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Development of data acquisition and control software for gamma-ray process tomography system

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Abstract. Data acquisition (DAQ) and control software has been developed for gamma-ray process tomography system in Malaysian Nuclear Agency. The gamma-ray computed tomography (CT) system uses Computer Automated Measurement and Control (CAMAC) standard for nuclear counting and data acquisition instead of the common Nuclear Instrumentation Module (NIM) standard. For scanning configuration, the system consists of an array of NaI(Tl) scintillation detectors that moves in a small degree of angle by using a stepper motor. The gamma-ray CT software comprises of graphical user interface (GUI) for the system automation that includes CAMAC modules setup, motor and scanning control, data acquisition from CAMAC crate controller via ethernet interface and data recording. The software is developed by using National Instruments LabView development package.

1. Introduction

Computed tomography (CT) has been widely used for industrial processes such as petrochemical industries in order to improve the design, operation, optimization and troubleshooting [1-2]. There are many types of CT such as x-ray, positron emission tomography (PET), single-photon emission computed tomography (SPECT) and gamma-ray. In Malaysian Nuclear Agency (Nuklear Malaysia), a gamma-ray CT system was developed for imaging and visualizing of industrial multiphase reactors [3].

Gamma-ray CT is a technique that can provide a two-dimensional (2D) concentration, or the hold-up distribution, of the phases in multiphase reactor systems. If several such individual layers, each with their measured distribution are stacked up, a three-dimensional (3D) field can be reconstructed. Gamma CT allows the visualization of failure points in 3D analysis and in sections compares to a well-known technique column scan. The column scan is able to analyze and identify failures in industrial processes but lack of visualization capabilities. A tomography system is an update methodology used to determine the cross-section density profile inside a processing vessel [4].



2. System Overview

Radiation detectors and a source of radiation are two primary elements of a tomography system. The third generation configuration was adopted for the scanner where the entire hardware arrangement in the scanning configuration which includes the detectors, source and collimators have to be rotated around the test section. Hence, the detector array has enough and high spatial resolution cells to allow measurement of a fan-beam projection of an entire sample cross-section. Penetrating radiation from an isotopic gamma-ray source of Cs-137 and a bank of NaI(Tl) scintillation detectors in combination with a dedicated mechanical gantry set-up were used to construct the gamma-ray CT system in Nuklear Malaysia. The schematic diagram of the developed industrial process gamma-ray CT is shown in Figure 1.

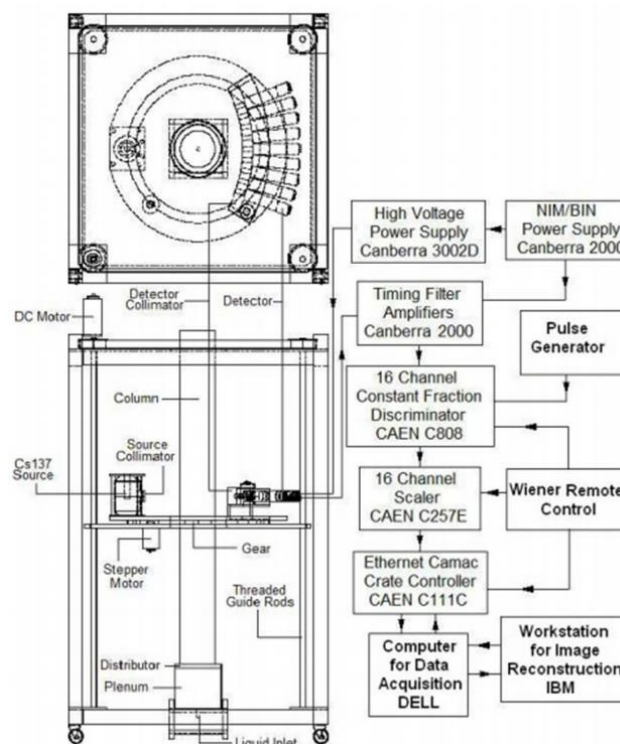
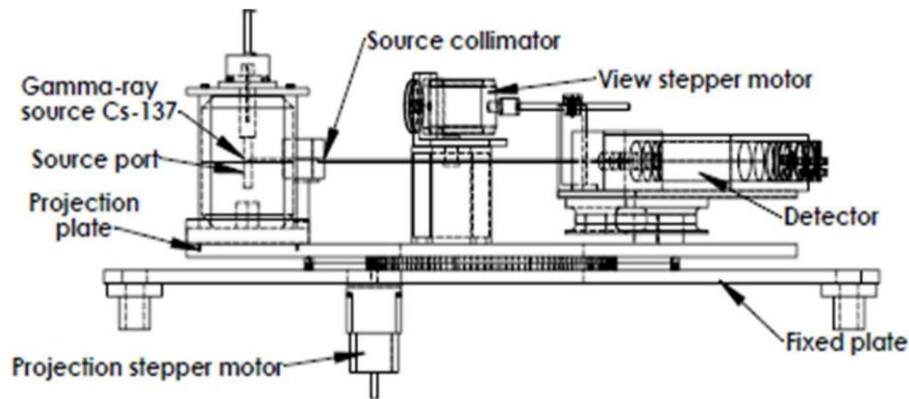


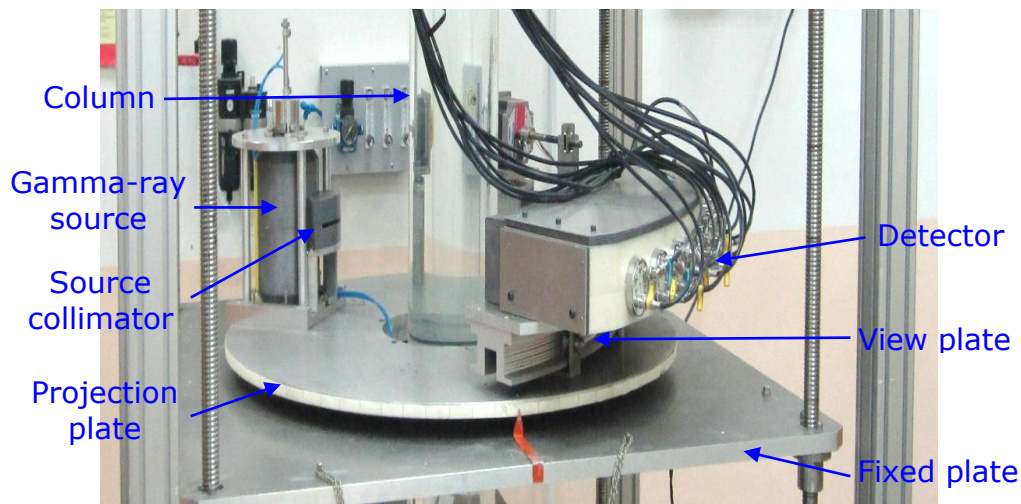
Figure 1. Schematic diagram of industrial process gamma-ray CT [3].

The mathematical methods used for image reconstruction are Expectation-Maximization (EM) and Alternating-Maximization (AM) algorithms. Both algorithms are written in Visual-Fortran programming language. However, this paper will not explained the reconstruction process using the algorithms as it is only focus on the development of data acquisition and motor control software. As shown in Figure 1, the gamma-ray CT hardware can be divided into two parts which are nuclear counting modules and scanning mechanism. The CAMAC modules for nuclear counting will be described in detailed in Section 3.1 while the close-up of scanning mechanism is shown in Figure 2.

The fan beam arrangement consists of an array of nine units of NaI(Tl) scintillation detector with a diameter and length of 2 x 2 inches to accommodate a fan angle of 40° where the detector pitch-to-pitch is 5°. An encapsulated Cs-137 sealed source located opposite from the center of the array of detectors. The detector plane and the sealed source are placed on a projection plate as shown in Figure 2. Since the inertia of the system to be moved in this configuration is large, a temporal resolution of the order of a few seconds cannot be expected.



(a) Illustration of industrial process gamma-ray CT mechanism [3].



(b) Photograph of industrial process gamma-ray CT.

Figure 2. Side view of industrial process gamma-ray CT.

3. Software Development

The software is designed and developed to control all associated nuclear electronics equipment and to acquire gamma-ray transmission data from the CAMAC counting system. The software is also designed to control the movement of the detector plane and projection plate for tomography scanning process. The software is developed by using an older version of National Instrument LabView package which is LabView 8.6. The flow chart of gamma-ray CT scanning process is shown in Figure 3. The finite-state machine (FSM) is used to write the software programs. FSM is a mathematical model of computation used to represent and control execution flow. The output of a state machine is a function of the input where the status or state changes from one state to another based on inputs or satisfied conditions, resulting the output [5].

The software is divided into two sub modules as follows:

- 1) System setup and data acquisition
- 2) Motor control and motion

Both modules are integrated and represented as shown in Figure 3. The software begins with system and data file setup. Then the software will acquire data from the nuclear counting system

where the data will be displayed and recorded. This step will be repeated according to the number of samples entered in the system setup. The next step is operating the scanning mechanism. The data acquisition and scanning operation will be repeated until the total scanning angle is reached.

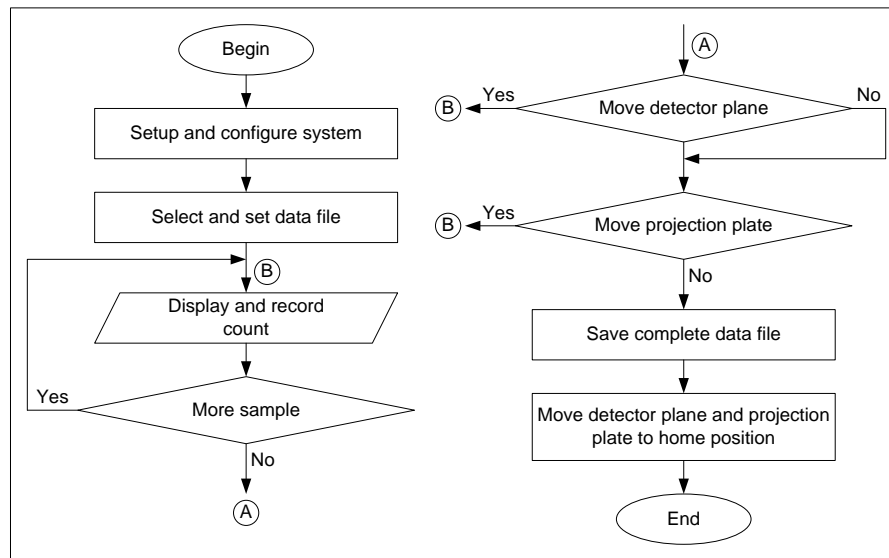


Figure 3. Flow chart of the gamma-ray CT scanning process.

3.1. System Setup and Data Acquisition

Nuclear counting system for the developed gamma-ray CT consists of high voltage power supply, amplifier and CAMAC modules as shown in Figure 1. The CAMAC modules play important role in the software development where the system setup and gamma count are controlled and acquired based on the modules. There are three CAMAC modules involve as hardware. The first one is Ethernet CAMAC crate controller (C111C) which is responsible as the communication interface between CAMAC crate and computer. The communication protocol is Transmission Control Protocol/Internet Protocol (TCP/IP) where the address and port number need to be determined prior to connection establishment. TCP control socket commands used in the software program are listed in Table 1.

Table 1. TCP control socket commands reference [6].

TCP control socket command	Description
CCCZ	Generate Dataway Init
CCCC	Generate Crate Clear
CSCAN	Executes a Crate scan and returns a built mask with bitn = 1 if in the slot n a CAMAC board is detected
CFSA <function> <slot> <addr> <data>	24-bit CAMAC command; returns Q and data

In order to configure the counting system parameters such as discriminator threshold, pulse width and dead time, 16-channel constant fraction discriminator (C808) is incorporated into the CAMAC crate. The parameters can be set up via computer by programming the software based on CAMAC functions listed in Table 2.

Table 2. C808 CAMAC functions [7].

CAMAC Function	Description
F(16) N A(0..15)	Writes Discriminator Threshold on W1..W8.
F(17) N A(0)	Writes Pattern of Inhibit on W1..W16 (1=enabled).
F(18) N A(0)	Writes Output Width on W1-W8 for channels 0 to 7.
F(18) N A(1)	Writes Output Width on W1-W8 for channels 8 to 15.
F(19) N A(0)	Writes Dead Time on W1-W8 for channels 0 to 7.
F(19) N A(1)	Writes Dead Time on W1-W8 for channels 8 to 15.

16-channel scaler (C257) is used to count the pulse generated by the array of detector which consists of nine units of scintillation detector resulted from the CT scanning process based on the counting system setup. The count for each detector then is acquired, displayed and recorded by the computer. Hence, the software is programmed in order to deliver this function. For this purpose, CAMAC functions in Table 3 are utilized.

Table 3. C257 CAMAC functions [8].

CAMAC Function	Description
F(0) N A(0..15)	Reads the value held in the counter addressed by A(0..15). Q is true only if the input is inhibited.
F(2) N A(0..15)	Same as above, but with A(15) reads the 15 th channel and if the input is inhibited, resets all the channels and the LAM line.

3.2 Motor Control and Motion

Motor control module for the CT is developed using electro-mechanical and digital electronic components such as stepper motor driver and stepper motor besides a computer unit. The function of the module is to control stepper motor angular movement either in clockwise or counter clockwise from one point to another. The stepper motor is controlled by the computer using parallel communication. It allows digital signals that have been set up from computer to operate the stepper motor. As shown in Figure 2(a), there are two stepper motors incorporated in the development. One stepper motor is for the movement of the detector plane called view stepper motor. Another one is for the rotation of projection plate called projection stepper motor.

Typically, a scan involves obtaining gamma ray counts for 100 projections around the column. Therefore, the projection plate is rotated in increments of 3.6° step angle for a total of 360° scanning angle. In each projection, the source and collimator is stationary while the detector plane which consists of an array of nine detectors sweeps from an angle range from a -2.4° to +2.4° which is from right to left. The default step angle for the detector plane is 0.2° which results in 25 projections for each detector. Since nine detectors are used, a total of 225 projections are scanned for the movement of the detector plane alone. The sweep operation is done such as equiangular fan beam is eventually created where each detector covers an angle of 4.8° [3].

Once the detector plane motion is completed, the stepper motor is programmed to bring the detectors back to their original position. Then, the projection plate where source and detectors are placed, is rotated clockwise by increment of the plate step angle with respect to the center of the

column. The next view is scanned in a similar manner. Two proximity sensors are utilized where they are placed at the detector plane and projection plate each in order to move the respective part to home position. The flow chart of the motion is shown in Figure 4.

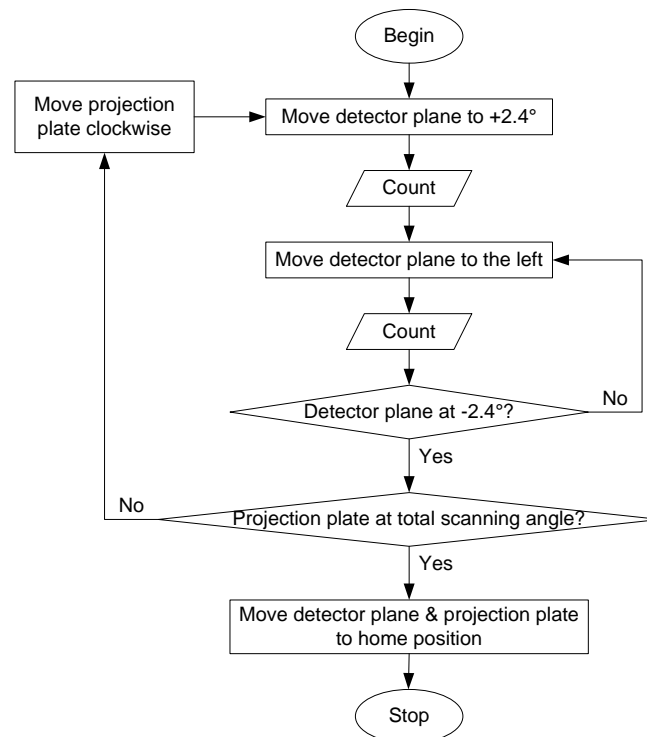


Figure 4. Flow chart of the motor motion.

4. Results and Discussion

The GUI of gamma-ray CT comprises of four panels. Top panel displays the operation status and name of selected menu. The left panel consists of menu and integration time in order to set up and configure the system. The motor status during scanning process is also located at the left panel. There are four menus that can be selected which are as follows:

- 1) System Setup and Configuration
- 2) C808 Discriminator Setup
- 3) Scan
- 4) Stepper Motor Adjustment

The centre panel which is the GUI main panel will change according to the selected menu above. Hence, there are four displays for the main panel. On the other hand, the right panel consists of setting related to the data files. There are three data files that can be selected which are Back-Projection (BP), Expectation-Maximization (EM) and Densitometry depends on the type of CT and process required by the user. The file is created based on the selected data file where the data header and arrangement will be different from each other. The data file is save in text format (.txt). The GUI of gamma-ray CT software is shown in Figure 5.

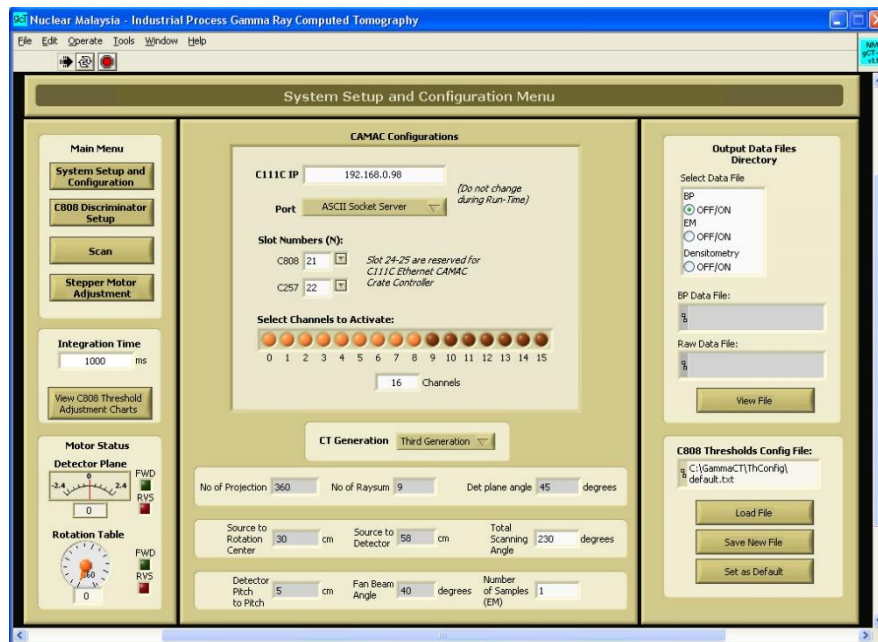


Figure 5. Gamma-ray CT software.

Figure 5 also shows the main panel for System Setup and Configuration menu. CAMAC crate controller and CT scanning parameters are set up under this menu. In order to configure C808 discriminator parameters which are discriminator threshold, pulse width and dead time, the second menu which is C808 Discriminator Setup needs to be selected by the user. The main panel and the LabView program for C808 Discriminator Setup are shown in Figure 6 (a) and 6(b) respectively.

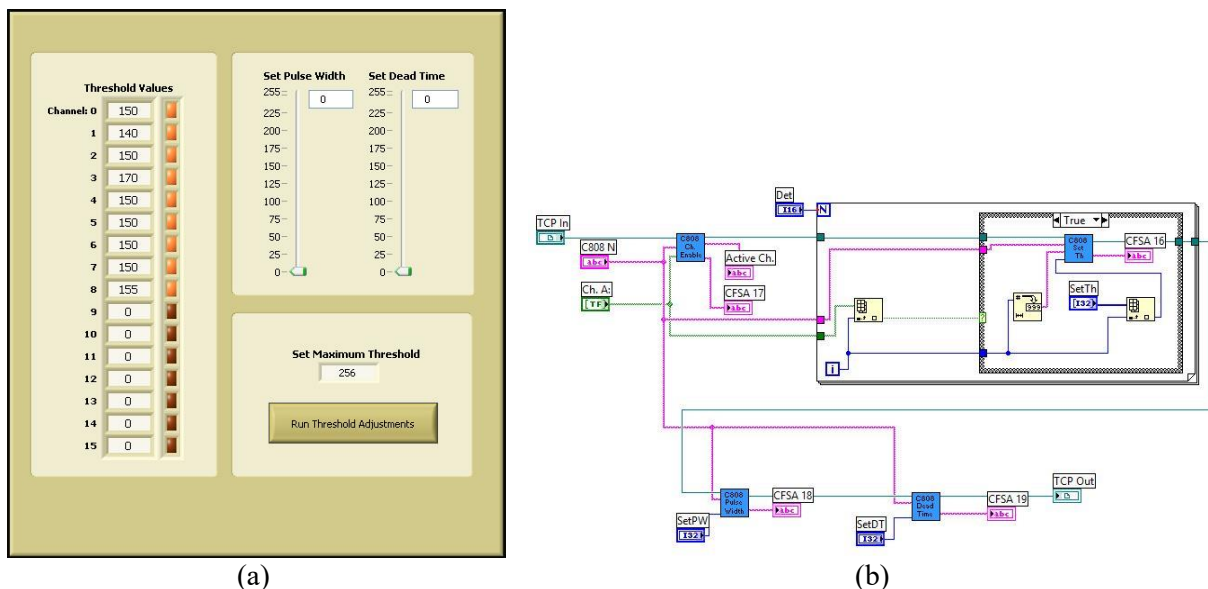


Figure 6. The main panel and LabView program for C808 Discriminator Setup.

The LabView program as shown in Figure 6(b) is developed based on the C808 CAMAC functions list in the Table 2. The program is written in sequence where the channel is enabled by sending functions CFS17 followed by other functions in order to set up the threshold value for each detector channel, besides pulse width and dead time of the acquired signals.

The gamma-ray CT scanning process where the count data of detectors are acquired is shown in Figure 7. The data is acquired and recorded periodically based on the integration time set up at the left panel. The status of the scanning process which includes the current number of sample, detector step and rotation step of the scanning process is also displayed in the Scan panel. Therefore, the user is able to know the progress of the on-going CT scanning process.

Figure 7. The main panel for scanning process.

The output is saved in text file according to the selected data file. The differences between the outputs of each data file are data header and count arrangement. The output sample is shown in Figure 8. The text file will be transferred to Visual-Fortran based program for image reconstruction.

```

114, 20 (No. of samples at each position, sample frequency)
0 0 (View number, projection number) → Projection 0 of view 0 begins
21 111 99 10 373 66 246 182 287 (Counts for detectors 1-9, sample one)
124 149 156 146 118 134 137 115 90 (Counts for detectors 1-9, sample two)
114 157 170 168 155 145 142 137 75 (Counts for detectors 1-9, sample three)
...
...
...
(Total of 114 samples)
...
...
...
0 1 (View number, Projection number) → Projection 1 of view 0 begins
150 194 136 12 486 45 439 315 383 (Counts for detectors 1-9, sample one)
105 143 165 130 117 132 132 161 97 (Counts for detectors 1-9, sample two)
116 191 159 144 162 151 134 126 108 (Counts for detectors 1-9, sample three)
...
...
...
(Total of 114 samples)
And so on for all the 100 (0-99) views and 25 (0-24) projections for each view

```

Figure 8. The sample of output for EM data file.

5. Conclusions

Software for gamma-ray CT has been developed and tested in Nuklear Malaysia. All features including data acquisition from CAMAC crate controller via Ethernet interface, scanning control, motor motion and data file generation work accordingly. In term of the scanning operation and automation, there is no difference between using CAMAC and NIM standard. Computer Ethernet and parallel connections need to be stable in order to ensure the reliability of the automatic data acquisition and scanning process. Since the software is developed in-house, it can be modified and improved based on the user requirement.

6. References

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