

Chapter 11

Conclusions

General radiography, using film/screen (F/S) combinations for image capture, has a major limitation of narrow latitude or dynamic range. The F/S latitude or dynamic range is often not wide enough to adequately record the differences in intensities of the exit radiation from the irradiated anatomical area. Consequently, anatomical regions of differing attenuation characteristics can appear either white or black on the image. Alternatively, the entire image is displayed with a low radiographic contrast.

Physical tissue compensation filters (TCFs), made from x-ray attenuating materials, can be placed in the beam to reduce the dynamic range of the exit radiation. Several physical TCFs were examined to determine their characteristics of linear attenuation coefficient and half value thickness. The shape and size of the physical TCFs were also evaluated. The evaluation of these properties provided the nexus to and the impetus for the development of radiographic contrast-enhancement masks (RCMs).

Digital radiography (DR), in its various forms, is an accepted method of undertaking general radiography. The dynamic range and linearity of DR recording methods are wider than those of F/S. Indeed, DR can capture and record the full dynamic range of intensities of the exit radiation. However, viewing of this full dynamic range of a DR image is difficult.

Various methods exist to facilitate the visualisation of all the anatomy in a single DR image, and were evaluated in this thesis. Contrast and brightness adjustment through the use of look-up tables (LUTs) is the simplest of these methods. Using a linear LUT reduces the radiographic or displayed contrast of the image. In reducing the displayed contrast this method also reduces the viewer's ability to differentiate between anatomical regions of similar optical density. The use of non-linear LUTs can increase radiographic

contrast in one region of the image, but then another region of the image will have low radiographic contrast. All LUTs are applied globally, and therefore non-linear LUTs may have undesirable effects in certain anatomical regions.

The two main methods to reduce the dynamic range of DR images used clinically by commercial DR manufacturers are unsharp masks with large kernel size and multi-scale processing. Both these methods reduce the dynamic range of the DR image and allow all anatomy to be visualised in the image. They do, however, suffer some drawbacks. The unsharp mask process is inherently an edge enhancement method. The use of large kernel sizes reduces this effect. Enhancement of noise in the image is also a drawback of the unsharp mask.

Multi-scale processing has been reported to increase the noise in the image (Vuylsteke & Schoeters, 1999). An image of metatarsal bones using a multi-scale process in Figure 7.17b also showed an increase in edge enhancement over the original image.

In this study RCMs were devised and developed. Their application to DR images also reduces the dynamic range of the image. The RCM is essentially an intensity map overlaid on the image. The plan-view shape of the RCM is user controlled to suit the anatomical region being visualised. The profile shape of the RCM, again controlled by the user, affects the amount of dynamic range reduction that occurs. User control of the location in the image at which the RCM is applied and the extent of the effect of the RCM are the main criteria for the effective use of RCMs.

RCMs were developed in three main shapes, the wedge RCM, the boomerang RCM and chest RCM. The development of the RCM was fully detailed. Currently the use of RCMs is limited to images that can be imported into the mathematical program Matlab[®] (MathWorks Inc., Natick, USA). Further development of the algorithms will allow a more generic use of the algorithms and a higher level of user-friendly tools, such the facility to drag the edges of the RCM and shift the RCM under mouse control to the user's desired location. It is also expected that further development of the algorithms

will reduce the time of the mapping of the RCM to the image. This will decrease the time taken between application of the RCM and viewing of the final result.

Only the wedge and the boomerang RCM shapes were fully evaluated on clinical DR images. Dynamic range reduction within the image occurred. Wedge shaped RCMs were shown to allow visualisation of all anatomy in a single image in the anatomical regions listed in Table 11.1.

Table 11.1 Anatomical regions where wedge shaped RCMs were evaluated

Anatomical Regions
thoracic spine
facial bone
cervical spine
thoraco-lumbar spine
femur
feet
hands
horizontal ray examinations of the abdomen

Boomerang RCMs are of use in DR examinations of the shoulder only. The dynamic range reduction in a shoulder image that results from the use of a boomerang RCM allowed visualisation of all of the anatomical regions within the image at a high radiographic contrast.

Comparisons of RCMs to unsharp mask and multi-scale processing methods were undertaken. RCM do not spatially enhance the image. It was shown that both the unsharp mask and multi-scale processing methods increase noise in the image in comparison to RCM methods. If an edge enhancement effect is desired in the image, this can be applied after the application of the RCM. No artefacts were visualised resulting from the use of wedge RCM. An artefact was present with the use of the boomerang RCM. Selection of the appropriate plan view shape of the boomerang RCM ensured that this artefactual appearance was external to the anatomy.

Clinical evaluation of the effects of the RCMs was undertaken. A pair of images of the same anatomical region, one being the original image and the other having an appropriate RCM applied, were compared in a side-by-side fashion.

A survey of 123 people was undertaken. Participants were radiographers or other people with experience in viewing medical images. The method of participant selection made it likely that they would have a high understanding of digital images, and this increased the validity of the survey.

The sample size of the survey was large. 984 image pairs were evaluated by 123 participants. Such a large sample size was shown to have a high power and as such was representative of the population of radiographers. Results showed a strong (80.1%) preference for the image that had been modified by the RCM over the original image. Participants responded to other survey questions as to which image had the best range of optical densities, in which image it was easiest to visualise all anatomy, and in which image it was easiest to optimise display factors. The responses to these questions also showed strong preferences for the RCM modified image.

The images were categorised by patient-related factor of size, age and presence of pathology. It was also found that the effect of the RCM in the image, as seen by the survey participants, was independent of these patient-related factors.

RCMs have the effect of dynamic range reduction on DR images without spatial enhancement of the images. It can be confidently stated that with further development of the algorithms, RCMs will be clinically useful in the viewing of DR images in a range of anatomical regions.

11.1 Recommendations for Future Research

RCM algorithms require further refinement in terms of ease of use and require a reduction of the time taken from being applied to the image to the generation of the modified image. These refinements would need to be incorporated into a commercial DR system. The benefit of this would be that the RCM would be an additional tool available to the radiographer to optimise the image as part of their overall role.

It is also suggested that RCMs be evaluated against existing methods of dynamic range reduction. This can only be undertaken when the RCM algorithms are incorporated into commercial DR systems. Images captured on a DR system could then output both a RCM modified image and an alternative method image. Given the vast range of dynamic range control methods provided by various manufacturers, many studies focused on specific anatomical regions for comparison of RCM and alternative method of dynamic range control would be required. These comparisons could be objectively based. This would further extend the work completed in this study. Subjective comparisons could also be undertaken using similar methods to that which has been discussed in Chapter 9.

It is not within the scope of this study to clinically evaluate RCM's in relation to actual diagnosis. The work undertaken as part of this doctoral project has not evaluated RCM modified images for improvements in sensitivity or specificity of the radiographic examination. This would need to be undertaken on an individual radiographic examination basis and would need to be tailored to the anatomical region being investigated.

11.2 Summary

On commercial and clinical acceptance of the RCM method, radiographers will be able to use RCMs to improve DR image quality. Radiographers will select the appropriate RCM for the DR image they have captured and using their clinical judgement, modify

the RCM parameters to optimise the final image. Radiographers will then be able to present the modified image to the appropriate clinicians. This approach will enable the image to be stored and then displayed, on first presentation, with the highest quality to the clinician. It should also reduce the time taken by clinicians in modifying the image quality for their own display.

Radiographers will be able to undertake further evaluation of the RCM algorithms. Quality comparison of the RCM modified images and alternative dynamic range reduction methods will be able to be undertaken. Once the RCM algorithms are built into commercial DR systems, output of images modified by both methods will be an easier task. Radiographers will be able to select specific radiographic examinations and patient related factors to compare and evaluate.

Radiographers will also be able to undertake clinical evaluations of the RCM modified images. Their involvement will be able to be either at the level of producing the highest quality images or, given the current trend for radiographers undertaking radiologic image interpretation, being in a blinded trial of RCM diagnostic capability.

It is expected that RCM methods will be available to radiographers to assist in their role of producing the highest quality DR images for that patient. In doing so, RCMs should ultimately be a benefit to the diagnosis of a patient's condition and potentially reduce patient dose through perfecting display using minimal general radiographic projections.