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NASA IMAGE PROCESSING TECHNOLOGY APPLIED TO MEDICINE:
TEN UNSOLVED PROBLEMS IN MEDICAL IMAGING

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ABSTRACT

The solutions to current diagnostic
imaging problems will be found, at least
in part, in digital image processing
technology developed by NASA. The
adaptation of appropriate technology
that can be applied clinically to
improve the care of patients is a major
concern of radiologists.

We have considered ten problems with
clinical significance in diagnostic
medical imaging, and discuss the impact
of NASA image processing technology
presently and predict future developments
in this area.

INTRODUCTION

Digital image processing technology has
developed in the civilian sector largely
as a result of the pioneering work done
in the late 1960's by NASA's Jet
Propulsion Laboratory.

Presently, diagnostic medical imaging
is undergoing a significant change in
character to incorporate digital methods
of image acquisition, processing,
transmission, storage and display. To
a surprising degree, the developments
in digital medical imaging parallel the
earlier work by NASA in planetary imaging
and remote sensing of environment.

In our own work at a large metropolitan
medical center, several NASA-developed
image processing techniques and software
modules have been incorporated in our
diagnostic imaging systems. We expect
that this area of development will in-
crease significantly in the future, and
have analyzed several new problems that
may find solution using this NASA
technology.

The digital imaging systems found in [21,22]
a modern radiology department include:

1. Nuclear Medicine - The scintigra-
phic data obtained after injection of
low level short-lived radionuclides
is digital since radioactive decay is
detected event by event. Nuclear
medicine has traditionally been most
sophisticated in the use of image
processing technology in all of
radiology.

2. Computed Tomography - Transaxial
x-ray computed tomography is based on
reconstruction from projections using
mathematical algorithms realized using
a digital computer or array processor.

3. Ultrasound - Whether B-mode or
real time, diagnostic ultrasound sys-
tems are almost always implemented
using digital hardware incorporating
a microprocessor controller and
discrete image frame buffer.

4. NMR or Magnetic Resonance imaging
systems - The newest modality, based
primarily on the weak paramagnetic
properties of protons (e.g. hydrogen)
in body tissues, reconstructs images
using 2-dimensional Fourier transform-
ation (usually) in a digital computer
and array processor.

5. Digital Vascular Imaging (some-
times called Digital Subtraction
Angiography) - By interfacing a
digital computer to a fluoroscopic x-
ray system, change detection in an
image sequence can be performed. The
change that is of most interest is due
to the presence of iodinated contrast
material in the subject's arteries
after intra-venous or arterial injection.

Digital imaging in radiology did not exist for routine clinical use more than 10 years ago. Within the last five, and especially the last three years, we have experienced a significant increase in the availability and capabilities of digital imaging systems in diagnostic radiology.

The availability of digital imaging systems has not been a panacea. The overall impact of the introduction of digital imaging technology has been positive in terms of improvement of patient management and outcome, but all the promises made with these systems have not been realized. The quality of digital images has improved in many of these systems, but the improvements that we see in the more mature technologies (CT, ultrasound, nuclear medicine) have been smaller and less frequent recently.

UNSOLVED PROBLEMS

There are many significant problems in diagnostic imaging that do not have satisfactory solutions at the present. These problems will probably be solved using digital techniques of image acquisition, processing, transmission and storage developed by NASA. We have had considerable experience with several of these problems, and are involved in planning and experimentation to derive solutions.

The problems we will consider include:

1. Direct visualization of the coronary arteries without cardiac catheterization. (1)

2. Tissue characterization in tomography. (2,3)

3. Three dimensional reconstruction from two dimensional images. (4,5)

4. Management of diagnostic information, especially image data.

5. Screening for early cancer.

6. When is a vascular stenosis significant?

7. Direct imaging of brain activity.

8. Early fracture healing and complications.

9. Direct visualization of pulmonary emboli without film angiography.

10. Early detection of hip disease due to bone mineral loss or aseptic necrosis.

Coronary arteries: Short of cardiac catheterization, a procedure that is costly and involves small but significant risk of complications, no cardiac diagnostic method directly images the coronary arteries. In the future, digital imaging of the heart should provide a means of directly imaging the coronaries, the most common site for development of heart disease.

Tissue characterization: We have good tools for non-invasively imaging the morphologic changes associated with many diseases. These tools include CT, NMR and ultrasound. At present, none of these modalities can accurately classify the type of tissue in a given scene. As an example, if a patient with a tumor is treated and images obtained as a follow-up, we cannot tell the difference between dead tumor (e.g. fibrosis) and a recurrence in many instances. Classification methods, based on multispectral remote sensing technology applied to medicine, may help resolve these cases.

Three dimensional reconstruction - We have been successful at computing high quality CT reconstructions (4,5) using air-soft tissue and soft tissue-bone interfaces. The problem becomes far more complex when soft tissue-soft tissue interfaces, such as brain gray and white matter or brain and CSF interfaces are used. We have, at this time, no satisfactory method for gray level segmentation in these monochrome (CT scan) scenes.

Picture archiving - The number of images produced during a single day in a radiology department is very large. Our institution performs roughly 300,000 examinations per year, nearly 1000 per day. Some examinations may require several hundred images. The management of this information is costly and in the future, automated methods for image acquisition, transmission, storage and display will be needed.

Cancer screening - Sensitive and specific imaging methods for cancer screening will likely develop as a result of the influence of digital technology on radiology. Computer aids to image understanding can be helpful in identifying subtle findings in high volume procedures performed for screening.

Vascular stenosis - If a narrowing (stenosis) in an artery is significant, surgical intervention is often warranted. These stenoses become significant when the narrowing impedes flow (less than 50% patency) or the artery's surface is so irregular (ulcerated) plaque) that it may cause clots to form and cause a stroke or heart attack. The assessment of vascular stenoses is usually performed by visual qualitative estimation. Digital methods may permit quantitative evaluation of vascular stenoses in routine clinical practice (6,10).

Brain imaging - We have excellent tools for morphologic study of the intact human brain (CT and NMR). The functional assessment of brain metabolic activity is performed quantitatively using positron emission tomography (PETT). In the future, Brain Electrical Activity Monitoring (BEAM) technology may be useful in imaging the brain using external measures of it's electrical activity. This will require high speed acqusition and reconstruction using digital computers and array processors.

Early fracture healing - The methods that are currently available for studying the healing of fractures are not completely satisfactory. For example, a fractured extremity or foot or wrist may have formed a solid bony union after casting, but we have difficulty in demonstrating this fact using conventional methods. In another case, union may be delayed and surgical intervention may be needed, but we may have difficulty in documenting the problem due to the alignment of the fracture and fragments, superimposed soft tissue injury, obscuration by orthopedic appliances or other factors. Future digital imaging research will be very helpful in this area.

Pulmonary emboli - The formation of clots in the veins of debilitated patients, and the migration of these clots to the lungs into the pulmonary arteries is often a catastrophic event, especially if not recognized and treated early. The methods we have for identifying and imaging these clots non-invasively (radionuclide lung scan) may be indeterminate. The use of pulmonary angiography for diagnosis requires special expertise and skill in these patients. Digital imaging of the pulmonary arteries could be very useful in the early diagnosis of pulmonary emboli.

Hip Disease - Good surgical methods for preserving hip function exist, but we often face a significant problem when early diagnosis of hip disease is needed.

We recognize hip disease now by searching for evidence of a destructive process. As digital methods improve, we expect to recognize these problems at a much earlier stage so surgical intervention can be made before the destructive process has advanced.

A summary of the imaging modalities and image processing problems found with each of the clinical problems described above is shown in Table 1.

We have summarized the specific technological needs for medical imaging associated with each of these problems in Table 2.

NASA IMAGE PROCESSING TECHNOLOGY

We have made use of several NASA-developed image processing developments in medical imaging research and practice. The sources of information on NASA image processing include the following:

1. NASA technical reports and related documents available from the National Technical Information Service (NTIS) or Superintendant of Documents (3, 7, 11, 14, 15, 17, 18).

2. NASA internal technical reports available from their authors. (6, 7, 11).

3. Articles in the image processing and geophysical literature by NASA authors. (8,9,10,12,13,19).

4. Computers, Control and Information Theory abstracts, a weekly newsletter published by NTIS.

5. Selected research in microfiche (SRIM), a service of NTIS where all US Government, foreign translations, contractor reports and abstract searches in image processing and pattern recognition are reproduced in microfiche and sent biweekly to subscribers.

6. NASA-developed software, procured through the Computer Software Management and Information Center (COSMIC). (20).

7. NASA Tech Briefs, published periodically by NASA Technology Utilization.

Table 1. Diagnostic Problems.

No.	Problem	Modality	Image Processing
1.	Coronary Arteries	DVI	Misregistration, poor image contrast (1,6,10)
2.	Tomographic Tissue Characterization	CT, NMR	Extraction of signatures from multispectral images. Extensio of signatures. (2,3)
3.	3-D Reconstruction	CT, NMR	Image segmentation. (4,5)
4.	PACS	All	Picture archiving and communications systems (PACS)
5.	Cancer Screening	?NMR	System cost, speed, efficacy. (7)
6.	Vascular Stenosis Assessment	DVI	Extraction of quantitative information from image intensifier-TV system (8,9).
7.	Brain Activity Imaging	PETT, BEAM ?NMR	Reconstruction from projections, data acquisition
8.	Fracture Healing	?CT, ?NMR ?digital x-ray	Spatial resolution, speed, cost, efficacy
9.	Pulmonary Emboli	DVI	Misregistration, spatial resolution
10.	Hip Disease	NMR, ?CT	Sensor-based variability, image quantification and calibration, signature extraction. (8,9).

Abbreviations:

DVI	Digital Vascular Imaging
CT	Computed Tomography
NMR	Nuclear Magnetic Resonance
BEAM	Brain Electrical Activity Monitoring
PETT	Positron Emission Tomography

Table 2. Specific Technological Needs for Medical Image Processing

Technology	Diagnostic Problems
Image Enhancement (10,11,12)	1. Coronary Arteries 8. Fracture Imaging
Multispectral Classification (14,15,16)	2. NMR Tissue Characterization 5. Early Cancer Detection 7. Brain Imaging 10. Hip Imaging
Gray Scale Image Segmentation (9,17)	3. Three Dimensional Imaging

Table 2 (continued)

Technology	Diagnostic Problems
Digital Image Compression, Transmission, Error Correction, Archiving and Data Base Management	4. Picture Archiving and Communications Systems
Sensor-Based Image Corrections, Radiometric and Geometric (8,9)	6. Vascular Stenoses 7. Brain Imaging 10. Hip Imaging
Image Pair Registration, Analysis of Time Varying Imagery.	1. Coronary Artery Imaging 9. Pulmonary Angiography

8. Direct contact with individual NASA employees at NASA centers, especially Kennedy Space Center, Jet Propulsion Lab, Goddard Space Flight Center, and National Space Technology Laboratory in our case.

By carefully following the unclassified image processing literature produced by NASA, we have been able to incorporate many of these techniques into our own systems with enouraging results (2-5).

Specifically, we have been involved in the development of

    1. Three dimensional surface reconstruction from CT scans for application in craniofacial surgical planning and evaluation, neurosurgery, orthopedics and other areas. (4,5)

    2. Application of multispectral analysis to NMR images of the human body. (2,3)

As a result of study of NASA developments and discussions with image processing experts at several centers, we have invested heavily in equipment and personnel to aggresively pursue the adaptation of more advanced image processing techniques to several of the problems outlined above.

WHERE WE ARE NOW

The contributions of R. Selzer of NASA Jet Propulsion Laboratory in biomedical image processing have significantly affected work done to date in our laboratory. (6, 10, 12, 13). Using the publications of the JPL Image Processing Laboratory as a guide, we have adapted this technology to our hardware environment.

This has resulted in the general availability of a digital image processing hardware/software environment, modeled after NASA's experience for use in diagnostic radiology. (24)

As a direct consequence of these developments, we have been able to produce an efficient 3-dimensional software system for surface reconstruction from CT scans (4,5). This has been applied to more than 500 patients and is in everyday use in our department. Provisions to export this software for use in other centers are underway.

More recently, we undertook a project with the assistance of R. Butterfield of KSC, to study the application of multispectral image classification techniques developed by NASA and contractors to NMR imagery (2,3). Faced with the complexity of extracting diagnostic information from a series of NMR images of the body, an inherently multispectral process, we encountered a very similar data processing problem to that found with Landsat multispectral scanner (MSS) data.

Access to a NASA-owned multispectral image processing system (GE Image 100) on loan to the University of Florida at Gainesville was arranged. In a collaborative effort by Washington University, NASA Kennedy Space Center, and the University of Florida, the demonstration of multispectral classification techniques to NMR imagery was accomplished with very promising results.

WHERE WE ARE HEADED

As a result of the encouraging results obtained with 3-D surface reconstruction and NMR multispectral analysis, we have recently increased our commitment to the adaptation and application of NASA developed image processing technology for diagnosis.

First, we have obtained a virtual memory minicomputer (VAX-11/730) that is compatible with the system control computer in our NMR scanner (Siemens Magnetom). To this was added a multichannel frame buffer and specialized image processing hardware (International Imaging Systems Model 75) with software for earth resources analysis, basically Landsat scene analysis.

With the assistance of McDonnell Douglas Automation Company in St. Louis, we have also added a computer aided design system workstation to the same computer (McAuto Unigraphics) for the planning and evaluation of complex surgical procedures. With the assistance of NASA-KSC and Doug Jordan, engineering manager of the remote sensing and image processing laboratory at the University of Florida, we have obtained the Earth Resources Laboratory Application System (ELAS software) (20), and are in the process of converting it to our configuration. We expect that parts of this software system will find its way into routine use in NMR imaging systems of the future. The solution of problems 2, 3 and 5 will be sought using this system.

As a result of discussions and demonstrations by R. Selzer (6,10) at NASA JPL, we have procured a hardware spatial warper system to perform rubber sheet transformations on medical images. This development promises to find application in the solution of problems 1, 6, and 9 above.

Sensor-based corrections for radiometric and geometric distortions have been a part of planetary and earth resources image processing for many years. (8, 9, 14, 15). Virtually no correction for instrumental factors is done for many medical imaging systems. Incorporating these corrections is likely to significantly improve our capabilities to approach problems 1, 2, 6, and 9.

WHAT WE WILL BE WATCHING

The direction that large organizations take on important technical issues can and should influence smaller users, especially those close to an application. We will be watching the literature carefully to follow the decisions made by NASA in digital image communications and archiving, computer graphics, robotics, expert systems and other areas. By following NASA's experience, the medical profession can benefit significantly by avoiding pitfalls and emulating successful hardware and software solutions to complex technological problems.

CONCLUSION

To a very significant degree, digital imaging is widely used in diagnostic radiology today (21,22) as a direct result of NASA's involvement in the development of the digital image processing technology we use. We can predict several of the developments that might take place in medical imaging, since the current state of image processing development in NASA is quite advanced in comparison to. that of medical imaging. We are only now becoming sophisticated enough in medical imaging to be able to formulate the questions we can put to NASA in asking for help in image processing (23).

The future of digital medical imaging is very bright as a result of the availability of advanced image processing technology and expertise found in the National Aeronautics and Space Administration.

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Figure 1. Sequence of high resolution CT scans through the facial structures in a child. Consider the difficulty of visualizing the patient's facial appearance given only these 25 scans. Surface reconstruction in three dimensions by computer is an effective aid in planning facial surgery.
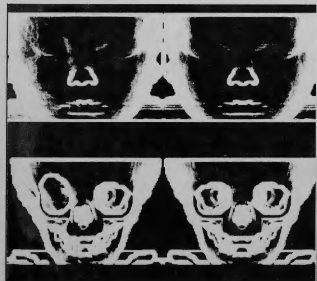

Figure 2. Surface reconstructions obtained from CT scans.

Top Left: Pre-op facial soft tissues.
Top Right: Computer simulated post-op result. Note symmetry has been restored.
Bottom Left: Pre-op frontal view of the patient's skull obtained from CT scans.
Bottom Right: Computer simulated post operative result. This constitutes a surgical plan, when the image is displayed life-size on film.
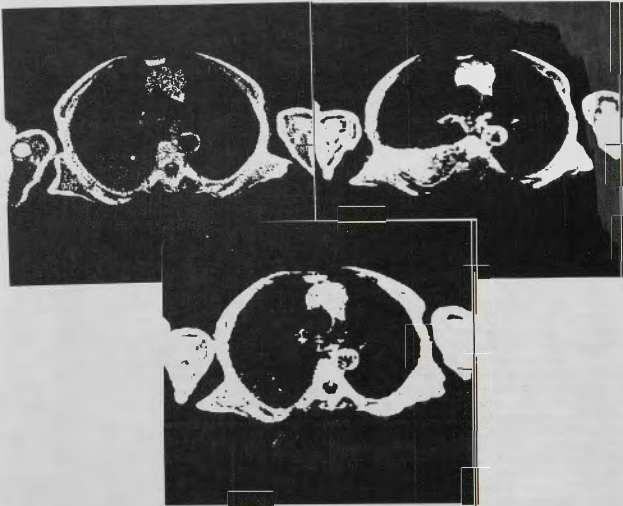
Figure 3. Three different spin echo NMR images of the same patient. All three sections were obtained at the same anatomic level (transverse sections through the chest), but each has different contrasts. This is similar to Landsat MSS images with different spectral sensitivities. Comprehension of the gray scale changes from image to image in this type of case is a formidable task for a human interpreter.
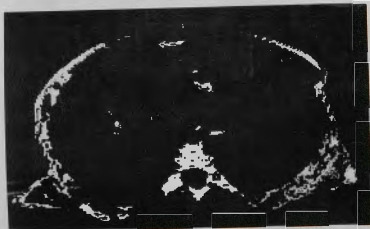

Figure 4. Theme map for the same section shown above. (Original was in color).

Using a supervised classification scheme on a Landsat image processing system, we have separated several of the important anatomic regions in the scene.

Significantly, we have used these methods to separate tissues and identify subtle abnormalities. In some clinically important situations, these techniques may be very useful for tissue characterization.