DESIGN AND CONSTRUCTION OF RENOGRAPH FOR RENAL FUNCTION TEST USING CsI(Tl) DETECTOR AND MICROCONTROLLER AT89C51

Setyadi[1], Rill Isaris[2]

ABSTRACT

The development of Renograph prototypes for renal function testing has been initiated in BATAN since 1983, five generation prototypes using NaI(Tl) Scintillation detector have been successfully constructed and utilized in hospitals. Due to the new regulation for human safety, then the use of low energy radioisotopes with shorter half life time should be considered. It requires to develop the new instrument of higher sensitivity and better performances.

This paper presents design of renograph using CsI(Tl) scintillation as a new type detector and a 16 bits Microcontroller AT89C51 as the data processor for renal function test, so renograph with a high reliable and better performances in application is achieved. The use of CsI(Tl) and Microcontroller as the data processor is the development made from the previous prototypes, the system is also provided with a serial communication facility to Personal Computer through serial-port RS 232. Static examination to the pulses generated by a Function Generator with fre-quency up to 12.000 Hz and the dynamic test using ^{137}Cs and ^{60}Co radiation sources have been carried out successfully. The non-linearity integral of the system shows the response is linear up to frequency of 65.000 Hz with strong correlation coefficient, that is R^2 ~ 0,9999. The calculation of the statistical feasibility counting to the both CsI(Tl) detector equipments for the two sources above with confidence level of 0,95 give the χ^2 are 0.238 and 0.078. These are much smaller than the χ^2 value in the table, that is 0.711 for N = 5. Hence, the modified renograph system using CsI(Tl) and Microcontroller AT89C51 has good counting linearity and fulfills the counting feasibility statistically.

Keywords : *Renograph, design improvement, microcontroller*

INTISARI

Pembuatan prototip Renograph di BATAN untuk pemeriksaan fungsi ginjal menggunakan perunut radioaktif telah berkembang sejak 1983, lima generasi prototip menggunakan detektor NaI(Tl) telah dihasilkan dan digunakan di rumahsakit. Dengan ketentuan keselamatan yang baru, maka pemakaian radioisotop dengan energi lebih rendah dan umur paroh pendek perlu dipikirkan. Hal ini menuntut adanya sistim instrumentasi yang lebih peka dan memiliki unjuk kerja yang lebih akurat.

Makalah ini mengemukakan rancangbangun renograph dengan detektor tipe baru CsI(Tl) dan 16 bit Mikrokontroler AT89C51 sebagai komponen pemroses data yang akurat dan me-miliki unjuk kerja yang handal. Pemakaian detektor CsI(Tl) dan Mikrokontroler adalah merupakan pengembangan teknologi pada sistem sebelumnya, sehingga juga dimungkinkan membuka komunikasi serial dengan *Personal Computer* menggunakan port-serial RS 232. Telah dilakukan pengujian statis di laboratorium menggunakan *Function Generator* dengan fre-kuensi sampai 12.000 Hz dan pengujian dinamis menggunakan sumber radioaktif ^{137}Cs dan ^{60}Co dengan hasil baik. Integral non-linearity sistim menunjukkan hasil yang linear sampai 65.000 Hz dengan koefisien korelasi R^2 ~ 0,9999. Perhitungan kelayakan statistik hasil cacah pada kedua sistim detektor CsI(Tl) terhadap sumber ^{137}Cs dan ^{60}Co dengan *confidence level* 0,95 adalah 0,238 dan 0,078. Kedua hasil perhitungan ini lebih kecil dibanding nilai χ^2 tabel, yaitu 0,711 untuk N = 5. Sehingga sistim dinyatakan memenuhi kelayakan secara statistik a-tas hasil cacah yang diperoleh.

Kata kunci : Renograph , pengembangan desain , mikrokontroler

INTRODUCTION

The application of radioactivity tracer methods in medical examination

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has a specific segment, because this method can show both of the anatomy morphology image and also the information of organ function as well as the kinetical process of chemical reaction (fisiology) that can be traced as the function of time and can not be obtained with the examination of X-rays and ultrasound modalities. The renography is an examination method to the kidney function through observation of the radioactive-tracer such as ^{131}I hippuran and ^{99m}Tc DTPA) that passed through kidneys after injected into intravena. The renal function curve that formed the distribution of radioactive matter that carrying by blood flow into the kidneys toward the time elapse is consist of three phases, i.e.: a) vascular, b) pharenchym and c) excretion. This curve is recognized as uro-dynamic curve renal function that have a specific shape in normal or up-normal conditions. The differrences from the standard curve on the three phases both on the shape and time indicates the up-normality on the kidney function.

The development of design and con-struction of renograph prototypes has been conducted since 20 years ago. According to evaluation report made on the BATAN's renograph prototypes (Suyitno,G. et.al., 1995, 1996) it was concluded that renograph prototype model BI-756M has been fulfilled as a diagnostic instrument for renal function examination and it has the opportunity and potency to develop furthermore as the demand and progress of technology. Also from the quality test results of that renographs it was concluded that the equipments were satisfactorily on the response linearity and the statistical counting feasibility (Supardiono, B. et.al., 1993).

The engineering of Dual Probes Renograph using NaI(Tl) Scintillation detectors has yielded a blue print of BI-756M Reno-graph, and it can be used as the proven prototype for large scale production (Isaris, R. et.al.). Moreover, a preliminary study on utilization of CsI(Tl) detector for a Portable Renograph was initiated since 1997 (Wydiosusanto.S., et. al., 1998). The construction of CsI(Tl) with PIN Photodiode and Nuclear Spectroscopy System gives a better characteristics such as the system resolution be 8.99% compared to 10.72% using NaI (Tl), the system do not supplied by a HV Power System but only by low level voltage using battery, the equipment dimension is more compact and cheaper. And then it came into the conclusion that there will a beneficial prospect from the simplicity and economical aspects of this design (Wydiosusanto,S., et.al., 2001)

Data saving and processing by microcontroller has been number utilized in Instrumentation System, numerous of microcontroller types have been available in the market. The AT 89C51 Microcontroller is suitable for counting system in Renograph with CsI(Tl) detectors. This device has On Chip Serial Port that can be used for serial data communication on Full Duplex, so that this port still be able to receive the data during transferring data was done. Although the microcontroller is reading the first data, while the second data is not yet completely received, and those data will not dissappear. This is because of the AT 89C51 has a register called SBUF that locates ad-dress of 99H that be functioned as a buffer (Nalwan, P.A., 2003)

The study on progress and development of BATAN's prototype up to the five generation was made. The last generation called Add on Card (AOC) Renograph is suggested to be used for refurbishment of Aged Renograph purpose that still available in the hospitals (Isaris, R.et.all.,2006). This refurbishment requires the work with rational budget. The design of AOC Renograph has the speciality in the compactness and integrated system design, they did not need an instrument panel, its easy for mobilization as well as it has met the experimental standard and test clinically.

With regard to the study on the requisite of renal function test equipment in hospital and the statistic data of renal diseases patient trends increasing in Indonesia, hence the procurement of this kind of equipment can have a good prospect for the beneficial to the realization of public health welfare.

Renal organ of human was formed of a turbulous system which functioning to prepare and secrete the liquid from body metabolism process and then took out the unused one as urine. Each kidney has about 1.2 million functional units called neufron, which all together doing the filtering, reabsorption and secretion process. With regard to their function, neufron consist of two parts :

1. Glomerolous , that function as a filter
2. Tubulous, for processing the filtered produce and then followed by re-absorption and secretion the remainder as urine.

Look at the mechanism of urine production, it describes the renal functions for the numerous purposes as the following:

a) To regulate the balance of body liquid volume and its composition, it covers the regulation of the volume of blood and the ionic concentration of K, Na, Mg, Ca elements, etc. Malfunction of kidney for this function causes the unbalance metabolism in the body and can cause complication to the other organs.
b) To regulate the balance of acid-base, which consist of the concentration regulation of hydrogen ion in body extracelular liquid. Failures of kidney in this function causes the patient be coma in case of the liquid was ultra-acid, and cause the patient be odem in case of the liquid was ultra-base.
c) To regulate the body blood pressure in the long-run. Failure in this function indicates the damage of neufron that showed by the change of glomerolous filtration coefficient. The regulation of blood pressure in the short and medium ranges was done by nerves and hormone as well as vascular stress relaxation respectively.

The indication of diseases caused by the failures above is a part of the failure of renal function damage indication. Renal disease showed the variation on clinical drawing, so that the grouping of renal disease types based on syndrome was made for diagnose purpose. In neufrology there are 10 renal disease syndromes, i.e.: neufrotic acute, syndrome neufrotic, urine asymphotic up normal, renal disfunction acute, chronic renal failure, bladder infectious, renal turbuly failure, hypertension and renal stone.

Renography methods is a technique to detect the radioactivity distribution come from a man organ that injected by radio-pharmaceutical matter. Number of radio-activity which go into, precipitates in and go out from kidney gives a specific distribution against time (like a hyperola curve). The radiopharmaceutial have commonly used are ^{131}I hippuran which have the half life time T½ = 8 days and emits gamma radiation of energy 364 keV and ^{99m}Tc DTPA of energy 140 keV.

The radioactive distribution curve produced by the detection system was recognized as renogram. According to the basis renal work mechanism, the renogram curve was divided into three phases (Suyitno,G., 1996), that is :

1. Vascular phase, that drawn the capacity and integrity of renal blood artery.
2. Parenchyma phase, that drawn the absorption capacity of kidneys
3. Excretion phase, that drawn the excretion process.
   Based on the shape of renogram curve and its correspond to the three phases above, (O'Reilly, et.al.,1979) it was defined five main kidney renogram patrons as shown in Figure 1.

Identification to renal function is based on the analysis of renogram curve and the result of renal parameters calculation, this data is very specific to the individual kidney condition. The analysis was made by refer-ring to the parameter definition as shown in Figure 2.

To analyze the kidney diseases for diagnose, there are 11 kidney parameters should be observed. The definition and formulation of these parameters are shown as the following, and their software for calculation have been made and used for BATAN's Renograph (Prajitno, 1997) :

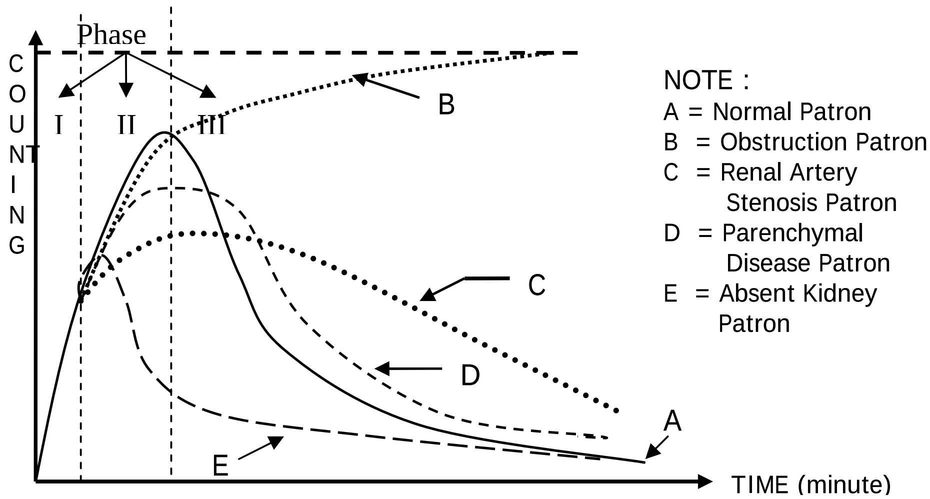

Figure 1 Patrons of Renogram Curve

1. T_{max} : the time needed to reach the maximum counting C_{max} (peak of the curve)
2. C_{max} : counting maximum
3. $T_{1/2}$: time interval between T_{max} and time when counting equal to a half of C_{max}.
4. $T_{2/3}$: time interval between T_{max} and time when counting equal to 2/3 of C_{max}.
5. C_{T10} : counting number at time interval = 10 minutes
6. Up-slope: gradient of the second phase,

$$US = \frac{C_{\max} - C_{T1}}{C_{\max}} x \frac{1}{T_{\max} - T_1} \quad (1)$$

with C_{T1} is counting number at time $= T_1$ (at the end of phase I)

7. Down-Slope $T_{1/2}$: gradient of the Curve between point at t = T_{max} with point at t = $T_{1/2}$

$$DS\ T_{1/2} = \frac{C_{\max} - C_{T1/2}}{C_{\max}} x \frac{1}{T_{1/2}} \quad (2)$$

8. Down-Slope $T_{2/3}$: gradient of the curve between point at t = T_{max} and point at t = $T_{2/3}$

$$DT\ T_{2/3} = \frac{C_{\max} - C_{T2/3}}{C_{\max}} x \frac{1}{T_{2/3}} \quad (3)$$

9. Reno Index (T_{80-140}) is the comparison between the integral curve of the second phase of renogram curve at the time interval t = 80 second up to 140 second for the two kidneys (left and right) , or :

$$RI = \frac{\int_{80}^{140} C_{left}(t).dt}{\int_{80}^{140} C_{Right}(t).dt} \quad (4)$$

10. Relative uptake distribution (%): the estimation of each kidney capacity to uptake radioactive, for right kidney is:

RUD_{Rigt}=

$$\frac{C_{ep}(II)_{Right} - C_{ep}(I)_{Right}}{[C_{ep}(II)_{Right} - C_{ep}(I)_{Right}][C_{ep}(II)_{Left} - C_{ep}(I)_{Left}]} x100\% \quad (5)$$

where

RUD_{Right} = Relative uptake distribution of the right kidney, $C_{ep}(I)_{Right}$ and $C_{ep}(II)_{Right}$ are the counting at the end of phase I and phase II respectively.The analogy interpretation as mentioned above is also valid for the left kidney.

11. Individual Excretion (%): the estimation of each kidney capacity to excrete the tracer radioactive absorbed at time t = 10 minutes after injecting.

$$\%Excretion = \frac{C_{ep}(II) - C_{T10}}{Cep(II)} x100\% \quad (6)$$

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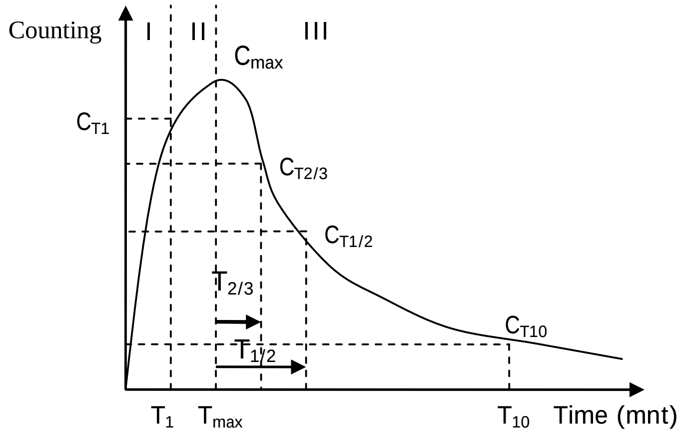

Figure 2 Parameter definition in Renogram Curve Analysis

Detection system play an important role in obtaining the optimum information from the radioactive measurement. There are numerous of scintillation elements can be used as nuclear detector (Knoll G.F., 2000, http://www.iaea.or.at.) as shown in Table 1. The emission spectrum of light yielded by a scintillation detector should be covered in the sensitive range of photoelectron devices that convert the light phenolmenon into electrons, so that a maximum conversion can be obtained. The application of NaI(Tl) combined with Photo Multiplier Tube (PMT) has been long time recognized in nuclear spectroscopy experiments. The spectral intensity of NaI(Tl) material is fit to the PMT spectral sensitivity, but not for CsI(Tl) material as shown in Figure 3. In order to get better conversion of the scintillation light produced, a light detection device which covered all the scintillation spectral intensity should be chosen. The device that has better response to the spectral intensity of CsI(Tl) was Silicon Photodiode (Hamamatsu, Co., 1997). Even though the characteristics of CsI(Tl) and NaI(Tl) materials are rather the same, but the CsI(Tl) has the superiority in yield of light, has better attenuation coefficient and density, and less hygroscopy. Also CsI(Tl) has better the spectrum quantum efficiency that is 69% compared to NaI(Tl) of 49% toward the spectrum response of Silicon Photodiode (Prat, V., et.al., 1996).

An example of this device is Hamamatsu S-3590-08 fabricated by Hamamatsu Co. Industry as shown in Figure 4. (http://www.Hamamatsu.com)

Table 1 Characteristic of Scintillation Detectors

Material	Max Wavelength λ_{max} (nm)	Decay Constant (µS)	Refraction Index λ_{max}	Conversion Efficiency (%)	Total Attenuation Coefficient (cm^{-1})		Density (gr/cm^3)	Hygroscopic ?
					150keV	500keV		
NaI(Tl)	415	0.23	1.85	100	2.3	0.37	3.67	Yes
CaI(Na)	420	0.63	1.83	85	4.2	0.55	4.51	Yes
CsI(Tl)	550	1.00	1.80	45	4.2	0.55	4.51	Rather
BGO	480	0.30	2.15	12	9.6	0.96	7.13	No
GSO(Ce)	430	0.06	1.90	16	-	-	6.71	No
$CdWO_4$	540	5.00	2.30	40	9.2	0.94	7.90	No
$ZnWO_4$	480	5.00	2.20	26	-	-	7.87	No
CaF_2(Eu)	435	0.94	1.44	50	0.49	0.28	3.19	No
BaF_2	325	0.63	1.49	20	3.90	0.43	4.88	No
CaF	390	0.006	1.48	3-5	3.30	0.45	4.64	Yes

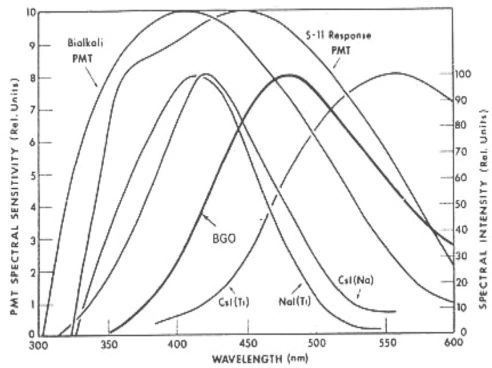

Figure 3 Emission Spectrum of inorganic Sintillators

Microcontroller technology has been widely used in many product to control a process in a system or machine, such as in a car, desk top computer, camera photo, camera video, CD player and scientific instruments. Microcontroller was set up within the instrument or system that will be controlled by them. Microcontroller is a computer within a chip with limited capacity, they have had CPU, memory, I/O Interface. Control program was saved inside of ROM, while the RAM is used for a temporary store included registers that been used by microcontroller itself (Achmad, B., and Arif, A., 2003) Some considerations usually be taken during designing a microcontroller circuit are:

1. Architecture model, example Harvard architecture (program memory and data memory is accessed through separate buses), von-Neumann architecture (those two memories are placed in one memory device and accessed through only one bus system). Harvard model is more convenience to make the speed of communication become faster.
2. Method of program store, commonly the microcontroller store its programs on the Chip. Examples of storing media are EPROM, EEPROM, ROM, NV-RAM and Flash-EPROM. The temporary data is usually stored on RAM, for it can be changed frequently.

A microcontroller was composed from combination between Central Processing Unit CPU, Memory, Input/Output and other Peripheral devices that planted in a chip in a compact configuration. In microcontroller the ROM capacity is greater than RAM has, the control programs were stored in ROM, while the RAM is used for temporary data store.

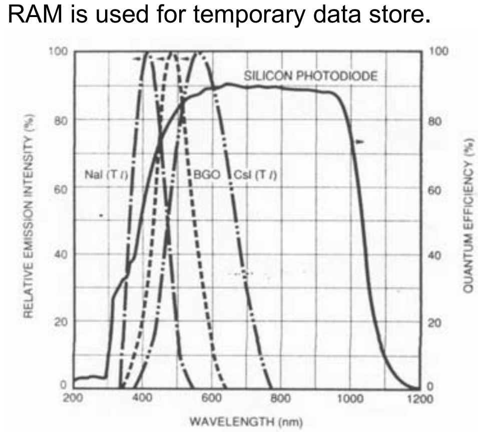

Figure 4 Spectrum respon of Hamamatsu Photo diode S3590-08 and emission spectrum of Sintillators

The AT89C51 is an eight bit Microcontroller which provided by a Processor, RAM (*Random Access Memory)*, 4 Kbytes Flash Programmable and EPROM, I/O facility and 16 bit timer or counter. The microcontroller consumes low power, it has the following fittings:

- Operated at 0 – 24 MHz range frequency with internal oscillator
- EPROM (Erasable Programmable Read Only Memory) 4 Kbytes
- Internal Read Access Memory (RAM) 128 bytes
- Four I/O ports with 8 bit for each port (P0-P3)
- Two unit 16 bit Timer/Counter
- Six interrupting sources
- A serial full duplex
- Program lock facility
- Low power operation mode

In this engineering design, AT89C51 Microcontroller fabricated by ATMEL was used as shown in Figure 5, and the pin connection data shown in attachment.Addressing mode in AT89C51 microcontroller was grouped into three, i.e.:

1. Direct addressing or immediate, to access internal RAM, both on arithmetic and logic operational.

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2. Indirect addressing, to access internal RAM both on arithmetic and logic operational.
3. Register addressing, to access the lowest of 32 bytes of internal data memory.

The CPU works at the frequency range 3.5 to 12 MHz with internal oscillation. One cycle of machine consist of 12 oscillator period, it means that for 12 MHz frequency oscillator, one machine cycle will spend 1 μS time. Three models of AT89C51 microcontroller configuration (ATMEL Data Sheet, 1997) are shown in Figure 5, and several its important set up are :

- Program memory and data memory is separated logically by separating the carrier signal for reading program or data. This will make the CPU able to access 64 Kbyt data. The internal ad-dress memory wide is 8 bit or 16 bit.
- It has RAM memory in the shape of re-gister for special function (Special Function Register SFR) with 128 Kbyt capacity.
- It has 4 I/O ports 8 bits, each port has bidirectional behavior, this means it can be used as input or output.
- It has interrupted system that initiated from 5 sources, two from external through pin INT-O and INT-1, two from each internal counter, and one from I/O serial port.
- AT89C51 Microcontroller has two timer units, they are Timer 0 and Timer 1 that can be functioned as a timer or a counter one, each one has 16 bit counter that can control its operation modes, set and reset with a certain value.

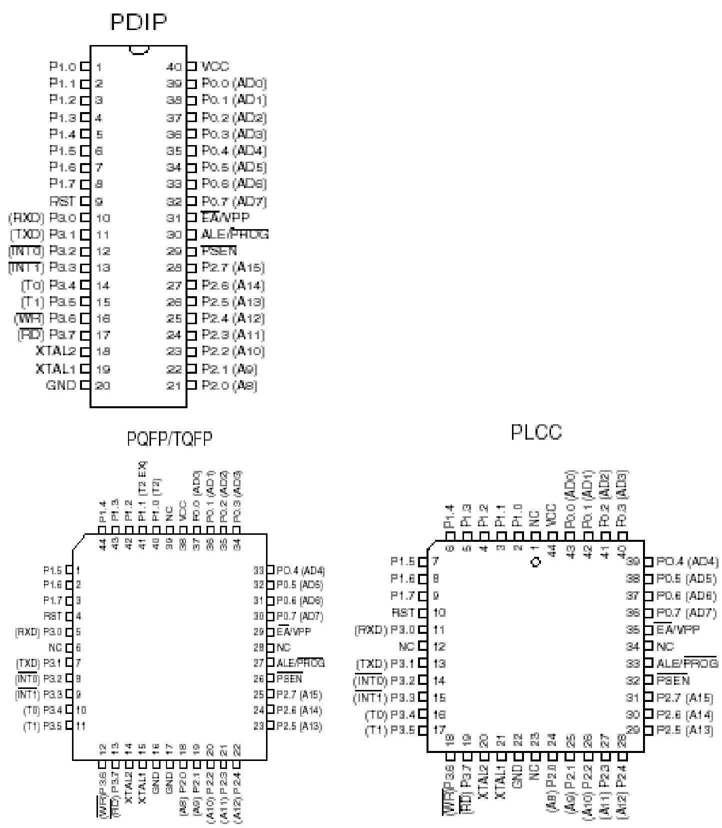

Figure 5 Three model and configuration of AT89C51 Microcontroller

There are six Special Function Register SFR for controlling these timers : Timer Mode Register TMOD (Timer 0 and Timer 1), Timer Control Register TCON (Register Timer and Register Interruption), High and Low Bit Timer Register (THx and TLx).

This controller has four timer operation modes (mode 0, mode 1, mode 2, and mode 3) that can be controlled by bit regis-ter on TMOD. These Timer 0, Timer 1, Ti-mer 2 and Timer 3 work as 13 bit counter, 16 bit counter, 2x8 bit counter and 3x8 bit counter respectively. Data communication with AT89C51 using serial way through port serial that has full duplex behavior, so it can receive and send data simultaneously. This port can be used for synchronous and asynchronous communication transmission. Asynchronous transmission is used to access the system that has UART Facility (Universal Asynchronous Receiver/ Transmitter). There are four modes of work serial port, they are : mode 0, mode 1, mode 2 and mode 3 (Budiharto,W., 2004). In this work, the serial interface RS232C (Recommended Standard No. 32, revision C) was used for data transfer process between the computer and other system. The output signal from AT89C51 is in TTL, so for communication with using RS 232 a converter Max 232 is required.

The development of Renograph prototypes by using an integrated device called Add On Card (AOC) System which consist of Amplifier, SCA, Counter/Timer and Interface have been performed by another group of scientist and used in hospital (Isaris, R., et.al, 2006). Count and time accuracy of the system as well as the statistical counting feasibility were technically good and accepted validation for clinical application. The limits for performance examination is also referred to the IAEA TecDoc 602

The block diagram of constructed Renograph was shown in Figure 6. As we can see from the block diagram, this hardware consist of two CsI(Tl) scintillation detectors that can detect the radioactive distribution from the two kidneys and the output signals then shaped into the digital pulses. The AT89C51 acts as a timer/counter and by converter TTL RS-232 these output then converted into the communication standard for RS-232 serial. The Personal Computer was functioned as the register, the processing unit and displaying and saving the detection data.

The counter and converter circuits are shown in Figure 7 and 8 which consist of microcontroller AT89C51 and IC MAX-232 that connected though pin RXD (port 3.0) and TXD (port 3.1)

In this circuit, the Timer 0 (port 3.4) is u-sed as a 16 bit counter, the output signal from the Surveymeter is fed to this port and then counted. For this purpose a 11.059 MHz crystal is applied. The crystal output is connected to the pin 19 (XTAL1) and pin 18 (XTAL2) as well as to the capasitor C2 and C3 and then to ground.

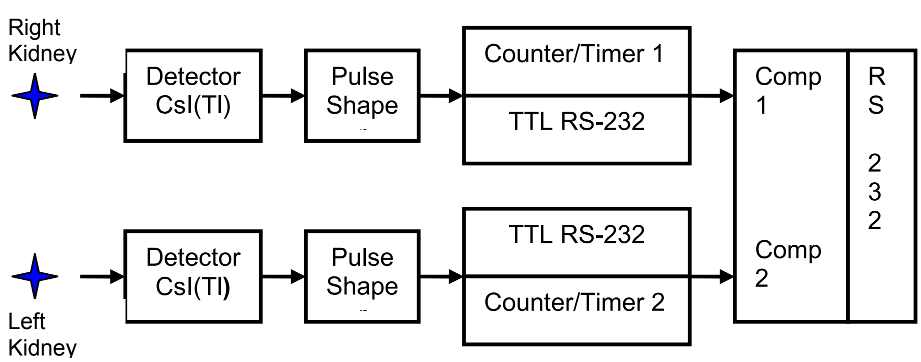

Figure 6 Block Diagram of Renograph with CsI(Tl) Detector and AT89C51 Microcontroller

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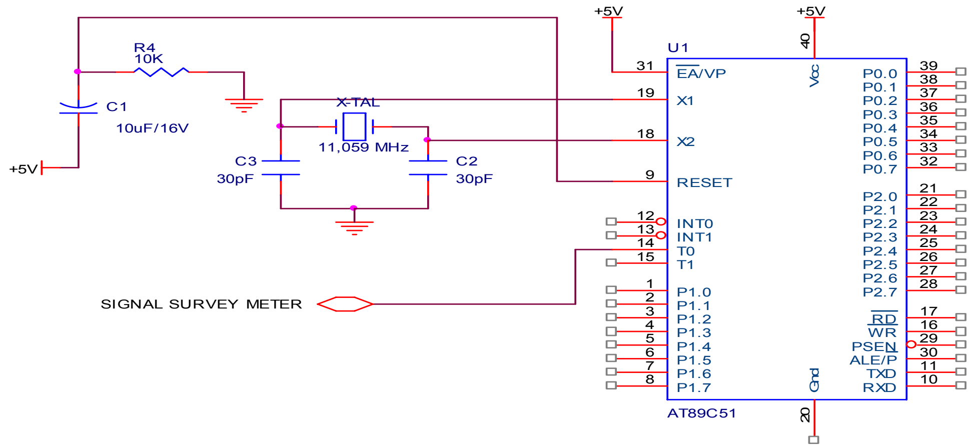

Figure 7 Counter Circuit

To convert the TTL logic of microcontroller output to be a standard codes of serial RS-232, a converter circuit is required as shown in Figure 8. In serial communication with the Computer, a serial interface system IC MAX232 was used. This IC was connected to the AT89C51 Microcontroller through pin RX-D (port 3.0) and pin TXD (port 3.1). So that, the serial data is sent by the Computer through its serial port in the RS232 codes and then is converted into the TTL codes by RS232 interface and addressed to the serial port of AT89C51. The serial port communication between computer and microcontroller using DB9 male-female connector.

Two software design were made, the first for microcontroller and the other for computer system as shown in Figure 9.

To get the confidence of the renograph prototype, two kind of test and examination to the system performances have been car-ried out, i.e. static and dynamic examination.

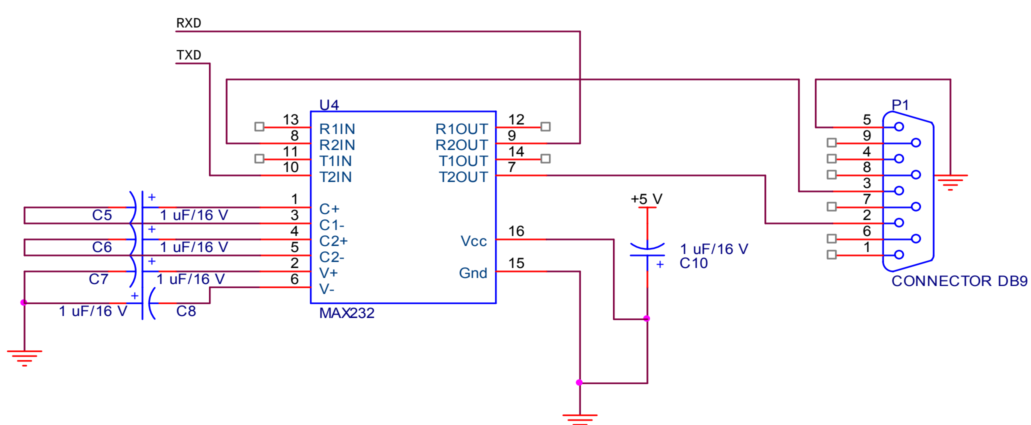

Figure 8 TTL-RS232 Converter Circuit

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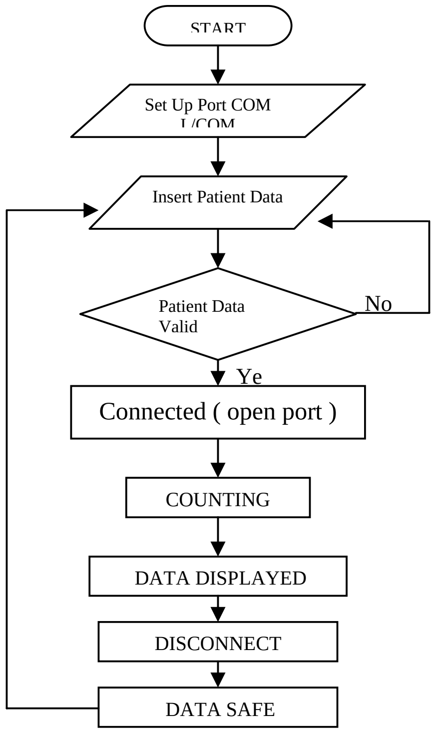
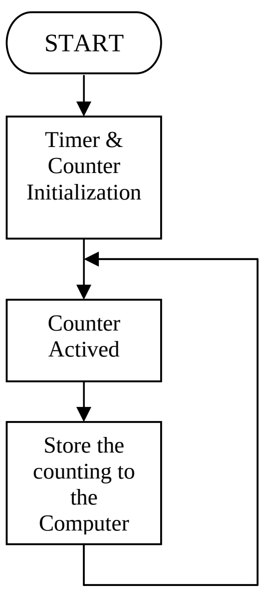


A. For Microcontroller



B. For Computer

Figure 9 Flow Chart of Program on Microcontroller and Computer System

Figure 10A shows the circuit configuration for static examination. The two spectroscopy channels of the renograph with parallel connected with standard and calibrated counter (manufactured by ORTEC) was fed with pulses from a Pulse Generator. The display of all counter were registered and then the linearity correlation curve between them can be obtained. If the correlation coefficient of these two para-meter (system and standard) R^2 ~ 1,0, its means the correlation is closed.

Figure 10B shows the circuit diagram for the dynamic examination. The radioactive gamma sources (^{137}Cesium and ^{60}Co) were used instead of the Pulse Generator. The counter channel 1 uses NaI(Tl) detector, while the channel 2 uses the CsI(Tl) detector. The statistical counting feasibility (χ2 = chi-square) of Renograph System can be calculated by the formula 7 (Sorenson, 1987).

$$\chi^2 = \sum_{i=1}^{n} \frac{\left(N_i - \overline{N}\right)^2}{\overline{N}} \qquad (7)$$

where
n = number of experiment
N_i = counting data number i
$\overline{N}$ = expected counting data

The value of counting is statisticcally accepted if the calculated χ^2 is smaller than the critical value of χ^2 in table with the certain confidence level and number of test (n) required.

DISCUSSION

Counting Rate Non-Linearity of the two channel of the electronic system (with-out detectors) towards the Function Gene-rator pulses was drawn in Figure 11. The correlation coefficient was almost ~ 1,0 or very close.

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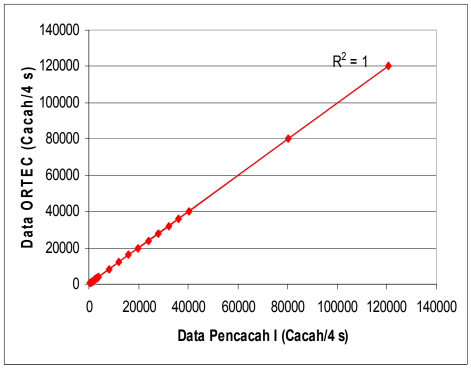
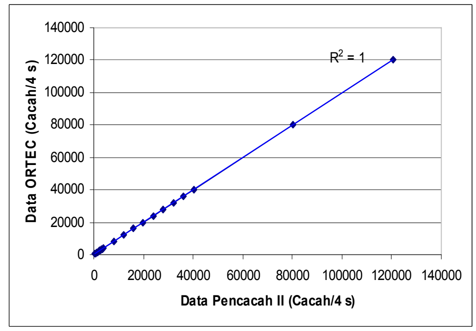
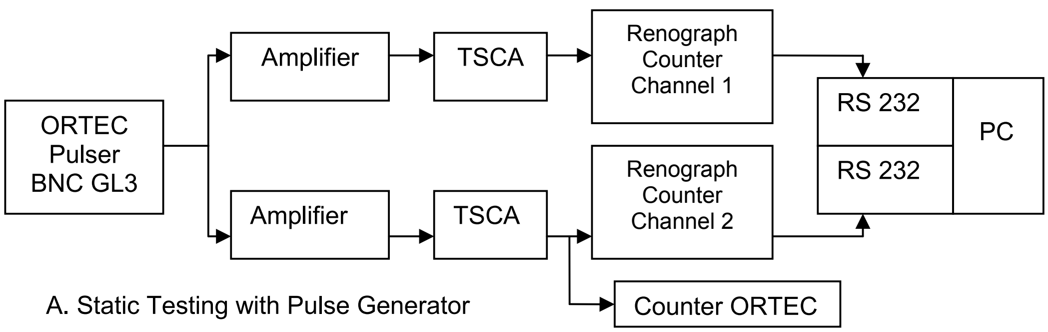


A. Channel 1

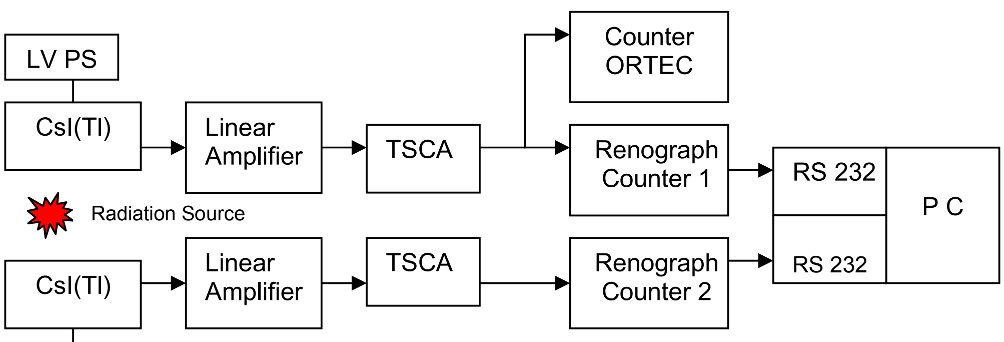


B. Channel 2

Figure 11 Counting rate non-linearity curve of CsI(TI) Renograph System



A. Static Testing with Pulse Generator



Note : TSCA = Timing Single Channel Analyzer
LV PS = Low Voltage Power Supply , PC = Personal Computer

B. Dynamic Testing with radioactive source

Figure 10 Block Diagram of CsI(TI) Renograph on the linearity examination

The non-linearity test results with pulse frequency from 10 cps to 14.000 cps show the linearity of the system is quite good. The maximum counter capacity is 65.535 counts (16 bits). In its application, the maximum rate of radioisotope counting from the patient's kidney is around 1200 ~ 1500 counts/second, or the counting capacity is quite enough.

Table 2 shows the test results of the counting feasibility and χ^2 calculation of those two channel of Renograph, with CsI(tl) and NaI(TI) detectors, respecttively.

The feasibility of system counting to-ward the ^{137}Cs source shows by the χ^2 calculated, they are is 0,211 and 0,238 for the two channels. The χ^2 in the table for number of counting N = 5 and 95% confidence level was 0,711. So, the χ^2 calculated is smalller than the χ^2 in table, or the result of counting of the system is statistically feasible.

The examination system with the ^{60}Co radioactive source also gives the χ^2 calculated as 0.057 and 0.078 for the two channels respectively. These values are smaller than the χ^2 in the Table (with N = 5 and confidence level = 0.95), so the results of counting of the system is statistically feasible.

The modified renograph has superiorrity to the previous prototypes or design by the following argument:

1) By using CsI(TI) semiconductor detector the electronic and mechanical handling become simple. Without high voltage supply the stability of detection is better, and the instruments weight is lighter, detector size is smaller and non-hygroscopy.
2) Energy resolution of system is improved from 10.72% to 8.99%,spectrum quantum efficiency increases from 49% to 69%.
3) Modified renograph is more economy, portable and easy to transport. So it is suitable for the application in rural region of the country. The development cost of system is lower than the conventional one.
4) Using the microcontroller in the system as data processing can build a compact system with high quality of performances, such as linearity and feasibility of counting.

Tabel 2. Statistical Feasibility Counting of Renograph by Chi Square Analysis

A. By using Cs^{137} source

No	Couter 1 NaI(TI) (C_1) (counts/4s)	Counter 2 CsI(TI) (C_2) (counts/4s)	ORTEC (O) (counts/4s)	$(C1-O)^2/O$	$(C2-O)^2/O$
1	4818,32	2311,44	4800	0,070	0,032
2	4810,88	2316	4924	0,025	0,007
3	4813,76	2310,16	4951	0,039	0,042
4	4807,60	2334,32	4898	0,012	0,088
5	4817,60	2362,72	4965	0,065	0,070
		χ^2 calculated		**0,211**	**0,238**

B. By using Co^{60} source

No	Counter 1 NaI(TI) (C_1) (counts/4s)	Counter 2 CsI(TI) (C_2) (counts/4s)	ORTEC (O) (counts/4s)	$(C1-O)^2/O$	$(C2-O)^2/O$
1	36,72	14,56	40	0,002	0,013
2	36,3	15,1	42	0,013	0,001
3	35,87	15,33	43	0,035	0,007
4	36,56	14,08	43	0,005	0,056
5	36,71	14,94	42	0,002	0,000
		χ^2 calculated		**0,057**	**0,078**

CONCLUSION

The microcontroller AT89C51 has the timer/counter facility, so it can be utilized as a nuclear counting system and built as a portable renograph instrumenttation with the CsI(TI) Scintillation detector.

CsI(TI) detector combined with microcontroller as the counting system and Personal Computer as the data processing can build a compact and portable Renograph Equipment with competetive advantages which is smaller, easier and smoother in application and cheaper in cost.

The linearity of the system counting along the frequency up to 120 kHz in the all two channels is very good which correlation coefficient to standard counting system (made by ORTEC) is almost of 1,0, so the display of the system is technically accurate.

The dynamic test to the system using the real radionuclide sources ^{137}Cs (662 keV) and ^{60}Co (1173 and 1332 keV) shows that the result of counting is statistically feasible. The Chi-square-test performed to the system (for N=5 and confidence level 95%) gives the value of χ^2 from experiments are all smalller than χ^2 in the table. It can conclude that the detection system to the radioactive distribution from the patient's kidney is reliable and fulfill the statistical counting rules.

This design can be simplified by replacing the function of PC by a microcontroller that can act as a control for processing and saving data, meanwhile the renogram curve can be displayed in LCD screen. This simplification will make the Renograph Equipment with CsI(Tl) detector be a stand alone system, easy to move and lower costly.

The system software for linearity testing and statistical feasibility counting can be created internally, so it will make simplicity in Quality Control test procedures.

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Attachment of the χ^2 critical values

Number of Determi-nations, n	Probability, P						
	0.99	0.95	0.90	0.50	0.10	0.05	0.01
3	0.020	0.103	0.211	1.386	4.605	5.991	9.210
4	0.115	0.352	0.584	2.366	6.251	7.815	11.345
5	0.297	0.711	1.064	3.357	7.779	9.488	13.277
6	0.554	1.145	1.610	4.351	9.236	11.070	15.086
7	0.872	1.635	2.204	5.348	10.645	12.592	16.812
8	1.239	2.167	2.833	6.346	12.017	14.067	18.475
9	1.646	2.733	3.490	7.344	13.362	15.507	20.090
10	2.088	3.325	4.168	8.343	14.684	16.919	21.166
11	2.558	3.940	4.865	9.342	15.987	18.307	23.209
12	3.053	4.575	5.578	10.341	17.275	19.675	24.725
13	3.571	5.226	6.304	11.340	18.549	21.026	26.217
14	4.107	5.892	7.042	12.340	19.812	22.362	27.688
15	4.660	6.571	7.790	13.339	21.064	23.685	29.141
16	5.229	7.261	8.547	14.339	22.307	24.996	30.578
17	5.812	7.962	9.312	15.338	23.542	26.296	32.000
18	6.408	8.672	10.085	16.338	24.769	27.587	33.409
19	7.015	9.390	10.865	17.338	25.989	28.869	34.805
20	7.633	10.117	11.651	18.338	27.204	30.144	36.191
21	8.260	10.851	12.443	19.337	28.412	31.410	37.566
22	8.897	11.591	13.240	20.337	29.615	32.671	38.932
23	9.542	12.338	14.041	21.337	30.813	33.942	40.289
24	10.196	13.091	14.848	22.337	32.007	35.172	41.638
25	10.856	13.848	15.649	23.337	33.196	36.415	42.980
26	11.524	14.611	16.473	24.337	34.382	37.382	44.314
27	12.128	15.379	17.292	25.336	35.563	38.885	45.642
28	12.879	16.151	18.114	26.336	36.741	40.113	46.963
29	13.565	16.928	18.939	27.336	37.916	41.337	48.278
30	14.256	17.708	19.768	28.336	39.087	42.557	49.588

(Phelps,1987)