Calibration of mechanical systems of in-house dynamic thorax phantom for radiotherapy dosimetry

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Abstract. The purpose of this study is to calibration a mechanical system of In-house Dynamic Thorax Phantom so that it can be used as a dosimetry on the Radiotherapy Real-Time Position Management (RPM) technique. In order to ensure the RPM technique had properly function, we need to employ a quality control tool that represents moving objects on the human body. Inspired by the CIRS Dynamic Thorax Phantom model 008A, we developed an In-house Dynamic Thorax Phantom using three Nema-17 stepper motors with 200 steps in a cycle as a mechanical system. In addition, the first stepper motor was used to move objects in superior-inferior direction; the second one was used to move the RPM marker in anterior-posterior direction; while the third one was used to move objects in rotation. Calibration of mechanical system was performed by finding out the number of counts needed each direction. Especially for rotational system, they were calibrated with Optical Interrupt Device. The result of calibration of the mechanical system between the actual readings compared with the system specification is 0.0% and < 1% for the measurement testing.

1. Introduction
Medical efforts, such as surgery, chemotherapy, and radiotherapy, have been made to overcome the problem of lung cancer. For example, the radiation treatment for Non-small cell lung cancer. Development of radiotherapy techniques will continue to evolve to achieve the maximum and conformal doses on the target and minimize doses at the organ at risk. For treating lung cancer in radiotherapy, the compensation of the organ movement due to the respiratory organs needs to be considered. Generally, to compensate the organ movement receiving the dose radiation, it could be handled either by performing real-time compensation during radiation treatment or by adding margins on Planning Target Volume (PTV) [1].

The treatment calculation of lung cancer movement is more interesting for the researchers to know the most appropriate radiotherapy technique. Moreover, Real-Time Positioning Management (RPM) techniques on a CT Simulator are needed to accurately acquire the location of tumor in moving organs [2]. Prunaretty et al studied about the different techniques of the compensation, namely tracking (T), gating (G), and free-breathing (FB), used for the SBRT of lung cancer in corresponding to the dose received in the gross tumor volume (GTV). This study outlined that the dose in the GTV for free-breathing technique is higher than GTV for other compensation techniques. Additionally, the study suggested that the real-time compensation for the radiation therapy of lung cancer could generate
optimal dose coverage on the PTV. Therefore, accuracy in determining of tumor position inside the human body is very important [3].

To validate the accuracy of the dose delivered on the lung cancer cases in real-time techniques compensation, the quality control with a dynamic thorax phantom is required to mimic the radiation treatment setup with the real motion of the organ target [4]. This phantom is specifically designed as a representation of the human lung that can move according to the respiratory cycle. The amplitude of the movement of lung tumors in humans is around 10 mm; but, for some people, the respiratory amplitude can reach up to 30-40 mm [5].

Motion management technique for lung cancer treatment will provide the better quality control of delivering the dose, but the level of accuracy of dose delivery must be considered [6]. Generally the dose verification for dynamic organ motion should be evaluated using the the dyamic phantom so that the accuracy of mechanical system is very important to be performed. Motor stepper were used to move the objects which is considered as target in phantoms and markers on RPM systems as showed on Figure 1. The working principle of the motor following the number of clocks was provided. It is expected that if the stepper motors are given the same number of clocks, it will produce the motion phase as found in the human breathing cycle.

Figure 1. In-house Dynamic Thorax Phantom using Three Stepper Motor as Mechanical System

2. Material and Method

In this study, three 1.8° NEMA-17 stepper motors were employed (Figure 2.a). Based on the system specification required 200 steps pulse to generate one full revolution (360°) then it would move around of 8 mm object linearly. Two toggles are required to rotate one-step a stepper motor then each toggle that is entered into the system will be count, which means 400 toggles or 400 counts are required to rotate one revolution of stepper motor. However, to be able to observe the movement of the stepper motor, divider 1/16 was applied to the system. Therefore, with the designed in-house software and the stepper motor specification, 6400 counts are required to move the stepper motor in one revolution.

The first and the second stepper motor are connected to a 7 cm long axis linear slide. The former stepper motor was used to move the objects in superior-inferior direction (SI system) and the later stepper motor was employed to move a cubic marker in anterior-posterior direction (AP system) on the RPM system. Additionally, the third stepper motor was used as rotational system to rotate object on the phantom.

Other supporting equipment used in this calibration process is the ruler placed on the axis linear slide connected to the SI system and AP system. Furthermore, the needle was attached on the front edge of the rotational system. The needle is used to read the position shift as a result of the value inserted to the in-house software and also as a pointer to the protractor. Optical Interrupt Device (OID) was
incorporated in the development of the system to provide a count reading for the rotational system (Figure 2.b). Microcontrollers, namely Arduino Nano and A4988, was also required to receive a signal then displayed on LCD screen.

The calibration of mechanical system was performed by reading the number of counts for each system to get mechanical conversion. For the SI and AP systems, the number of counts was set in the range of 0 to 60 mm with 5 mm increment. Additionally, for the rotational system the number of counts was set when the needle passes the OID. From this calibration the actual movement and rotation of the system was determined using Equation 1 and 2.

\[
\text{Actual Movement} = \frac{\text{No.of Count for Full Rotation}}{\text{Gradient of Calibration Curve}} \quad (1)
\]

\[
\text{Actual Rotation} = \frac{\text{No.of Count for Full Rotation}}{\text{Gradient of Calibration Curve}} \quad (2)
\]

Measurement of the position accuracy was performed after calibration of the mechanical system. This measurement was designed by inserting a known value of distance on the software and examining the real movement of the mechanical system indicated on the ruler, needle and protractor. The SI and AP system were driven as far as ± 5 mm to ± 25 mm with fivefold increment. For the rotational system, the movement test was performed by rotating the object from 5° to 90° clockwise and counterclockwise with ten-fold increment.

![Figure 2](image1.png) (a) ![Figure 2](image2.png) (b)

**Figure 2.** Mechanical System of In-house Dynamic Thorax Phantom (a), Optical Interrupt Device setup on Rotational System (b).

### 3. Result and Discussion

The result of the calibration of mechanical system was in a good agreement, it can be seen from the linear curve in Figure 3. Graphical method was used to see the changes without having to know the initial condition of the system. The gradient curve of the SI and AP systems was about of 800.52 and 797.41, respectively. According to equation 1 the actual movement for one revolution of the SI and AP systems is 7.99 mm and 8.02 mm, respectively. For the rotational system, the actual rotation based on equation 2 was found at 359.99° for one revolution.

Figure 4 showed the result of a motion distance measurement for the mechanical system. Pertaining to the Figure 4.a and 4.b, it seems no error has been generated since all the system moved as the known distance inserted in the in-house software. This movement also indicated the amplitude range of the SI and AP systems developed in the measurement system. As for the respiration amplitude of human being, the SI and AP systems could mimic the human respiration amplitude that could attain 1.9 mm up to 40
mm [5], [7], [8]. Figure 4.c demonstrated errors in the range of $0.1^\circ \leq \text{error} \leq 0.6^\circ$ on positions of $30^\circ$, $60^\circ$, and $70^\circ$. This errors possibly arose from the vibrations occurred at low speeds during the operation of the stepper motor [9].

![Graphs showing the calibration curve.](image)

**Figure 3.** Calibration Curve of the System, Superior-Inferior System (a), Anterior-Posterior System (b), and Rotation System (c).

The calibration for mechanical system of in-house dynamic thorax phantom generated a regression value ($R^2$) equal to 1, which indicated the regression predictions perfectly fit the data. The mechanical specification of all systems required 6400 counts with 8 mm of linear movement for one revolution ($360^\circ$). Since the instrument employed in the measurement provided 0.5 mm and 1° of accuracy, it could be inferred that the calibration of mechanical system generated 0.0% of standard deviation as shown in Table 1.

| Mechanical System          | System Specifications | Mechanical Calibration | Deviation (%) |
|----------------------------|-----------------------|------------------------|---------------|
| Superior - Inferior (no.1) | 8 mm                  | 8 mm                   | 0.0           |
| Anterior - Posterior (no.2)| 8 mm                  | 8 mm                   | 0.0           |
| Object Rotation (no.3)     | $360^\circ$           | $360^\circ$            | 0.0           |
Figure 4. Motion Distance Measurement, Superior-Inferior System (a), Anterior-Posterior System (b), and Rotation System (c).

Figure 3.a and 3.b presented parallax error when viewing the results of the measurement since the gradient curves were not exactly 800. The gradient curve displayed in Figure 3.c, which was of 17.78, had a good agreement with data of the systems specification, which was of 17.78. The gradient data from the specification was generated by dividing 6400 counts with 360° for one revolution. Figure 4.a and 4.b also presented that the movement of the SI and AP system followed the input programmed in the software. This result was validated with ten repetitions of the measurement for each linear distance and all data showed that the derived data was in good agreement with the programmed linear distance inserted in the software. Parallax error while observing the measurement and considering the level of accuracy of the instrument caused a slight deviation as seen in Figure 4.c. Additionally, standard deviation of the rotational movement <1° was allowed on the radiotherapy technique [4] such that the properties of the systems in term of the rotational movement attained the expected result.

The mechanical test in this study was performed by moving the motor system in superior-inferior and anterior-posterior direction as well as rotational movement. The movement accuracy in all directions of the systems was accepted corresponding to the actual value set on the software. Based on the datasheet from CIRS Dynamic Thorax Phantom model 008A [10], we believed that the development of the in-house dynamic thorax phantom using stepper motor as a mechanical systems is encouraging. In
conjunction with the better control of the phantom, we are working on the development of in-house software such that the integrated system of the in-house phantom and in-house software could be utilized for the quality control measurement in real-time gating dosimetry.

4. Conclusions
The results of this study showed that 1% of an error was presented. In addition, the microcontroller selected for this measurement worked properly. With this condition, the mechanical system incorporating three stepper motors generated good precision result and it could be a candidate for a mechanical system of In-house Dynamic Thorax Phantom.

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References
[1] S. Dieterich and Y. Suh, “Tumor motion ranges due to respiration and respiratory motion characteristics,” Treat. Tumors that Move with Respir., pp. 3–13, 2007.
[2] J. Prunaretty et al., “Tracking, gating, free-breathing, which technique to use for lung stereotactic treatments? A dosimetric comparison,” Reports Pract. Oncol. Radiother., vol. 24, no. 1, pp. 97–104, 2019.
[3] P. Giraud, E. Yorke, S. Jiang, L. Simon, K. Rosenzweig, and G. Mageras, “Reduction of organ motion effects in IMRT and conformal 3D radiation delivery by using gating and tracking techniques,” Cancer/Radiotherapie, vol. 10, no. 5, pp. 269–282, 2006.
[4] S. Ehrbar et al., “Respiratory motion-management in stereotactic body radiation therapy for lung cancer – A dosimetric comparison in an anthropomorphic lung phantom (LuCa),” Radiother. Oncol., vol. 121, no. 2, pp. 328–334, 2016.
[5] Y. Matsuo et al., “Evaluation of dynamic tumour tracking radiotherapy with real-time monitoring for lung tumours using a gimbal mounted linac,” Radiother. Oncol., vol. 112, no. 3, pp. 360–364, 2014.
[6] P. Sibolt, C. E. Andersen, W. Ottoosson, and C. F. Behrens, “Time-resolved plastic scintillator dosimetry in a dynamic thorax phantom,” Radiat. Meas., vol. 106, pp. 373–377, 2017.
[7] H. A. McNair, A. Kavanagh, C. Powell, J. R. N. Symonds-Tayler, M. Brada, and P. M. Evans, “Fluoroscopy as a surrogate for lung tumour motion,” Br. J. Radiol., vol. 85, no. 1010, pp. 168–175, 2012.
[8] A. T. Group et al., The management of respiratory motion in radiation oncology report of AAPM Task Group 76., vol. 33, no. 10. 2006.
[9] L. Wargula, P. Krawiec, J. M. Adamiec, and K. J. Waluś, “The Investigations of Dynamic Characteristics of a Stepper Motor,” Procedia Eng., vol. 177, pp. 318–323, 2017.
[10] CIRS, “Dynamic Thorax Phantom,” Http://Www.Cirsinc.Com/Products/All/18/Dynamic-Thorax-Phantom/, 2016.