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

Min Sun Lee[a*], Jun Lee[b], Mee Jang[a], Jong-Myoung Lim[a]
[a]*Environmental Radioactivity Assessment Team, Korea Atomic Energy Research Institute*
[b]*Center for Nuclear Nonproliferation Strategy & Technology, Korea Institute of Nuclear Nonproliferation and Control*
**Corresponding author: mlee1024@kaeri.re.kr*

1. Introduction

The Arduino is an open-source hardware and software platform that consists of a single-board microcontroller (MCU) [1]. Arduino offers low-cost and low-power operation which allows to design a mobile battery-operated device and offers easy programming with wide range of compatible sensors. Hence, recently, Arduino is being widely used as an inexpensive solution to build educational and evaluation tools. However, due to its low MCU processing power and limited memory, it is unlikely to use Arduino boards for scientific instruments that requires highly computational tasks.

In this study, we implemented Arduino processors as a solution for a low-cost mobile radiation detection system. In order to avoid performance degradation using Arduino processor, we used time-based signal readout scheme that is coupled with time-to-digital converter (TDC). We tested two commercial Arduino processors to compare their performance on the developed time-based data acquisition for a radiation detector.

2. Materials and Methods

2.1 Low-cost mobile radiation detection system

2.1.1 Low-cost time-based signal readout

To develop a low-cost mobile radiation detector, we used a time-based signal readout approach, "time-over-threshold (ToT)" technique [2]. The ToT technique converts a scintillation signal into a digital signal by using a discriminator with a specific threshold and the pulse width of the converted digital signal is proportional to the charge of a scintillation pulse. Compared to the conventional pulse-height analysis technique [3], ToT technique has simplified electronics utilizing fewer electronic components which leads to low-cost and low-power instrumentation resulting in high level of integration. On the other hand, the main limitation of ToT technique is that the relation between charge and pulse width is non-linear, however, this non-linear relationship can be improved by applying linearity correction.

Fig. 1 shows a circuit diagram for the time-based readout circuit developed in this study. The amplified SiPM signal is fed into a comparator with a threshold (V_{th}) to generate a ToT signal. The ToT signal is then fed into logic gates to generate the START and STOP signal, which are the rising and falling edge of the ToT signal. The low-cost and low-power TDC (TDC7200) receives the START and STOP signal and generates time-of-flight (ToF) value and send it to the processor.

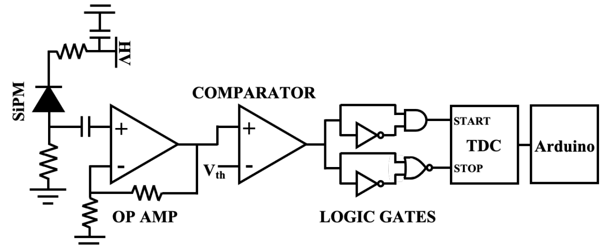

Fig. 1. Circuit diagram for the time-based radiation detection system developed in this study that is consisted of SiPM, opamp, comparator, TDC, and Arduino.

2.1.2 Low-cost data acquisition using Arduino

In this study, we used Arduino processor as a low-cost data acquisition solution for the mobile radiation detection system. Arduino processor was used to configure TDC and comparator chip and to receive real-time ToF values. Two Arduino processors with different specifications were combined with our time-based signal readout to find the proper one the compact and low-cost solution: 1) Arduino Nano, which consists of one of the common 8-bit MCUs and provides low-power and compact size, and 2) Arduino Due, which consists of a high-performance 32-bit MCU but has higher power consumption and larger size. Table I summarizes the characteristics of the Arduino Nano and Due boards.

Table I: Comparison between two commercial Arduino boards.

Specification	Nano	Due
MCU	ATmega328P	AT91SAM3X8E (Coretex-M3)
Architecture	AVR	ARM
Bit	8-bit	32-bit
Clock Speed	16 MHz	84 MHz
Analog I/O	8	12
Digital I/O	22	54
Size	18×45 mm^2	53.3×101.52 mm^2
Power consumption	19 mA	Not provided by a vendor
Price	$20.70	$40.30

2.3 Performance comparison using Function generator

In order to evaluate and compare the performance of time-based signal readout combined with the Arduino Nano and Due processors, an arbitrary waveform generator (Tektronix 3390) was used to simulate different input pulses. First, square pulse (V_{peak}=500 mV, V_{offset}=250 mV, t_{rise} and t_{fall}=5 ns, freq.=100 Hz) was generated with different pulse width ranging from 40 to 2000 ns. ToF_{jitter}, the difference in acquired ToF value to the generated square pulse width, and its standard deviation (σ_{jitter}) were evaluated. Second, square pulse (V_{peak}=500 mV, V_{offset}=250 mV, t_{rise} and t_{fall}=5 ns, width=100 ns) with different frequency ranging from 100 to 1500 Hz were tested to evaluate the packet loss (%) in two processors with different baud rates (bps). Packet loss is defined as the number of received ToF values to the number of generated square pulses.

2.4 Validation with a real detector signal

To validate our proposed low-cost data acquisition system with a real detector signal, we combined the developed time-based signal readout board with 48×48×20 mm^3 GAGG crystal coupled with 8×8 SiPM array (ArrayJ-60035-64P-PCB). Arduino Nano was used as a processor. The developed prototype detector module was experimentally evaluated using a ^{137}Cs point source. The energy performance was tested with different ToT thresholds (V_{th}) from 50 to 90 mV to find the optimal condition. Detector was tested in different environments by using point source with activities of 37kBq and 370 kBq and with source-to-detector distance from 0 to 30 cm. Measurements were conducted for 5 min, while V_{th} set to 80mV and baud rate was set to 115,200. Energy spectrum was generated based on the ToF values generated from TDC. Energy linearity correction was not applied in this study.

3. Results and Discussion

3.1 Performance comparison using Function generator

Fig.2 shows ToF_{jitter} and σ_{jitter} of ToF values acquired from the time-based readout combined with Arduino Nano and Due. Both Nano and Due showed similar jitters in overall, while Nano showed slightly better performance. Both ToF_{jitter} and σ_{jitter} increased with increasing pulse width, as expected.

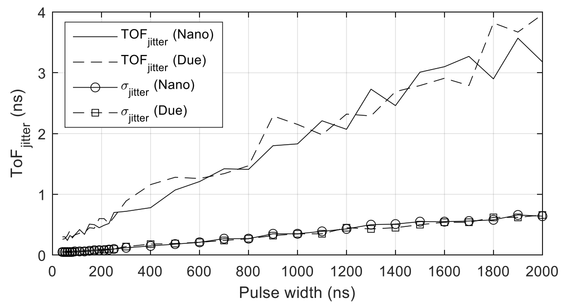

Fig. 2. ToF_{jitter} with different pulse widths. Solid lines show results of Nano and dotted line show results of Due.

However, with increasing pulse frequency, indeed, performances of Arduino processor had impact on the data throughputs. For Nano, there was loss in packets when input pulse is faster than 600 Hz, while Due showed packet loss with pulse faster than 1000 Hz (Table II). Higher baud rate of Arduino showed better data throughputs.

In overall, considering the size and power consumption of Arduino Nano and Due, we chose Arduino Nano processor (ATmega328P) as our data acquisition processor to build a compact low-cost mobile radiation detector.

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

Processor	**Nano**				**Due**			
Baud rate (bps) / **Freq. (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

3.2 Results with a real detector

Fig. 3. shows output signals from the developed prototype detector module. Once the input signal is fed into comparator, ToT signal is generated. START and STOP signals are generated consequently at the rising and falling edge of the ToT signal. And TDC measures the ToF between START and STOP signals.

With different ToT thresholds (V_{th}), energy resolution performances varied, and we found 80 mV showed the optimal value with energy resolution of 9.35% at 662 keV. Fig. 4 shows the energy spectra at background, low activity and high activity environment. As shown in Fig. 4, energy spectra were acquired successfully with good energy resolution at different environments. The detector showed stable photopeak positions and energy resolutions with different source-to-detector distances, except for the one with 370kBq at 0 cm distance, which showed slightly shifted photopeak position to the left.

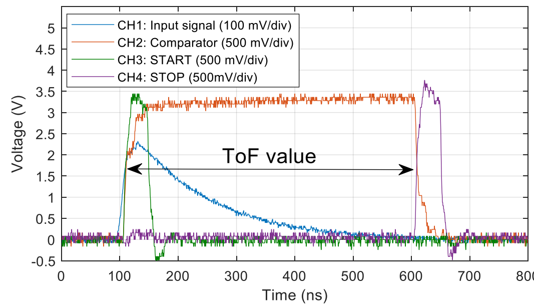

Fig. 3. Signals from the developed time-based signal readout board. (V_{th} = 20 mV).

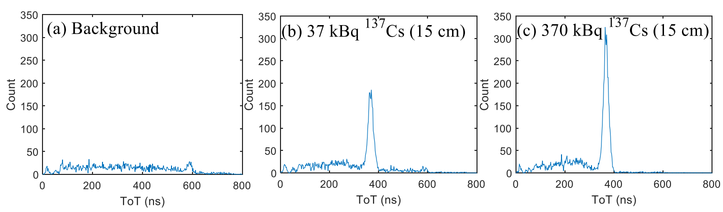

Fig. 4. Energy spectra acquired (a) at background, (b) with 37kBq ^{137}Cs that is 15 cm apart, and (c) with 370kBq ^{137}Cs that is 15 cm apart from the detector module.

4. 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.

ACKNOWLEDGMENTS

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