were combined with time-based signal readout board
  - **Nano**: common 8-bit MCU in Arduino
  - **Due**: high-performance 32-bit MCU in Arduino
- Arduino processor was used for chip configurations, data processing and communication

Experimental evaluation

Arduino performance comparison using Function generator

1) Square pulse with different pulse width ranging from 40 to 2000 ns
   - V_{peak}=500 mV, V_{offset}=250 mV, t_{rise} and t_{fall}=5 ns, freq.=100 Hz
   - Arduino baud rate = 115,200 bps
   - ToF_{jitter} ($TOF_{jitter} = |TOF - pulse\ width|$) and its standard deviation (σ_{jitter}) were evaluated

2) Square pulse with different frequency ranging from 100 to 1500 Hz
   - V_{peak}=500 mV, V_{offset}=250 mV, t_{rise} and t_{fall}=5 ns, pulse width=100 ns
   - Arduino baud rate tested from 57,600 to 250,000 bps
   - Packet loss (%) = $\frac{\#\ of\ received\ ToF\ values}{\#\ of\ generated\ square\ pulses} \times 100$ was evaluated

Validation with a real detector

- Developed time-based signal readout system was combined with 48 × 48 × 20 mm³ GAGG crystal coupled with 8 × 8 SiPM array (SensL ArrayJ-60035-64P-PCB, 6 mm pixel)
- Compact size of 50 × 50 × 60 mm³ with 600 g weight
- Arduino Nano was used as a processor

1) **Energy performance optimization**
   - ToT thresholds (V_{th}) from 50 to 90 mV
   - Arduino baud rate = 115,200

2) **Detector performance in different environments**
   - Source-to-detector distance from 0 to 30 cm with 37 kBq and 370 kBq ^{137}Cs point source, 5 min measurement

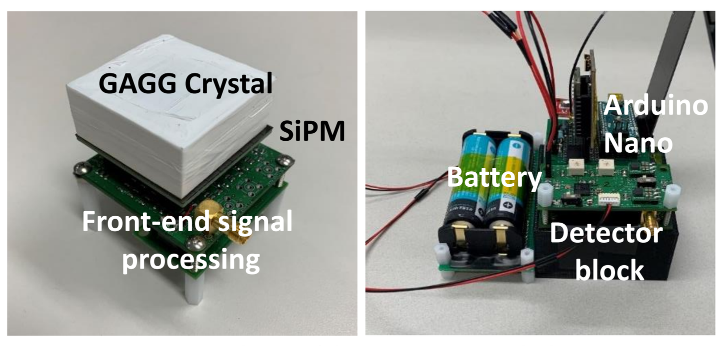

Figure 3. Developed low-cost mobile radiation detector system.

RESULTS & DISCUSSION

Performance of Arudino Nano vs. Due using Function generator

ToF_{jitter} and σ_{jitter} performance

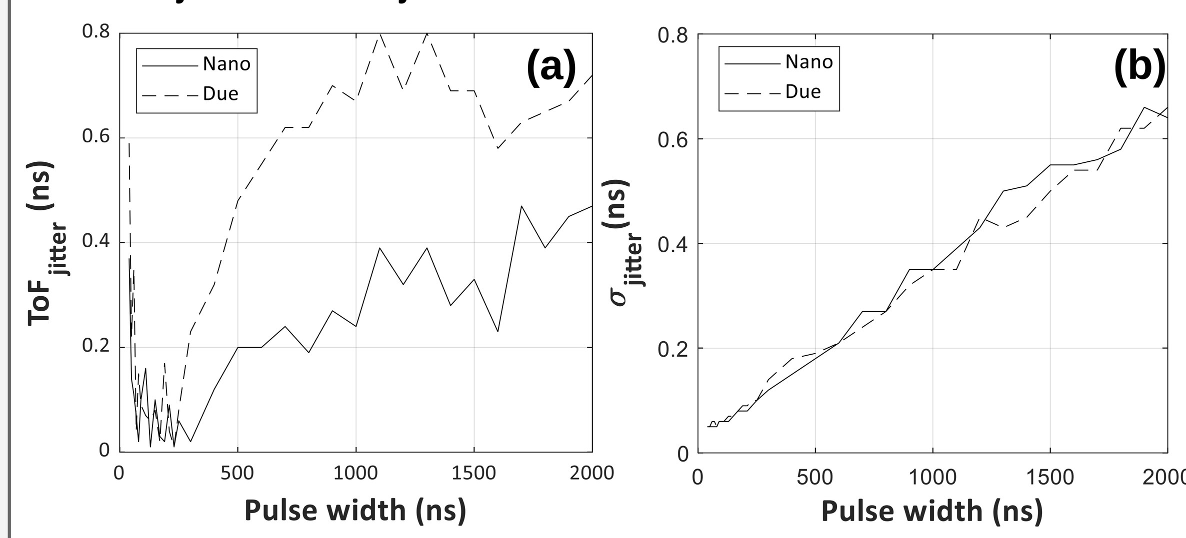

Figure 4. ToF_{jitter} and σ_{jitter} with different pulse widths. Solid lines show results of Nano and dotted line show results of Due processor.

- Both Arduino Nano and Due showed < ns jitter
- Nano showed slightly better TOF_{jitter} performance
- With larger pulse width, jitter increased accordingly

Packet loss (%) performance

- Packet loss occurred when Nano receives input pulse faster than 600 Hz and Due receives pulse faster than 1000 Hz
- Higher Arduino baud rate showed better data throughputs

Table 2. Packet loss (%) results with different pulse frequency (Hz) and Arduino baud rate (bps)

Processor	Nano				Due			
Baudrate (bps) / Frequency (Hz)	57,600	115,200	230,400	250,000	57,600	115,200	230,400	250,000
100	0	1	0	0	0	0	0	0
300	0	0	1	1	0	0	0	0
500	0	0	0	0	12	0	0	0
700	27	27	13	27	37	0	0	1
1000	49	49	49	49	56	11	1	0
1500	73	66	66	66	71	50	50	50
2000	80	69	69	69	78	55	50	50

Performance evaluation with a real detector

- @ 30V SiPM bias voltage
- Best energy resolution (@662 keV) of 9.35 % in FWHM achieved at V_{th} = 80 mV
- Detector showed stable 662 keV photopeak position and energy resolution with different source-to-detector distances, except for 370 kBq at 0 cm distance due to saturation.

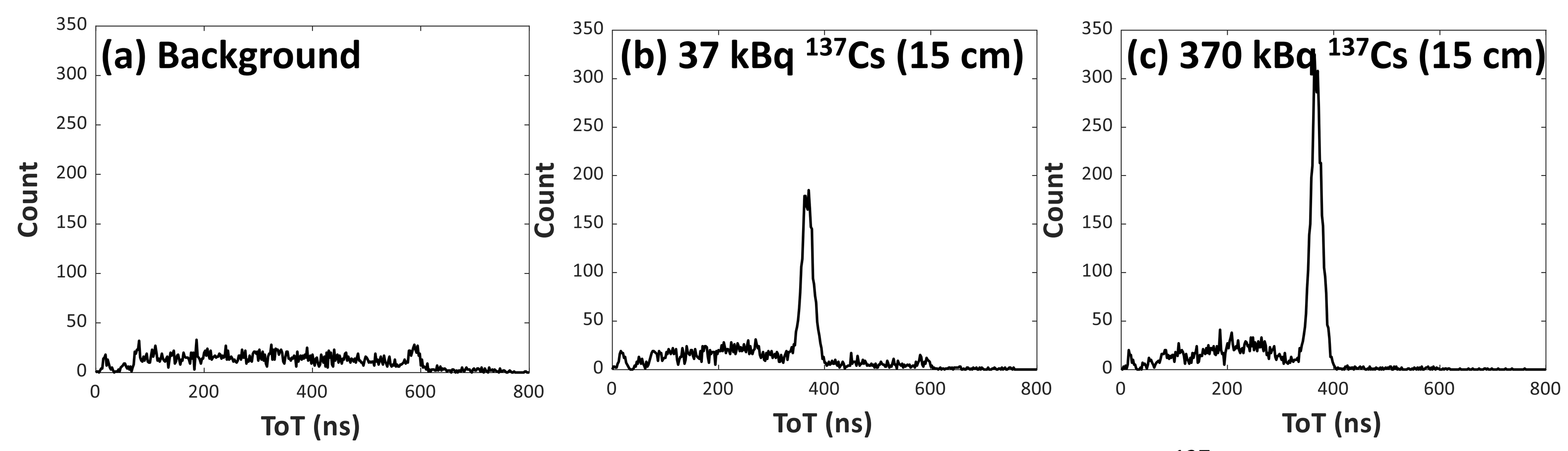

Figure 5. Energy spectra acquired (a) at background, (b) with 37 kBq ^{137}Cs that is 15 cm apart, and (c) with 370 kBq ^{137}Cs that is 15 cm apart from the detector module.

CONCLUSION

In this study, we implemented Arduino processors as a solution for the compact low-cost the radiation detection system. The developed Arduino-based radiation detection system showed good and stable performance. The developed readout system is advantages compared to the conventional detection system in terms of its compactness and cost resulting in roughly $50 which includes front-end signal processing and data acquisition.

REFERENCES

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[3] Shimazoe K et al 2012 Dynamic Time Over Threshold Method IEEE Trans. Nucl. Sci. 59 3213-3217

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