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Microcontroller ATMega328P Timer/Counter for Single Channel Gamma Spectroscopy

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A B S T R A C T

Soil contamination may occur in the upcoming decommissioning activities of the TRIGA2000 Reactor. Measurement of contaminant radioactivity, which can be performed using single-channel spectroscopy, is required in soil decontamination processes. This research develops a timer/counter system for single-channel spectroscopy using a microcontroller. The performance of the ATMega328P microcontroller Timer/Counter on Arduino has been tested for single-channel spectroscopy. Microcontroller's Timer/Counter1 is used as a counter while Timer/Counter2 is used as a timer. Tests include the linearity test, comparative test, and chi-square test. The test results show that the ATMega328P microcontroller Timer/Counter works well and can be used as the end of a single-channel spectroscopic system.

1. INTRODUCTION

Soil contamination can occur in accidents or nuclear reactor decommissioning. Currently, there are three main techniques for soil decontamination: soil washing, soil flushing, and the electrokinetic process [1]. Soil washing is one of the most recommended for decontaminating large areas of soil in a relatively short period of time because it is proven to be relatively very efficient. Measurement of the concentration of soil contaminants can be carried out using plasma spectroscopy and gamma spectroscopy [1–3].

In the Bandung nuclear area, there are TRIGA2000 research reactors, single-channel, and multi-channel spectroscopic equipment. Single-channel spectroscopy is used for environmental radioactivity research activities such as the phytoremediation research conducted by Tjahaja [4]. The system consists of a NaI(Tl) detector, Tennelec TC-241 Amplifier, Canberra Timing-SCA 2037A, and Canberra Dual Counter Timer 2071A. In the future, this single-channel spectroscopic system can also be used in the TRIGA2000 reactor decommissioning process.

Even though the counting process is digital, the Canberra 2071A can only take one measurement. The first step to counting begins with setting the timer using the thumbwheel switch, then pressing the toggle switch start on the Canberra 2071A. Counting results are displayed on the LCD. To repeat the counting process, the reset button is pressed, then the toggle switch start is pressed again. With a counter-timer system using a microcontroller,

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repeated counting can be performed, and the data are automatically stored on the computer.

Several studies have developed systems that use microcontroller timers/counters for nuclear instrumentation such as survey meters and radiation monitoring devices using GM (Geiger Muller) detectors [5–12] and scintillation detectors [13, 14]. Jumari has developed a Timer/Counter system for gamma spectroscopy using the 89c51 microcontroller [15]. In this study, a counter timer was made using Arduino with an interface on a PC via USB which is widely used today. The device is expected to replace the Canberra 2071A so that the measurement process is more automated and can be developed further.

Previous research has created a counter timer system using Arduino, which uses the interrupt feature of the microcontroller as the counter and the millis() function as the timer. It was found that the system can count pulses up to 150,000 cps [16]. This research also useds Arduino, but the Timer/Counter feature on the ATMega328P microcontroller was used as a counter and timer with the aim of obtaining better counting results.

2. THEORY

Gamma radiation spectroscopy is a measurement system that can identify radioisotopes. These systems use a scintillation or semiconductor detector, with a high-voltage supply that can detect gamma radiation. The detector output signal is then amplified by an amplifier. In single channel spectroscopy, the amplifier output signal goes through SCA (Single Channel Analyzer) to select the gamma energy range to be counted. SCA produces a TTL (Transistor-Transistor Logic) signal that can be processed digitally using a counter and timer.

Arduino Uno is a module that uses an ATMega328P microcontroller which has features including 20 digital IO (Input/Output), 6 of which can function as analog IO, crystal speed of 16 MHz, 3 Timer/Counter and interrupt [17]. Timer/Counter the Atmega328P consists of an 8-bit Timer/Counter0, 16-bit Timer/Counter1, and 8-bit Timer/Counter2.

There is a library for frequency calculations on Arduino as used by Purwowibowo [18], but the counting time cannot be changed, which is 1 second. Rahman set the Timer1 register as the counter and the delay() function as the timer [7]. In this study, Timer/Counter1 was used as a counter and Timer/Counter2 as a timer.

3. METHODOLOGY

Timer1 ATMega328P was set as a counter with an external clock source on the Arduino D5 pin, while Timer2 as a timer useds an internal clock source. Each clock that went into the timer adds the value of TCNTx (Timer/Counter) in memory. Timer/Counter1 and Timer/Counter2 settings are shown in table 1.

Table 1. Timer/Counter setup on Arduino

Line.	Command
1	TCCR1A = 0; TCCR1B = 0;
2	TCCR2A = 0; TCCR2B = 0;
3	TIMSK1 |= 0b00000001;
4	TCCR2A |= 0b00000010;
5	OCR2A = 124;
6	TIMSK2 |= 0b00000010;
7	TCNT1 = 0; TCNT2 = 0;
8	TCCR2B |= 0b00000101;

At the initial setting, Timer1 and Timer2 were reset by setting a value of 0 to the TCCR (Timer/Counter Control Register). Then bit TOIE1 (Timer/Counter1 Overflow Interrupt Enable) in TIMSK1 (Timer/Counter1 Interrupt Mask Register), so that if the value of TCNT1 exceeds the capacity of Timer1 which is 16-bit or 65,535, the program will enter the ISR (Interrupt Service Routine) Timer1.-

CTC mode (Clear Timer on Compare) Timer 2 was set to TCCR2A (Timer/Counter2 Control Register A) where Timer2 will overflow when the value of TCNT2 is equal to OCR2A (Output Compare Register A). TIMSK2 settings make the program will enter into ISR Timer2.

Setting TCCR2B (Timer/Counter Control Register B) was intended to set the prescaler, the internal clock divider, by 128. While the OCR2A value was obtained from the Eq. (1).

$$OCR2A = \frac{f}{prescaler \times t} - 1 \quad (1)$$

where f is the frequency of the Arduino system which is 16 MHz, the prescaler is the divisor value and t is the time interval between overflows. If the desired time interval between overflows is 1 ms, the OCR2A value is 124.

Every time overflow on Timer1 and Timer2 was reached, the program will be handled by a void ISR (Interrupt Service Routine). Fig. 1 shows the Timer1 and Timer2 ISRs used in this work.

```
ISR(TIMER1_OVF_vect)
{
  Timer1overflowCounts++;
}

//================================================================

ISR (TIMER2_COMPA_vect)
{
  overflowCounts = Timer1overflowCounts;
  timer++;
  if(timer < Period) return;

  TCCR1A = 0; TCCR1B = 0;   //Timer 1 reset
  TCCR2A = 0; TCCR2B = 0;   //Timer 2 reset
  TIMSK1 = 0; TIMSK2 = 0;   //Timer 1 & 2 disable interrupts

  totalCounts = (overflowCounts * 65536) + TCNT1;

  if(nCount<cntIter){
    Serial.println(totalCounts);
    nCount++;
    startCount(cntTime);
    return;
  }else{
    Serial.println("dn");
    inputString = "";
    cntTime = 0;
    cntIter = 0;
    nCount = 0;
    nextCount = true;
  }
}
```

Fig. 1. Timer1 and Timer2 Interrupt Service Routine

In ISR Timer1, there is a command line to increase the Timer1overflowCounts variable with a long integer data type. Thus, when the number of pulses that enter Timer1 from SCA exceeded 65,535 this variable will store and become a multiplier factor in the calculation of the total counts variable which is also a long integer data type. In theory, this system can count up to 4 million pulses.-

In ISR Timer2, the value of the timer variable will be increased and then compared to the Period variable. When the timer value reaches the Period value, the total count will be calculated and sent to the computer via USB serial communication. The period value can be set in the program or taken from data sent by the computer via USB serial communication. How long the counting system takes can be set via the Period value.

The Arduino Timer/Counter linearity test was carried out using the GW-INSTEK SFG-2004 function generator. The output of the function generator was connected to pin D5 Arduino. Then Arduino was connected to one-channel spectroscopy for the chi-square test and comparative test. The SCA (Single Channel Analyzer) output was connected in parallel with Arduino and Canberra 2071A, then the counting was done simultaneously. The count data was sent by Arduino to the computer and stored in the form of a CSV (comma-separated value) file, while the results of the Canberra 2071A count were recorded manually.

4. RESULTS AND DISCUSSION

The linearity test using a pulse generator was carried out with a frequency range from 1 Hz to 1 MHz. Each function generator output frequency is counted 10 times and the average is plotted in Fig. 2.

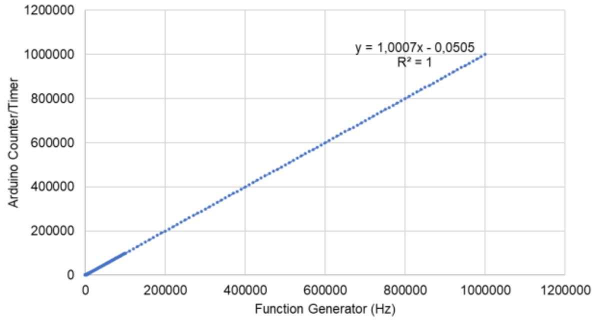

Fig. 2. Linearity test result

From Fig. 2 it can be seen that the Arduino count is proportional to the pulse generator output with $R^2 = 1$. The counting system developed by Rahman can count a maximum of 65,535 cps[7], while the results of a previous study obtained a system that can count up to 150,000 cps [16]. Based on Fig. 2, this system can count linearly up to 1 million cps. Therefore, high-activity radioactive sources can be counted using this system.

A comparative test using single-channel spectroscopy was carried out with variable count times from 30 to 900 seconds. The radiation source used is Cesium-134 with an activity of 1678 Bq in 2006. The results of the comparison test can be seen in Table 2.

Table 2. Comparison test results

No.	Counting Time (sec)	Canberra 2071A	Arduino Timer/Counter	% error
1	30	709	708	0.14
2	60	1393	1389	0.29
3	180	4182	4183	0.02
4	300	6900	6905	0.07
5	480	11304	11302	0.02
6	600	13970	13976	0.04
7	780	18215	18221	0.03
8	900	21068	21101	0.16

From Table 2, the biggest deviation compared to Canberra 2071A is at a count time of 30 seconds with a percentage of 0.14%. Meanwhile, the smallest deviation is at the time of counting of 480 seconds with a percentage of 0.02%.

The chi-square test was carried out by counting the radiation source at 10 seconds intervals 10 times. The radiation source used is Cobalt-60 with an activity of 1080 Bq in 2013. From the results, the chi-square value is calculated. Table 3 shows the chi-square test data.

Table 3. Chi square test results

No.	Canberra 2071A		Arduino Timer/Counter	
	x_i	$(x_i - \bar{x})^2$	x_i	$(x_i - \bar{x})^2$
1	34	9.61	35	6.25
2	52	222.01	51	182.25
3	39	3.61	38	0.25
4	37	0.01	37	0.25
5	40	8.41	39	2.25
6	25	146.41	27	110.25
7	38	0.81	38	0.25
8	36	1.21	38	0.25
9	35	4.41	36	2.25
10	35	4.41	36	2.25
$\chi^2 = \frac{\sum(x_i - \bar{x})^2}{\bar{x}}$		10.81		8.17

The results of the chi-square test based on table 2 are 10.81 for Canberra 2071A and 8.17 for Arduino Timer/Counter. Based on IAEA-TECDOC-602, systems with chi-square values between 3.32 – 16.92 have good stability. This shows that the Arduino Timer/Counter system has good stability.

5. CONCLUSION

The test results show that the Arduino Timer/Counter has a good linearity with R^2 = 1. Counting can be done up to 1 million cps, surpassing the results of previous studies which were only 150,000 cps.

The results of the chi-square test obtained a value of 8.17, while the comparative test with Canberra 2071A obtained the largest percentage error of 0.14% and the smallest of 0.02%. It can be concluded that the Arduino Timer/Counter has a good performance as a counter in single-channel spectroscopy.

AUTHOR CONTRIBUTION

Santiko Tri Sulaksono, Putu Sukmabuana, and Nanda Nagara equally contributed as the main contributors to this paper. All authors read and approved the final version of the paper.

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