How to Optimize Radiological Images Captured from Digital Cameras, Using the *Adobe Photoshop 6.0 Program*

A. N. Chalazonitis, MD, Ph.D,¹ D. Koumarianos, RT,² J. Tzovara, MD,³ and P. Chronopoulos, MD¹

Over the past decade, the technology that permits images to be digitized and the reduction in the cost of digital equipment allows quick digital transfer of any conventional radiological film. Images then can be transferred to a personal computer, and several software programs are available that can manipulate their digital appearance. In this article, the fundamentals of digital imaging are discussed, as well as the wide variety of optional adjustments that the Adobe Photoshop 6.0 (Adobe Systems, San Jose, CA) program can offer to present radiological images with satisfactory digital imaging quality.

KEY WORDS: Images, digital imaging, digital camera, computers, processing, software application

EVEN THOUGH DIRECT DIGITAL IMAGING and a picture archiving and communication system (PACS) are already available in many radiology departments, hard-copy radiographic images are still present in every department. Most of the radiographs are obtained in the traditional way, and the use of a digital camera is one way of getting hard-copy radiographs into digital format. The other way is the use of laser scanners, which offer maximum resolution at a premium price, or charge-coupling device (CCD) scanners which are widespread and less expensive. Digital camera technology captures an image on a CCD array through the optics of a photographic camera.¹¹ The technology related to digital cameras is improving rapidly in quality and is becoming more financially accessible and user-friendly, even to people who are not technologically inclined. Nowadays, the market is full of digital cameras, ranging in price and capability. Some commonly used digital cameras have already been evaluated for reproducing radiologic

images.^{1,2} Before the radiologist starts composing radiologic illustrations in real time, it is important to understand the digital images' characteristics as well as the fundamentals of digital imaging manipulation.

Software is used to transfer images from the camera to the computer, to convert images into other file formats for use in documents and slides, and to add text, lines, or graphics. Software supplied with the cameras allows some simple image modification. However when radiological images are stored in this way, image quality is usually disappointing.³ Adobe Photoshop 6.0 (Adobe Systems, San Jose, CA) is an excellent image-editing software program for editing and annotating radiological images intended for presentation and publication.⁴ This program can be used on either MS-Windows (Microsoft, Redmond, WA) or Macintosh (Apple Computers, Cupertino, CA) platforms. The 400-page manual⁵ distributed with the program is oriented to commercial color users, and image manipulation tricks and tips useful to radiologists are not emphasized. This article is more a sampling of the powerful tools of the Adobe Photoshop program than a tutorial. Additionally, some particular tips are suggest-

¹From the Department of Radiology, NIMTS, Army Veterans Hospital, Athens, Greece; ²the Department of Radiology, ELPIS General Hospital, Athens, Greece; and the ³Department of Radiology, University of Ioannina, Ioannina, Greece.

Correspondence to: A. N. Chalazonitis, MD, Ph.D, 110 Vas. Sophias, 11527 Athens, Greece; e-mail: red-rad@ath.forthnet.gr

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ed, closely related to radiologic images rather than other photographic subjects. Both experienced and inexperienced users will find items of value in this article.

Other image manipulation programs are available for both the MS-Windows and Macintosh platforms. Photoshop Elements (Adobe Systems, San Jose, CA) is a limited version of Photoshop that performs almost all basic functions discussed in this article. PhotoDelux (Adobe Systems, San Jose, CA), Photo-Paint (Corel, Ottawa, Ontario, Canada), and Picture Publisher (Micrografx, Dallas, TX) also provide most of the techniques discussed.⁶

SYSTEM REQUIREMENTS

A modern computer with at least 256 Mb RAM (Random Access Memory) is necessary to open and manipulate files with radiological images.⁶ A video card with at least 16 MB memory, and a 1024 × 768 pixels resolution monitor are also required.

The most commonly used digital cameras have 2- to 3- megapixel resolution. The term *megapixel* indicates that a camera can obtain an image approximately 1 million picture elements or more. A 2.1 megapixel camera gives the flexibility to obtain decent image quality. An auto-focus zoom lens with macro capabilities (the ability of the camera to focus on objects very close to the lens) is essential for the camera used by radiologists with little camera experience.⁷ Digital cameras usually come with accessories or built-in mechanisms that facilitate the transfer of images to PC. A common way to transfer pictures from the camera to the computer is via USB ports and cables. Most digital cameras use flash memory cards to store images. Images can be transferred to a computer, and then erased from the card. There are three major types of memory cards in use today; Compact Flash, SmartMedia, and Memory Stick. The latest cameras don't even require special download software, because their memory cards can be automatically read by the host operating system. Probably the most important point to make about memory cards is that nearly all cameras come with very small ones, often holding 20 or fewer pictures at highest resolution. The radiologist should

budget for enough memory to take at least 48 pictures at your desired resolution and compression settings.

CHARACTERISTICS OF DIGITAL IMAGES

Digital images are composed of pixels, or Picture Elements, which are used to define every point of the digital image matrix. Each digital image has four basic characteristics: image resolution, bit depth, color model, and image size.

Resolution refers to the quality of an image, measured in pixels per inch (ppi). High-resolution images are comprised of more ppi and reproduce more information and detail than low-resolution images. *Monitor resolution* refers to dots per inch (dpi). To determine the optimal image resolution, the medium of final distribution for the image should be taken into account. For example, computer screens support considerably lower resolution than the printed page. PC monitors may display 72–96 dpi, whereas a laser printer can print images at 300 dpi or even more. When creating image databases for the Web or images that will be presented on screen, it is not as important to use maximum resolution.⁸ Printed material, however, requires the highest possible resolution.⁶ The major drawback to using very high resolution is an increase in the file size that slows the printing process of the image. Large files require long download times.

Bits are the basic elements of digital data. A single bit is either on or off, usually expressed as 1 or 0, so that there are only two variations. 1-bit images are black and white (e.g., line art). An 8-bit pixel can vary anywhere within the full range of 256 gray values that can be reproduced. 24-bit images are actually three 8-bit channels, one each for red, green, and light blue.

The *color model* for an image reflects the number of memory bits devoted to storage of the color information for each pixel. There are three different image models commonly used: bitmap, grayscale, and RGB color. RGB is a color mode, which separates the image into Red, Green, and Blue (similar to the way a TV screen creates color). Grayscale mode supports 256 shades of gray. The human eye can discern about 200 different levels, or shades, of gray. The importance of determining levels is to avoid

posterization. Bitmap mode uses only two colors: black and white. One bit of color is used to display each pixel. The bit is recognized as being either on or off and generates a gamut of only two colors.

The *image size* refers to both its physical size and the file’s size. The physical size of an image, in width and height, is usually expressed in pixels rather than inches or millimeters, whereas the size of the file is expressed in bytes or megabytes. The size of the file comprises overall document dimensions, resolution, and bit depth. The file size of an image is proportional to its pixel dimensions and can be calculated by using the following formula:

$$(\text{Pixel Width} \times \text{Pixel Height}) \times (\text{Bit Depth}/8).$$

The result represents the file size in bytes. Divided by 1024, the file size is measured in kilobytes (and by 1024 again, in megabytes). For example, a 24-bit RGB image that is 459 pixels wide and 612 pixels high would have a file size of $(459 \times 612) \times (24/8) = 842,724$ bytes/1024 = 823K.

IMAGE MANIPULATION FUNDAMENTALS

Before starting to manipulate images using Photoshop’s numerous powerful capabilities, it is important to become familiar with the following essentials: tools and palettes in Photoshop, importing images, opening existing files, file formats, and conversion of color model.⁵

Tools and Palettes

When launching the Photoshop working area, the user is presented with a bevy of tools: the toolbox, a collection of painting tools and the palette groups, that help the user monitor and modify images. These are the tabbed windows containing options that allow modifications to the initial appearance of images.

The toolbox [Fig 1] includes four tool groups:

1. Selection Tools: These tools at the top of the toolbox are used to select all or part of an image. The selection tools all work in the same way; first, by selecting the tool, then by clicking and dragging over the section of the selected image.
2. Painting Tools: Add, remove, or modify “paint” on an image.
3. View Tools: Allow the user to zoom in and out, or move a part of an image to another

Fig 1. Tools palette. Shows the tools that can be used to edit images. The Crop tool is highlighted in white because it was the active tool.

area for a closer look. This feature is helpful for particularly detailed work.

4. Other Tools: This group of tools could easily be called “Useful Tools that don’t fit in any other group.” With these tools, one can add type, measure dimensions, or add shading or gradients to colors or backgrounds.

With Photoshop palettes, one can add layers and colors while keeping an eye on the components of the active image. Some palettes provide information such as color type and dimensions; others allow changes to the brush size or a close look at image layers. Exiting Photoshop saves the current position of the palettes in the working area.

Importing Images

In with Photoshop, the user can also open and import images in various file formats and have multiple images open at one time. A va-

riety of importing methods exist, including digital cameras and scanners. Other sources are the World Wide Web or CD-ROMs. To open DICOM (Digital Imaging and Communications in Medicine) files, Photoshop 6.0 requires the addition of a plug-in.⁶

Opening Existing Files

To open a file, choose File > Open and then navigate to the preferred file in the Open Dialog Box. The Open Dialog Box (Fig 2) displays all the files in Adobe Photoshop’s supported formats. The thumbnail feature places a miniature version of the file in the Open window, providing image preview.

The Image Family

Digital images appear in a variety of types, also called file formats. File formats differ in the way

Fig 2. Open file window. Selection of Open, allows browsing through files and folders, to find the desired one.

they represent graphic information (either as vector drawings or as bitmap images) and in the way they compress image data. Some formats contain only vector drawings or bitmap images, but many include both in the same file. Some of the most commonly used file formats include:

1. Bitmap (.bmp): the standard Windows Image File Format. A bitmap image is resolution-dependent—that is, it contains a fixed number of pixels to represent its image data.
2. GIF (.gif): Graphical Interchange Format files containing only 256 colors.
3. JPEG (.jpg): Joint Photographic Experts Group Format commonly used over the World Wide Web. When saving in JPEG format, the user can specify the compression level: bigger compression levels may interfere with image quality.
4. TIFF (.jpg): Tagged Image File Format is a flexible bitmap image format supported by virtually all applications. It is the most widely used file format in print publishing. Virtually all desktop scanners can produce TIFF images.
5. PSD (.psd): is the default format for newly created images in Photoshop and the only format supporting Layers and Type Formatting.

Converting an Image to Grayscale

The Image Mode menu enables changes at the Color Model. To save disk space, the user can convert any color image to grayscale by choosing Image > Mode > Grayscale [Fig 3]. To discard color information, the user clicks OK.

BASIC IMAGE TRANSFORMATION PROCESSES

Photoshop provides many forms of editing or improvement of an imported image. Once an image is loaded on the Photoshop program, it can be rotated, cropped, and resized to specific dimensions and resolutions.⁵

Rotation of an Image

The user can rotate an image by choosing Image > Rotate Canvas and choosing from the submenu [Fig 4]:

1. 180 to rotate the image by a half turn
2. 90 CW to rotate the image clockwise by a quarter turn
3. 90 CCW to rotate the image counter clockwise by a quarter turn
4. Arbitrary to rotate the image by a specified angle clockwise or counterclockwise.

Fig 3. Detail of the Image mode menu. The user can convert any color image to grayscale.

Fig 4. Detail of the Image mode menu. The user can rotate or reverse an image.

Image Cropping

Cropping is the process of selecting and removing a portion of an image. The user should first select the cropping tool and then drag the cropping cursor onto the loaded image [Fig 5]. By releasing the mouse button, a selection rectangle, with “handles” on the sides and in each corner, is visible on the working area. Possible adjustments to the crop area can be achieved by dragging one of the handles in such a direction so as to increase or decrease its size. When desired selections have been made, double-clicking inside the crop area finalizes the process. Everything outside the crop area is detached from the image. Cropping is an essential tool for file size management. It excludes excess information or, in other words, excess bytes. One may also impose specific cropping constraints on resolution (e.g., 300 dpi) and size proportion (e.g., 5 × 7 inches, 3 × 5 inches), which facilitates making images suitable for publication.

Image Resizing

Once an imported image is loaded on the Photoshop program, its size or resolution can be adjusted. The Image Size command allows

adjustments of the pixel dimensions, print dimensions, and resolution of an image. To change the size of an image, the user should select Image > Image size [Fig 6]. When the image size dialog box appears, the first option refers to changes in the pixel dimensions of the selected image. Pixel dimensions are translated directly into monitor pixel dimensions. By selecting inches (or centimeters), the physical size of the image is changed.

Proportional transformation of the image in both dimensions requires checking the “constrain proportions” box before choosing the width or height numeric values. These values are instantly adapted to fit the desired proportions of the image. As a result, the file size changes, but the resolution remains unchanged. When checking the “resample image” checkbox, the bicubic interpolation method is selected by default; it is the most advanced form of sampling.

Making Selections

Clicking and dragging with the “marquee,” “lasso,” “polygon lasso,” or “magnetic lasso” tool, or targeting areas with the “magic wand” tool are some of the options that facilitate

Fig 5. Detail of the Image mode menu. Everything outside the crop area is detached from the image.

partial changes to an image. The choices associated with a selection tool appear in its Options palette. Making a new selection replaces the existing one.

Marquees may be used for simple geometrical selections within an image—a rectangle, an ellipse, or a single horizontal or vertical line of pixels. For example, when the rectangular marquee tool is clicked and the selected area is defined, the cursor changes to crosshairs over this area. Positioning and dragging the crosshairs over the region of interest create a small rectangle.

The lasso tools are perfect for odd-shaped selections. The use of the simple lasso tool requires clicking and dragging around the region of interest without releasing the right mouse button until setting the selection borders. The polygon lasso tool creates selections from a series of points that are joined together by a straight-line marquee.

The magnetic lasso tool is especially useful for irregular shapes that stand out of the

background. When dragging the magnetic lasso tool around a well-defined shape, it hugs the edges of the shape.

The magic wand is useful for selecting a uniform colored area without having to trace its contour. In the magic wand options, “tolerance” refers to the number of similar colors that are selected. The default setting is 32, meaning that 32 tones lighter and 32 tones darker than the color will be selected.

Tonal Adjustments

Tonal range optimization is an essential when processing a radiological image and can be performed in either of the following ways: “brightness and contrast” adjustments, or “levels and curves” adjustments.

The Brightness/Contrast dialog box is the most popular dialog box, leading to simple and independent alterations in the brightness and contrast of the selected image [Fig 7]. The

Fig 6. Detail of the Image mode menu. The image size command allows adjustments at the pixel dimensions, print dimensions, and resolution of an image.

slider triangles move in one direction or its opposite, resulting in an increase or decrease in the level of brightness/contrast. The numeric values correspond to the respective changes in the position of the slider triangles. A preview checkbox can be clicked for instantaneous observation of changes in brightness and contrast.

The levels dialog box leads to corrections in the tonal range of an image, by adjusting intensity levels of the image's shadows, midtones, and hightones. The histogram in the levels dialog box serves as a visual guide for adjusting the image's key tones and allows discarding information at either end of the tonal range [Fig 8]. One useful strategy which, for the most part,

Fig 7. Detail of the Image mode menu > Brightness/Contrast window. The slider triangles move in one direction or its opposite, resulting to an increase or decrease in the level of brightness/contrast.

fixes low and high levels (sets the window width) is to first use auto level and then, using the mouse, manipulate the window level (center) to adjust the contrast by sliding the middle triangle.

Like levels, the Curves dialog box modifies the entire tonal range of an image by adjusting any point along a scale with 255 gray values. The horizontal axis of the graph in the curves dialog box represents the original intensity values of the pixels; the vertical axis represents the new color values. In the default diagonal line, all pixels have identical input and output values over the image. To determine the lightest and darkest areas in the image, the user should drag the cursor over the image. The intensity values of the area under the pointer, along with the corresponding location on the curve, are displayed on the curves dialog box. The points on the curve that remain fixed should be clicked and the curve should be dragged to the desired position.

The conventional wisdom is that curves are the best tool for tonal adjustments, levels are a decent tool, and brightness/contrast is only for amateurs. We don't really agree with this. In many cases, contrast/brightness is just fine, and quite often the precise control available in curves leads to very unnatural images. The human eye is exquisitely sensitive to variations in lighting. Curves can make local changes that often lead to unreal results. Levels spread or compress the overall tones of the image without losing any image detail. This looks natural to the radiologist's eye because the adjustments are applied overall. Brightness/contrast adjustments are also made to the whole image. One

drawback about the brightness/contrast adjustment is that it does not permit setting the endpoints of the tonal scale.

Image Sharpening

To create the illusion of variation of gray or continuous color, images in printed media are broken down into a series of dots. This process is called halftoning. Digital cameras and scanners love to accentuate these patterns that our eye hardly notices. Suddenly the image has a bad case of "measles," a problem known as the moiré effect.

To solve the problem of moiré patterns, one standard method is to use a blurring filter along with an un-sharpening filter and thus disperse the pattern to the satisfied level. Often though, the pattern is too coarse and an unacceptable amount of image quality is lost in the repair process. The aim is to blur the image in order to conceal the pattern and then re-sharpen to regain edge quality.

Blur filters smooth transitions by averaging the pixels next to the hard edges of defined lines and shaded areas in an image. The most useful blur filter for x-ray images is the gaussian blur filter, which quickly blurs a selection by an adjustable amount. From the menu Filter, one can choose Blur > Gaussian Blur [Fig 9]. *Gaussian* refers to the bell-shaped curve that is generated when Photoshop applies a weighted average to the pixels. The Gaussian Blur Filter adds low-frequency detail and can produce a hazy effect.

The Sharpen filters focus blurry images by increasing the contrast of adjacent pixels. The most useful unsharp filter for x-ray images is the Unsharp mask filter. Choose Filter > Sharpen > Unsharp Mask [Fig 10]. *Amount* refers to the increase in contrast that will be applied to a change in color. *Radius* is how far from each pixel the increase in contrast will be applied. *Threshold* defines how many tones will be ignored before the change in contrast is applied. Sharpening an image is rather subjective. According to our experience for x-ray images, an amount of 50–200, radius between 1 and 3, and threshold 1–5 are the most commonly used options. If the final appearance of the sharpened image is not satisfactory, one can choose

Fig 8. Detail of the Image mode menu > Levels window. The user can make corrections in the tonal range of an image.

from the menu Edit > fade immediately after applying the sharpening.

Annotating Images

A new image in Photoshop has a single layer, the background layer. Text or graphics in an image can be added to a new layer. Layers are very useful tools because they allow alterations

to a single element of an image while leaving the rest untouched. Layers have their own palette. Clicking on the small page icon with the turned up corner at the bottom of the “Layers palette” creates a new layer [Fig 11]. The thumbnail on the left shows the contents of the layer. A black frame, indicating that it is the layer currently being processed, marks the active layer on the Layers palette. It is obvious that one or multiple

Fig 9. Detail of the Filter menu. The Blur filter smooths transitions by averaging the pixels next to the hard edges of defined lines and shaded areas in an image.

Fig 10. Detail of the Filter menu > Sharpen > Unsharpen mask. The user can make changes to Amount, Radius, and Threshold levels.

new layers can be created. When discarding a layer, one should simply click on it and drag it into the small trash icon at the bottom of the Layers palette. However, to preserve layers and to maintain each layer's information as separate, the entire file will have to be saved as a .psd file.

Adding Text

Typing text anywhere in an image is essential and easy to perform. After the type tool (T) is selected, an insertion point for the type can be made to appear by clicking on the image. Additional type options in the options bar may

Fig 11. Layers menu. Every image in Photoshop has a single layer, the background layer. Text or graphics in an image can be added to a new layer.

be chosen, such as character palette, and paragraph palette. When typing, a new Type Layer is added to the Layers palette. Once a type layer is created, layer commands are activated.

DISCUSSION

The digitization of radiographic films has become a necessity in today's practice of radiology. The extensive use of computers in radiology has made image digitization essential for publications, reference books, educational projects, and multimedia presentations. A cost-effective method of digitizing conventional radiographic films may be achieved through the use of a digital camera. Even though expensive digitization options do exist, a recent study showed that low-cost digital cameras are able to produce quality digital images, depending though on the means of displaying the output.^{1,2,7,9}

The software supplied with the digital camera allows simple forms of image processing. Adobe Photoshop 6.0 can provide reasonably good results when manipulating an image. Once radiologic images are on the Photoshop program, they can be cropped, resized, cut, and pasted to fit side-by-side. Brightness, contrast, and saturation can be adjusted. Text and arrows can be added. Confidential or distracting data can be cropped from a radiological image, and background colors can be modified using, for example, a "magic wandtool".¹⁰

Radiological images are difficult photographic subjects. Optimal electronic image display is critical to accurate medical image display and interpretation. The need to maximize resolution to maintain image quality while striving to achieve the smallest file size possible is an ongoing challenge. Resolution, compression, and color depth of the images have to be optimized to enable fast access and to offer acceptable image quality. When a high resolution is chosen, problems with storage space and required computing power may arise; this implies that access times may be too long. The use of a resolution that is too low may result in a loss of diagnostic information. An ideal set of specifications for a digital camera that would be used for reproducing radiological images has been proposed.¹ Other investigators suggest that radiological subjects require the highest possible resolution. Detail present in the

original radiograph that is not captured by the digital camera cannot be revealed.³

On a PC, the images are usually converted to a JPEG or GIF format. The JPEG format is used more often than GIF format because JPEG images are subjectively of the same quality as the GIF images, but they require 10% less memory space. TIFF and bitmap image files are larger and use more memory.^{6,8}

Permission should be obtained from the owner of an original illustration when capturing it with a digital camera. Failure to do so may result in a copyright infringement lawsuit. Digital watermarks of ownership can be examined using the Adobe Photoshop program.¹⁰

Digital image manipulation is not without its problems. Although such manipulation is favorable when done for appropriate reasons, the ease of digital manipulation is such that it may become attractive to surpass the realm of altering images for educational purposes and move to the realm of digital falsification. Computed tomography, ultrasound and magnetic resonance images are relatively impoverished electronically when compared with plain films. The latter depict matter across a wide spectrum of black, gray, and white shadows making it more difficult to retain pictorial fidelity after manipulation by digitization and transmission.

THE BOTTOM LINE

As digital technology continues to evolve rapidly in several fields, the routine use of digital photography in radiology education and publishing seems inevitable. The highly technical orientation of radiology as a speciality is rather challenging. The continuous upgrading of technology tools, as far as digital optimization of radiological images is concerned, should not become an obstacle for the up-to-date radiologist if the basic skills are acquired. Fundamental knowledge of this subject will aid him or her to keep up with, or learn faster newer methods of digital image optimization.

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