2006-1047: LABORATORY DEVICE FOR DEMONSTRATING MEDICAL IMAGING IN THE CLASSROOM

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Laboratory Device for Demonstrating Medical Imaging in the Classroom

Abstract

In this paper, we describe the details of the experimental setup developed with the objective of demonstrating the principles of tomography using visible light. Most tomographic methods use invisible forms of radiation (e.g., x-rays or ultrasound) and therefore it is not very instructive to see them in operation. The proposed setup consists of a translucent object illuminated by a simple white-light source and imaged with the digital camera at different angles. Collimation is provided by using a readily available telecentric lens to perform the imaging. This eliminates the need for a collimated light source, which can increase the cost of the system, and which usually involves hazardous sources such as lasers or laser diodes. By using visible light, students can observe the whole process directly. The students can control the image acquisition parameters and observe the reconstruction process on a computer. In this paper we focus on providing detailed design information so that the experimental setup can be reproduced by interested educators. A separate paper[3] discusses the educational issues relating to the proposed experiment including assessment results.

Introduction

In computed tomography (CT) the cross sectional distribution of some property of an object is reconstructed from a large number of line integrals of that distribution measured at many different angles and radial positions[4]. For example, x-ray CT provides images of the distribution of x-ray attenuation coefficient. X-rays have a desirable property to travel through tissue with negligible refraction. Therefore, line integrals of x-ray attenuation coefficient distribution can be easily estimated by measuring the intensity of x-rays transmitted thorough the object[1].

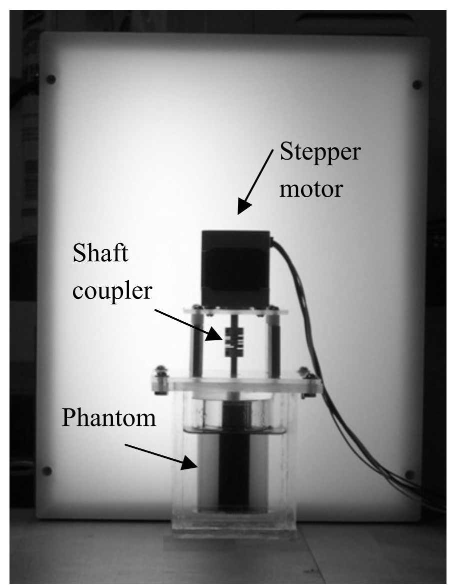

Figure 1. A photograph of the phantom assembly illuminated by the light box. The translucent phantom object is immersed within a square tank with a stepper motor mounted on top. The phantom is coupled to the motor shaft with the shaft coupler.

For a student demonstration x-rays are not convenient because they are invisible and hazardous. To circumvent this problem we have developed an experiment that uses visible light, allowing students to directly observe the process and eliminating any hazards. To eliminate refraction (which is not negligible for visible light) the phantom object is designed from translucent material (acrylic plastic) and immersed within a refractive-index-matching fluid. The phantom is rotated by a stepper motor and imaged by a digital camera from many different angles. An uncollimated light source is used for illumination and the collimation is achieved by using a telecentric lens.

The setup consists of a digital camera equipped with a telecentric lens, a translucent object to image, a stepper motor to rotate the object so it can be imaged from many different angles and a light box to provide illumination. The digital camera and stepper motor are controlled by a PC computer. A photograph of the phantom assembly illuminated by the light box is shown in Figure 1.

Imaging system

In the parallel-beam geometry, which is the basis for the simplest configuration of CT, the imaging system records only the light rays traveling parallel to the object-camera axis. One way to achieve this is to use a collimated light source. This solution can be potentially hazardous because it involves the use of lasers or laser diodes. Instead we decided to use an uncollimated light source and achieve collimation with a telecentric lens[4].

The basic concept of a telecentric lens is illustrated in Figure 3. The main feature of a telecentric lens is an aperture stop which ensures that only the rays entering the lens from directions nearly parallel to the optical axis are used to create an image. Therefore, unlike with a conventional lens, the size of an object in the image is independent of the object's distance from the lens. If we used a conventional lens in our design instead, parallax effects would violate the parallel-beam imaging model and would lead to severe artifacts in the reconstructed images.

The uncollimated light source we used for illumination is a light box sold by art suppliers (Porta Trace 10"x12"). For image acquisition we used a monochromatic CCD camera (DMK 21F04 by TheImagingSource) with a resolution of 640x480 pixels equipped by a telecentric lens (TEC-M55 by Computar). In practice the lens is telecentric only in a certain range of working distances. For the selected camera and lens it was experimentally determined that the range of working distances is from 55" to 57" from the camera base. Therefore the distance between the camera and the phantom center was set to 56", and the entire 2"-diameter phantom fell within this acceptable range of working distances.

Figure 2. A CCD camera (DMK 21F04 by TheImagingSource) and a telecentric lens (TEC-M55 by Computar).

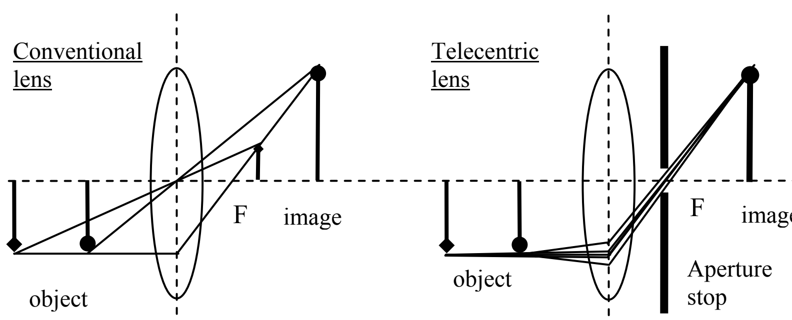

Figure 3. Left: Operation of the conventional lens. Object closer to the lens appears larger in the image. Right: Operation of a telecentric lens. The aperture stop causes the chief ray of the optical system to travel parallel to the optical axis

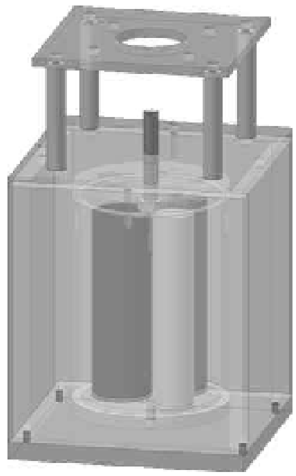

Figure 4. A 3D model of the phantom assembly showing its main components: 1) a 3”x3”x3.5” clear acrylic square tank; 2) phantom body shown in Figure 5; and 3) a motor mount sitting on top of the square tank.

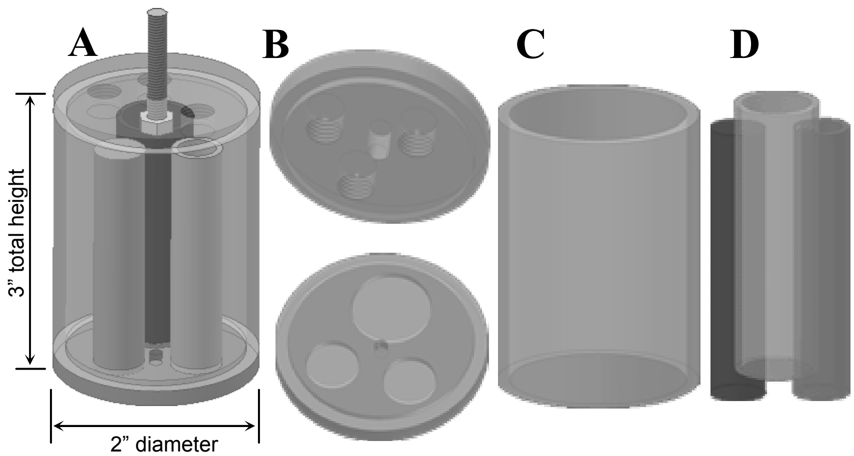

Figure 5. A 3D model of the phantom and its parts. Assembled phantom body (A) consists of a 2”-diameter, 2.5”-high acrylic tube (C) covered on both ends with 2”-diameter, ¼”-thick acrylic circles (B) (available at www.tapplastics.com). Smaller tubes and rods (D) are placed inside the main tube to create several compartments. These compartments are then filled with a liquid of different color to create an absorption coefficient distribution that can be imaged.

Phantom

Whereas refraction is negligible for x-rays, it is very significant for visible light. To maintain the line-integral imaging model, it was necessary for us to eliminate refraction effects in our design. To achieve this we constructed the entire phantom from materials having the same index of refraction, specifically clear acrylic filled with refractive-index-matching fluid.

Figure 4 shows the phantom assembly. It consists of a square acrylic tank, phantom body and motor mount. All parts are made of clear acrylic. The phantom body is suspended within a square tank and a stepper motor mounted on top of the square tank (not shown in Figure 4) is coupled with the screw protruding from the top of the phantom using a shaft coupler (not shown in Figure 4).

The main phantom body shown in Figure 5 consists of a 2”-diameter, 2.5”-high acrylic tube (Figure 5C) covered on both ends with 2”-diameter, ¼”-thick acrylic circles (Figure 5B) (available at www.tapplastics.com). The bottom circle has three machined indentations for smaller tubes and rods shown in Figure 5D. It also has a 0.13” diameter half-through hole in the center drilled on its bottom side. This hole accommodates a 0.13”-diameter metal pin used to center the phantom inside the square container and define the axis of rotation. The axis of rotation is defined by the centering pin on the bottom and the 5mm screw on the top of the phantom body. Smaller tubes and rods (Figure 5D) are placed inside the main tube to create several compartments. These compartments are then filled with a liquid of different color to create an absorption coefficient distribution that can be imaged. The largest inner tube has a diameter of 0.75”. The smaller tube and rod have the same diameter (0.5”). The top circle has a hole in the center to accommodate a 5mm screw. It also has three other holes used to fill the inner compartments with the liquid. All parts are machined at the machine shop at Illinois Institute of Technology and fastened together with acrylic cement.

To eliminate refraction, the square tank and phantom body were filled with a refractive-index-matching fluid produced by Cargille Laboratories, Inc. (catalog number 19507, code 5040, refractive index n=1.492). To obtain an interesting distribution of absorption coefficients for imaging, small amounts of oil-based wood stain (MinWax Wood Finish, Dark Walnut - 2716) were added to the liquid to create two different shades. The darker shade was produced by mixing 17 l of wood stain per 10ml of the immersion liquid and the lighter shade was produced by mixing 8 l of wood stain per 10ml of the immersion liquid. The amount of stain was small enough to avoid significantly perturbing the refractive index of the fluid. The space within the phantom body surrounding the inner tubes and rods was then filled with the lighter shade of the liquid. The inner tubes can be filled with either the clear liquid or the darker shade liquid. Filling an inner tube with the lighter shade liquid would make only the wall of the tube visible in the reconstructed images. The space within the square tank surrounding the phantom body was filled with the clear liquid.

The square tank can be built in many different ways. We show our design in Figure 7. The main features of the tank are the centering pin at the bottom and a hole on the top to fit the phantom screw. These two points define the axis of rotation of the phantom. It is extremely important that the axis of rotation be parallel to the vertical axis of the camera. If it is not, artifacts will appear in the reconstructed images. In our design, the sides and the bottom of the square tank are made of ¼”-thick acrylic sheets. The top of the box is made of 1/8” acrylic sheet. The bottom of a size 3”x3” has a half-through 0.13”-diameter hole in the center for the centering pin used to position

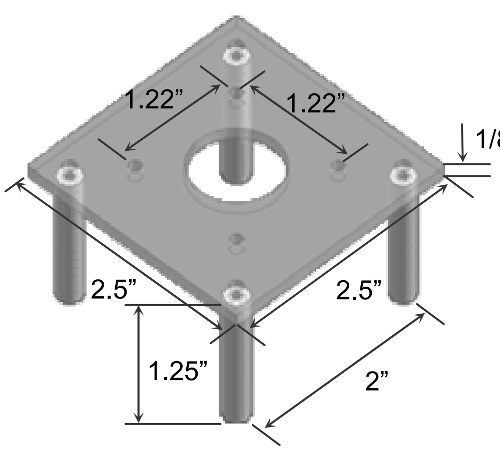

Figure 6. Motor mount consists of a 2.5”x2.5”, 1/8”-thick, acrylic sheet and four 1.25”-high standoffs. It has a large circular opening at the center and four holes at the distance of 1.22” from each other to attach the motor.

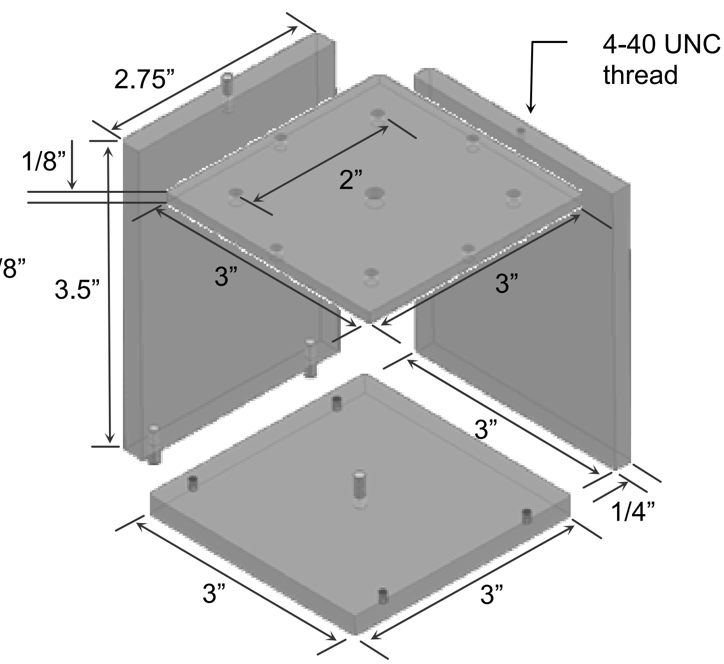

Figure 7. The square tank assembly. The bottom has a placeholder for the centering pin and the top has a hole for the phantom screw. These two points define the axis of rotation of the phantom.

the phantom. It also has four half-through 0.9"-diameter holes close to the two opposite edges. These holes accommodate the metal pins (www.mscdirect.com) used to attach the two tank sides to the bottom. The top has a hole in the center to allow the phantom body screw to be coupled to the motor. The four holes near the corners are used to attach the motor mount (Figure 6) and the four remaining holes are used to attach the tank sides. The sides of the tank are cemented to the bottom of the tank but not to the top. The top is attached to the sides with two pins and two 4-40 thread screws so that it can be removed to provide access to the phantom inside.

The motor mount shown in Figure 6 consists of a 2.5"x2.5", 1/8- thick, acrylic sheet and four 1.25"-high standoffs (www.allelectronics.com, cat# SP-132). It has a large circular opening at the center and four holes at the distance of 1.22" from each other to attach the motor.

Rotation

In an actual CT imaging system the patient being imaged is stationary while the radiation source-detector pair rotates. To simplify the experiment design we instead rotate the phantom while keeping the light source and camera stationary. Rotation is provided by a stepper motor (PK245M-01AA, 0.9° step, from www.orientalmotor.com) mounted on top of the square tank. The motor shaft is coupled with the phantom screw with a shaft coupler (S50MSTMA12P05P05 from www.sdp-si.com). The motor is controlled by a PC computer via motor controller A200SMC from www.steppercontrol.com.

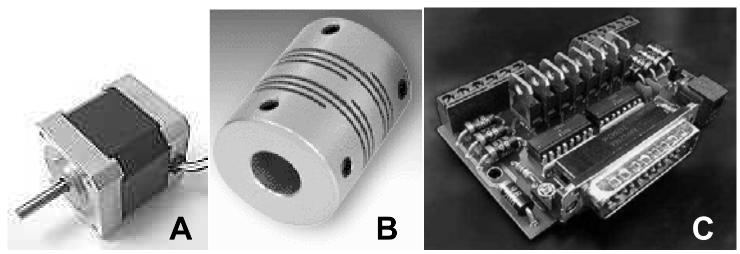

Figure 8. A) stepper motor, B) shaft coupler, C) motor controller

Data Acquisition and Analysis

The data acquisition process is controlled by a PC. We have developed a custom software which provides a graphical user interface for camera and motor control. The software is developed in MS Visual C++ using library functions for the Firewire camera provided by the manufacturer (TheImagingSource) and another library for the motor controller provided by www.steppercontrol.com. We have also developed a set of MATLAB[2] functions for data preprocessing and image reconstruction. All software is available upon request.

Conclusions

In this paper we have presented a detailed design of an experimental setup for demonstration of the basic principles of tomography. The setup utilizes a visible light source and a telecentric lens for collimation. The problem of refraction is resolved by constructing the phantom using the materials of the same refraction index. The phantom consists of a 2"-diameter acrylic tube with smaller tubes and rods inside which create several compartments. The compartments are filled with the refractive-index-matching fluid of different attenuation coefficient to create a distribution of attenuation coefficient to image. Small amounts of wood stain were added to a clear refractive-index-matching fluid to vary the object's attenuation coefficient. The phantom is immersed in an acrylic square tank also filled with the refractive-index-matching fluid and rotated by a stepper motor mounted on the top of the square tank. Images of the phantom at different angles are recorded by a digital camera. A personal computer (PC) is used to control the stepper motor and the camera and to process the acquired images in MATLAB. All custom developed software is available upon request (contact Ana Lukic: lukic@iit.edu).

Bibliography

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