31540 Introduction to Medical imaging

Self-tutorial on pixels, voxels, spatial resolution size and other interesting imaging aspects

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(Ver. 3.2 1/10/10) © 2010 by JW

1 Introduction

The present document is a self-tutorial that you can work with under supervision while your group is waiting for its turn to experience the medical scanners. This tutorial might be used at both hospital visits since you might not be ready to solve all problems during the first visit. Since learning is best achieved by being active and since insight into medical imaging often can be achieved by visualisation, this self-tutorial will lead you through a number of drawing exercises.

Specifically, this guide will try to walk you through the concepts of pixels (picture elements), voxels (volume elements), spatial resolution size as well as some considerations on how X-ray pictures can be interpreted.

2 2D projection

First consider a conventional X-ray system as shown in Figure 1: It works this way:

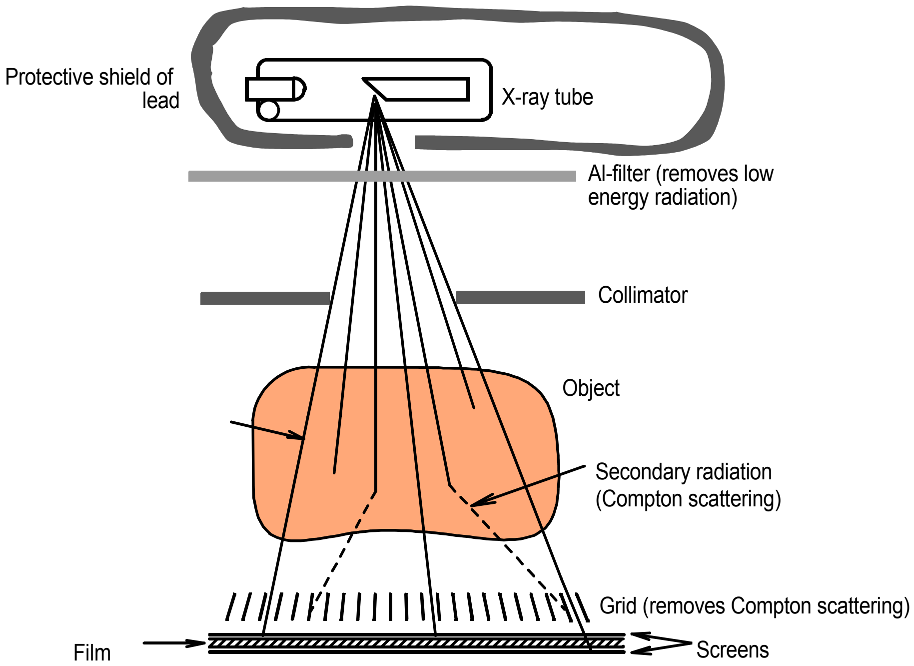

Figure 1 A typical planar X-ray system.

- The X-rays are generated by the X-ray tube (in Danish: *Røntgenrør*). If you do not know much about X-ray at this time, just think of visible light penetrating a partly transparent object under investigation.
- The light first goes through an Al filter (aluminium plate) that removes low energy photons (= elementary particles of light) that are not able to penetrate the object and thus not able to contribute to the information on the film. Therefore, it just constitutes a needless dose of radiation to the object.
- X-ray radiation outside the image region on the film is removed by the collimator (in Danish: *primærblænde*).
- *Attenuation* and *Compton scattering* take place at the object. Compton scattering change the direction of the photons. However, only photons moving directly in a straight line from the source to the film are allowed through the grid at the bottom (in Danish: *sekundærblænde*). Thus, it is only the attenuation that is measured on the film.

All in all, the picture on the film is thus a projection of the 3D attenuation distribution on a 2D film. If you put a semi-transparent object on an overhead projector, you would get a somewhat similar situation.

Now, imaging that the film is digital and discrete. Thus, you should consider the film as an array of - let's say - 10 by 10 equal-sized detectors sitting right next to each other. The surface of each detector is quadratic. They cover an area of 10 cm by 10 cm.

Each square will integrate the energy of all the photons that it receives and produce *one* value, which will be the image value of the pixel it represents.

Problem 1 Draw (sketch) the detector seen from above. Also sketch the pixels of the corresponding image (we do not have an object, so you cannot sketch the image itself). On the physical sketch, indicate the size of a detector. On the image, indicate the size of a pixel.

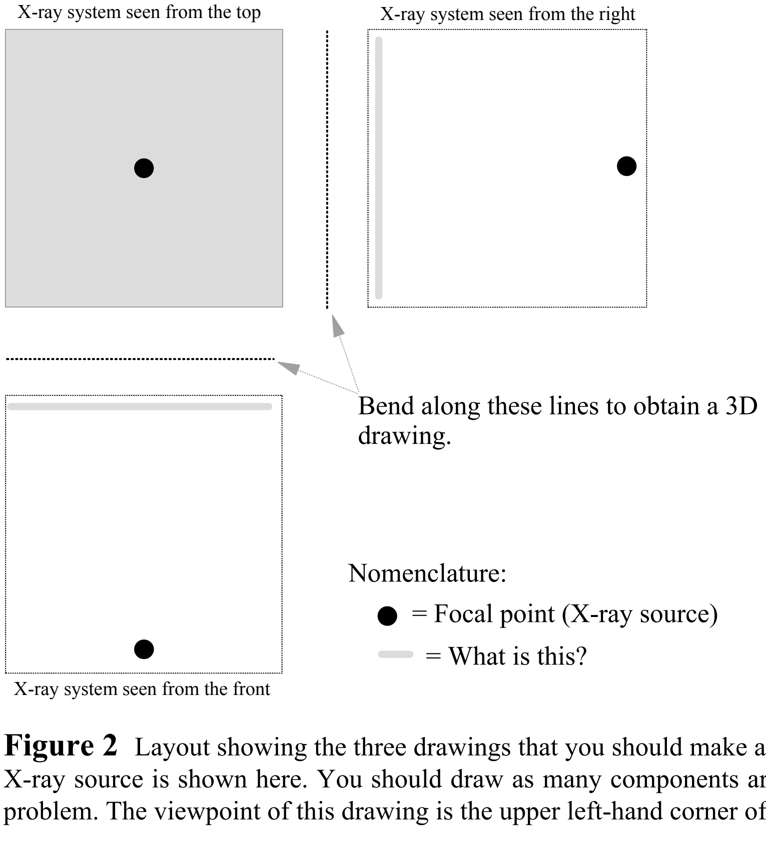

Figure 2 Layout showing the three drawings that you should make after Problem 1. Only the X-ray source is shown here. You should draw as many components are necessary to solve the problem. The viewpoint of this drawing is the upper left-hand corner of the figure.

We will next try to investigate which part of the object that contributes to a given pixel.

As it is difficult to make a 3D drawing, we will now make a copy of the first drawing and then add two frontal drawings where you will - on each - see

- the focal point of the X-ray tube at the top and
- the side of the detector array as a horizontal bar at the bottom of the drawing.

All three drawings are perpendicular to each other. The layout should follow that of Figure 2.

Problem 2 On the first drawing (seen from above), select a given detector (pixel) in the 10 by 10 array of detectors. Then mark the same detector (pixel) on the two other drawings. Finally, sketch the volume that contributes to the detector (pixel) value for this particular pixel (from focal point to pixel). Hint: If a butterfly is flying around, in which volume will it cast a shadow on the detector? What kind of shape does this volume have?

Problem 3 How would you define the spatial resolution size and what will it be in our case? *Hint*: how many dimensions does the spatial resolution size have in this case?

Problem 4 Now imagine that the detectors are made smaller, *e.g.,* the area of a detector is decreased to a quarter of the original one and the number of detectors are increased so as to cover the same physical area. What happens to the spatial resolution size?

Problem 5 What gives the most detailed image, a high spatial resolution size or a low spatial resolution size? Are there any disadvantages by changing the size of the detectors?

Problem 6 The final image, does it consist of pixels or voxels?

3 Tomographic imaging

If you do not have knowledge of computed tomography yet, please jump to Chapter 4.

We will now turn to tomographic imaging, specifically what is done in CT (Computed Tomography). However, in this situation we will consider a simplified system as shown in Figure 3 which is using a simple narrow beam, *not* a fan beam as used by the scanner at the hospital.

Let's first consider the physics of the beam itself.

We will start by assuming that we have one X-ray tube that sends out a narrow beam.

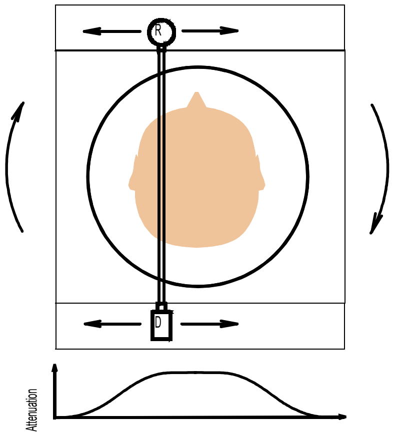

Figure 3 Geometry of simple CT scanner. The x-ray tube emits a thin beam.

Problem 7 Draw the beam as if you look at it directly from below in Figure 3 (*i.e.,* just draw a circle. Why?). Then draw an axis through a diameter of this circle. Let the axis be longer than the diameter. Give the axis a name (e.g. x-axis). Now make a sketch of the intensity of this beam as a function of distance along the axis you have defined. Remember to name both axis properly (also units); however, you do not need numbers on the axis. What shape will this function have? And why? Discuss different choices of shapes with your fellow students.

Problem 8 Now if this is the beam that is used to create a CT image, what is the shape of a volume inside a body that contributes with information to the image? Try to sketch this, maybe with several 2D drawings.

Next, we shall consider the image that comes out of the reconstruction. Remember that if we desire an image with four pixels (2 by 2), then we need four projection values in order to solve four equations with four unknowns. When we require more pixels than this, we will need more projection values.

The 2D image from a CT scan consists of a number of pixels, say N x N pixels. The image is generated from a number of projections. The more pixels that are desired in the image, the larger are the number of projection values needed (which can be increased by increasing the number of projections and/or the number of detectors within the same over-all size of the detector).

Now let’s define the spatial resolution size: Imagine a point target (*e.g.* a lead sphere in air) that is imaged. The diameter is d. The diameter of the sphere on the image, $\Delta d + d$, will always be larger than d. However, Δd might not be a constant, but will depend somewhat on d. The extra “size”, Δd, is a result of the fact that on any imaging system, an object will appear larger than it is. This “spreading” is described by the so-called *point spread function*, which is the “dot” you will see on an image, in case a very small object is imaged. We will set the width of this point spread function equal to the spatial resolution size.

Problem 9 Now, if we increase the number of pixels in the image, will the spatial resolution size decrease? Will the diameter of the X-ray have any importance?

Problem 10 Does the image consist of pixels or voxels?

Problem 11 What is the third dimension of the spatial resolution size and what defines it?

Problem 12 Could we measure Δd by just using a infinitely small sphere?

Problem 13 When dealing with 3D images, often the term *interslice distance* is used. What is this with respect to voxel size.

4 Appearance on planar X-ray

Consider the X-ray picture of Figure 4. The picture is taken in 2007 and represents one of the phantoms (it is not known which). It only shows the phantom itself including the acrylic box. One the right, there is a colour bar, but the unit that is supposed to be stated below the bar is marked with a “?”.

Problem 14 What is the unit? Are the values relative or absolute? And now that we are at it: what are the units used in a CT image?

The next question concerns the appearance of the tube. Assumed that it is filled with air. A cross-sectional view is shown in Figure 5. The physical density of the agar is assumed to be that of water, while the physical density of the silicone rubber tube is assumed to be lower.

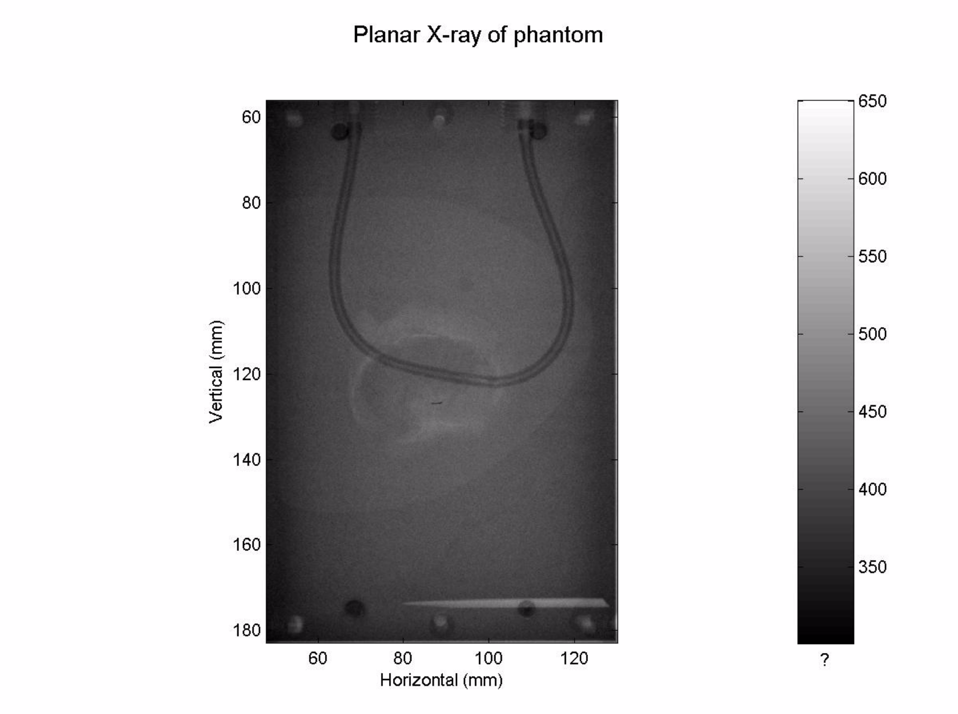

Figure 4 Planar X-ray image of one of the phantoms used in the course.

Problem 15 In this situation, draw the intensity profile as seen by the film. Also draw the same profile in the case where the density of the silicone rubber is assumed to be higher than that of water. In both cases, we assume that attenuation of X-rays varies directly with physical density.

Notice that you cannot be sure that the analysis you will do here will be identical for your phantom. One of the aspects that could change is the content of the tube which might not always be air.

5 Acknowledgements

Sara K. Møllenbach og Dorthe Bodholt Nielsen are gratefully acknowledged for their help in commenting and proofreading this document

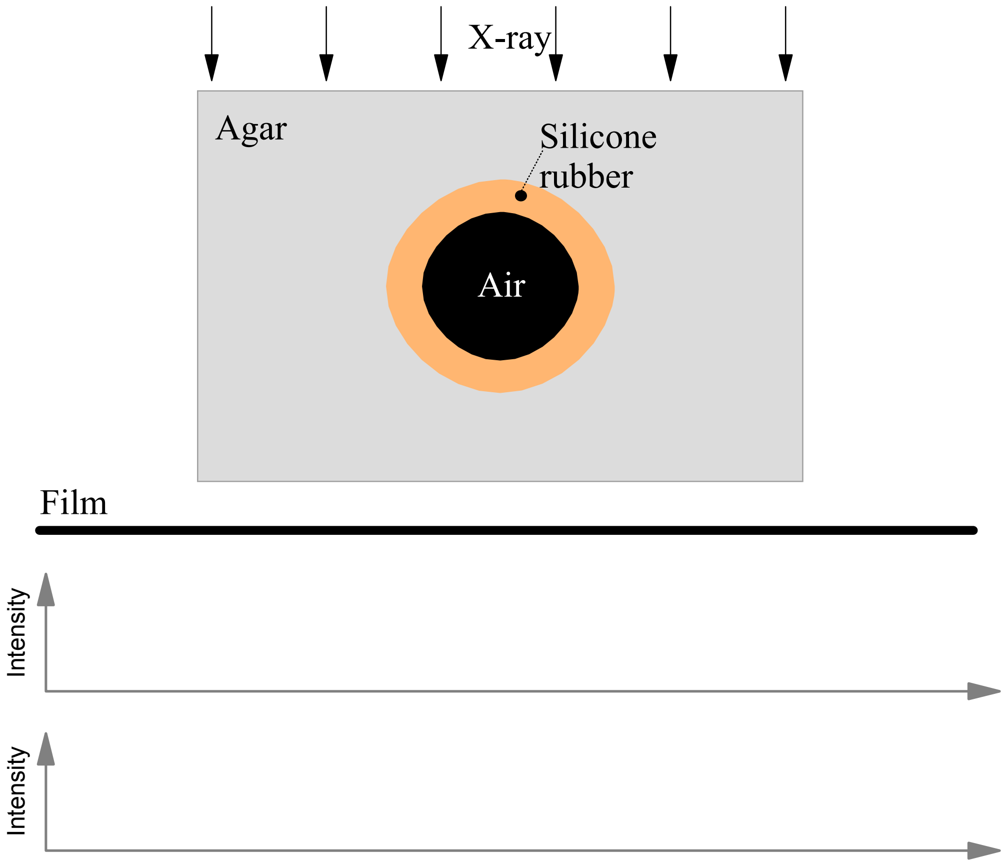

Figure 5 Illustration of the measurement situation. Under the film, you should draw the profile of the intensity of the X-ray hitting the film.

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