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TECHNICAL REPORT

Image processing and enhancement provided by commercial dental software programs

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Objectives: To identify and analyse methods/algorithms for image processing provided by various commercial software programs used in direct digital dental imaging and to map them onto a standardized nomenclature.

Methods: Twelve programs presented at the 28th International Dental-Show, March, 2001, Cologne, Germany and the Emago advanced software were included in this study. An artificial test image, comprised of gray scale ramps, step wedges, fields with Gaussian-distributed noise, and salt and pepper noise, was synthesized and imported to all programs to classify algorithms for display; linear, non-linear and histogram-based point processing; pseudo-coloration; linear and non-linear spatial filtering; frequency domain filtering; measurements; image analysis; and annotations.

Results: The 13 programs were found to possess a great variety of image processing and enhancement facilities. All programs offer gray-scale image display with interactive brightness and contrast adjustment and gray-scale inversion as well as calibration and length measurements. While Emago enables arbitrary spatial filtering with user-defined masks up to 7×7 pixels in size, most programs sparsely include filters and tools for image analysis and comparison. Moreover, the naming and implementation of provided functions differ. Some functions inappropriately use standardized image processing terms to describe their operations.

Conclusions: Image processing and enhancement functions are rarely incorporated in commercial software for direct digital imaging in dental radiology. Until now, comparison of software was limited by the arbitrary naming used in each system. Standardized terminology and increased functionality of image processing should be offered to the dental profession.

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Introduction

Direct digital dental imaging has been established over the past decade, and its usage by dental practitioners is steadily increasing.[1] Therefore, more companies are offering hardware and software for direct digital imaging. Usually, the systems rely on solid state sensors, such as charge coupled devices (CCD) or complementary metal oxide semiconductors (CMOS), and/or storage phosphor plates. Sensitometric properties, resolution, and technical parameters of competing hardware concepts have been evaluated exhaustively and compared to intra-oral films, as well as other digital systems.[2]

Digital acquisition of radiographs enables digital image enhancement and processing. Several studies have shown that digital contrast enhancement and filtering may increase diagnostic accuracy for the detection of lesions and estimation of lesion depth.[3,4] For instance, there is evidence that certain digital image enhancements of direct digitally acquired radiographic images may improve accuracy of detection and quantification of carious lesions.[5] However, other authors observed in their studies the contrary, i.e. deterioration of accuracy by digital image enhancement of directly digitally acquired radiographs.[6] Applied to secondary digitized radiographs of high quality, basic

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digital manipulations may also fail to result in more valid measurements demonstrating statistical significance.[7,8] In conclusion, it is undisputed that diagnostic impact depends on the task at hand, the quality of source data, and the kind of image processing applied. However, this does not imply that for any given task there is some image processing operation improving diagnostic efficiency.

Nonetheless all systems for direct digital imaging offer some type of image manipulation methods. Embedded in the menu structure by ingenious identifiers and/or accessible by buttons with descriptive symbols, a great variety of linear and non-linear techniques in the spatial or frequency domain are provided to modify one image or a combination of two images. However, a standardized nomenclature for such tools with respect to all programs is missing. The same image processing technique may have different names, and, even more crucial, functions with common names may have different effects on the image.

The goal of this work was to analyse and compare the procedures of image processing and enhancement provided by certain commercial software systems for direct digital dental imaging and to map them onto a standardized nomenclature.

Material and methods

Selection of programs

In 2001, a total of 63 companies, including manufacturers and providers, registered at the Cologne international dental exhibition using the keyword 'X-ray technology'. Based on this pre-selection, 12 software systems were identified for this study. Although not displayed at the meeting, the Emago software program was also included because of its frequent use in academic research, particularly for digital subtraction radiography.[9]

Table 1 lists all programs, versions, and providers. (In general, we found the web-site to be more helpful because it often links directly to the manufacturer's home page.) The hardware and software requirements were obtained from the providers' or manufacturers' descriptions. Most programs require a personal computer (PC) with Pentium processor and at least 64 megabyte (MB) random access memory for the client operating on Windows or Linux and recommend at least 4 gigabyte (GB) of free disk space for storing the images. While some programs offer a 800×600 pixel mode, the majority uses 1024×768 pixel displays in high or true color modes, which are 16 bit or 24 bit color depth, respectively.

Terminology

Image enhancement and filtering Analoui[10,11] recently provided an overview of underlying concepts along with algorithms commonly used for radiographic image enhancement in dental radiology.[10,11] Linear and non-linear point processing, the histogram-based approach, as well as spatial and frequency domain filters were defined and applied to dental radiographs. With respect to these image-processing techniques, we refer to the terminology introduced in the review.

In addition, some of the programs offer special filters such as thresholding, gradient filtering, and relief imaging. In thresholding, a binary image is obtained by turning all pixels to black or white if their gray value is below or above the chosen threshold, respectively. A gradient filter computes the first derivative of the gray values in the image and displays them in white on a black background, where the gray value in the gradient image denotes the strength of the edge. Hence, a gradient filter results in a contour image. Similarly, a relief image is obtained if the derivative is displayed on a gray background, and positive or negative gradients are coded in white or black, respectively. In several programs, this filter is also called '3demboss'. In addition, the three-dimensional (3D) embossing is frequently overlaid on the original image to maintain the initial gray distribution of the radiographs, resulting in some kind of image sharpening.

Image display Several programs offer special facilities for display and image measurements or analysis. A one-dimensional (1D) line profile graphically plots the pixel values, which are read along a straight line in the image. Using interpolation, the line can be oriented arbitrarily on the discrete pixel grid. Beside this 1D and the normal two-dimensional (2D) display of a radiograph, a 3D surface model is obtained when pixel gray values are interpreted as a certain altitude in a landscape formed from the image (Figure 1).

Pseudo-coloring Since human perception of gray values is limited, coloring images might enhance small local contrast. Arbitrary colors are usually obtained following the edges of the red, green, blue (RGB) cube. Clark and Leonhard recommended pseudo-coloring with constant brightness,[12] while Lehmann, Kaser and Repges proposed a simple parametric equation for pseudo-coloring gray-scale images keeping their original brightness progression.[13] The latter approach can be reduced to one color (e.g., brown in Trophy) or two colors (e.g., blue/green in Digora or red/yellow in Dimaxis). Furthermore, a certain range of equal gray scales can be shown with one, two, or three colors.

Measurements and image analysis Length and area measurements require calibration, i.e., a certain well-known distance within the image (e.g., the main axis of an implant) is marked and measured by the user. However, effects of different foreshortening in cone beam projection, which results from different object to sensor plane distances within one image, are neglected by all programs. To assist the comparison of two or more radiographs from the same dental region of the same patient, which have been serially acquired,

Table 1 Software systems

System software	Version	Company or provider Name	Address	Web-page	Hardware and software requirements CPU	RAM	HD space	Video	Operating system	Features Supported file formats	Variable paths
CDR	2.0 Demo	Schick Technologies, Inc.	31-00 47th Avenue Long Island City, NY 11101 USA	www.Schicktech.com	Pentium	64 MB	1 GB	800×600 8 Bit 1 MB	Win 95/98 Win NT	BMP TGA TIFF	•
Cliniview	R 3.00	Instrumentarium Imaging	Po Box 20 Nahekelantie 20 FIN-04301 Tuusla Finland	www.instrumentarium.fi/imaging	Pentium 300 MHz	256 MB	6.4 GB	1024×768 24 Bit 4 MB	Win 2000 Win NT	BMP JPG TIFF	•
Dexis	3.1.4	IC Med GmbH	Walther Rathenau Str. 4 D-06116 Halle/Saale Germany	ww.ic-med.de	Pentium	16 MB	1 GB	800×600 16 Bit	Win 2000 Win NT	DICOM TIFF	•
Digora	2.1 Rev 1 Demo	Orion Corporation Sorodex	PO Box 79 Nilsiänkatu 10-14 FIN-00511 Helsinki Finland	www.soredex.com	Pentium II	C: 64 MB S: 128 MB	2 GB	1024×768 24 Bit 70 Hz	Win 95/98 Win 2000 Win NT4	JFIF JPG TIFF	—
Dimaxis	2.4.1	Planmeca GmbH	Mühlfelderstr. 66 D-82211 Hersching Germany	www.planmeca.de	C: 133 MHz S: 266 MHz	C: 64 MB S: 128 MB	C: 35 MB S: 20 GB	1024×768 4 MB	Win 95/98 Win NT	BMP DICOM JPEG TIFF	—
Emago advanced	3.2	Stichting Oral Diagnostic Systems	c/o ACTA Oral Radiology Louwesweg 1 NL-1066 EA Amsterdam The Netherlands	www.radiology.acta.ne/emago/emago.html	Pentium II	32 MB	1 GB	1024×768 16 Bit	Win 3.1 Win 95/98 Win NT	BMP TGA TIFF	•
Friacom Dental Office	2.4.183	Friadent GmbH	Steinzeugstr.50 D-68229 Mannheim Germany	www.friadent.de	Pentium II	128 MB (256 MB for Win 2000)		1024×768 24 Bit	Win NT Win 2000 Linux	DICOM TIFF	•
IOX Image Viewer	2.2.0.10	Fimet OY	Teollisuustie 6 FIN-07230 Monninkylä Finland	www.fimet.fi	Pentium 120 MHz	16 MB	1 GB	1024×768 16 Bit	Win 98 SE Win 2000 Win ME	BMP	•
multiXray	1.0 Q	Rapp Informatik Systeme GmbH	Rosenbühlstr. 24 D-89182 Bernstadt/Ulm	www.rapp-informatik.de	Pentium III 800 MHz	64 MB	4 GB	1024×768 24 Bit	Linux RedHat 7.2	BMP DICOM GIF JPEG TGA TIFF	•
Proimage	3.1.0	Dent-X/Visiplex Medical Systems GmbH	Von-Braun-Str. 25 D-52511 Geilenkirchen Germany	www.visiplex.de	Pentium 133 MHz	32 MB	20 MB (without images)	800×600 16 Bit	Win 95/98	BMP GIF JPEG TIFF	•
Sidexis	5.3	Sinora Dental Siemens GmbH	Fabrikstr. 31 D-64625 Bensheim Germany	www.sinora.de	Pentium 166 MHz	64 MB	4 GB	800×600 8 Bit 4 MB	Win 98 Win 2000 Win NT	JPEG TIFF	•
Trophy	4.1 h Demo	Trophy Radiologie GmbH	Gerbereistr. 7 D-77649 Kehl-Kork Germany	www.trophy-digital.de	Pentium 400 MHz	128 MB		800×600 16 Bit 4 MB	Win 95/98 Win 2000 Win NT	JPEG TIFF	•
VixWin 2000	1.4 Demo	Dentsply Gendex Dental Systeme	Hamburg Innovation Park Albert Einstein Ring 13 D-22761 Hamburg Germany	www.gendex.de	Pentium 133 MHz	C: 64 MB S: 128 MB	4 GB	800×600 24 Bit 2 MB	Win 95/98 Win 2000 Win NT 4	JFIF JPEG TIFF	—

CPU, central processing unit; C, client; S, server; BMP, Windows Bitmap; DICOM, Digital Imaging and Communications in Medicine; GIF, Graphics Interchange Format; HD, hard disk; JFIF, JPEG File Interchange Format; JPEG, Joint Photographic Experts Group; RAM, random access memory; TGA, Truevision Targa; TIFF, Tagged Image File Format

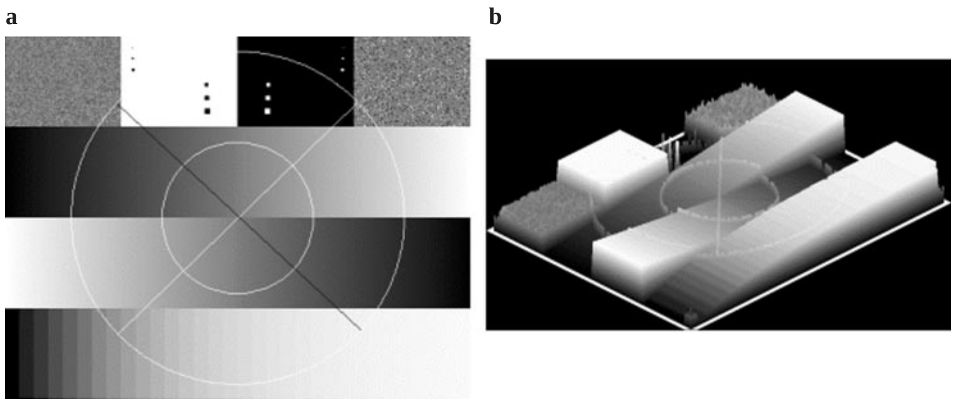

Figure 1 The artificial test image (a) is used to determine the algorithms of image processing. The 3D surface model (b) was obtained with the Trophy software system. Image gray values are interpreted as surface lines, which has been named ISO-surfaces by the International Organization of Standardization. Note that this visualization emphasizes the logarithmic nature of the step wedge ascending in the lower part of the image

contrast adjustment and geometry registration are provided to enable subtraction[14] or color addition.[15]

Annotation and miscellaneous Annotations of radiographs with lines or arrows, delimited regions, and text are useful to indicate a certain region of interest (ROI). After appropriate calibration, annotations can also be used for implant planning. Furthermore, pixel manipulation can be applied to alter the original radiograph. Such functions include brushes and pencils in any width, gray scale, or color. We also noted the ROI features that allow the application of a spatial filter to only a certain window within the image, as well as important functions that allow for selective 'undo' and 'reset' to be performed.

Test image

Linear and shift invariant filters were identified by the result obtained from filtering a single bright spot on a dark background regardless of whether such filters were implemented in the spatial or the frequency domain. In addition, non-linear filters, such as the median filter, can be identified by inspecting the response to salt and pepper noise, also referred to as shot noise or spot noise. Histogram spreading is easily distinguished from histogram equalization by noting whether the initial image occupies the full range of gray scales.

Based on this fundamental coherence, a 512×400 pixel sized test image with 8 bit gray-value depth was designed and synthesized using the Khoros Pro 2.2 system (Khoral Inc., Albuquerque, NM, USA). Basically, the image is composed of four stripes (Figure 1). The upper stripe contains four fields: Gaussian-distributed noise with mean 128 and variance 1 (histogram stretched); black squares of increasing size on a white ground; the same structure vertically flipped and gray scale inverted; and salt and pepper noise on a gray background where the spots have an incidence of 5% for each of black and white. The middle two stripes show continuous gray progression from black to white and vice versa, respectively. The lower stripe contains 32 steps of gray values (0, 30, 56, 80, 99, 119, 135, 149, 161, 172, 182, 191, 198, 205, 211, 216, 220, 225, 228, 231, 234, 237, 239, 241, 242, 244, 245, 246, 247, 248, 249 and 250) imitating the logarithmic response of X-ray imaging of an aluminum wedge of constant step height. In the foreground, two concentric white circles with a centered cross are drawn to simplify navigation in the zoomed image.

Installation and testing

Linux (RedHat 7.2), Windows 98 and Windows NT 4.0 operating systems were installed on a common PC computer. The computer hosts a Winner 2000 AVI graphics card (Elsa GmbH, Aachen, Germany) connected to a 21″ color monitor with 1155×864 pixel resolution (Elsa GmbH, Aachen, Germany). All dental software was installed in the single user mode on a 4 GB hard disk drive with 128 MB random access memory. The test image was loaded to all programs preferably in the tagged image file format (TIFF) using the import/export functions. Since some demo versions had disabled import or export functions (e.g., Emago), the test image was manually copied over existing images of demo patients on the hard disk.

Results

Installation and software features

The multiXray software operates on Linux only. The IOX Image Viewer and the ProImage software currently do not support Windows NT; hence, these programs were installed on Windows 98, while all others ran on Windows NT (Table 1). The Digora, Dimaxis, and VixWin programs did not offer user-determined installation paths but required installation on the system C drive, which might be inconvenient. To import and export images, we determined the supported file formats from the manufacturers' descriptions. Only Dexis, Dimaxis, Friacom, and multiXray provided an interface for the digital imaging and communication in medicine (DICOM) file format. Note that the ability to read or write this file format does not mean DICOM compliance or conformance, since that is intended to mean that the device containing the software could be plugged into a DICOM network, or read a piece of DICOM media, and neither is the case. The IOX Image Viewer imports only 8 bit files in 1200×800 pixel resolution landscape format using the Windows bitmap format (BMP), while all others support TIFF images with arbitrary image size and resolution. However, as a consequence of the various existing versions of TIFF, the format in use might differ within the applications resulting in incompatibilities. For example, Friacom displayed a black bar above the imported image, which might be a result of the variable length of the TIFF header, and Dimaxis showed the test image split in two vertical parts showing the left half of the image displayed to the right of the right half.

Image enhancement and analysis

Table 2 summarizes the overall results. However, this table indicates only the fact that a function is provided by the software. As indicated below large differences were found with respect to their implementation and usefulness.

Image display Of course, all programs can display images. While half of the programs offer 1D line profiles, only the Trophy software can display an image in 3D surface view. While Cliniview is capable of reducing images in size, it can not magnify them. Dimaxis, Emago, IOX Image Viewer, multiXray, Sidexis, and ProImage can interpolate images to any size, while all others restrict zooming to integer multiples of two by pixel doubling. Friacom does not offer tools for rotation or flipping, which are required for intra-oral imaging in portrait or landscape mode.

Point processing All programs enable interactive contrast and brightness adjustment, as well as image inversion. Only half incorporate more sophisticated image transforms, such as gamma correction. CDR, Friacom, multiXray, and Sidexis do not display the histogram of a radiograph. Direct thresholding is possible with Dexis and Emago only. Using multiXray, thresholding is obtained indirectly by interactively forming the corresponding mapping curve,[10] which is quite cumbersome. However, Dexis is the only software that does not offer any automatic contrast enhancement. Although the technical terms are well defined in the case of point processing, the function named equalization within the CDR software, in fact, performs a histogram spreading or stretching (clipping). The implementation in Friacom is 'buggy' in such a way that white (gray value 255) is switched to black (gray value 0) in any histogram transform. CDR, Cliniview, Dimaxis, Friacom, multiXray, and Trophy feature local adaptive histogram enhancement. The Cliniview, Friacom, and IOX Image Viewer programs do not offer any pseudo-coloration.

Spatial and frequency filtering The Emago software allows spatial filtering with user-defined masks up to 7×7 pixels in size. Therefore, one can define all common masks for noise reduction, unsharp masking, and gradient or relief computation. Contrarily, Friacom does not offer any filter at all.

Only Dimaxis, Emago, multiXray, Proimage, and Sidexis offer a non-linear median filter, which is capable of 'removing' salt and pepper noise or dead pixels in CCD arrays. Furthermore, Sidexis comes with a so-called 'black point filter', which replaces black pixels with the mean of their eight neighbors but leaves all other pixels unchanged. Hence, this filter removes dead pixels but avoids the smoothing incorporated by a median filter. Likewise, Trophy's 'advanced sharpness filter' emphasizes the contrast of bright structures (assumed to be bone or teeth) more than that of dark structures (assumed to be background). Trophy also comes with an inverse Wiener filter specially designed to enhance intra-oral images acquired with the RVG-5 sensor.

Measurements and image analysis All programs measure distances and lengths in the images after calibration. However, angles could not be determined with Dexis, IOX multiXray, ProImage, or Trophy. Areas can be measured only with Emago, Sidexis, and VixWin. Dexis and Emago offer a feature for comparing serially acquired images from the same patient's dental region. While Dexis performs a color addition without geometrical registration and contrast adjustment, Emago incorporates all tools required for digital subtraction studies. However, all Emago procedures are performed manually.

Annotations and miscellaneous About half of the programs allow the annotation of radiographs. Using the Friacom software, annotations are not restricted to text and lines; instead, the dentist can access a large database of implant shapes for computer assisted implant planning. Dimaxis, Friacom, multiXray, and Sidexis offer a region of interest where image processing and enhancement is performed exclusively, while all other parts of the image remain unchanged. The ProImage software offers advanced tools for pixel modification, which are usually found in common programs like Paint (Microsoft Corp., Redmond, WA, USA), PaintShopPro (Jasc Software Inc., Eden Prairie, MN, USA), or PhotoShop (Adobe Systems Inc., San Jose, CA, USA). System functions like undo and reset

Table 2 Image processing and enhancement

Image processing and enhancement	*CDR*	*Cliniview*	*Dexis*	*Digora*	*Dimaxis*	*Emago advanced*	*Friacom dental office*	*IOX image viewer*	*multiXray*	*Proimage*	*Sidexis*	*Trophy*	*VixWin 2000*
Image display													
Line profile (1D)	•	—	—	—	•	•	—	—	—	—	•	•	•
Image (2D)	•	•	•	•	•	•	•	•	•	•	•	•	•
Surface model (3D)	—	—	—	—	—	—	—	—	—	—	—	•	—
Zoom	•	—	•	•	•	•	•	•	•	•	•	•	•
Mirroring (flipping)	•	•	—	•	•	•	—	•	•	•	—	•	•
Rotation	•	•	•	•	•	•	—	•	•	•	•	•	•
Linear point processing													
Brightness adjustment	•	•	•	•	•	•	•	•	•	•	•	•	•
Contrast adjustment	•	•	•	•	•	•	•	•	•	•	•	•	•
Gray scale inversion	•	•	•	•	•	•	•	•	•	•	•	•	•
Non-linear point processing													
Gamma correction	—	•	—	•	—	•	—	•	•	—	—	•	•
Thresholding, binarization	—	—	•	—	—	•	—	—	•	—	—	—	—
Histogram-based point processing													
Display a histogram	—	•	•	•	•	•	—	•	—	•	—	•	•
Stretching (clipping)	•	—	—	•	•	•	•	•	•	•	•	•	•
Equalization	—	•	—	•	•	•	•	•	•	•	—	—	—
Local adaptive enhancement (AHE)	•	•	—	—	•	—	•	—	•	—	—	•	—
Pseudocoloration													
Arbitrary colors	•	—	—	—	—	—	—	—	—	•	—	•	—
Constant brightness	—	—	—	—	•	—	—	—	•	—	•	—	—
Increasing brightness	—	—	•	•	•	—	—	—	—	—	—	•	•
Equal gray value coloration	•	—	—	—	—	•	—	—	—	•	—	•	•
Linear spatial filtering													
Noise reduction	•	•	—	—	—	•	—	—	•	•	•	—	•
Unsharp masking	•	—	•	•	—	•	—	•	•	—	•	—	•
Gradient filter	—	—	—	—	•	•	—	—	•	—	—	—	—
Relief		—	—	•	•	•	—	—	•	•	•	•	•
Relief overlay	—	•	—	•	—	•	—	—	—	—	—	—	—
User-specific filter	—	—	—	—	—	•	—	—	—	—	—	—	—
Non-linear spatial filtering													
Median filter	—	—	—	—	•	•	—	—	•	•	•	—	—
Local adaptive filter	—	—	—	—	—	—	—	—	—	—	•	•	—
Frequency domain filtering													
Standard filtering	—	—	—	—	—	—	—	—	—	—	—	—	—
Inverse (Wiener) filtering	—	—	—	—	—	—	—	—	—	—	—	•	—
Measurements													
Calibration	•	•	•	•	•	•	•	•	•	•	•	•	•
Length	•	•	•	•	•	•	•	•	•	•	•	•	•
Angle	•	•	•	•	•	•	•	—	—	—	•	—	•
Area	—	—	—	—	—	•	—	—	—	—	•	—	•

continued

Table 2 continued

Image processing and enhancement	*CDR*	*Cliniview*	*Dexis*	*Digora*	*Dimaxis*	*Emago advanced*	*Friarcom dental office*	*IOX image viewer*	*multiXray*	*Proimage*	*Sidexis*	*Trophy*	*VixWin 2000*
Image analysis													
Contrast adjustment	–	–	–	–	–	•	–	–	–	–	–	–	–
Geometry registration	–	–	–	–	–	•	–	–	–	–	–	–	–
Subtraction	–	–	–	–	–	•	–	–	–	–	–	–	–
Color addition	–	–	•	–	–	•	–	–	–	–	–	–	–
Annotations													
Lines, arrows	•	•	–	–	•	–	•	–	–	•	–	•	•
Areas (circle, ellipse, rectangle)	–	–	–	–	•	–	–	–	–	•	–	•	•
Text	•	•	–	–	•	–	•	–	•	•	–	•	•
Implants	–	–	–	–	–	–	•	–	–	–	–	–	–
Miscellaneous													
Region of interest	–	–	–	–	•	–	•	–	•	–	•	–	–
Pixel manipulation	–	–	–	–	–	–	–	–	–	•	–	–	–
Undo function	•	–	•	•	•	–	–	–	–	–	•	•	•
Reset function	–	•	–	–	–	•	•	•	•	•	•	–	•

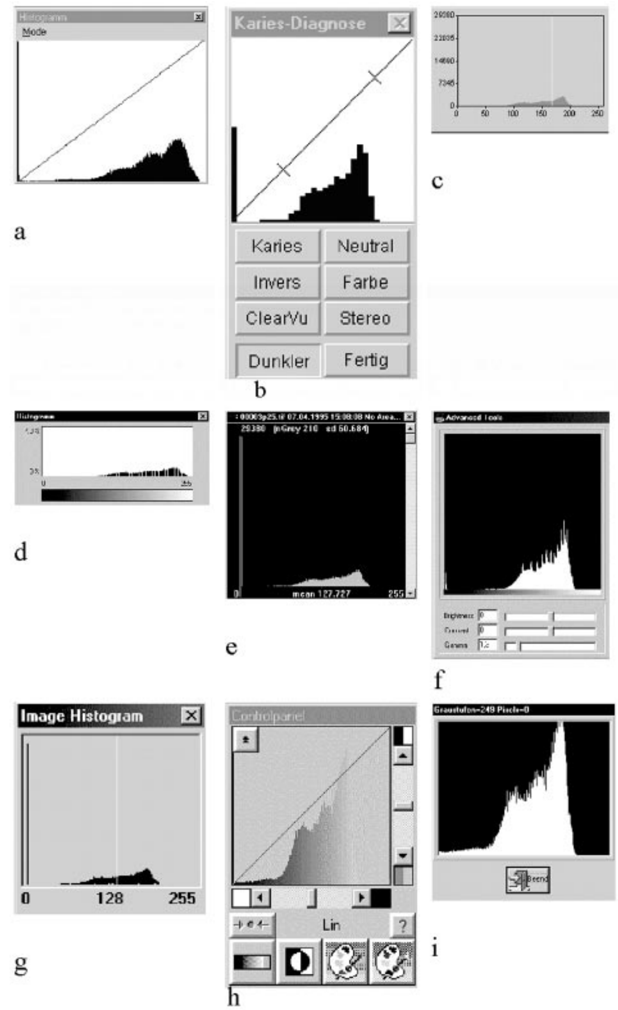

Figure 2 Histograms provided by Cliniview, Dexis, Digora, Dimaxis, Emago, IOX, Proimage, Trophy, and VixWin are shown in parts (a) to (i), respectively

become essential when applying any filter to an image; surprisingly, only Sidexis and VixWin offer both.

Discussion

The use of digital radiography is steadily increasing in dental radiology. A great variety of computer software is commercially available providing several functions for image processing and enhancement. Although technical terms and names of filters are well standardized, fancy names and symbols in dental software hide the underlying algorithms. Hence, dentists can neither compare the functionality of different software nor control the results of filters applied to assist or improve diagnosis. The results of this investigation elucidate the functionality and differences of 13 software programs. While all programs offer sufficient tools for point processing, spatial filtering is generally underrepresented. Only a small minority of programs supports serial studies and comparison of images. Except the Emago program, advanced image processing for automated registration and subtraction is not yet offered.

The findings in Table 2 are rather general. In some programs, not all functions are applicable to all images. Of course, the restriction of inverse Wiener filtering to images acquired with the corresponding sensor seems appropriate, but, for example, there is no reason to disable pseudo-coloring or spatial filtering for imported images.

Resulting from different details of implementation, the offered functions may vary significantly with respect to user friendliness and usefulness. For instance, Figure 2 shows the histograms of the same intra-oral radiograph computed by nine of the software programs under investigation. Typically, image regions, where the primary beam is unattenuated by the teeth or their supporting structures, may be comprised of adequate fluence to cause sensor saturation (i.e., signal clipping). Hence, each image contains a rather large number of black pixels. Therefore, a linear plot of the histogram reduces to a high bar on the left, as obtained by Digora, Dimaxis, Emago, and Proimage. VixWin optimally scales the histogram and hence, its visualization of the histogram has the most impact. Trophy colors the histogram with respect to the gray levels resulting in partly low contrast of the curve to the background.

In some programs, filters can only be turned on and off, but different filters cannot be combined or repetitively performed. A large collection of tools may not necessarily result in a useful program.[16] On the one hand, usage and handling must be intuitive and easy. For instance, 'playing' with the Emago's user defined filter is impeded by a missing undo function. One needs to leave the menu for general reset and then return to modify the filter function, which is a cumbersome procedure. On the other hand, the diagnostic value of some software features already offered still needs clinical evaluation.

The human eye has learned to analyse structures of pictures in a unique way. Psychophysical experiments indicate that photographic and radiographic images with enhanced edges are often more pleasing to the human visual system than the original pictures. But the tuning of an image with respect to a certain person might not provide the best view for other readers. In conclusion, one is attempted to assume that various methods for image enhancement are required to serve individual demands. However, standardized nomenclature must be used when those functions are incorporated in commercial dental software programs. Therefore, users should perform appropriate tests to assure themselves that image operations are doing what they are supposed to do. More specifically, users should assure themselves that they exactly know what an image operation is doing to their data.

Four programs can already import or export the DICOM file format. However, we did not analyse in this study whether this feature really offers an easy exchange of data. It is well known that the DICOM file format contains several trapdoors. Nonetheless, since the interchange of images will surely become easier in the future and the choice of a certain sensor technology will not necessarily determine the choice of software, manufacturers will definitely need to improve the quantity and quality of tools they provide for image exchange, enhancement, processing, and analysis. A good guideline for complete functionality can be adopted from NIH Image (National Institutes of Health, Bethesda, MD, USA) or ImageJ (National Institutes of Health, Bethesda, MD, USA), which are public domain image processing and analysis programs specially designed for medicine. In any case, manufactures have to acknowledge the technical nomenclature, which has been established for dental image processing.[10,11]

In conclusion, image processing and enhancement functions are rarely incorporated in commercial software for direct digital imaging in dental radiology. Until now, comparison of software was limited by the arbitrary naming used in each system. In future, standardized terminology and increased functionality of image processing should be offered to the dental profession.

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