INCREDIBLE JOURNEY: Part II

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By

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About twenty-five years ago while I was a graduate student at Colorado State University I became interested in a Japanese art form called Sumi. The technique uses an ink made by grinding animal charcoal in water, which is then applied to specially made, slightly absorbent paper. The rather large brush that is held more like a pen than a typical artist brush has around cross-section and is made from very fine animal hair such as sable. As a result of its construction the brush holds a rather large quantity of the ink. When the brush is applied to the special paper the ink will diffuse into the areas surrounding the actual contact areas giving a "fuzzy" effect. The degree of fuzziness depends on the wetness of the brush, the contact pressure and the amount of contact time. This is a very dynamic process, which appears easy to do but is difficult to learn -- like most of the other oriental techniques I have attempted.

One evening, while my family and I were entertaining a Japanese student friend, I learned my friend knew "a little" about Sumi art. After some gentle persuasion he agreed to demonstrate a few of the classic techniques for us. While we were trying to decide on the subject for the painting my wife mentioned that earlier in the day she had seen a small plump Chickadee perched on a limb outside the kitchen window. It was all puffed up and fluffy as if It was getting ready for a very cold winter. Our friend thought that would make a suitable subject for his demonstration and began preparations.

After a great deal of time consuming and seemingly trivial fussing he suddenly applied the brush to paper and within no more than three seconds we were looking at a beautiful plump little bird perched on a most realistic twig. It was complete with tiny feathers (a result of the fuzziness effect mentioned above) and much other detail from a very few sharp marks made quickly with the tip of the brush.

As I studied the painting I began to realize that my personal "interpretation" of the image was being supplemented to a great degree by my imagination. In time, I came to understand that my friend had the ability to reduce the image he formed in his "mind's eye" to a minimum number of visual clues -- through the medium of the Sumi art form -- so that another person would "see" a similar image upon viewing the clues. I also came to realize that other art forms depend on this same idea. Sumi just carries it to an extreme.

This concept is probably no surprise at all to most of you, but because I was isolated from the pursuit of the "fine arts" by the demands of my time consuming ventures into physics and engineering I was definitely a late bloomer in this garden.

That incident was, for me, the beginning of a persistent interest in the processes of human perception. Shortly after that experience I purchased a 3-D still camera that simultaneously exposes two images formed through lenses that are spaced about the same as human eyes. I am sure all of you who enjoy binocular vision have experienced the three-dimensional effect from exposures made by this type of camera. Experiments with this camera and with the theories of human color perception proposed by Edwin Land, founder of the Polaroid Land Corporation, provided me with more insight into this fascinating field.

IMAGE TECHNOLOGY in MEDICAL DIAGNOSTICS

X-Ray

The discovery of x-rays by Wilhelm Rontgen launched the development of the technology for medical diagnostic imaging. In the traditional process images are made by exposing a photographic negative film to x-rays from a point source with the object of interest placed within the intervening space and as close as possible to the plane of the film. The physical size of the resulting image is slightly larger than actual due to the geometry of the process.

Because the various materials making up the patient's body differ in their relative transparency to x-rays the unequal exposure of the film results in a "shadow gram" that shows a two dimensional view of the relative location of the various bodily components. (The attenuation of x-rays passing through a material depends on the atomic structure, or more specifically, the electronic structure of the elements making of the material.) If exposures can be made from different directions the resulting set of images can provide some information about the actual three dimensional arrangements of the biological structures.

An inherent problem with this imaging modality is that it depends on "optical" principles for the production of images and there exists, as yet, no practical x-ray lens. These systems thus must operate as simple "pin-hole" cameras and are limited to the same constraints. Because x-ray sources are not true point sources images will not be in focus unless the object being imaged is in direct contact with the x-ray plate. Because of the three-dimensional nature of typical objects of interest some image resolution is always sacrificed, and images of humans are limited to transverse rather than longitudinal or axial views.

Ultrasound

Diagnostic ultrasound depends on differences in the degree of reflection of pressure (acoustic) wave fronts by different materials. To create an ultrasound image a wave is launched into the patient by a small transducer in contact with the body's surface and the amount of the incident wave, or echo, that is reflected back to the transducer is recorded over a period of time. The process is rapidly and continuously repeated while the transducer is scanned over a range of directions covering the area of interest.

The data being gathered is displayed on a cathode ray screen that depicts the amount of reflected energy as screen brightness. Screen location is established by using the time delay as one coordinate and transducer position as the other. The image thus formed depends on the molecular nature of the bodily components rather than on the atomic nature of the elements as in the case of the x-ray modality. Another difference is that the image is a two-dimensional transverse "cut" rather than a planar view.

CAT

An axial or tomographic view of bodily components is often very desirable for diagnosing and locating many kinds of problems that are not well resolved with ultrasound imaging. The development of computer generated image technology gave rise to the CAT scan (Computerized Axial Tomography). In this modality an x-ray beam (rather than a wave front) is passed through the patient's body and received by a sensor placed on the other side of the body opposite the x-ray source. Both the source and the receiving sensor are attached to a rotatable frame so that they can be scanned over a full 360 degrees. In the scanning process the beam passes through a plane of the body in all directions. The data being generated during the scanning process is converted to a digital format and stored in the computer. An image is then generated showing what an axial view of the structure must look like in order to have produced the recorded data.

The image is produced on a cathode ray screen and also can be transferred to a photographic film so that it looks much like a conventional x-ray film. Since the image is produced entirely by the computer it can be "enhanced" through the application of various processing techniques such as the removal of noise artifacts, the removal of some motion that occurred during the scanning process, and the enhancement of contrast by exaggerating a specified contrast range or the substitution of contrasting colors for the different contrast levels.

Because this modality utilizes x-rays it again deals with atomic structure.

MRI

An entirely different imaging modality became available with the development of diagnostic quality nuclear magnetic resonance technology (NMR). This process depends on the behavior of atomic nuclei when placed in a magnetic field. (Note: to avoid confusion and possible association with nuclear radiation the medical imaging use of nuclear magnetic resonance is called magnetic resonance imaging, or MRI.)

This modality depends on the behavior of certain atomic nuclei when immersed in a magnetic field. For example, the nucleus of a hydrogen atom will behave as if it is a tiny bar magnet. When any material containing hydrogen atoms is placed into a magnetic field the hydrogen nuclei will align themselves with the field. Because of quantum effects the alignment will be in one of two energy states. If the material is in thermal equilibrium most of the nuclei will be in the lower of the two possible states. If an oscillating magnetic field at the correct frequency is then applied low energy hydrogen nuclei will absorb a quantum of the incident radio-frequency energy and flip to the higher energy state. This energy absorption process can be detected and an image can then be created through a scanning and recording process similar to that used in the CA T scan.

Nuclei other than hydrogen can be utilized, but because the magnetization of the nuclear proton is only about one millionth that of typical atomic paramagnetism only those materials which have no atomic magnetism can be used. Because this modality reveals the location of specific nuclei it is sensitive to the chemical structure rather than the physical properties of the bodily components.

SPECT-PET

Other imaging modalities such as PET (Photon Emission Tomography) and SPECT (Single Photon Emission Computed Tomography) depend on detecting photons released by the radioactive decay of an injected material. The injected material is chosen to be chemically attracted to, or otherwise likely to be concentrated in, the region of interest. It also has a very short half-life.

Natural radioactive decay of the injected material results in the production of high energy photons that easily pass through surrounding tissue and can then be detected. Highly collimated detectors are physically scanned around the patient and the number of photons and the direction from which each arrived IS recorded. A computer then creates an image as in CAT and MRI.

General

It should be noted that in each of the modern diagnostic imaging modalities the images produced are actually created by the computer system. Digital display systems are now capable of the very high spatial resolution required for diagnostic use. The production of "hard copy" films is an ancillary capability that will eventually become less important and little used. In fact, I will predict that x-ray film will be completely replaced by digitally stored images within ten years. Even conventional x- ray images can be originally produced in digital format and viewed on digital display system.

Significant advantages of this approach include a considerable reduction in cost and a very large increase ill convenience and availability of images.

The field of modern medical imagery is still in its infancy. Diagnostic interpretation presently treats each modality as a stand-alone technique. Radiologists are highly trained "artists" who have developed a critical eye for interpreting the subtle contrast differences in the generated images, but they are still more comfortable with images on film than with digitally displayed images. This situation will, of course, change with experience, allowing the transition from film to totally digital systems.

In my role as consultant to a large mobile imaging company headquartered in the area I have much occasion to see the whole process from the inside. My background in applied physics and engineering and my natural urge to "make things work better" has caused me to look for ways of integrating and presenting information from multiple modalities so as to increase their value to the medical diagnostician.

NASA's Project

While considering this problem I came upon information from another field that also caught my interest. NASA is greatly concerned about the hazards associated with manned extra-vehicular activity (EVA) in space. The very high cost of training astronauts and placing them in orbit has made it mandatory to develop techniques and procedures to eliminate unnecessary risk. This effort includes development of a new technology that can eliminate the need for most EVA.

The idea of using remotely controlled robots is not new, of course, but the practical uses have been limited to a few rather trivial applications. The handling of radioactive or other hazardous materials on the other side of a leaded glass window is one we are all familiar with. One problem is that it is difficult for the operator to "visualize" just what he is dealing with at the remote location. When working through a window on something in another room, distance is a problem. Video images from cameras placed near the work area or actually carried on the "robot" take care of the distance problem but introduce a loss of reality. (dimension, relative spatial orientation among components, etc.) Poor results with conventional techniques led NASA into another approach that is an off-shoot of simulation technology developed in the APOLLO program.

When Neil Armstrong made his historic landing on the lunar surface it was not the first time he performed that delicate feat. He had previously made hundreds of “landings” with the lunar lander simulator at NASA Houston.

This facility included a large room containing a highly accurate model of the area of the lunar surface that was to be the landing site. A video camera array was “flown” over the model in step with the scaled location of the lunar module during the landing. A full-sized mock-up of the lander module was equipped with actuators and sound generators to provide "feel" and feedback to the pilot.

A key component in the simulator was a very large specially ground lens system that replaced the lunar module pilot's window. Behind the window was placed a special computer controlled video display system that projected the images from the model of the lunar surface. The combination of the video system and the special lens serving as the pilot's window produced an image with the proper perspective.

As the pilot flew the landing maneuver his control actions as interpreted by the computer system produced both the "feel" and the “look" of the lunar landing. Debriefing reports from the astronauts show that the simulation was very realistic.

One problem with the special lens used in the lunar landing simulator is that it requires the observer's eyes be accurately positioned relative to the fixed lens. The system is also very limited in the way it handles three-dimensional information.

To provide realistic three-dimensional information to the observer it is necessary to send specific visual information to the two eyes separately. We are all familiar with the stereopticon and its successors. 3-D movies were also a popular, if short lived, craze. In the stereopticon two separate images are placed before the eyes with a suitable physical barrier that prevents each eye from seeing the image intended for the other.

The movie system utilizes polarizing techniques that enable a pair of glasses worn by each viewer to provide the limiting function. I recently saw the 3-D movie at Disney's EPCOT Theater and was very impressed with the way my brain decided objects were actually flying toward me from the stage.

NASA's approach to providing appropriate visual information to the operator of a remotely controlled robot is to have a computer generate the appropriate visual "stereo pair" that are then projected directly into the operator's eyes. The optical system IS contained in a helmet worn by the operator so that it follows all head motions keeping the projection system aligned. This technology already exists (remember the helmets worn by the A-I0 and Apache helicopter flight crews in the Desert Storm footage?). The computer creating the images can generate all perspective information from a group of cameras, or other sensors, carried by the robot. Information about the position of the operator's head is picked up by sensors mounted on the helmet. The operator's natural interpretive processes will then generate the illusion that he is actually present at the location of the robot. Special glove-like equipment will pick up the operator's hand movements to provide control information for the robot's manipulators.

A well developed system can provide the operator with Superman-like visual abilities. For example, if the system is being used to perform a task on the exterior of the space shuttle the images seen by the observer are not limited to those picked up by the visual sensors mounted on the robot. Since the computer can also have access to all structural design information about the shuttle it can easily depict what the view would be like if the robot could literally see through walls. The operator could call on this capability as needed to "see", for example, where a particular object originates from on the other side of a bulkhead.

While "virtual reality" (VR) is a very new field it is benefiting greatly from the rapid advances in computer technology. A few years ago the computer capacity needed to generate even simple dynamic scenarios would have been outside the reach of all but the owners of the large Cray computers. These days we are surrounded by computer generated images that are so natural we may not even realize what we are seeing. This is the result not only of the obvious advances in inexpensive computer speed and capacity, but of significant advances in image processing software. An important advantage for VR image processing is that it is only necessary for the computer to generate views corresponding to the observer's current line-of-sight. This dramatically reduces the processing load.

Almost all the TV commercials we see now days are generated by computers, and the colorized versions of older black & white originals are processed frame-by-frame in a computer. One variation on this idea produces commercials where color has been removed from all objects except the sponsor's product.

Virtual reality is also being studied and developed by designers of other simulators such as those used to train and test airline and military pilots.

The mind boggles when considering just some of the possibilities for educational or recreational use. Imagine a VR trip to anywhere in the universe that can be described in sufficient detail to the computer.

A Marriage of VR and Medical Diagnostic Imaging

It was this realization that gave me the idea for a method of integrating the information from the different imaging modalities and presenting it to the radiologist. Utilizing all of the information gathered and the techniques of VR the computer can generate a "reality" that takes the diagnostician right "inside" the patient. Wearing an appropriate helmet and sitting at the control console the radiologist will be reduced to a tiny presence moving about at will within the patient.
The combined information from the various modalities can be used to enhance the imagery to provide sophisticated information to the diagnostician --such as specific chemical information about the components being visited. For example, tumors might appear in a particular color depending on their properties.

The use of injected agents could add still more information as the diagnostician "observes" the flow of the material and the specific uptake processes.

The common and slightly risky cardiac catheterization examination might easily be replaced --along with its risks --with a simple "trip" through the coronary arteries. Physical visualization of the reduction in the lumen diameter of the arteries would negate the need for injection of the contrast medium now used to determine the decreased blood flow in restricted vessels.

Microsurgery is another area that will benefit greatly from this technology. It should be relatively simple to reposition and suture a microscopically small, severed nerve channel if the surgeon is virtually reduced in size to the same scale as the nerve fiber. And rather than coronary by-pass surgery to correct severe blockage problems, why not send in the surgeon to simply remove the blockage?

Further development of microsurgical tools would, of course, be required, but I have no doubt about the success of such an effort.

Medical education will be completely revolutionized. Hospital "rounds" will take on a whole new meaning for medical students as they put on their VR helmets and accompany their instructor on a visit to the tiny tumor situated at the base of Mrs. Smith's pituitary so they can see for themselves how it is irritating the gland and affecting its function.

CONCLUSIONS

The scenarios described above may seem more like science fiction than practical technology, but the required ingredients have already been developed to a significant degree. The new technology, Virtual Reality, is just in its embryonic stage. It is not unreasonable to expect enormous advancements as we begin to grasp the concepts involved and apply our technological muscle to the task.

A favorite discovery of mine is that while "truth" itself is absolute, it seems it is always the "perception of truth" that motivates human action. Manipulation of perception has long been the game of marketers and politicians. Perhaps the field is now open to scientists and engineers.