Development of a Test-Bench for the Accurate Positioning of Scintillation Detector Modules for Medical Imaging Applications

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Summary

When assessing the impact of novel concepts of scintillation block detectors for PET tomography by measuring the performance of single modules, or one module in coincidence with another, it is not trivial to translate the results of these investigations into a real PET scanner, made of several rings of modules. In particular, the real sensitivity, the signal to noise ratio of reconstructed images, and the spatial resolution (especially in the areas far from the center of field of view) among others are very critical to understand how good a PET scanner will perform for a real patient, and they are specific of the fully assembled scanner. Hence, demonstrating that a new idea under development is worth implementing in a real scanner requires more than just a measurement with two modules one in front of the other. For this reason, the set-up described in the present work will permit to reproduce full ring conditions using only a few modules at the price of a very good positioning accuracy.

1. Motivation

The aim of the present work is to ease and accelerate the implementation of novel concepts in positron emission tomography (PET) and cut the costs associated to the prototyping phase. For this purpose, it was developed and manufactured a test-bench capable of mimicking real full ring acquisitions of a PET system using only two blocks of detectors or groups of detectors. The proposed solution is an autonomous mechatronic system consisting on two polar arms that move independently to position accurately the detectors along predefined trajectories. The possibility to mimic the positions of the crystals along the theoretical locations of the detectors in a small animal PET device will result in reduced costs and faster development of novel scintillators and detectors for PET imaging by mimicking the positions of the crystals along the theoretical locations of the detectors in a small animal PET device. The scope of the project ranges from the preliminary studies to the commissioning of the test-bench, and included the selection of the most appropriate actuators, the necessary structural calculations, the design of the mechanical parts, and the development of a methodology for the evaluation and testing of the test-bench.

2. Problem definition

Most of the research performed nowadays on PET scintillation consists assessing the impact of new ideas by measuring the performance of single modules, or one module in coincidence with another. Translating the results of these investigations into a real PET scanner made of several rings of modules is not trivial. In particular, the real sensitivity, the signal to noise ratio of reconstructed images, and the spatial resolution (especially in the areas far from the center of field of view) among others are very critical to understand how good a PET scanner will perform for a real patient, and they are specific of the fully assembled scanner[1]. Hence, demonstrating that a new idea under development is worth implementing in a real scanner requires more than just a measurement with two modules one in front of the other. For this reason, the set-up described in the present work will permit to reproduce full ring conditions using only a few modules at the price of a very good positioning accuracy.

3. Design description

The complete test set-up consists in two detector modules, which will include both the block detectors (one or more depending on the configuration) as well as the ancillary PCB boards for the data acquisition. Each one of these detector modules will be mounted on one polar arm able to rotate independently and follow automatically trajectories defined by the user. A source in the shape of a point or a phantom, depending on the needs and objectives of the tests will be placed in the centre of the set-up.

As depicted in figure 1, the test-bench is composed of a bottom base (figure 2a) meant to be bolted to an optical table or breadboard. Four columns (figure 2b) bolted to the upper surface of the base support the bottom rotary actuator (figure 2c).

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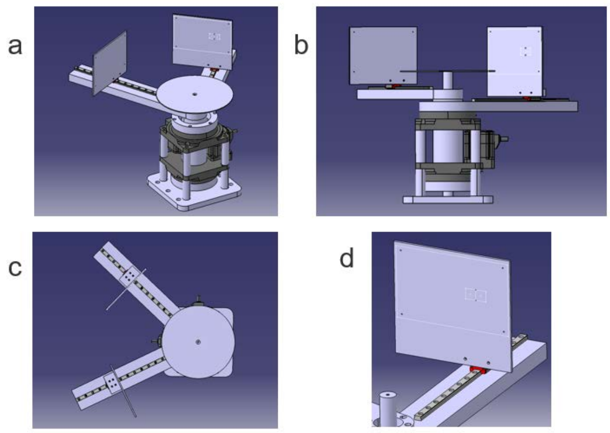

Figure 1. *Different views of the test-bench*

The bottom rotary actuator is mounted upside down, and from the top surface of its flange depart four additional columns devoted to support the top rotary actuator.

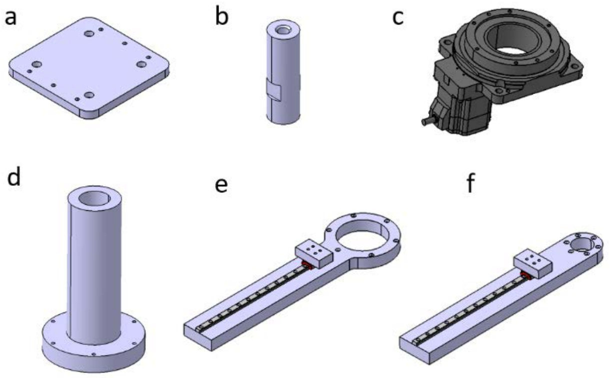

Figure 2. *Mechanical components of the test-bench*

On the table of the bottom rotary actuator is mounted a hollow axis (figure 2d) which goes through the bodies of both actuators and drives the top arm (figure 2f) of the test-bench. The bottom arm (figure 2e) of the set-up is directly mounted on the table of the top rotary actuator.

The arms of the set-up are equipped with linear guides (visible in figures (figure 2) e and f) that allow the radial positioning of the detectors. The slider of the linear guides is equipped with different plates (figure 2d) in accordance with the kind of PCB boards and block detectors to be mounted.

The set-up is completed with a central column affixed to the base plate which goes through the hollow axis and serves as a support for the source platform.

3.1. Use

The main goal of the test-bench is to allow the recording of full ring PET scans by using a minimum of two detectors. For this reason, the intended purpose of the set-up is to position the detectors of each of the two arms in a series of preprogrammed positions.

Prior to a scan, several parameters should be defined:

- Radial position of the detectors: It is defined as a function of the object to be scanned and other acquisition parameters.
- Angular pitch of the acquisition: In order to cover the full circumference, this parameter is calculated as a function of the radial position of the detectors (R), and the width of the detectors itself (DWidth) (figure 3.10):

$$\alpha = R \times DWidth$$

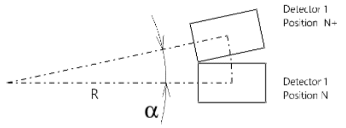

Figure 3. *Pitch definition as a function of the radial position and the detectors width*

Relative initial and final position of the arms: Due to the space taken by the PCB, that surrounds the detectors, the angles between the arms at the beginning and end of each acquisition step will be bigger than the angles allowed solely by the detectors. This is a parameter that involves the safety of the test-bench and must be carefully determined after the mounting of a new detector.

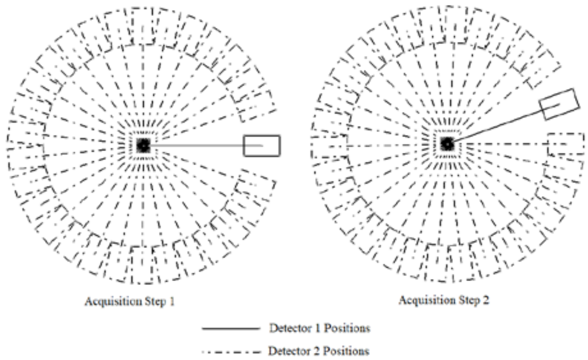

Figure 4. *Schematics of the first two acquisition steps*

The most usual positioning routine consists in mimicking the positions of the crystals in a full body scan. The most efficient way to do this is to perform consecutive acquisition steps in which one of the arms of the test-bench will have a fixed position, while the second arm will follow a series of positions (sub-step) around the subject as shown in figure 4.

Upon the arrival of the arms to a target position, the set-up will send a trigger to the acquisition system ("record trigger") in order to communicate that the detectors are in the correct position, and the recording can start. Whenever the quantity and quality of the acquired data is judged to be enough, the acquisition system will send a trigger ("jog trigger") to the test-bench which will move the arms to the next target position.

4. Evaluation

The verification of the functionality of the proposed solution against the stated requirements, as well as further validation will be based on the experimental assessment of the built prototype.

Amongst all the measurable mechatronic parameters, a number of them is considered as critical, as long as either they are part of the specifications, or are the result of the combination of multiple parameters and can greatly determine the performance of the set-up. Therefore its characterization must be promptly done:

- Accuracy
- Unidirectional repeatability

The evaluation of this set of parameters will not only permit a clear assessment of the performance of the test-bench, but also to undertake the necessary corrective actions.

The experience in the usage of the set-up or a different usage than the one described in previous chapters might unveil the need to characterize other parameters

4.1. Testing methods

Two possible approaches are proposed in the present work. The first one is a classic method described in ISO 9283[2] standard, using a coordinate measuring machine or laser scanning triangulation (trilateration).

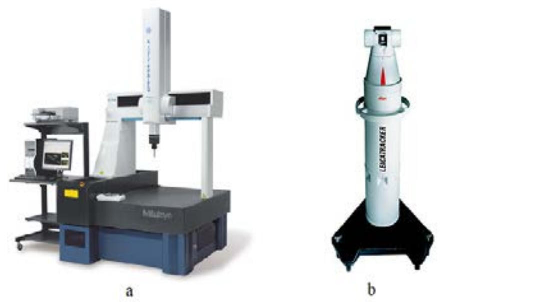

Figure 5. *Coordinate measuring machine (a) and laser scanning triangulation de-vice (b) (Image: Mitutoyo/Leica)*

An alternative to the classical approach is the solution described by Pierce et al.[3] determination of the six degrees of freedom for block detector positioning errors by utilizing a rotating point source over stepped axial intervals.

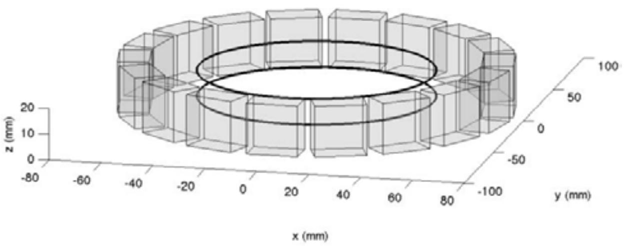

Figure 6. Side view of the MiCES scanner detector ring illustrating two axially-stepped rotational paths of the point source.

The proposed experimental set-up uses a commercially available 1 mm diameter 20µCi^{22}Na point source that is rotated within the detector ring at stepped axial intervals. The radius of rotation and the axial offset is determined by the geometry of the scanner to be calibrated. In the experiment described by the previously mentioned article, for the MiCES scanner a rotational radius of rotation of 45 mm, and an axial offset of 10 mm were chosen, as shown in figure 6.

5. Current status of the project

As of the date of this paper, the study phase has been finalised, comprising preliminary studies, mechanical design and control architecture definition. The procurement of the actuators has been completed, and its functionality has been validated in laboratory tests. The manufacturing of the mechanical parts is ongoing.

The assembly of the set up as well as the first validation tests are to be performed during the first quarter of 2018.

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