

Simple Post-Processing of Medical Images

Eun-Kee Jeong

Most of medical images, especially tomographic images, are in digital. It is worth getting these digital data onto the personal computer and doing extra post-processing without much difficulties. The extra processing of obtained medical images may not give the great benefits for clinical purpose, however it is recommended to analyze obtained images more quantitatively for publication or presentation of one's results. Simple post-processing of MR and SPECT images was achieved using a public domain image processing software (NIH Image 1.56) on a Macintosh computer. The general concepts of the file transfer, the reading of the images into the software, and some examples of the processing are to be discussed.

Key Words: Post image processing, medical images

The plain X-ray radiography has played very important role as a diagnostic tool in diagnostic radiology, since it was developed. It still does for directing next step of diagnostic measurement. In these days, much more sophisticated imaging systems, such as X-ray CT, MRI, SPECT, and PET, are used for more accurate diagnosis. All these systems are controlled by, at least, medium ranged workstations. Computers in medicine, especially in radiology, are used for controlling the system, and for constructing relevant images from measured raw data. The constructed images may be transferred to a workstation for planning of radiation therapy. We get more convenience and accessibility in imaging of internal sections of human body, with the help of computerized operation.

In general, one may get two major benefits of using computers in radiology. First is the flexibility of selecting the values of param-

eters involved in scanning. For example, there are many different techniques (pulse sequences) for MR imaging. The relevant parameters are different for different pulse sequences. They are, in general, repetition time TR, echo time TE, flip angle α , inversion time TI, etc. timized by choosing appropriate values of pulse parameters with respect to the disease and anatomy to be imaged. Secondly, in contrast to plain X-ray images, images obtained by these computerized systems are in digital, i.e., in number, so that the post-processing of images is possible. Radiologists are trained to see the difference between images to be compared, such as images with and without contrast agent, or images of normal and abnormal tissues. Sometimes, the difference is too small to be seen with bare eyes, and an important feature may be missed. In this case, one may subtract one image from the other, and the resultant image would show the difference in signal intensity, pixel by pixel. This kind of processing may be more helpful for pursuing researches than for clinical applications.

Even though the computer system of a clinical imager, especially an MRI system, is very powerful, only very minimal post-process of

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Department of Diagnostic Radiology, Yonsei University College of Medicine, Seoul, Korea

Address reprint requests to Dr. E-K Jeong Department of Diagnostic Radiology, Yonsei University College of Medicine, C.P.O. Box 8044, Seoul 120-72, Korea

obtained images is allowed for a user, except for the clinical needs. Since doing any post-processing takes extra time, it may interrupt scanning next patients. Thus, if one needs to do more quantitative analysis on the images especially for presentation or publication of his/her result, it is recommended to move the image data off the imaging system to a personal computer, and use a PC based image processing program. It may be fair to say that an article with quantifying image analysis is more scientific than the one with just visual

analysis. Many radiologists may not be accustomed to manipulate their image data on personal computers. A method of non-sophisticated image processing will be described in this article.

MATERIALS AND METHOD

A very simple image analysis is shown in Figure 1. The array of phantoms with differ-

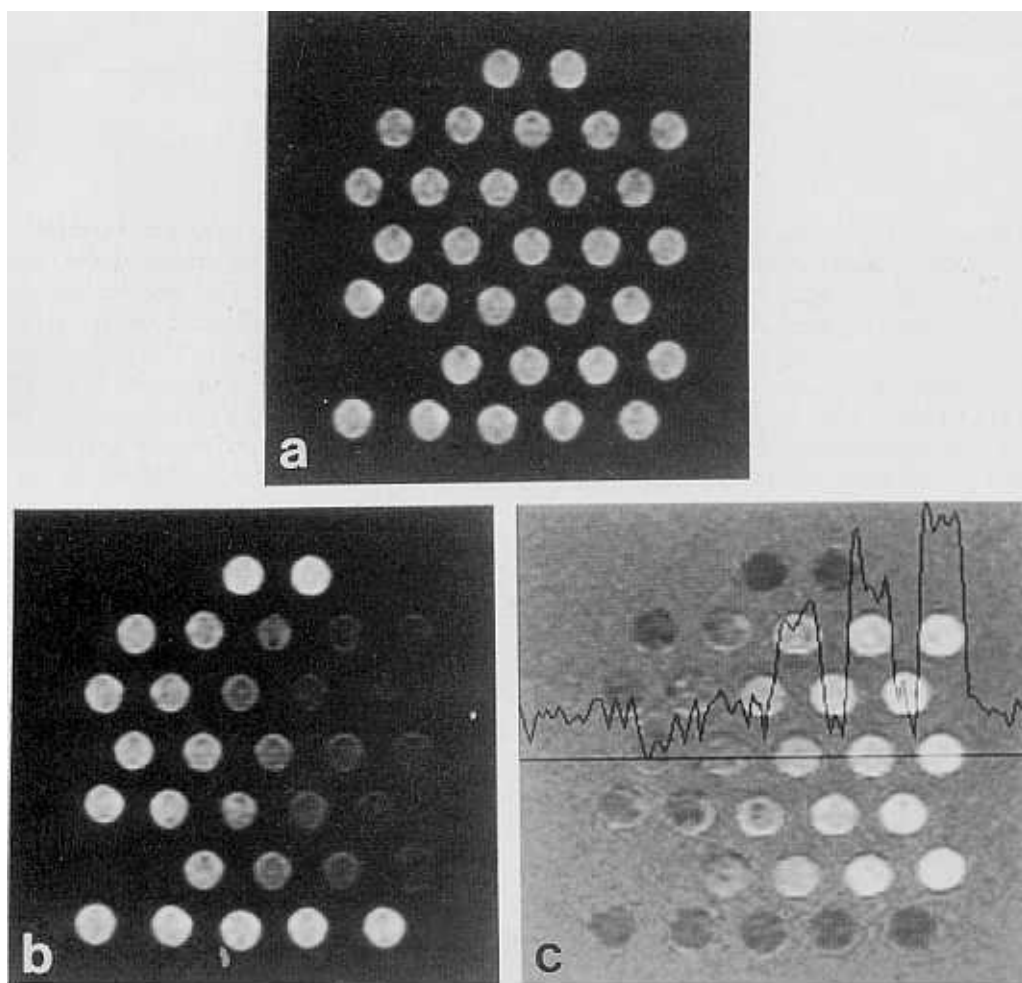


Fig. 1. Figure (a) and (b) are a sum (in-phase) and a difference (out-of-phase) images of protons in water and fat molecule in the array of phantoms. The image (c) was obtained by subtracting (b) from (a), and represents the distribution of fat. The profile plot on (c) is an intensity plot along the middle horizontal line.

ent concentrations of oil and water was imaged with in-phase (a) and out-of-phase (b) techniques of MR. Fig. 1(a), and (b) are the sum and the difference of images of the protons in fat and water molecules in the array of phantoms, respectively. The obtained images were transferred to a Macintosh^a computer, then subtracted. The subtracted image (c) represents the spatial distribution of oil in the phantoms. The profile plot on (c) is an intensity plot along the middle horizontal line.

Once the raw data is taken and the images are constructed on an imaging machine, they need to be transferred to the computer, in which the post-processing is to be performed. And the transferred image has to be correctly read by software. It is not straightforward to transfer and read the digital images, as one may hope. The details will be described in this section.

Materials

There exist many commercialized image processing softwares for personal computers or midsize workstations. Even though the capability varies, they basically do similar jobs. Some of them, such as PV Wave^b and IDL^c are very powerful and for professional use. With those professional image processing softwares, one can perform complicated processing, such as 2 and 3 dimensional FFT, inverse FFT, designing filters, and 3D rendering, etc. But these are too much for general purpose, especially for the simple post-processing of medical images for publications.

A public domain software *NIH Image* (written by Wayne Rasband at the U.S. National Institutes of Health and available from the Internet by anonymous ftp from [zippy.nimh.nih.gov](ftp://zippy.nimh.nih.gov) or on floppy disk from NTIS, 5285 Port Royal Rd., Springfield, VA 22161, part number PB93-504868), will be discussed in this article. This software exists only for Macintosh, which is known to have the best graphic capability and the easiness of operation among personal computers on the market. It is being updated once a month on the average for fixing programming bugs and for enhancement, and well maintained. Even though it is not as

powerful as some professional software, *NIH Image* has most of the functions, by which the medical images may be processed. It even supports macro programming for frequently used routine (Wayne Rasband, 1994).

The images to be used as examples are MR images taken by Siemens MR system^d, GE MR system^e, and SPECT image from ADAC Gamma Camera^f. The same idea can be applied for processing of images from other imaging systems, as long as the information about the file is known.

The computer used for the image processing is a Macintosh LC(16MHz clock speed) with FPU(floating-point unit) coprocessor, 8 bit video, and 10 Mbytes of physical RAM. 2.5 MByte or more of RAM was assigned for *NIH Image*.

Image data transfer

A medical image in a computer is stored in a file as the array of numbers corresponding to the array of pixels or voxels, and displayed on the computer monitor as different color depending on color look-up-table or different depth of gray. This file needs to be transferred to a computer, on which the image is to be post-processed. The methods of data transfer are described as following. Whichever method is used, the initial hardware setups are not trivial. The best way might be the consideration of the preferred setup at the purchasing stage of the imaging system.

Network transfer: Files in one computer can be transferred to others through network, with Ethernet board or LAN card installed on both parties. This is the fastest and the most convenient way of transferring files among different computers without losing any information. It does not matter what OS is used by each side, as long as the Ethernet board and necessary software are installed. There are 3 popular ways of connection, Twisted-pair, 10-BaseT (TPE), and AUI, using phone-line-like 6 wires, BNC, and AUI cable respectively. They can be networked as far as 50, 150, and 500m respectively. These days, Twisted-pair and 10-BaseT(TPE) are becoming standard.

Once the hardware is ready on both sides, softwares have to be installed. The Ethernet communication requires TCP/IP software as the driver. The basic softwares using Ethernet and TCP/IP are "telnet" and "ftp". "Telnet" is a typical protocol for accessing account on main computer from PC or Macintosh. There exists other communication softwares which implement telnet function. But for the Macintosh, *NCSA Telnet*⁸ is a very good public domain software. One can download *NCSA Telnet* by login as anonymous ftp to ftp.ncsa.uiuc.edu. (See Appendix A for obtaining files via anonymous ftp.) Files can be downloaded or uploaded by using "ftp", which is a method of file transfer between Ethernet networked computers.

Serial line transfer: In addition to Ethernet networking, one may use serial port communication with modem—a device which converts a digital signal to an analog signal for the telephone line transmission, or the other way around. A desktop computer generally has two RS232 or IEEE422 serial ports. Modem transfer uses these serial ports and the telephone line, and this can go as far as from one city to others, as long as one is willing to pay long distance bill for file transfer. Typical modem communication is much slower than Ethernet communication, and the noise in the telephone line may damage file while it is being transferred, so that it is not appropriate for the transfer of large volume of files.

A null modem cable, which does not use actual modem but just a cable, can be used. It is simply 3 or 4 line cable connection between two serial ports. Two parties can communicate as fast as 57600 Baud, as long as computer hardwares support. This method is safe, as far as the distance between two computers is in the order of several meters, and it is very cheap way.

Media transfer: These days, most of the computers are equipped with at least one media drive—floppy disk drive, hopefully 3.5". There are better and more capacitive media, such as magnetic tape, optical disk drive (ODD), magneto-optical drive (MOD), or digital archive tape (DAT). These media can be used for file transfer. This method is slow, and

more expensive (if not using floppy disk transfer) than network transfer, but it is not limited by distance. If there are many different kinds of computers, among which the files are to be shared, media transfer may cost quite high because of media drivers.

A popular operating system (OS) for workstation, UNIX, uses "tar" for file backup. A personal computer should have a software to read and write "tar" file. As an example, there are two public domain softwares *suntar* and *tar* for Macintosh. And *mtool* on UNIX may be used for accessing MSDOS formatted PC diskets.

Using scanner: If network and media transfer are not available, the printed film may be scanned using a scanner. Overall contrast can be retained, but information will be lost in printing film and scanning process. Therefore the reliability of quantitative analysis decreases. It can be neglected for certain circumstances, but in general, any information is too valuable to be lost, because much effort has been put into developing software and hardware to improve image quality.

Reading image

Image file formed by a medical imager is consisted of a header, a body of image in binary numbers, and maybe a tail. The image header contains all the informations related to scanning, for example in an MR file, matrix size, pulse sequence name, value of TR, TE, and flip angle, and patient's name and age, etc. are stored in the header. Each manufacture uses different file structure, with different file header format and size. For example, an image file of GE MR, Siemens MR, and ADAC SPECT has 14,336 bytes, 8192 bytes, and 2048 bytes of header respectively.

Following the header, a binary image data is stored in the ascending order from coordinate (1, 1) in 2 dimension or (1, 1, 1) in 3 dimensional image. Each pixel (2D) or voxel (3D) has signal intensity as a number. This number is stored in corresponding address in a file. Generally, 16 bit (2 Byte) resolution is enough for MR image. GE Signa MR and Siemens MR use 16 bit signed integer as their binary raw data. 16 bit can represent numbers

ranging from 0 to 65535 (16-bit unsigned integer), which has $2^{16}=65536$ different steps. It can be re-written as -32768, -32767, ..., 0, 1, 2, ..., 32767, and called 16-bit signed integer. Typical MR imager displays MR images in 8 bit (256 scale) gray level, even if data are stored in 16 bit.

When an image file transferred from a different platform (CPU based computer) is to be read on one computer, whether byte swapping is necessary or not should be considered. 16 bit is 2 bytes, which corresponds to 2 rooms *A* and *B* in a computer memory. One can put two persons *a* and *b* in the order of *A(a)B(b)* or *B(a)A(b)*. If the transferred file is originated from *A(a)B(b)* order and is to be read on a computer with *B(a)A(b)* order, every two neighboring bytes should be swapped-byte swapping.

PC (Intel 80×86 CPU) and Siemens MRI software running under VMS OS, use Intel byte order, and SUN with UNIX OS and Macintosh use Motorola byte order. Byte swapping is necessary between Intel and Motorola byte order, and not between files with same byte order.

Image analysis software requires minimum information about the image file to be read.

They are matrix size, header size, number of slices for stacked image file such as 3D image file, resolution (8 bit or 16 bit), and if byte swapping is needed.

Image post-processing with *NIH Image*

NIH Image is a image processing software for Macintosh, which has the best graphic ability among personal computers. Its function is not limited for post-processing of only medical images (Wayne Rasband, 1994). Since *NIH Image* is not commercialized software but public, it is worth trying its power as long as the necessary hardware (computer) is available.

Once the image file is read into the software memory, it is ready for various processing. They may be colorized for presentation, simple mathematical analysis such as subtraction, filtering, or copying into a slide-making software for presentation, etc.

Many mega-Bytes of RAM (Random Access Memory) is needed for image processing, depending upon how many images to be read into. *NIH Image* requires minimum of 2.5 MBytes of RAM. Video has to provide 256 colors or gray levels(8 bit). Since *NIH Image* does not have heavy math functions such as FFT, it runs fine on low-cost Macintosh.

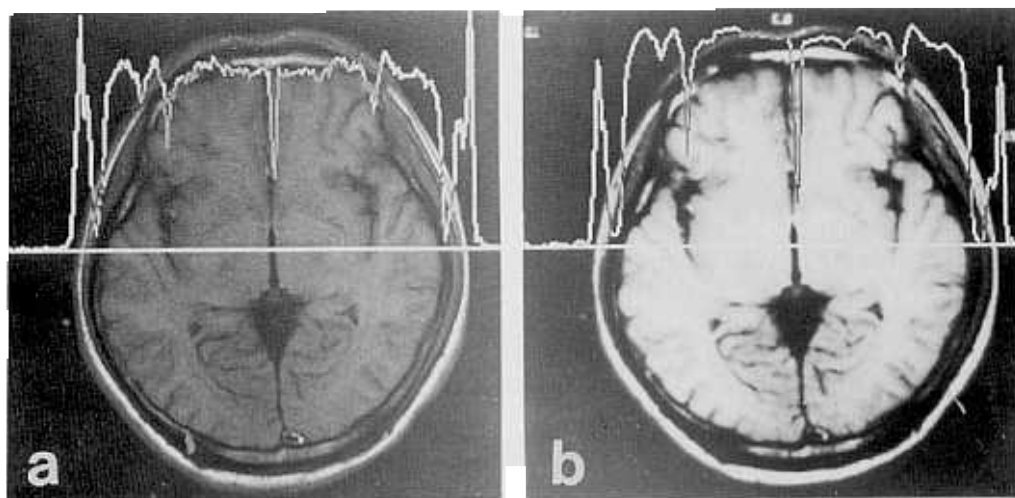


Fig. 2. Above figure is for comparing the qualities of a digitally transferred image (a) and a scanned image (b) of the same MR image. Graphs in the middle of each image are intensity plots along the same horizontal lines.

Sample Session

An MR image will be read in and some simple processed images will be shown. This image was taken on Siemens Magnetom 1.0T MR imager, which a Macintosh is networked through Ethernet. A Siemens MR image has 8192 bytes of header, and the raw image is in 16-bit signed. Main host computer of Siemens Magnetom is MicroVAX, running with VMS OS, and it uses Intel byte order. Byte swapping is necessary to read VMS image on Macintosh correctly. The image to be read has

256×256 matrix.

Reading an MR image: As described in previous section, proper values of several parameters should be given into the software to read an image correctly. Following is an example session for reading a 256×256 Siemens MR image into *NIH Image*.

- 1) First, launch *NIH Image*. This will load necessary code from harddisk to RAM for program execution.
- 2) Select "Import" under "File" menu.
- 3) Look for an image file to be opened, and click "custom" and "Set..." buttons in a row.
- 4) Type 256, 256, 8192 into "Width",

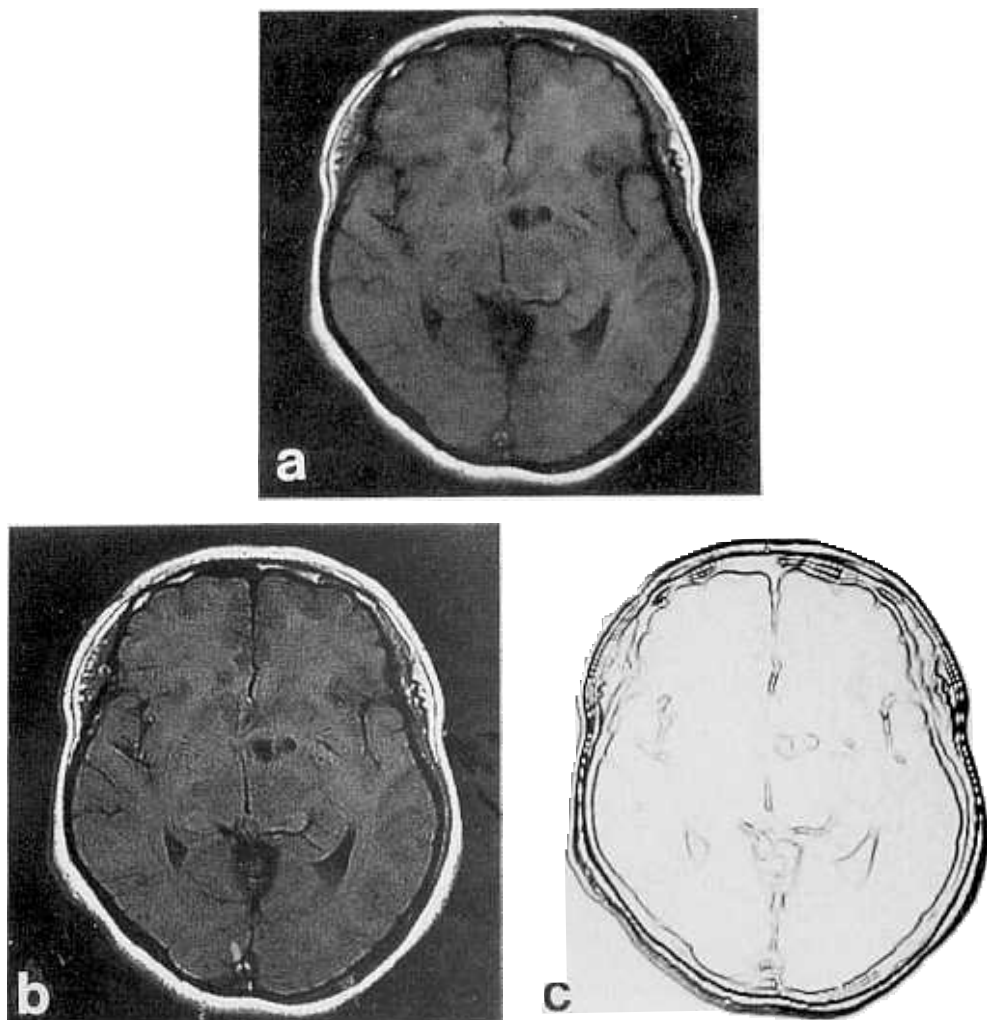


Fig. 3. An MR T1 image (left) was processed with sharpening filter (middle), and edge-tracing filter (right).

"Height", "Offset" of next selection dialog box respectively. These numbers may differ for different images. The offset value for GE MR images is 14,336 bytes.

5) Input number of slice into "Slices" and click "OK". In this case it is 1, because the image is a 2D planar image. But if a 3D image is to be read, one may input other number of slices as long as the allocated RAM allows. As an example, a 256×256 , 2 Bytes (16 bit) image takes 131,072 bytes, and 10 of them will take 1.3 Mbyte.

6) File selection box will appear again, then select "16-bit Signed" and "Swap Bytes". The

button "Open" is ready to be clicked. If reading GE MR images, "Swap Bytes" option should not be checked.

The selected image will be displayed in gray scale, and ready for post-processing.

Comparison of transferred and scanned images: As mentioned in previous section, images(or graphics) scanned via a graphic scanner, generally introduce arbitrary distortion during scanning process, so that the quality of the obtained images is obviously worse than that of the digitally transferred image, which no information is lost. It may not be important if the images are only for the routine

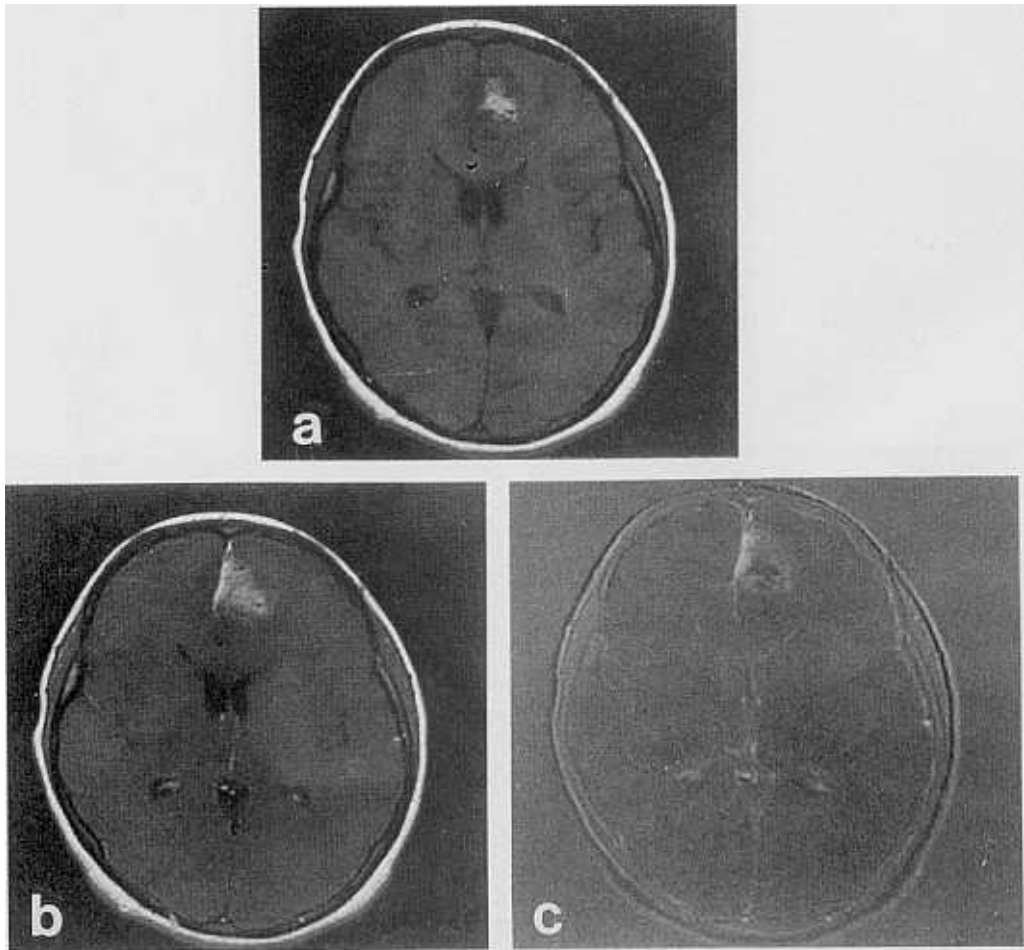


Fig. 4. Above figures are (a) T1 MR image, (b) Gd-DTPA enhanced image with same parameters as (a), and (c) subtraction image (a-b). Enhanced regions are seen more clearly on the subtracted image.

and clinical diagnosis. But it is not desirable for the quantifying analysis of the images.

Figure 2 (b) is an extreme example of image degradation by scanning. The image (a) was digitally transferred to Macintosh via the Ethernet, and (b) was scanned from the printed film of the same MR image as (a). Each image has a profile plot along the same horizontal line. Although the scanned image quality may be improved by adjusting some scanning parameters, there is always degradation through scanning compared to the origi-

nal digital image.

Post-processing: Once the image files are successfully read into the software, one can perform many different post processing, as one desires. This section will introduce some basic examples of image manipulation.

An MR image may be filtered by, such as sharpening, edge-tracing, or smoothing for better visualization. (a) in Figure 3 is an original MR image, and it is sharpened (b) and edge-traced (c). There are many other filters, and user may even design his/her own filter. It is

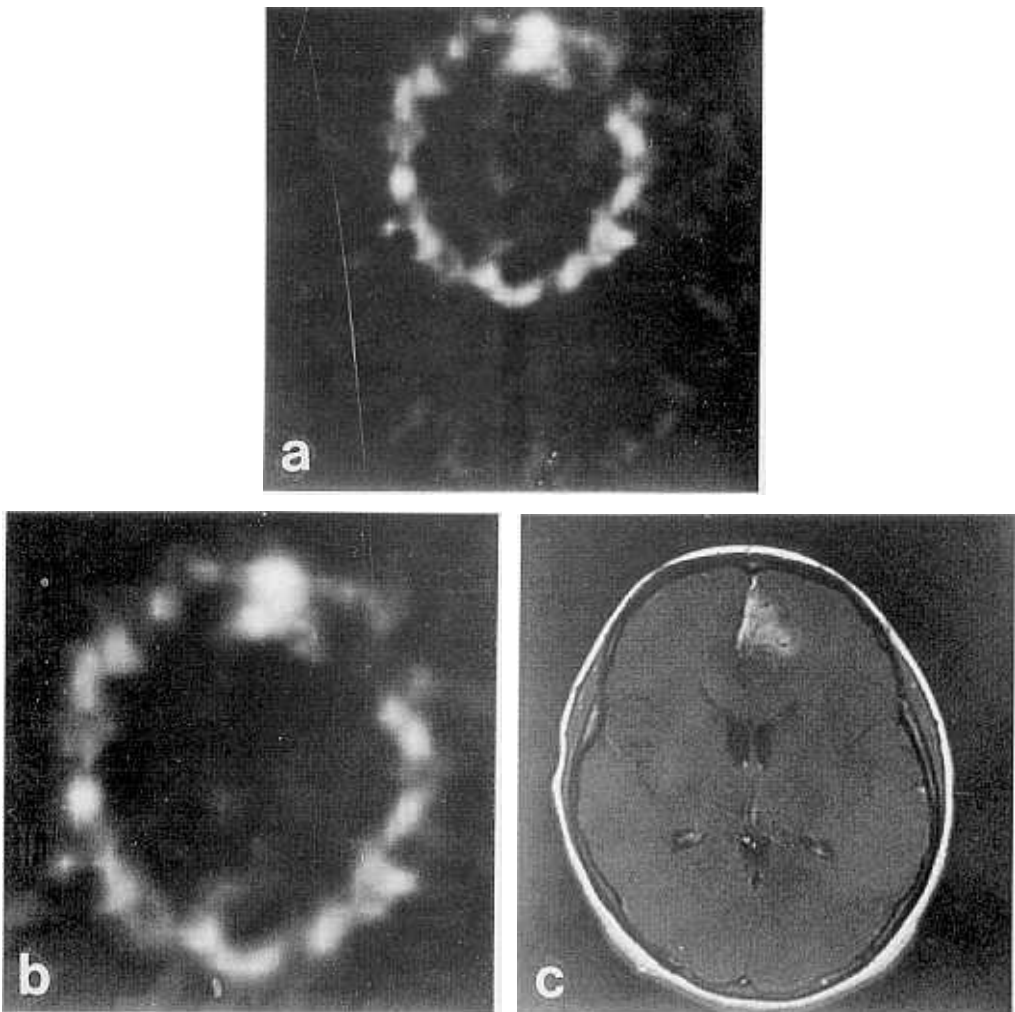


Fig. 5. Above figures are (a) a SPECT image, (b) scaled and rotated image of (a) to fit MR image (c), and (c) MR image of corresponding slice of SPECT image (a).

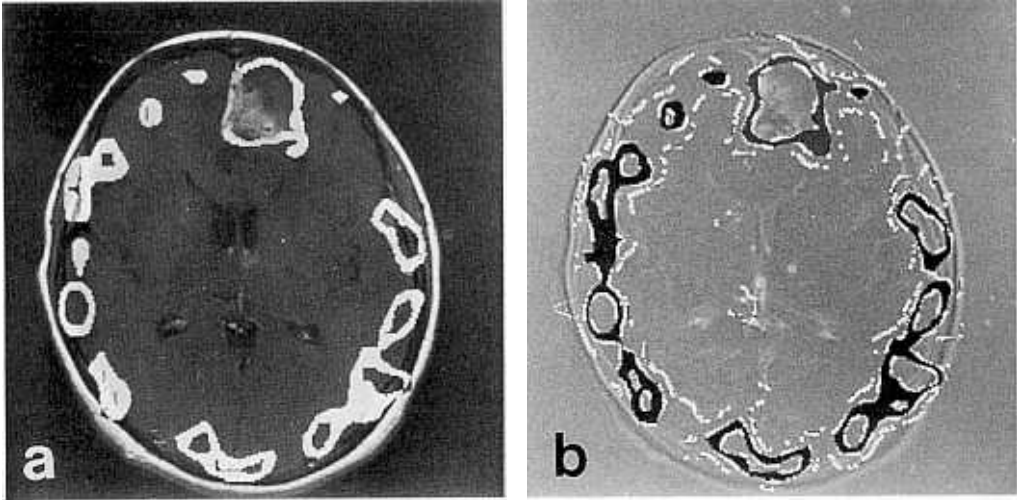


Fig. 6. Image (b) and (c) of Figure 5 are co-registered with different effects. Figure (b) is overlaid image onto the subtracted output of Figure 4 (c).

as simple as manipulating numbers. But mostly, designing of new filter was not necessary for author's case. The effects of different filters are generally obvious, because their outputs are graphically displayed.

Simple algebraic manipulation of images is a basic and very useful technique for the post-processing. Figure 4 shows MR images of a patient's brain, without and with Gd-DTPA injected, and a subtracted image. Figure 4 (b) is supposed to represent the enhancement by Gd-DTPA on top of the image 4 (a). As seen on subtracted image 4 (c), the difference is sometimes very small to be seen by bare eye. *NIH Image* provides add, subtraction, multiplication, and division between two images.

One of the most important processes with the medical images may be the co-registration (or overlaying) of two or more images (Kapoulea *et al.* 1991; Turkington *et al.* 1993). SPECT and PET images are very valuable in functional mapping of certain microscopic metabolism, but are known to give poor anatomic information. Co-registered image of such a functional image onto a corresponding anatomic image like an MR or a CT may help radiologists and neurosurgeon to pin-point exact location of region of interest. Figure 5

show unregistered SPECT and MR images of similar slice of a person's head, which are different in resolution and rotated each other. A SPECT image (Figure 5 (a)) was scaled (b) to fit onto MR image (c). Before overlaying of two images, one needs to be rotated corresponding to the other. Figure 6 represents co-registered images of base SPECT and MR images with different filters or different representation. Log (logarithm) was applied onto the image in Figure 5 (c), and after thresholding the 5 (b), they were co-registered each other as in Figure 6 (a). Figure 6 (b) is the fused image of 5 (b) and Figure 4 (c) of the same person.

Overlaying of images can be used not only for the representation of SPECT and PET images onto the anatomic image, but for better display of an MR angiography onto a T₂ spin-echo image for an anatomic background [4]. This technique may be used for routine clinical diagnosis. The overlaid image (c) of an MRA of brain in Figure 7 (a) onto a T₁ spin-echo MR image (b) looks very clear.

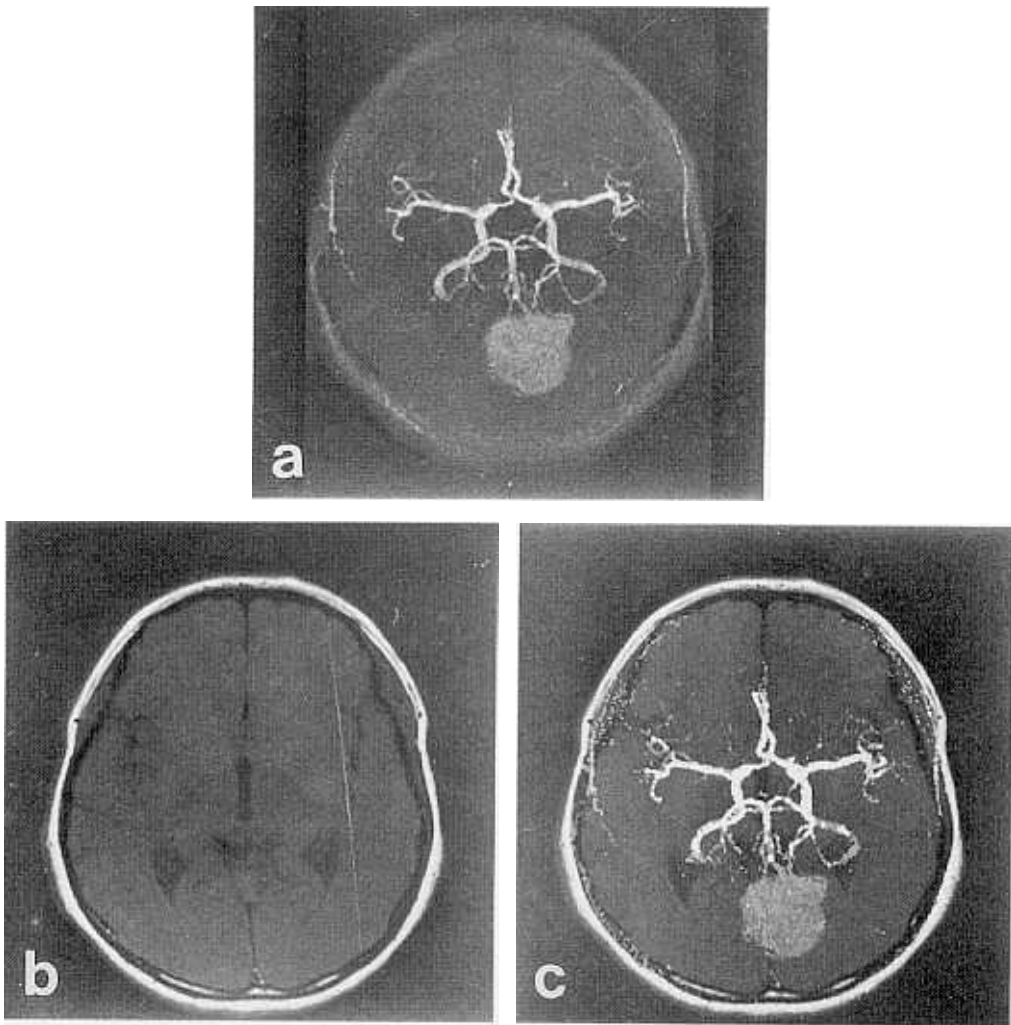


Fig. 7. An MR angiography (a) is overlayed onto an anatomic T1 spin-echo image (b), and the output (c) gives quite different effect.

RESULTS

MR images from GE Signa and Siemens Magnetom, and the SPECT image from ADAC were successfully read and processed.

Some basic post-processing such as algebraic processes, filtering, and measurement in a selected region of interest (ROI) were performed

and yielded in various different results. Sometimes, colorizing specific region helped for discriminating ROI from the rest of the region. In general, the post-processed images gave good outputs depending on the purpose.

More precise co-registration of SPECT and relevant MR images can be performed with the reference markers like using a stereotactic frame, which can give both MR and SPECT signals.

The overlayed angiography is easily ob-

tained without difficulty, once the image data are transferred to a Macintosh computer. This technique may be clinically useful for MRA of knee, and brain.

It is intended to help analyzing medical images, such as MR, CT, and images of nuclear medicine, more quantitatively. It is hoped that the examples given in the sample session give enough help for one to get started without much difficulties. Then, once got started, a user can try various functions in the program and see the effects. The post-processing may exaggerate a lesion on the resultant image and result in decreasing the quality of un-processed image, so that one must be careful not to over-emphasize the images. Except for this problem, the extra processing of the obtained images can be very useful, especially for publication and presentation of one's result.

Even though some professional help may be necessary to establish the initial setup of hardware and software, especially for file transfer, it will be worth spending such efforts for valuable outputs.

APPENDIX A. Binary number

When one says a number, it is generally a decimal number. But a computer treats every number in binary. For example, a decimal number 59 is 0011 1011 in 8 bit binary, or 0000 0000 0011 1011 in 16 bit. Here 1/0 may be considered as ON/OFF. Let's consider a row of 8 light bulbs, which have separate switches. In this system, 256 different array can be arranged as 0000 0000 (=0: OFF OFF OFF OFF OFF OFF OFF OFF), 0000 0001 (=1: OFF OFF OFF OFF OFF OFF OFF ON), ..., 1111 1111(=255: ON ON ON ON ON ON ON ON). This is 8 bit or 1 byte

Computer, in general, treats an information in unit of byte, as 1, 2, 4 byte integers, or 4 byte floating point numbers. *NIH Image* can read only 1 byte (8 bit) or 2 byte (16 bit) binary files.

APPENDIX B. Obtaining *NIH Image*

NIH Image is an open software for public, but it is not ready for use next to us. Public domain softwares are stored in so called

"anonymous ftp" site, typically a workstation located in some university computer centers. This can be accessed via internet, a universal network. Some effort has to be made to get these public domain softwares. One needs to have a UNIX account on a computer connected to internet, and some basic UNIX knowledge may help for further process. Otherwise, he/she has to seek for a help for getting the software.

Following is an example session for obtaining a public domain software *NIH Image* and some relevant files via "anonymous ftp". "phy>" is the prompt on the local host computer in this example session.

```
phy> ftp zippy. nimh. nih. gov.
Connected to zippy. nimh. nih. gov.
220 zippy FTP server (Version 1. 7. 109. 2 Tue
    Jul 28 23: 32: 34 GMT 1992) ready.
Name (zippy. nimh. nih. gov: ekj): anonymous
331 Guest login ok, send ident as password.
Password: (ekj@)
230 Guest login ok, access restrictions apply.
ftp> cd pub/nih-image
250 CWD command successful.
ftp> ls
200 PORT command successful.
150 Opening ASCII mode data connection for
    /bin/ls.
total 4474
contrib
user-macros
plug-ins
00README.txt
nih-image156beta18. hqx
programs
nih-image-spinoffs
stacks
nih-image155-source. hqx
nih-image155-nonfpu. hqx
nih-image155-fpu. hqx
nih-image155-docs. hqx
documents
images
226 Transfer complete.
1058 bytes received in 5.8 seconds (0.18 Kbytes
    /s)
ftp> get nih-image155-fpu. hqx
200 PORT command successful.
```

```
150 Opening ASCII mode data connection for
    nih-image155-fpu.hqx (404597 bytes).
226 Transfer complete.
local: nih-image155-fpu.  hqx  remote: nih-
    image155-fpu.  hqx
1809 bytes received in 1503.1 seconds (0.57
    Kbytes/s)
ftp> quit
221 Goodbye.
phya>
```

The file "nih-image155-fpu.hqx" will be transferred into the internet server, and it now has to be transferred to a personal computer(Macintosh). One may use modem communication, or floppy disket if the host computer is equipped with floppy disket drive. Details for this will not be described here, but it is not too complicated.

Even though the file "nih-image155-fpu.hqx" is transferred onto a Mac, it is not ready for use. It is compressed and encoded, so another software StuffIt Expander is needed for decoding and uncompressing. This public domain software StuffIt Expander may be obtained in local Apple dealer with no cost.

If one has a Macintosh without a FPU, the file "nih-image155-nonfpu.hqx" is the right version for that. The user manual is encoded as "nih image155-docs.hqx", which is necessary for the beginner. But most of the functions may be tried by just selecting menus, as in most window based softwares.

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- a. Apple Computer, Inc., Cupertino, CA 95014, USA
- b. Visual Numerics, Huston, TX 77042, USA
- c. Research System, Inc., Boulder, CO 80303, USA
- d. Siemens Medical System, Henkestrasse 127, D-91052 Erlangen, Germany
- e GE Medical System, Milwaukee, WI 53201, U.S.A.
- f. ADAC Lab., Milipitas, CA 95035, USA
- g. NCSA, Univ. of Illinois, Urbana-Champaign, IL, USA