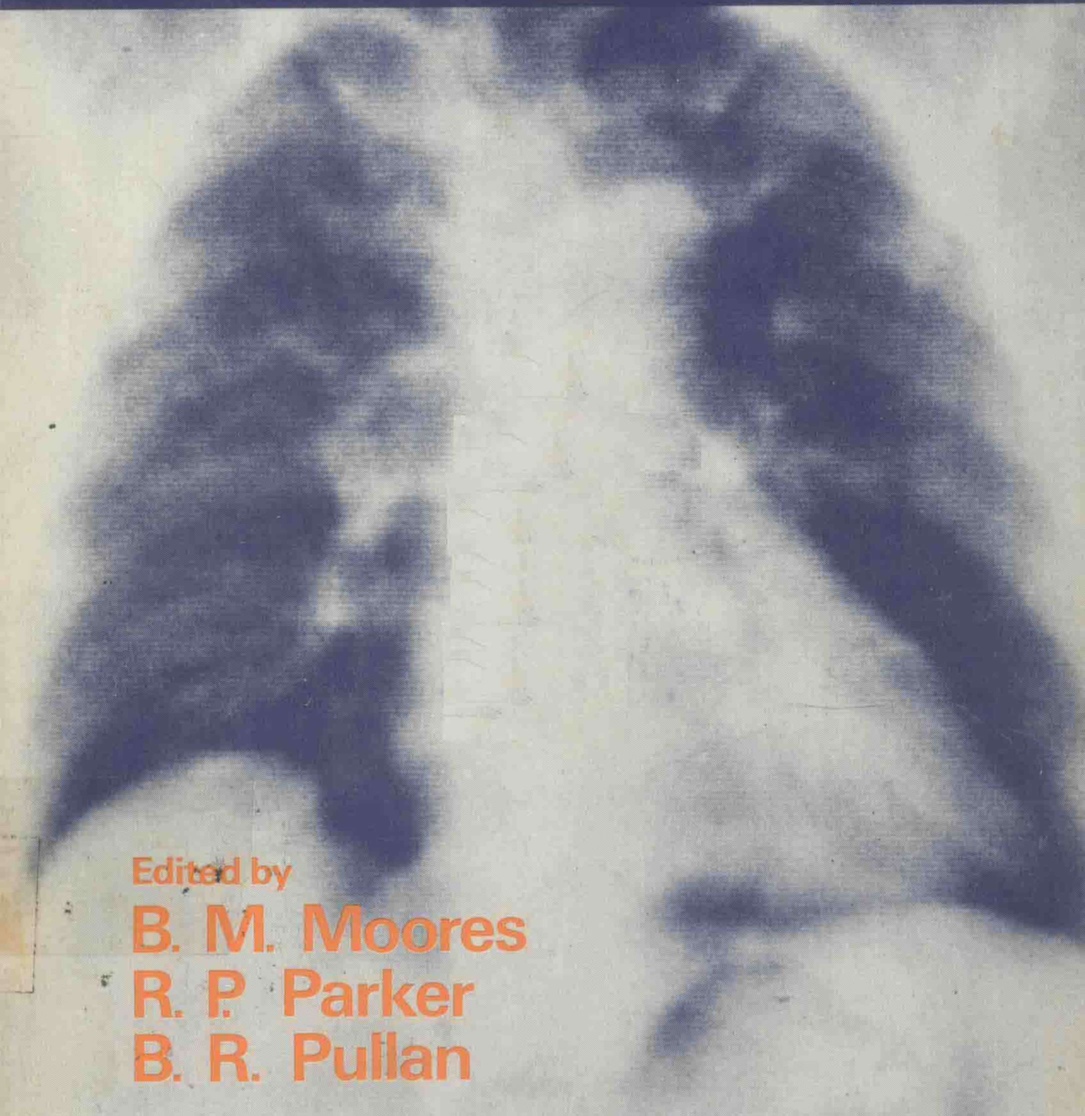
PHYSICAL ASPECTS OF Medical Imaging



Edited by

B. M. Moores
R. P. Parker
B. R. Pullan

PHYSICAL ASPECTS OF

Medical Imaging

PROCEEDINGS OF A MEETING HELD AT THE UNIVERSITY OF MANCHESTER, 25th–27th JUNE, 1980

Edited by:

B. M. Moores,
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FOREWORD

Diagnostic imaging techniques are amonst the most widely used and useful investigative procedures employed in health care. The variety of techniques and also the technology incorporated within them has undergone tremendous development over the past two decades and there are signs that this will continue for the foreseeable future. There is, therefore, a need within the health care industry to develop the basic scientific principles underlying diagnostic imaging techniques and to investigate the way in which these have been applied in order to produce practical systems. Based upon a greater understanding of these physical principles together with a more comprehensive understanding of the relative performance of difference systems, it should be possible to highlight the most likely clinical areas where new techniques or equipment could be most useful. Correspondingly, it should be possible to specify more clearly the desirable features of prospective systems.

The purpose of this meeting was, therefore, to explore the basic scientific principles underlying imaging techniques. The aims of both the meeting and subsequent proceedings are:-

- (i) to review the scientific basis of medical imaging;
- (ii) to highlight those areas which do not fall within a common framework;
- (iii) to stimulate further work in these and any other areas;
- (iv) to encourage development of those areas of medical imaging which will provide the links between its physical and clinical aspects and help to produce a coherent framework upon which to develop cost-risk-benefit analysis within the specialty.

An understanding of the physical aspects of any imaging modality should itself have three components:-

- (a) the fundamental physical principles involved;
- (b) the range of meaningful physical measurements which can be used to assess performance;
- (c) an understanding of how these measurements should be applied and the results interpreted for individual modalities and/or techniques.

The overall structure of the proceedings attempts to incorporate these three components.

Section 1 covers the theory of the imaging process and attempts to outline those parameters and their interplay, which can be used to describe the objective performance of an imaging system. Because much of the theoretical work in medical imaging has been applied to radiological systems, this provides the underlying modality in this session. Furthermore, an industrial radiological framework has been used to provide practical examples since the structures involved are relatively simple and readily amenable to theoretical description. This somewhat simplistic approach does highlight the need to develop a firmer theoretical understanding of clinical imaging systems where psycho-physical considerations are extremely important.

Section 2 deals with the physical measurements which can be undertaken on imaging systems in order to describe their performance and also gain some insight into their design characteristics. Consideration is first of all given to objective physical measurements on those parameters which arise from imaging theory and are mainly concerned with the transfer of high contrast signals. Because clinical performance is often concerned with small or threshold signals this session then considers subjective visual measurements which attempt to quantify system performance in terms which are more closely related to the clinical situation. Since the eye is an important component in this form of assessment, some of the basic aspects of its performance have been considered separately, thus enabling a less ambiguous interpretation of this form of measurement. Measurement of threshold signals will involve statistical variability in the results in that incorrect decisions will be made. Statistical techniques which are applicable to threshold visual detection tasks are included, in particular receiver operating characteristic analysis. This analysis can also be used to provide a link between physical assessment and cost-benefit analysis since image quality will affect true positive/false positive detection rates which must relate to clinical performance hence clinical benefit. If we can begin to understand how objective physical performance relates to subjective visual performance we will then have established a strong link between physical and clinical assessment of diagnostic imaging systems.

The remaining four sections deal with the way in which physical principles affect the overall design of realistic imaging systems with individual sections covering ultrasound, radioisotopes, radiology and CAT. A common structure has been employed in each of these sections which it is hoped will help in comparing and contrasting the underlying principles of each modality. Each section deals with the source of radiation or clinical probe, its interaction with the patient, its detection and then display and/or storage. Finally, each of these sections concludes with an appraisal of one of the most recent developments within each modality.

This book contains a printed version of the conference papers and thanks are due to the speakers for all their effort in the preparation and production of the manuscripts.

The conference was attended by approximately 150 participants from a number of different countries. It was held in the University of Manchester Medical School and our grateful thanks are due to the

University for the use of its facilities. Our thanks are also due to the Hospital Physicists' Association, in particular the assistance of Mr. Derek Field. During the conference an exhibition of manufacturers' equipment was held; we thank Dr. Alan Hufton and Dr. Harbans Sharma who organised it and the various manufacturers who supported it. We are also indebted to Irene Hartley and Anne Marie McNeilly for their help in the preparation of the final manuscripts.

It is hoped that this book will provide a useful overview of the physical aspects of medical imaging techniques for all those who are working in or are interested in the field.

B.M. Moores
R.P. Parker
B.R. Pullan

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1. Basic Theory of the Imaging Process in the Context of Industrial Radiology

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BASIC THEORY OF THE IMAGING PROCESS IN THE CONTEXT OF INDUSTRIAL RADIOLOGY PART 1. FORMATION OF IMAGES

R. Halmshaw

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INTRODUCTION

In industrial radiology the physics of the imaging process is the same as in the medical field. The approach to radiological imaging has however been different and parts of this treatment may appear rather strange. The reasons for differences are that a much wider range of radiation energies is used compared with diagnostic medical radiography. The range is from 8 kV up to 10 MV with the bulk of industrial radiography being done in the range 150-300 kV. The use of very high energies is for the penetration of thick steel - up to 300 mm. The second major point of difference is that with film recording polycrystalline intensifying screens are very rarely used. Because radiation dose to our "patient" is not important, we use metal intensifying screens; these have an intensification factor of only 3 to 5, but they are grainless and cause only a marginal deterioration to the image; in some cases, because of radiation scatter, they actually improve the image compared with bare film. Exposure times are generally measured in minutes, as our specimens are static and we have no object movement problem.

The third point of difference is that gamma-rays are used extensively and the most widely used sources are Iridium-192 and Cobalt-60, both of which are high energy sources, very roughly equivalent to 900 kV and 3 MV X-rays respectively.

In spite of these differences the basic theory of the imaging process is the same in industrial radiology as in medical radiology.

GENERAL CONCEPTS

Interest in the theory of image formation arises from a desire to understand the processes involved and consequently to obtain the best possible image in the sense of more detail, sharpness and contrast. This is not necessarily the practical radiographer's criterion of satisfactory radiography; they are also interested in latitude, convenience of film viewing, processing, cost, and a host of other factors which may also have some relation to the factors controlling image formation.

Radiographic imaging is a shadowing, silhouette process; an image is formed because at the edge of detail in the object there is a change in X-ray absorption. It is in no way imaging in the optical sense - there is no diffraction or scattering of radiation to form the image. There is, of course, X-ray scattering, which will be discussed later, but this has nothing to do with the actual formation of an image as in an optical system.

The radiographic image - spatial X-ray intensity variation - is converted to light by a fluorescent screen, or recorded on a film, and the human eye sees the image, whether it is on a film laid on an illuminated screen or an X-ray fluorescent screen, or a television monitor.

The eye is remarkably good at adapting itself to different light intensities in the image - luminances - but is not a perfect instrument, and its ability to detect small changes in luminance decreases if the average luminance is above or below the optimum value (Fig. 1). Radiologists are rarely interested in luminances above the optimum, but are sometimes interested in low values, both in the case of a high density radiograph on a not-so-good viewing screen and in fluoroscopy.

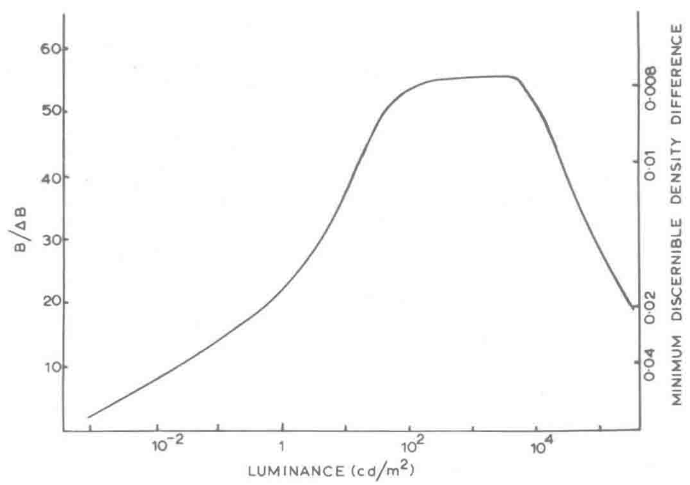

Fig. 1. The change in discernible contrast of the image of an edge, or the minimum discernible density difference, with luminance.

This then is "image contrast". If the luminance is low, we simply cannot discern very small changes in luminance which we would see on a higher luminance image.

On a film image the density difference between the detail and the background ΔD is usually taken as a measure of image contrast.

Secondly, to be a representation of something, the image must have edges - contours, and intuitively we know that an image is better - in scientific terms it contains more information, if these edges are sharp rather than blurred. The effect of unsharpness of an image is quite complicated, and will be discussed later.

If a broad image is considered - a patch on a uniform background - the contrast sensitivity does not change until the unsharpness of the edge is increased beyond about 0.7 mm (Kruitoff, 1950) but if fine detail in an image is considered any unsharpness greater than the width of the image detail can cause a reduction in image discernibility. As in industrial film radiography fine cracks of width 0.02 mm are required to be detected, any practical value of unsharpness will have some effect on image detail discernibility. The effect of unsharpness on an image detail such as a crack image is a double one - the image is spread out and it is reduced in contrast (Fig. 2).

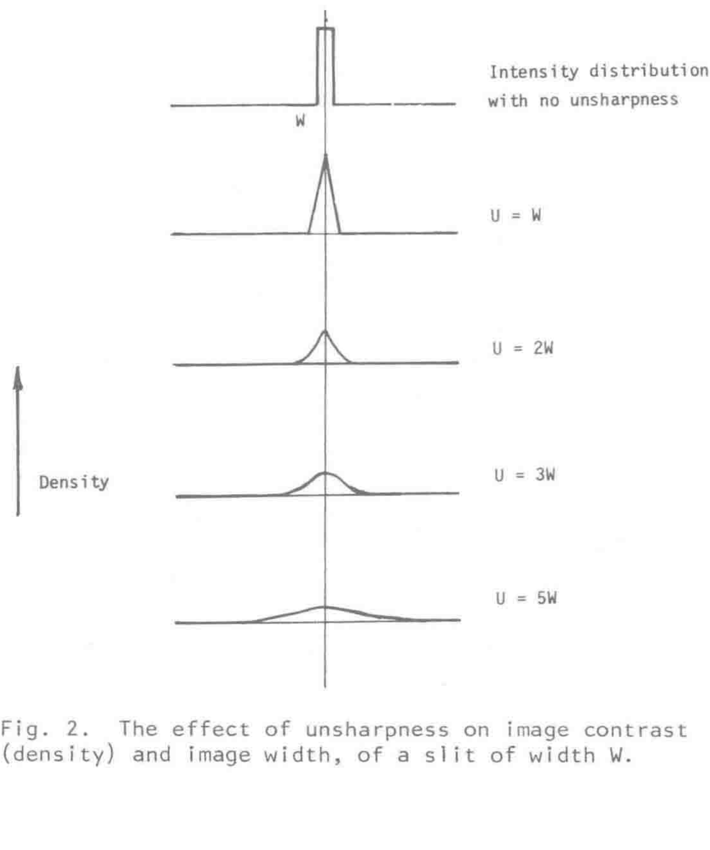

Fig. 2. The effect of unsharpness on image contrast (density) and image width, of a slit of width W.

In radiography there is a third factor affecting image detail - the granular appearance of the image, whether it is on film or fluorescent screen. Graininess breaks up the image of fine detail, making it less discernible and so reducing detail sensitivity. Although the actual particles of silver in a film emulsion or the particles of fluorescent material in a screen are too small to be seen by eye individually, the graininess can be seen at very low magnifications - x2 - even on a so-called fine-grain film, and the reason for this is quite complicated.

All radiographic image analysis can then be broken down into considerations of:

contrast
definition
granularity/graininess - (noise)

although these are not necessarily independent parameters.

It will be convenient to consider imaging on photographic film and on a fluorescent screen separately. Industrially, the film case, i.e. radiography, is by far the most important.

RADIOGRAPHY ON FILM

If one considers an image on a film - for simplicity, the image of a small air cavity of cubic shape in a uniform-thickness plate, which will be recorded on the radiograph as a small square patch of higher-than-background film density, commonsense suggests three criteria regarding the visibility of this image.

1. It will be more easily visible if the difference in density between the image and the background is made larger.

2. It will be more easily visible if its outlines are sharply defined, rather than blurred - smaller unsharpness.

3. As the image is built up of small silver particles, a small image will be more discernible if these grains are small rather than large.

All these statements are qualitative rather than quantitative in nature, but are nonetheless valuable. The first concerns contrast, which can be defined as the difference between the image and the background; higher contrast will result in better discernibility.

The second and third statements both concern factors affecting the definition of the image. Taking the third statement first, it is necessary to recall that a photographic emulsion, before exposure, consists of very small grains of silver halide in suspension in a layer of gelatine. On development after exposure, these grains of silver halide are chemically reduced to metallic silver, which is in the form of a spongy mass which is usually larger in volume than the original halide grain. The developed grains are randomly distributed and the visual appearance of the irregularities of density of a uniformly exposed area of film is referred to as "graininess" and is a subjective property of the film. The irregularities of density may also be measured by instruments, in which case the measured property is referred to as "granularity".

Radiographic Unsharpness. The second of the three statements was concerned with the blurring of the edges of the image and I have been using the term "unsharpness" rather freely. If it is assumed that a radiograph be taken of a physically sharp metal edge with the beam of radiation perpendicular to the surface of the specimen, a theoretically ideal radiograph would be comprised of a uniform region of high density on the film with a sudden discontinuous change to a region of lower density. This density distribution curve is often called the "unsharpness curve". In practice the curve is not discontinuous and the image of the edge of the specimen is blurred, the width of the band of density change (see Fig. 3) is defined as the radiographic unsharpness U measured in millimetres.

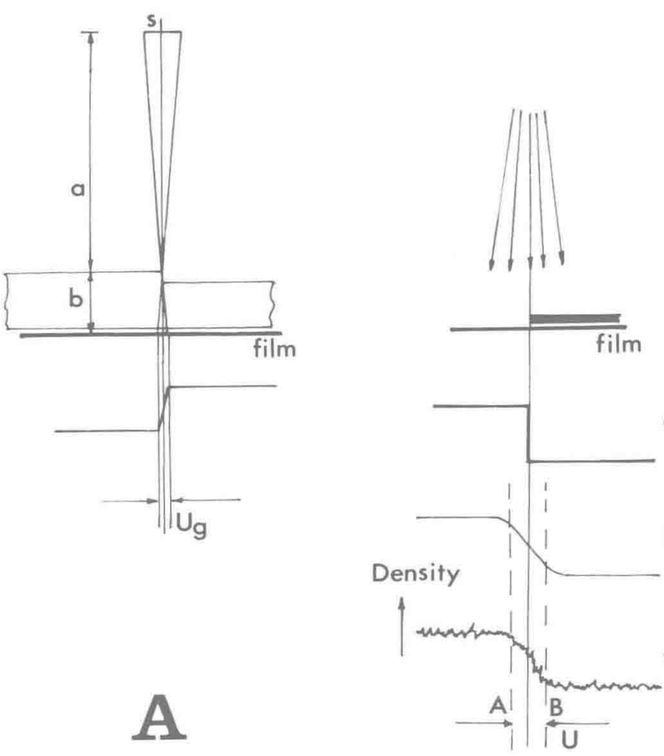

Fig. 3. Geometric and film unsharpness.