Design of rotating table control for acquiring an image in industrial gamma-ray CT prototype using Raspberry Pi 3B+ module

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Abstract. The rotating table on an industrial gamma-ray CT device is used to rotate the detector consisting of a line scanner and a gamma-ray source around the test object. The process of acquiring the image is done by rotating the detector and the source 360 degrees around the object, and at a certain angle, the object projection image is captured through the line scanner. A stepper motor is used to rotate the rotating table. The rotary motion of the stepper motor is controlled using the Raspberry Pi 3B+ control module which can be accessed remotely using the TCP/IP communication protocol. As an interface to control the motion of the rotating table, a software that is created using the python programming language is used. The gear ratio between the motor and the rotating table is 23 : 161 which takes 7 full rotations on the stepper motor to produce one full rotation on the rotating table. Based on the test results, 25200 pulses input is needed to rotate the rotating table 360 degrees, while one pulse is able to move the rotating table by 0.0143 degrees.

1. Introduction
Non-destructive test (NDT) is one of the methods which is used by the manufacturing industry in ensuring the quality of the products. Compared with the destructive test that requires several random samples to be tested, the non-destructive test is far more efficient because the testing process is not done by destroying the sample and can be done on the entire production. The non-destructive test process can be carried out with radiographic techniques that utilize radiation from radioactive sources with high penetrability such as gamma rays or X-rays [1]. The utilization of radiation with high penetrability is intended to determine the inner structure of the object.

The results from the object irradiation process are detected by a detector that has a spectrum in accordance with the used radiation source. In conventional radiographic techniques, the used detector is film sheets. But the use of film as a detector requires chemicals that are not environmentally friendly. In addition, film processing also time-consuming [2]. Today, digital radiography techniques have been developed that do not use film as a detector. This digital radiography technique has some advantages, such as the test time is relatively faster than conventional radiography techniques and also the results can be stored in the form of digital images. Another advantage of digital radiography techniques is that the resulting 2D digital images can be reconstructed into 3D digital images. This radiographic technique is better known as a Computed Tomography (CT) procedure. This procedure is done by taking the image of the test object from various angles and then the image data is reconstructed into a 3D digital image [3].
The CT procedure utilizes a detector which is different from conventional radiographic techniques. The detector that is used in the CT procedure is a detector that can capture radiation results and then convert it into digital data. The detection method consists of 2 methods, including *indirect digital radiography* (IDR) and *direct digital radiography* (DDR). In the IDR method, radiation is first detected by a luminescent screen and then the resulting image is captured using a camera [4]. In the DDR method, the results of radiation are detected directly by a digital detector that is sensitive to radiation so that it does not need to go through the stage of converting gamma radiation or X-rays into visible light [5]. DDR technique is the latest technology in which the digital image is obtained by using a photoconductor, scintillation method or a CMOS detector [6].

To capture the image of the test object from various angles, it can be done by rotating the radiation source and the detector around the test object. The procedure of rotating the radiation source and detector around the test object is carried out using a rotating table. A stepper motor is used as an actuator from the rotating table so it can move around in accordance with the desired rotation angle. This paper presents the stepper motor control method with the Raspberry Pi 3B+ control module. This control module can be accessed remotely by utilizing VNC Connect software with the TCP/IP (*Transmission Control Protocol/Internet Protocol*) communication protocol [7].

The rotating table system in this paper is a subsystem of a gamma-ray CT device that will be integrated with other subsystems, including the image acquisition subsystem and the image processing subsystem. The results of the integration of these subsystems will form gamma-ray CT devices for industries that are able to produce 3D images digitally from the tested object.

2. Theory

The stepper motor that is used on the rotating table for gamma-ray CT devices requires input in the form of the electric voltage pulse. These pulses are inputted through a driver that is connected directly to the stepper motor. The number of electrical voltage pulses will determine the number of steps taken by the motor, while the frequency of the electrical voltage pulses will determine the rotational speed of the motor. The angle for each step of the motor is determined based on the settings set in the motor driver and also the gear ratio in the motor. The rotation direction of the motor can be determined based on the chosen control method in the motor driver and the used port to input the pulses. A comparison of the timing diagram between the 1-pulse input method and 2-pulse input method which is available in the motor driver is shown in figure 1.

![Figure 1. 1-pulse input method and 2-pulse input method timing diagram[11].](image-url)
The control module is used to generate an electrical voltage pulse that will be inputted to the motor driver. To generate an electric voltage pulse, an electrical voltage is generated on one of the pins which are available on the control module and then the voltage is lowered back to the base level after a certain period of time. To produce chained pulses, a looping logic is performed on the control module to obtain the number of pulses as desired [8]. The time span from minimum voltage to maximum voltage and the time span from maximum voltage to minimum voltage will determine the period and frequency of the voltage pulse. Therefore, this time span variable can be used to control the rotational speed of the motor.

To access the control module remotely, VNC Connect software is used. This software is used to control a computer using another computer that is connected through a network with the TCP/IP communication protocol. The used network can be in the form of a network with a cable or wireless network. To increase flexibility in control, wireless networks can be used so that the control process can be done remotely without being tied to cables. One form of the wireless network that can be used is a WiFi network based on the IEEE 802.2 standard [9]. To connect each computer, one or more wireless access points (WAP) can be used.

3. Methods

The design process of the motor control system for the rotating table starts with studying the process of image acquisition for reconstruction purposes. The image acquisition process is an important process because it will determine the main algorithm of the motor control program. The next step is the requirement analysis to determine the features and functions that must be provided in the control program. The next step is program design and writing based on the results of the requirements analysis in the Raspberry module. Testing is done after the program runs successfully without writing errors. The test aims to check the features of the motor control program in accordance with the desired function. During the test it will be observed the number of steps taken by the rotating table and also the rotation angle was taken by the stepper motor.

3.1. Tools and materials

In this device, the user control module is the Raspberry Pi 3B+ module. In this Raspberry module, Raspbian operating system from Debian already installed. In addition, in this module is also installed Python Thonny IDE software as a facility to develop stepper motor control software. This Raspberry module had been also installed an interpreter module for the Python programming language version 2.7. As a means of communication, VNC Server software had to be installed in the Raspberry module. A computer that has VNC Viewer is used to build stepper motor control software inside the Raspberry module. The TP-Link TL-MR3420 module is used as a WAP for communication between Raspberry and the computer.

The used stepper motor is a stepper motor from Autonics with model A200K-M599-G7.2, while the motor driver is Autonics model MD5-HF14. Some other components which are needed include a 5V/3A adapter as a power source for Raspberry and several connector wires to connect the pin of the Raspberry with the port on the motor driver.

3.2. Design

The rotating table control algorithm is adjusted to the image data acquisition process. Image data is taken by rotating the source of gamma rays and detectors around the test object at a certain angle to obtain several images for the reconstruction process. For example, 63 image data are needed for reconstruction, then the rotating table will be rotated 63 times to reach a 360° full rotation. Or in other words, every single move from the rotating table has a rotating angle of 5.71°. Between each movement is given a delay time so that the image capture process can take place.

Autonics A200K-M599-G7.2 stepper motor that is used to actuate the rotating table has a gearbox with a ratio of 1 : 7.2, where 7.2 rotations on the motor will generate 1 rotation on the gearbox shaft. The MD5-HF14 motor driver has a basic resolution of 0.72° and can be divided up to 0.00288°. For
rotating table purposes, a basic resolution of 0.72° is used so that to produce one full rotation of 360° on a motor it takes 500 movements or 500 pulses of electrical voltage. Thus, to achieve one full rotation on the gearbox shaft 3600 movements or 3600 pulses of electrical voltage are needed. The specifications of the stepper motor and motor driver that is used for rotating table purposes are shown in table 1 and table 2.

Table 1. Autonics A200K-M599-G7.2 stepper motor specification [10].

| Parameter                | Range                      |
|--------------------------|----------------------------|
| Diameter                 | 85 mm                      |
| Max. Allowable torque    | 200 kgf.cm/(5.0 N.m)       |
|Rated current             | 1.4 A/Phase                |
|Basic Step angle          | 0.1°/0.05° (Full/Half)     |
|Permissible speed range   | 0 – 250 rpm                |

Table 2. Autonics MD5-HF14 motor driver specification [11].

| Parameter                  | Range                                                      |
|----------------------------|------------------------------------------------------------|
| Power supply               | 100 – 220 VAC 50/60 Hz                                     |
| Allowable voltage range    | ± 10 % of rated voltage                                   |
|Max. current consumption    | 3 A                                                       |
|RUN current                | 0.4 – 1.4 A/Phase                                         |
|Resolution                 | 1, 2, 4, 5, 8, 10, 16, 20, 25, 40, 50, 80, 100, 125, 250 division |
|                           | (0.72° to 0.0028°/step)                                   |
|Input pulse characteristics | Pulse interval Min. : 0.1 µs                               |
|                           | Rising/falling Max. : 1 µs                                 |
|                           | Pulse input voltage : [H] 4 – 8 VDC, [L] 0 – 0.5 VDC      |
|                           | Max input pulse frequency : Max. 500 kHz                  |
|Ambient humidity           | 0 – 50 °C                                                 |
|Ambient temperature        | 35 – 85 %RH                                               |

Between the gearbox shaft and the rotating table shaft are connected through gears in a ratio of 23 : 161 or 1 : 7. Therefore, to achieve one full rotation on the rotating table requires 7 full rotations on the gearbox shaft. Thus, to achieve 1 full rotation of 360° requires 25200 movements or 25200 pulses of electrical voltage. To get a rotation with a certain angle, the motor rotation is divided into several parts by limiting the number of electric voltage pulses that are inputted into the motor driver.

Menu options that are used to control the motor include the following:
- Option to determine the rotation direction (clockwise / counter-clockwise)
- Option to determine the rotational angle for each step
- Option to determine the rotational speed of the stepper motor
- Option to determine the time delay given between each movement
The control algorithm is written as a control program and embedded in the Raspberry module. This control program is written using the Python programming language version 2.7 with the Python Thonny IDE software. This program also formed a graphical user interface (GUI) that facilitates the stepper motor control process. This control program and GUI software are integrated into an application that can run on Raspberry. The algorithm in the form of a flow chart is shown in figure 2.

![Flowchart for stepper motor control program](image)

**Figure 2.** Flowchart for stepper motor control program.

To access the Raspberry module, input/output devices as in most computers can be used, including monitors, keyboards, and mouse. Raspberry can also be accessed and controlled from other computers remotely by using VNC Connect software which is installed on the Raspberry and the computer. Raspberry and computer can communicate over the network with TCP/IP protocols, both wired and wireless communication. Communication with cable can be done by using an ethernet cable, while wireless communication can be done using WiFi networks. Raspberry and computer must be ensured to be connected to the same network before starting communication between devices. Therefore, a wireless access point is used as a means of communication between Raspberry and the computer.
4. Result

The screenshot of the GUI of the control program that is used in the stepper motor control is shown in Figure 3. The rotational angle option for each step consists of several decimal numbers which result in the odd number of steps. The odd number of steps is chosen so that no exact opposite position is obtained which is the resulting image captured on one side is only a mirror image of the image on the other side. This will result in a significant reduction in information resulting from the acquisition. If the number of steps is odd, then there is no stop position that is the exact opposite. Therefore, there is no image data that is similar to other image data.

![GUI for stepper motor control program](image)

**Figure 3.** GUI for stepper motor control program.

Motor speeds can vary between 1 degree/second to 50 degrees/second. This speed is the result of the conversion of the electric voltage pulse period. One pulse will cause the gearbox shaft to rotate 0.1 degrees, so that the gearbox shaft rotational speed is 0.1 degrees/pulse period. The pulse period is determined based on the delay time given at the time of generation and removal of the voltage on the Raspberry pin. A maximum number of 50 degrees/second is obtained based on the test results. When the pulse period is less than $2 \times 10^{-3}$ seconds, the stepper motor will stop moving and only vibrate. This is caused by the characteristics of a stepper motor that requires an acceleration algorithm so that it can rotate faster than 50 degrees/second.

Table 3 shows the results of the test. Based on the test results, it is known that the number of steps taken by the rotating table is in accordance with the number of steps specified in the program. The result also shows that the rotational angle from the stepper motor is consistent with the program. The number of pulses that are generated from the control module is in accordance with the program so that it can actuate the stepper motor to rotate precisely. But the difference is seen in the angle of rotation taken by the rotating table. The rotating table does not stop exact at 360°. This difference can be caused by several things, including the inaccuracy of the measurement scale and due to mechanical factors on the gears between the motor gearbox shaft and the rotating table. Based on the results of the average calculation, each pulse of electrical voltage inputted to the motor driver will cause the rotating table to rotate as far as 0.0143°.
Table 3. Measurement data.

| Setting parameter | Number of steps | Motor rotational angle per step | Number of generated pulse per step |
|-------------------|----------------|--------------------------------|-----------------------------------|
| 5.71°             | 63             | 40°                            | 400                               |
| 1.60°             | 225            | 11.2°                          | 112                               |
| 1.14°             | 315            | 8°                             | 80                                |
| 0.69°             | 525            | 4.8°                           | 48                                |
| 0.51°             | 700            | 3.6°                           | 36                                |

5. Conclusion
The design and engineering of the rotating table control system have been carried out that will be used in the process of image acquisition for image reconstruction purposes on gamma-ray CT devices. The results of this engineering cannot yet be integrated with other subsystems because the sub-system is not yet available. The test results show the motor control system can function properly, but there is a slight difference in the total rotational angle which is traveled by the rotating table. This difference can be caused by a mechanical slip that can occur on the gear that connects the stepper motor and the rotating table.

Acknowledgments
Authors wishing to acknowledge assistance or encouragement from Digital Radiography and gamma-Ray CT Engineering Team.

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