Theoretical method for detecting a 3D point in space with one X-ray exposure

R Nell Nat Dip Rad (D), B Tech (Elec. Eng) (CPUT)

Abstract

Two x-ray exposures are normally done to detect the position of an artifact in space. This is achieved by either moving the X-ray tube or the patient to obtain a 90-degree view from the previous one. In the movement of the patient, the position of the artifact is moved from the anterior posterior (AP) to the lateral (Lat) position [1]. This technique results in dose to the patient. A method to detect the position in space with only one X-ray exposure was developed to limit the amount of radiation for detection of an artifact. This article discusses this technique as well as methods to improve image quality in terms of position detection is space [2-7].

Keywords: Stereoscope, horopter, pseudoscopic, point focus, finite focus, penumbra

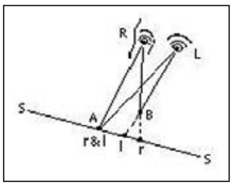

Figure 1: Depth perception (7)

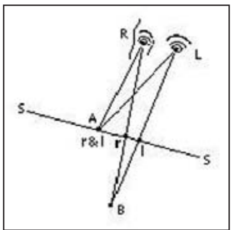

Figure 2: Depth perception

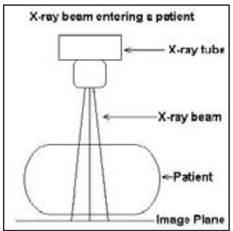

Figure 3: X-ray set-up for patient examination (1)

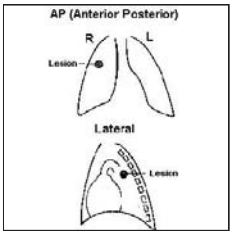

Figure 4: Example of localising a lesion in an X-ray examination of the chest

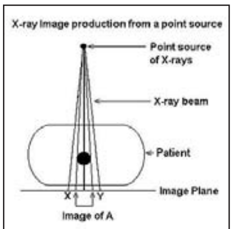

Figure 5: X-ray source from a point focus (1)

Introduction

An article covering X-Ray holograms states if such holograms become possible, one exposure could provide a radiographic image which the radiologist or clinician could examine from different angles presenting a different radiographic presentation to the observer [1]. Although this is one aspect, the techniques developed can be used for position detection of artifacts

Stereoscopic vision

Humans are capable of stereoscopic vision which is fundamental to depth perception as they are able to focus both eyes on a single object (see Figures 1 and 2). Stereoscopic vision can be described in terms of the vision process involved in the use of a stereoscope, which presents an image from two slightly different angles so that the eyes can merge them into a single image in three dimensions. A horopter is the projection of the points in the visual field corresponding to the aggregate of points registering on the two retinas as depicted by line SS on Figure 1. Figures 1 and 2 show L and R as representing the two eyes and line SS the horopter [5] drawn through the point A where the optic axes LA and RA intersect, and parallel to a line joining the two eyes L and R. Point A is seen in corresponding points of the two eyes, axially situated. Two points r and l, however, may be so placed, either in the plane of the horopter or outside it so that the two eyes together perceive the points r and l as one point, namely B. In Figure 1 point B is nearer to the eye, and in Figure 2 point B is further from the eye than the horopter SS itself. In Figure 1, a diagram is made, representing l and A, and another representing r and A. Let us suppose the former is laid in front of the left eye and the latter in front of the right eye then the two optic axes are made to converge; the image of A is formed in corresponding points in the two eyes. As a result the points l and r will appear to blend into one, situated either nearer the eye than A or further from it. This explains the action of the stereoscope and also the pseudoscopic effect produced when the pictures are reversed.

Anterior Posterior (AP) and Lateral (Lat) positions using two exposures

To detect the position in space we normally do two exposures [4]. Figure 4 is an example of a lesion seen on AP and lateral projections [1].

Method to detect the position in space with only one exposure

Two techniques, namely (i) a graphical method using the enlargement technique and the penumbra of the image, and (ii) a theoretical method using the characteristics of the X-ray image system, have been developed to detect the position of an artifact in 3D space.

Definitions

i) Point focus
This is the ideal situation in which the source of the X-rays is a point focus (see Figure 5).

ii) Finite focus
The X-ray source has a finite area (see Figure 6).

iii) Image from finite area
In Figure 6 consider the image production from a source of finite area. Rays traced from the edges of the source divide the image plane into regions L, M and N where M is the penumbra.

iv) Penumbra
This is a partial shadow when the image is created and is called the penumbra (see Figure 7).

Technique 1: Graphical method using the enlargement technique.

In this case two X-ray image planes are used as positioned in Figure 8. As can be see only one exposure will produce two different images in size hence by using this enlargement technique the position of the artifact can be determined. The image on image plane 1 can be projected at another position as from image two with a different setup.

If viewed from the sides, two different images are obtained with slightly different co-ordinates. The image as projected from the side can be viewed in two directions, namely

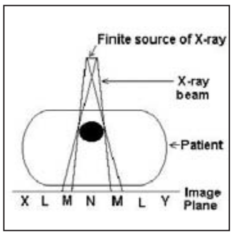

Figure 6: X-ray source from a finite area (1)

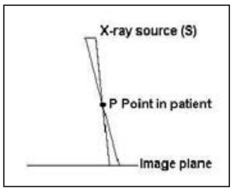

Figure 7: Penumbra produced from point

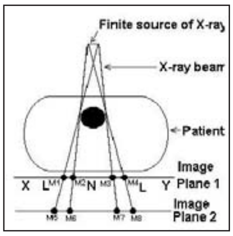

Figure 8: Detecting the penumbra of an artefact

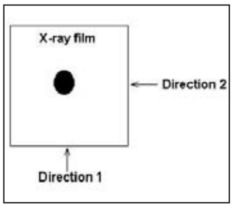

Figure 9: X-ray image view from above

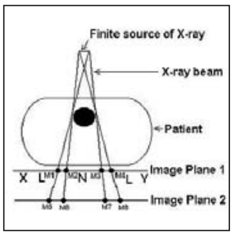

Figure 10: Using the penumbra to detect the position

direction 1 and direction 2 (see Figure 9). The penumbra on image plane 1 and image plane 2 are projected with different co-ordinates.

Examination of the images as viewed from direction 1

As depicted in Figure 10 the distance between image plane 1 and image plane 2 is a set value. With this known distance and the points M1, M2, M3, M4, M5, M6, M7, M8 marked and determined, there are eight co-ordinates (four per image plane) and this information is used to determine the position.

If line M5 is extended through M1 and line M6 through M2 then the position of the right point of the artifact is given by the intersection of line M5, M1 and line M6, M2 on Figure 10. By doing the same with M7, M3 and M8 and M4 the left point is determined. The same process can be followed when viewing the image from direction 2 as viewed on Figure 9.

Certainly a practical consideration must be considered and this aspect gives an explanation for 3D position detection with one exposure.

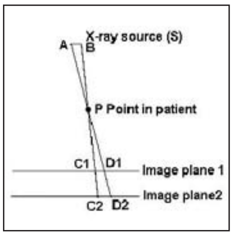

Figure 11: Detecting a point in space

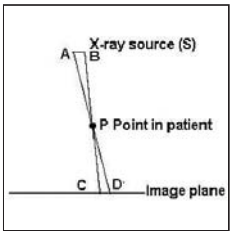

Figure 12: Theoretical method

Detecting a single point in space

Figure 11 shows a finite source of X-ray (S), a point (P) in an object, and the two image planes 1 and 2.

At the image planes the images of P are represented by C1, D1 and C2, D2. The image P should be a point but because of the finite size of the X-ray source it is imaged as a disk with diameters C1, D1 and C2, D2.

Since the distance between image plane 1 and image plane 2 is a set distance, the co-ordinates of C1, D1, C2, D2 can be determined from a reference point. Using the graphical method lines C2 and C1 can be extended and also lines D2 and D1. This will provide two lines that will cross at point P.

For the above methods two image planes are required; with the next method only one-image plane is needed.

Technique 2: Theoretical method using the characteristics of the X-ray system

Consider the image in Figure 12 which shows only one image plane. Here certain characteristics of the system must be known, namely the focus size as well position of the focus in the system. The penumbra is also used, but the position in space is calculated using the characteristics of the image system. The formation of the penumbra is a consequence of the finite size of the X-ray source. Figure 12 shows a finite source of X-ray (S), a point P in an object and the image plane which would normally be accompanied by a film, screen cassette or image intensifier input phosphor. At the image plane, CD represents the image of P. The image P should be a point but, because of the finite size of the X-ray source, it is imaged as a disk with a diameter CD. Triangles ABP and CDP are geometrically similar therefore AB/CD=BP/CP. Re-arranging this gives CD=(AB X CP)/BP.

Let us now determine the co-ordinates of the positions of A, B, C and D from a reference point. Since the position of C and D is projected on the image plane, their co-ordinates can be determined. If the size and position of focus (S) is known, the co-ordinates of A and B must be determined. Now we have the co-ordinates of A, B, C and D and we then draw a line from A to D and from B to C. By getting the mathematical formula of these lines and at their crossing point, the position of point P can be determined.

By using the same method as previously explained the position of point P can be calculated with only one image plane and only one X-ray exposure by using the characteristics of the system and references.

Point spread function

The tissues displayed by X-ray imaging consist of a number of minute points of anatomical detail. A point structure in an object should produce a point image. In practice the image of a point will be unsharp and will appear as a small blurred disk. This will make recognizing of the penumbra very difficult.

Limitations to consider

One of the major limitations is the measurement of the penumbra. In many cases the penumbra will be very small due to the long source to object distance and small size of the focal spot [1]. The size of the penumbra is dependent on the position of the object from the X-ray source. Another limitation is the fact than most of the objects block X-rays partially (radiolucent material). The point-spread function will also contribute to the unsharp point in space.

Concluding remarks

This discussion covers a theoretical method of determining the height of a point in space and two methods to determine the Z co-ordinate by using only one X-ray exposure. Certainly the technique and methods can be refined to obtain better results. The two methods can be used as a checking method for each other.

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