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Superman's not dead

Exploring X-ray vision

If you have gone through airport security you may have taken a peek at the screen next to the baggage scanner. It's interesting to see your bag, with the shapes of your phone and earphones, your wallet, pencil case, and book – perhaps even some lost coins at the bottom. As Silvia Pani explains, this is only one of many things you can do with X-rays.

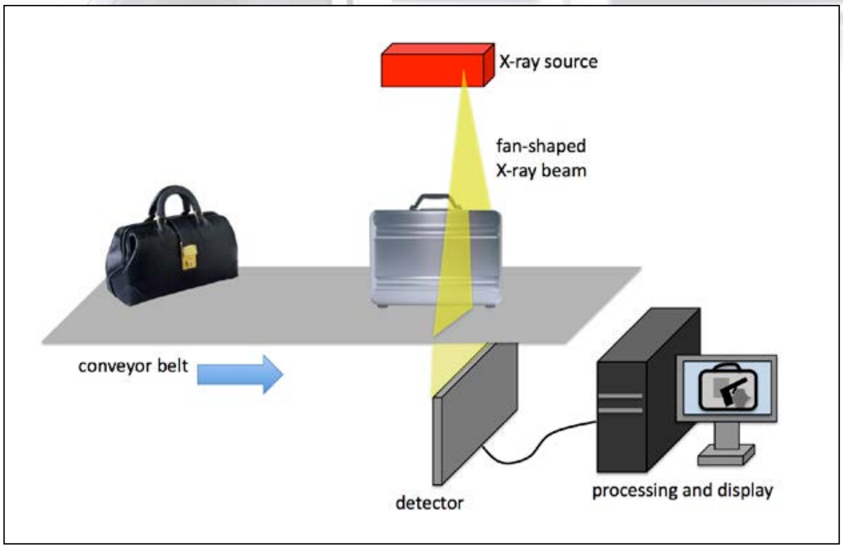

Figure 1 *An airport X-ray scanner*

Key words

X-rays

absorption

CT scanning

radiation dose

Baggage scanner

Airport baggage scanners have two aims: finding weapons and finding illegal substances such as drugs or explosives. **Figure 1** shows how a scanner works.X-rays are emitted in a fan-shaped beam by an X-ray source above the luggage conveyor belt; an image is acquired by a detector placed underneath the conveyor belt while the object moves.

The detector works by collecting the X-rays that have not been stopped by the object and converting their intensity into a grey scale: high intensity (no X-rays stopped by the object) appears white, and low intensity (X-rays almost completely blocked) is black. So X-ray imaging is imaging of shadows: the thicker the shadow an object casts for X-rays, the darker it will look.

A gun hidden in a suitcase would look something like **Figure 2**, very dark amidst the grey shapes of other objects.

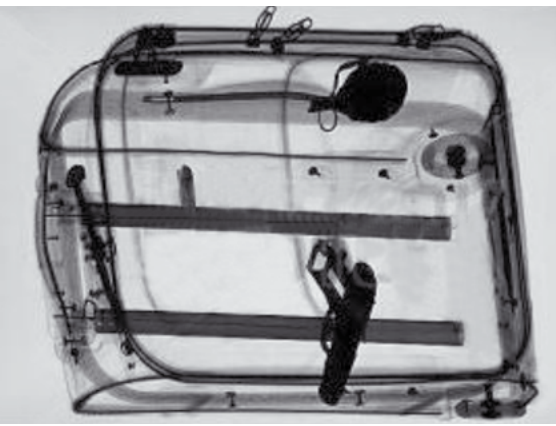

Figure 2 *An X-ray image of a bag with a gun inside it*

Why does a gun appear black whilst a book appears grey? The answer lies in the way X-rays interact with different materials. When an X-ray beam traverses an object, it is partially absorbed; a higher fraction of X-rays is absorbed by a thicker object. At the same time, a material made of atoms of high atomic number also absorbs more X-rays. A gun is made out of metals, such as iron, with high atomic numbers while paper is a compound of low atomic number elements such as carbon, hydrogen and oxygen. Therefore a greater fraction of X-rays pass through a book than through a gun and the paper appears grey while the gun appears black.

What are X-rays?

X-rays are electromagnetic waves just like visible light, infrared or radio waves; the difference is their wavelength which, for X-rays, is one of the shortest ones in the electromagnetic spectrum.

X-rays get stopped in materials by various processes, most importantly the photoelectric effect. An X-ray knocks an electron from the inner shells of an atom – the orbits closest to the nucleus – and is removed from the beam. The denser the material and the higher its atomic number, the more the X-rays are absorbed. An atom which loses an electron in this way becomes an ion, and so X-rays are classed as **ionising radiation**.

Seeing things in depth

The image in **Figure 2** is called a projection image; all structures are projected onto a plane, and there is no way of telling the arrangement of two objects that overlap. We would have the same image whether the gun was sitting on top of the suitcase or inside it. To understand how this may prevent the detection of objects, have a look at **Figure 3a**. It's an X-ray image of a plastic pot containing some objects. Can you tell what they are?

Looking at one view only can prove tricky; what if we look at the same object from different angles? The following images show the same object rotated: is it clearer now? (The solution is at the end of this article.)

Figure 3 *X-ray images of an object made at different angles*

So looking at an object from different angles helps identifying the structures inside it. This is the principle of Computed Tomography (CT). CT goes further, and uses computer algorithms to combine many views from different angles into a single image, showing a cross-sectional slice of the patient.

Look for instance at **Figure 4**, which shows a plastic spider. **Figure 4a** shows a projection image, and **Figure 4b** shows a cross-section of the spider obtained by combining many single views at different angles (imagine cutting the spider along a horizontal plane, shown by the red line in **Figure 4a**, the way you would cut an orange).

From the CT image you can see that the body of the toy is hollow, which you would hardly have guessed from a single image. Also, it is made of different materials; the feet appear brighter, so must be made of a denser material than the body. By stacking up many slices, a three-dimensional image can be obtained, as shown in **Figure 4c**.

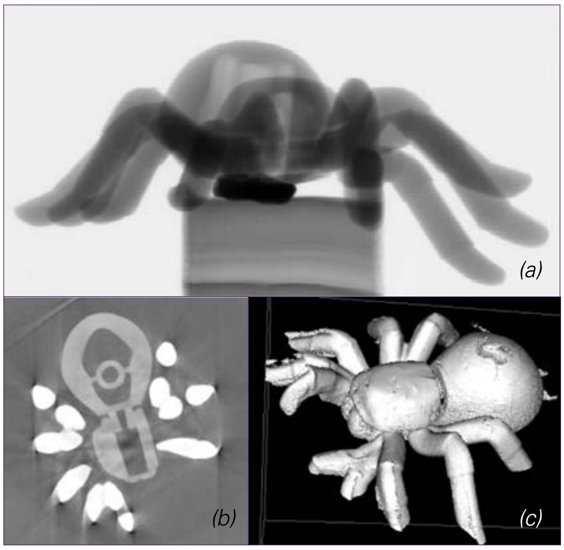

Figure 4 ***(a)*** *Single-view image,* ***(b)*** *CT reconstruction and* ***(c)*** *three-dimensional reconstruction of a plastic toy spider; note that, in CT, the greyscale is inverted: non-absorbing regions such as the air surrounding the object are black, and strongly absorbing regions are white (images by R. Ealden).*

Medical applications

Staff examining baggage scans must assess whether a bag contains a threat or not. They have to make a decision based on their experience so that no weapons or illegal substances get missed, but also to ensure that no false alarms are raised for harmless objects.

This is not too dissimilar from the task faced by doctors examining X-ray images of a patient. They won't know if the patient has a disease, but they aim at getting as many 'true positives' as possible (i.e. identifying a disease that is present) and as few 'false positives' as possible (i.e. thinking that a disease is there when it isn't). If a disease is missed, the patient may not get treatment and their condition may get worse; if a disease is believed to be there when the patient is healthy, the patient will have to undergo costly and stressful extra examinations for no reason.

However, there is a big difference: if your object is a human, one extra factor to take into account is that X-rays are ionising radiation. They knock electrons from atoms and such electrons will ionise other atoms. Removing electrons from the DNA of cells may cause damage to the cell and therefore poses a risk for the patient. Medical X-rays must therefore limit as much as possible the amount of radiation stopped within the patient, or *patient dose*.

Nowadays images with amazing quality can be obtained at low dose. **Figure 5** compares the first image of a human, obtained by Dr Roentgen in 1895, and a modern image of a hand. You can see how much more defined the structures are in the modern image, with subtle variations in density (different grey levels) in different regions of the hand.

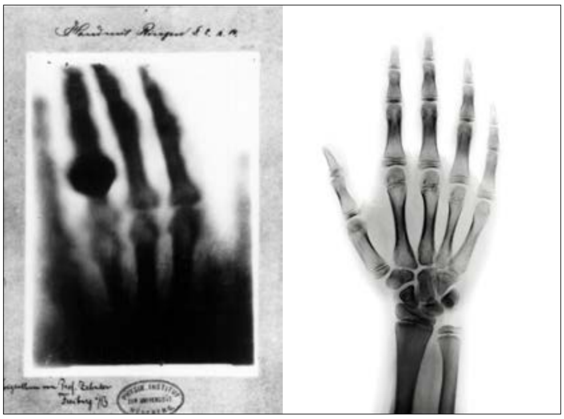

Figure 5 ***(a)*** *The first X-ray image of a human (Mrs Roentgen's hand), and* ***(b)*** *a modern radiograph of a hand*

CT is particularly useful for thicker regions of the body such as the abdomen (**Figure 6**), where the overlap of many structures may prevent detection of illnesses.

Figure 6 ***(a)*** *In this projection image of the abdominal region you can hardly make out any structures other than the bones;* ***(b)*** *These CT slices show the positions of the organs in different planes without overlap, making diagnosis a lot easier.*

Looking ahead – synchrotron radiation

For very specific applications, a standard X-ray generator is not sufficient, and X-rays from a synchrotron source may be used. In a synchrotron, electrons are accelerated in a circular trajectory; when their trajectory bends, they emit X-rays described as synchrotron radiation.

Synchrotron radiation has many properties that make it the ideal tool for imaging, but one of the most appealing ones is that it can be exploited for *phase contrast imaging* – see **Figure 7**. In phase contrast you exploit the wave nature of X-rays, and you indirectly see details that are too small to be detected with conventional imaging by seeing the distortion they cause to the wave. It's like looking at a pole in the sea; from a distance, you can't see the pole, but you can see that a wave incident upon it gets distorted.

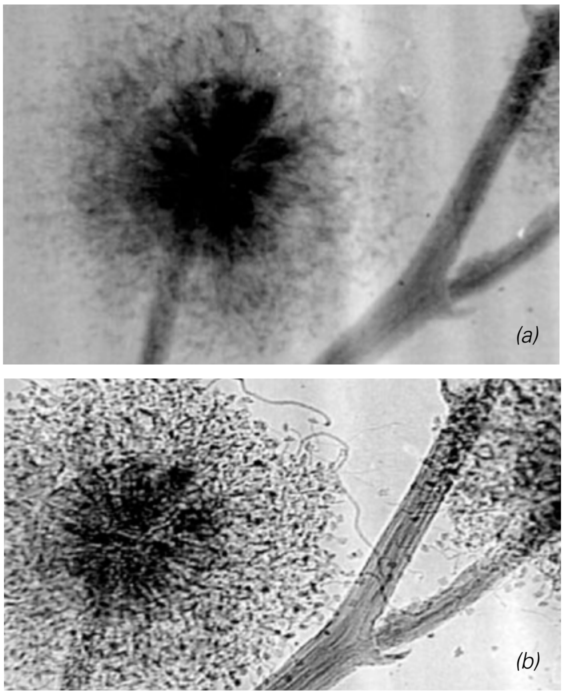

Figure 7 *X-ray images of a mimosa flower obtained* ***(a)*** *with conventional methods, and* ***(b)*** *with phase contrast imaging to show all the fine structures of the flower (courtesy The SYRMEP Collaboration)*

Phase contrast would be ideal for diagnosing illnesses in their early stages as it allows detection of very fine structures. However, a synchrotron cannot be available in every hospital, and research is going on to develop X-ray sources that reproduce the characteristics of synchrotron radiation.

The main streams of research in X-ray imaging are the development of new X-ray sources and new X-ray detectors, so that the maximum information is obtained at the minimum dose cost for the patients.

X-ray imaging is a truly interdisciplinary field, bringing together the expertise of physicists, engineers and computer scientists for the development of the technology and of the data processing algorithms, and doctors to identify the areas for improvement of the current technologies and provide advice and support for the new developments.

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The objects in Figure 3 are a plastic fork, a pencil, a cherry, a thimble and a coin.