Summer Research Final Report

Medical Imaging

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Summary

This paper is intended to present the findings of a twelve week research, focused mainly on medical imaging. The application to medical imaging is suppose to be broadly understood as well as the modern imaging technology. Modern imaging technologies are the different procedures involved and widely used in medical imaging. With this research, we should be able to know what procedure is what and what it should and can be used for. We also get to know the advantages and drawbacks of each procedure.
Introduction

Medical imaging is the process by which physicians evaluate an area of the subject's body that is not normally visible. Medical imaging may be "clinical", seeking to diagnose and examine diseases in specific human patients (see pathology). Alternatively, it may be research-motivated, attempting to understand processes in humans or animal models. Many of the techniques developed for medical imaging also have scientific and industrial applications.
**Applications to Medical Imaging**

Medical imaging detects critical illnesses at their most curable stage – and, in many cases, when they are least costly to treat. Medical imaging is center-stage in America's efforts at prevention and early detection.

Medical imaging enables a range of less-invasive, highly targeted medical therapies that translate into better and more comfortable care for patients. Because they are less invasive, these treatments mean fewer complications, shorter hospital stays, and, in many cases, no incisions or surgery.

Medical imaging is widely acclaimed as a hallmark of modern medicine by physician specialty groups, independent organizations, and peer-reviewed journals. Medical experts caution that, without imaging to guide diagnosis and treatment, patient safety would be compromised and quality of care diminished.

Medical imaging helps keep workers healthy and on the job – often avoiding surgery, long recuperation, and disability. It also serves as a barometer for quality in value-based purchasing. And when teamed with information technology, medical imaging becomes an active partner in efforts to reduce errors and inefficiencies.
Modern Imaging Technology

1. Radiography
2. Cat scan
3. MRI
4. Microwave Imaging
5. Ultrasound
6. Mammography
Radiography

Radiography is the creation of radiographs, photographs made by exposing a photographic film or other image receptor to X-rays. Since X-rays penetrate solid objects, but are slightly attenuated by them, the picture resulting from the exposure reveals the internal structure of the object. The most common use of radiography is in the medical field (where it is known as medical imaging).

Theory

The type of electromagnetic radiation of most interest to radiography is x-ray and gamma radiation. This radiation is much more energetic than the more familiar types such as radio waves and visible light. It is this relatively high energy, which makes gamma rays useful in radiography but potentially hazardous to living organisms.

They are produced by X-ray tubes, high energy X-ray equipment or natural radioactive elements, such as Radium and Radon, and artificially produced radioactive isotopes of elements, such as Cobalt 60 and Iridium 192. Electromagnetic radiation consists of oscillating electric and magnetic fields. It is generally pictured as a single sinusoidal wave.

It is characterized by its wavelength (the distance from a point on one cycle to the point on the next cycle) or its frequency (the number of oscillations per second). All electromagnetic waves travel at the same speed, the speed of light (c). The wavelength ($W$) and the frequency ($v$) are all related by the equation:

$$Wv = c$$

This is true for all electromagnetic radiation.

Electromagnetic radiation is known by various names, depending on its energy. The energy of these waves is related to the frequency and the wavelength by the relationship:

$$E = hv = hc / W$$

Where $h$ is a constant known as Planck's constant.
Gamma rays are indirectly ionizing radiation. A gamma ray passes through matter until it undergoes an interaction with an atomic particle, usually an electron. During this interaction, energy is transferred from the gamma ray to the electron, which is a directly ionizing particle. As a result of this energy transfer, the electron is liberated from the atom and proceeds to ionize matter by colliding with other electrons along its path.

For the range of energies commonly used in radiography, the interaction between gamma rays and electrons occurs in two ways. One effect takes place where all the gamma ray's energy is transmitted to an entire atom. The gamma ray no longer exists and an electron emerges from the atom with kinetic (motion in relation to force) energy almost equal to the gamma energy. This effect is predominant at low gamma energies and is known as the photoelectric effect. The other major effect occurs when a gamma ray interacts with an atomic electron, freeing it from the atom and imparting to it only a fraction of the gamma ray's kinetic energy. A secondary gamma ray with less energy (hence lower frequency) also emerges from the interaction. This effect predominates at higher gamma energies and is known as the Compton Effect.

In both of these effects the emergent electrons lose their kinetic energy by ionizing surrounding atoms. The density of ions so generated is a measure of the energy delivered to the material by the gamma rays.

The most common means of measuring the variations in a beam of radiation is by utilizing its effects onto a photographic film. This effect is the same as that of light, and the more intense the radiation is, it will produce a darker film, or a more exposed film. Other methods are in use, such as the ionizing effect measured electronically, its ability to discharge an electro statically charged plate or to cause certain chemicals to fluoresce as in fluoroscopy.
**X-RAYS**

X rays were discovered in 1895 by **W. C. Roentgen**, who called them X rays because their nature was at first unknown; they are sometimes also called Roentgen, or Röntgen, rays. X-ray line spectra were used by H. G. J. Moseley in his important work on atomic numbers (1913) and also provided further confirmation of the quantum theory of atomic structure. Also important historically is the discovery of X-ray diffraction by Max von Laue (1912) and its subsequent application by W. H. and W. L. Bragg to the study of crystal structure.

**X ray**, invisible, highly penetrating electromagnetic radiation of much shorter wavelength (higher frequency) than visible light. The wavelength range for X rays is from about $10^{-8}$ m to about $10^{-11}$ m, or from less than a billionth of an inch to less than a trillionth of an inch; the corresponding frequency range is from about $3 \times 10^{16}$ Hz to about $3 \times 10^{19}$ Hz (1 Hz = 1 cps).

**Production of X-Rays**

An important source of X rays is synchrotron radiation. X rays are also produced in a highly evacuated glass bulb, called an X-ray tube, that contains essentially two electrodes—an anode made of platinum, tungsten, or another heavy metal of high melting point, and a cathode. When a high voltage is applied between the electrodes, streams of electrons (cathode rays) are accelerated from the cathode to the anode and produce X rays as they strike the anode.

Two different processes give rise to radiation of X-ray frequency. In one process radiation is emitted by the high-speed electrons themselves as they are slowed or even stopped in passing near the positively charged nuclei of the anode material. This radiation is often called *brehmsstrahlung* [Ger., =braking radiation]. In a second process radiation is emitted by the electrons of the anode atoms when incoming electrons from the cathode knock electrons near the nuclei out of orbit and they are replaced by other electrons from outer orbits. The spectrum of frequencies given off with any particular anode material thus consists of a continuous range of frequencies emitted in the first process, and superimposed on it a number of sharp peaks of intensity corresponding to discrete frequencies at which X rays are emitted in the second process.
The sharp peaks constitute the X-ray line spectrum for the anode material and will differ for different materials.

Applications of X-Rays

Most applications of X-rays are based on their ability to pass through matter. This ability varies with different substances; e.g., wood and flesh are easily penetrated, but denser substances such as lead and bone are more opaque. The penetrating power of X-rays also depends on their energy. The more penetrating X-rays, known as hard X-rays, are of higher frequency and are thus more energetic, while the less penetrating X-rays, called soft X-rays, have lower energies. X-rays that have passed through a body provide a visual image of its interior structure when they strike a photographic plate or a fluorescent screen; the darkness of the shadows produced on the plate or screen depends on the relative opacity of different parts of the body.

Photographs made with X-rays are known as radiographs or skiographs. Radiography has applications in both medicine and industry, where it is valuable for diagnosis and nondestructive testing of products for defects. Fluoroscopy is based on the same techniques, with the photographic plate replaced by a fluorescent screen (see fluorescence; fluoroscope); its advantages over radiography in time and cost are balanced by some loss in sharpness of the image. X-rays are also used with computers in CAT (computerized axial tomography) scans to produce cross-sectional images of the inside of the body.

Another use of radiography is in the examination and analysis of paintings, where studies can reveal such details as the age of a painting and underlying brushstroke techniques that help to identify or verify the artist. X-rays are used in several techniques that can provide enlarged images of the structure of opaque objects. These techniques collectively referred to as X-ray microscopy or micro-radiography can also be used in the quantitative analysis of many materials. One of the dangers in the use of X-rays is that they can destroy living tissue and can cause severe skin burns on human flesh exposed for too long a time. This destructive power is used in X-ray therapy to destroy diseased cells.
Cat Scan

A computerized axial tomography scan is more commonly known by its abbreviated name, CAT scan or CT scan. It is an x-ray procedure which combines many x-ray images with the aid of a computer to generate cross-sectional views and, if needed, three-dimensional images of the internal organs and structures of the body. A CAT scan is used to define normal and abnormal structures in the body and/or assist in procedures by helping to accurately guide the placement of instruments or treatments. A large donut-shaped x-ray machine takes x-ray images at many different angles around the body. These images are processed by a computer to produce cross-sectional pictures of the body. In each of these pictures the body is seen as an x-ray "slice" of the body, which is recorded on a film. This recorded image is called a tomogram. "Computerized Axial Tomography" refers to the recorded tomogram "sections" at different levels of the body.

Imagine the body as a loaf of bread and you are looking at one end of the loaf. As you remove each slice of bread, you can see the entire surface of that slice from the crust to the center. The body is seen on CAT scan slices in a similar fashion from the skin to the central part of the body being examined. When these levels are further "added" together, a three-dimensional picture of an organ or abnormal body structure can be obtained.

History

The CT system was invented in 1972 by Godfrey Newbold Hounsfield using X-rays. Allan McLeo Cormack of Tufts University independently invented the same process and they shared a Nobel Prize in medicine in 1979. The first scanner took several hours to acquire the raw data and several days to produce the images. Modern multi-detector CT systems can complete a scan of the chest in less time than it takes for a single breath and display the computed images in a few seconds.
Why are CAT scans performed?

Since its introduction in the 1970s, CT has become an important tool in medical imaging to supplement X-rays and medical ultrasonography. Although it is still quite expensive, it is the gold standard in the diagnosis of a large number of different disease entities.

CAT scans are performed to analyze the internal structures of various parts of the body. This includes the head, where traumatic injuries, (such as blood clots or skull fractures), tumors, and infections can be identified. In the spine, the bony structure of the vertebrae can be accurately defined, as can the anatomy of the inter-vertebral discs and spinal cord. In fact, CAT scan methods can be used to accurately measure the density of bone in evaluating osteoporosis.

Occasionally, contrast material (an x-ray dye) is placed into the spinal fluid to further enhance the scan and the various structural relationships of the spine, the spinal cord, and its nerves. CAT scans are also used in the chest to identify tumors, cysts, or infections that may be suspected on a chest x-ray. CAT scans of the abdomen are extremely helpful in defining body organ anatomy, including visualizing the liver, gallbladder, pancreas, spleen, aorta, kidneys, uterus, and ovaries. CAT scans in this area are used to verify the presence or absence of tumors, infection, abnormal anatomy, or changes of the body from trauma.

The technique is painless and can provide extremely accurate images of body structures in addition to guiding the radiologist in performing certain procedures, such as biopsies of suspected cancers, removal of internal body fluids for various tests, and the draining of abscesses which are deep in the body. Many of these procedures are minimally invasive and have markedly decreased the need to perform surgery to accomplish the same goal.
Risks that might be involved in performing CAT scan?

A CAT scan is a very low-risk procedure. The most common problem is an adverse reaction to intravenous contrast material. Intravenous contrast is usually an iodine-based liquid given in the vein, which makes many organs and structures, such as the kidneys and blood vessels much more visible on the CAT scan. There may be resulting itching, a rash, hives, or a feeling of warmth throughout the body. These are usually self-limiting reactions and go away rather quickly. If needed, antihistamines can be given to help relieve the symptoms. A more serious reaction to intravenous contrast is called an anaphylactic reaction. When this occurs, the patient may experience severe hives and/or extreme difficulty in breathing. This reaction is quite rare, but is potentially life-threatening if not treated. Medications which may include corticosteroids, antihistamines, and epinephrine reverse this adverse reaction.

Toxicity to the kidneys which can result in kidney failure is an extremely rare complication of the intravenous contrast used in CAT scans. Diabetics, dehydrated individuals, or patients who already have impaired kidney function are most prone to this reaction. Newer intravenous contrast agents have been developed, such as Isovue, which have nearly eliminated this complication.

The amount of radiation a person receives during a CAT scan is minimal. In men and non-pregnant women, it has not been shown to produce any adverse effects. If a woman is pregnant, there may be a potential risk to the fetus, especially in the first trimester of the pregnancy. If a woman is pregnant, she should inform her doctor of her condition and discuss other potential methods of testing, such as an ultrasound, which are not harmful to the fetus.

How does a patient prepare for CAT scanning, and how is it performed?

In preparation for a CAT scan, patients are often asked to avoid food, especially when contrast material is to be used. Contrast material may be injected intravenously, or administered by mouth or by an enema in order to increase the distinction between various organs or areas of the body. Therefore, fluids and food may be restricted for several hours
prior to the examination. If the patient has a history of allergy to contrast material (such as iodine), the requesting physician and radiology staff should be notified. All metallic materials and certain clothing around the body are removed because they can interfere with the clarity of the images.

Patients are placed on a movable table, and the table is slipped into the center of a large donut-shaped machine which takes the x-ray images around the body. The actual procedure can take from a half an hour to an hour and a half. If specific tests, biopsies, or intervention are performed by the radiologist during CAT scanning, additional time and monitoring may be required. It is important during the CAT scan procedure that the patient minimizes any body movement by remaining as still and quiet as is possible. This significantly increases the clarity of the x-ray images. The CAT scan technologist tells the patient when to breathe or hold his/her breathe during scans of the chest and abdomen. If any problems are experienced during the CAT scan, the technologist should be informed immediately. The technologist directly watches the patient through an observation window during the procedure and there is an intercom system in the room for added patient safety.

CAT scans have vastly improved the ability of doctors to diagnose many diseases earlier in their course and with much less risk than previous methods. Further refinements in CAT scan technology continue to evolve which promise even better picture quality and patient safety. Newer CAT scans called "spiral" or "helical" CAT scans can provide more rapid and accurate visualization of internal organs. For example, many trauma centers are using these scans to more rapidly diagnose internal injuries after serious body trauma.
**Magnetic Resonance Imaging (MRI)**

<table>
<thead>
<tr>
<th>Where It's Done</th>
<th>Who Does It</th>
<th>How Long It Takes</th>
<th>Discomfort/Pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic clinic,</td>
<td>Radiologist or qualified</td>
<td>30-90 minutes.</td>
<td>None, but some people find the noise and being in a</td>
</tr>
<tr>
<td>radiology lab, or</td>
<td>technician.</td>
<td></td>
<td>confined space upsetting.</td>
</tr>
<tr>
<td>hospital.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Results Ready When</th>
<th>Special Equipment</th>
<th>Risks/Complications</th>
<th>Average Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Often within a few hours.</td>
<td>MRI scanner, computer, and</td>
<td>None, unless the</td>
<td>$$$</td>
</tr>
<tr>
<td></td>
<td>display screen or monitor;</td>
<td>patient has an</td>
<td></td>
</tr>
<tr>
<td></td>
<td>film or magnetic tape</td>
<td>implanted pacemaker</td>
<td></td>
</tr>
<tr>
<td></td>
<td>recorder.</td>
<td>or other implanted</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>metal devices.</td>
<td></td>
</tr>
</tbody>
</table>

**Magnetic resonance imaging (MRI)** - also called **magnetic resonance tomography (MRT)** - is a method of creating images of the inside of opaque organs in living organisms as well as detecting the amount of bound water in geological structures. It is primarily used to demonstrate pathological or other physiological alterations of living tissues and is a commonly used form of medical imaging. MRI has also found many niche applications outside of the medical and biological fields such as rock permeability to hydrocarbons and certain non-destructive testing methods such as produce and timber quality characterization.

Magnetic resonance imaging was developed from knowledge gained in the study of nuclear magnetic resonance. The original name for the medical technology is **nuclear magnetic resonance imaging (NMRI)**, but the word *nuclear* is almost universally dropped. This is done to avoid the negative connotations of the word *nuclear*, and to prevent patients from associating the examination with radiation exposure. Scientists still use NMR when discussing non-medical devices operating on the same principles.

MRI provides an unparalleled view inside the human body. The level of detail we can see is extraordinary compared with any
other imaging modality. MRI is the method of choice for the diagnosis of many types of injuries and conditions because of the incredible ability to tailor the exam to the particular medical question being asked. By changing exam parameters, the MRI system can cause tissues in the body to take on different appearances. This is very helpful to the radiologist (who reads the MRI) in determining if something seen is normal or not. We know that when we do "A," normal tissue will look like "B" -- if it doesn't, there might be an abnormality. MRI systems can also image flowing blood in virtually any part of the body. This allows us to perform studies that show the arterial system in the body, but not the tissue around it. In many cases, the MRI system can do this without a contrast injection, which is required in vascular radiology.

**How MRI works**

The biggest and most important component in an MRI system is the magnet. The magnet in an MRI system is rated using a unit of measure known as a tesla. Another unit of measure commonly used with magnets is the gauss (1 tesla = 10,000 gauss). The magnets in use today in MRI are in the 0.5-tesla to 2.0-tesla range, or 5,000 to 20,000 gauss. Magnetic fields greater than 2 tesla have not been approved for use in medical imaging, though much more powerful magnets -- up to 60 tesla -- are used in research. Compared with the Earth's 0.5-gauss magnetic field, you can see how incredibly powerful these magnets are.

Numbers like that help provide an intellectual understanding of the magnetic strength, but everyday examples are also helpful. The MRI suite can be a very dangerous place if strict precautions are not observed. Metal objects can become dangerous projectiles if they are taken into the scan room. For example, paperclips, pens, keys, scissors, hemostats, stethoscopes and any other small objects can be pulled out of pockets and off the body without warning, at which point they fly toward the opening of the magnet (where the patient is placed) at very high speeds, posing a threat to everyone in the room. Credit card, bank cards and anything else with magnetic encoding will be erased by most MRI systems.

The magnetic force exerted on an object increases exponentially as it nears the magnet. Imagine standing 15 feet (4.6 m) away from the magnet with a large pipe wrench in your
hand. You might feel a slight pull. Take a couple of steps closer and that pull is much stronger. When you get to within 3 feet (1 meter) of the magnet, the wrench likely is pulled from your grasp. The more mass an object has, the more dangerous it can be -- the force with which it is attracted to the magnet is much stronger. Mop buckets, vacuum cleaners, IV poles, oxygen tanks, patient stretchers, heart monitors and countless other objects have all been pulled into the magnetic fields of MRI machines. The largest object I know of being pulled into a magnet is a fully loaded pallet jack (see below). Smaller objects can usually be pulled free of the magnet by hand. Large ones may have to be pulled away with a winch, or the magnetic field may even have to be shut down.
**Ultrasound**

**Medical ultrasonography** is an ultrasound-based diagnostic imaging technique used to visualize internal organs, their size, structure and their pathological lesions.

**Uses**

Ultrasonography is widely utilized in medicine. It is possible to perform diagnosis or therapeutic procedures with the guidance of ultrasonography (for instance biopsies or drainage of fluid collections). Typically uses a hand-held probe (often called a scan head) that is placed directly on and moved over the patient: a water-based gel ensures good coupling between the patient and scan head.

Medical ultrasonography is used in, for example:

- gastroenterology
- cardiology
- gynecology
- obstetrics
- urology
- endocrinology

**Technology**

Ultrasonography uses a probe containing one or more acoustic transducers to send pulses of sound into a material. Whenever a sound wave encounters a material with different acoustical impedance, part of the sound wave is reflected, which the probe detects as an echo. The time it takes for the echo to travel back to the probe is measured and used to calculate the depth of the tissue interface causing the echo. The greater the difference between acoustic impedances, the larger the echo is. The difference between gases and solids is so great that most of the acoustic energy is reflected, and so imaging of objects beyond that region is not possible.

The speed of sound is different in different materials, and is dependent on the acoustical impedance of the material. Part of the acoustic energy is lost every time an echo is formed.

Unlike regular sound, ultrasound can be directed into a single direction. The echoes received by a stationary probe will result
in a single dimensional signal showing peaks for every major material change.

To generate a 2D-image, the probe is swiveled, either mechanically or through a phased array of ultrasound transducers. The data is analyzed by computer and used to construct the image. In a similar way, 3D images can be generated by computer using a specialized probe.

Some ultrasonography machines can produce color images, of sorts. From the amount of energy in each echo, the difference in acoustic impedance can be calculated and a color is then assigned accordingly.

The frequencies used for medical imaging are generally in the range of 1 to 10 MHz. Higher frequencies have a correspondingly lower wavelength, and so images can have a greater resolution. However, the attenuation of the sound wave is increased at higher frequencies, so in order to better penetration of deeper tissues, a lower frequency (3-5MHz) may be used.

**Doppler ultrasonography**

Ultrasonography can be enhanced with Doppler measurements, which employ the Doppler Effect to assess whether structures (usually blood) are moving towards or away from the probe. By calculating the frequency shift of a particular sample volume, for example a jet of blood flow over a heart valve, its speed and direction can be determined and visualized. This is particularly useful in cardiovascular studies (ultrasonography of the vasculature and heart) and essential in many areas such as determining reverse blood flow in the liver vasculature in portal hypertension. The Doppler information is displayed graphically using spectral Doppler, or as an image using color Doppler or power Doppler. It is often presented audibly using stereo speakers: this produces a very distinctive, although synthetic, sound.

**Strengths and weaknesses**

**Strengths of ultrasound imaging**

- It images muscle and soft tissue very well and is particularly useful for delineating the interfaces between solid and fluid-filled spaces.
• It renders "live" images, where the operator can dynamically select the most useful section for diagnosing and documenting changes, often enabling rapid diagnoses.
• It shows the structure as well as some aspects of the function of organs.
• It has no known long-term side effects and rarely causes any discomfort to the patient.
• Equipment is widely available and comparatively flexible.
• Small, easily carried scanners are available; examinations can be performed at the bedside.
• Relatively inexpensive compared to other modes of investigation (e.g. DEXA, computed X-ray tomography or magnetic resonance imaging).

Weaknesses of ultrasound imaging

• Classical ultrasound devices have trouble penetrating bone but current research on ultrasound bone imaging will make it possible with dedicated devices in the future.
• Ultrasound performs very poorly when there is a gas between the scan head and the organ of interest, due to the extreme differences in acoustical impedance. For example, overlying gas in the gastrointestinal tract often makes ultrasound scanning of the pancreas difficult, and lung imaging is not possible (apart from demarcating pleural effusions).
• Even in the absence of bone or air, the depth penetration of ultrasound is limited, making it difficult to image structures that are far removed from the body surface, especially in obese patients.
• The method is operator-dependent. A high level of skill and experience is needed to acquire good-quality images and make accurate diagnoses.
Mammography

Mammography is a specific type of imaging that uses a low-dose x-ray system for examining the breasts. The images of the breasts can be viewed on film at a view box or as soft copy on a digital mammography work station. Most medical experts agree that successful treatment of breast cancer often is linked to early diagnosis.

Mammography plays a central part in early detection of breast cancers because it can show changes in the breast up to two years before a patient or physician can feel them. Current guidelines from the U.S. Department of Health and Human Services (HHS), the American Cancer Society (ACS), the American Medical Association (AMA) and the American College of Radiology (ACR) recommend screening mammography every year for women, beginning at age 40.

What are some common uses of the procedure?

Mammography is used to aid in the diagnosis of breast diseases in women. Screening mammography can assist your physician in the detection of disease even if you have no complaints or symptoms.

Initial mammographic images themselves are not always enough to determine the existence of a benign or malignant disease with certainty. If a finding or spot seems suspicious, your radiologist may recommend further diagnostic studies.

Diagnostic mammography is used to evaluate a patient with abnormal clinical findings, such as a breast lump or lumps, which have been found by the woman or her doctor. Diagnostic mammography may also be done after an abnormal screening mammography in order to determine the cause of the area of concern on the screening exam.

How should I prepare for a mammogram?

Before scheduling a mammogram, the ACS and other specialty organizations recommend that you discuss any new findings or problems in your breasts with your doctor. In addition, inform
Microwave Imaging

The term microwave imaging covers all processes in which measurements of electromagnetic fields in the microwave region from 300 MHz to 30 GHz are used for creating images.

To create images from microwave measurements, it is necessary to construct a microwave camera, which is able to transmit microwaves and measure the scattered waves at one or more antennas. Different types of microwave cameras are currently being used for imaging in such areas as ground penetrating radar and remote sensing. Depending on the items to be imaged, different types of microwave cameras are needed. These range from small antennas used for near field measurements in ground penetrating radar to the large airborne systems used in remote sensing.

There are two key issues to address when designing a microwave camera. One is the increase of the signal to noise ratio in the system and the other is to assure that the system has a large dynamic range. The importance of both of these is closely related to the fact that the scattered signal is often very weak in comparison to the transmitted signal. This implies that any noise in the system will have a large impact on the image quality and that the system must be able to distinguish even small differences in the received signals.

To obtain the maximum amount of information from the microwave measurements, inverse scattering techniques must be applied. The term inverse scattering is used to describe techniques in which the images are created by inverting a model of the scattering mechanisms derived from Maxwell's equations. When using inverse scattering for microwave imaging, two things determine the quality of the images. The first thing is the accuracy of the forward model and the other is the accuracy of the inversion algorithm. By using Maxwell equations, an exact solution to the forward scattering problem can be determined. The forward model, however, is often too complex to efficiently be inverted and certain approximations and assumptions must therefore be applied. Consequently, the application of physically viable assumptions and simplifications to the forward model is as important in inverse scattering as the pure mathematical procedure of inverting the model.
At the present, the only suitable screening tool for the detection of breast cancer is X-ray imaging of the breasts, known as mammography. When using mammography, the breast is illuminated by X-rays and onto a photo-sensitive material. The resulting projection of the X-ray absorption in the breast can then be used for locating tumors. Mammography has proven itself as a very suitable screening tool for post-menopausal women with sensitivity and specificity reaching as much as 90%. In addition to the high sensitivity and specificity, the screening process is fast, with a screening taking as little as seven minutes.

When mammography screening is combined with a follow-up ultrasonic examination of those women whose mammographies show signs of possible cancer, the sensitivity and specificity can reach as much as 95%. Mammography, however, is not suitable for screening of pre-menopausal women, as the sensitivity for this group of women is as low as 60%. Consequently, the Danish screening program does not include women under the age of 50 years, a group who makes up around 20% of the annual diagnosed breast-cancer cases in Denmark. In addition to the pre-menopausal women, mammography also performs poorly on the increasing number of postmenopausal women receiving hormonal treatment.

To understand the reason for the low sensitivity for younger women it is necessary to realize what is imaged when performing mammography screenings. The mammography is an image of how much of the X-ray radiation is dissipated in the breast. The dissipation of the energy in the X-rays is dependent upon the type of tissue the X-rays need to propagate through from the source to the photo-sensitive detector. Certain types of tissue, such as fat, cause low dissipation while other types, such as tumors and breast tissue, cause high dissipation of the energy of the X-rays. In the breasts of postmenopausal women, the hormonal change implies that most of the breast tissue has been transformed to fat. Consequently, highly dissipating tissue such as malignant tumors will stand out in the mammographies. For pre-menopausal women, however, the presence of dense breast tissue means that tumors are more likely to be undetected by X-rays.

As opposed to X-rays, the interaction between microwaves and breast tissue is not governed by the dissipation of energy in
the breast tissue, but rather by scattering of the incident microwaves. This scattering is caused by in homogeneities in the electrical constitutive parameters of the tissue.

As early as in the late 1940's it was discovered that the constitutive parameters of malignant breast tissue is 3-10 times that of normal tissue. This difference will cause the microwaves to scatter, and by applying signal processing to the measured scattered waves, the size and position of the in homogeneities, including malignant tumors, in the breast can be determined. The most intuitive way to present the information extracted from the scattered signal is by producing three-dimensional images. This approach is known as microwave imaging.
Your doctor of any prior surgeries, hormone use and family or personal history of breast cancer.

Do not schedule your mammogram for the week before your period if your breasts are usually tender during this time. The best time is one week following your period? Always inform your doctor or x-ray technologist if there is any possibility that you are pregnant.

The ACS also recommends you:

- Do not wear deodorant, talcum powder or lotion under your arms or on your breasts on the day of the exam. These can appear on the mammogram as calcium spots.
- Describe any breast symptoms or problems to the technologist performing the exam.
- If possible, obtain prior mammograms and make them available to the radiologist at the time of the current exam.
- Ask when your results will be available; do not assume the results are normal if you do not hear from your doctor or the mammography facility.

In addition, before the examination you will be asked to remove all jewelry and clothing above the waist and you will be given a gown or loose-fitting material that opens in the front.

How does the procedure work?

The breast is exposed to a small dose of radiation to produce an image of internal breast tissue. The image of the breast is produced as a result of some of the x-rays being absorbed (attenuation) while others pass through the breast to expose either a film (conventional mammography) or digital image receptor (digital mammography). The exposed film is either placed in a developing machine—producing images much like the negatives from a 35mm camera—or images are digitally stored on computer.

How is the procedure performed?

During mammography, a specially qualified radiologist will position you to image your breast. The breast is first placed on a special platform and compressed with a paddle (often made of clear Plexiglas or other plastic).
Breast compression is necessary in order to:

- Even out the breast thickness so that all of the tissue can be visualized.
- Spread out the tissue so that small abnormalities won't be obscured by overlying breast tissue.
- Allow the use of a lower x-ray dose since a thinner amount of breast tissue is being imaged.
- Hold the breast still in order to eliminate blurring of the image caused by motion.
- Reduce x-ray scatter to increase sharpness of picture.

The technologist will go behind a glass shield while making the x-ray exposure, which will send a beam of x-rays through the breast to the image receptor behind the plate, thus exposing the film or digital receptor.

You will be asked to change positions slightly between images. The routine views are a top-to-bottom view and an oblique side view. The process is repeated for the other breast.

The examination process should take about half an hour. When the mammography is completed you will be asked to wait until the technologist examines the images to determine if more are needed.

What are the benefits vs. risks?

Benefits

- Imaging of the breast improves a physician's ability to detect small tumors. When cancers are small, the woman has more treatment options and a cure is more likely.
- The use of screening mammography increases the detection of small abnormal tissue growths confined to the milk ducts in the breast, called ductal carcinoma in situ (DCIS). These early tumors cannot harm patients if they are removed at this stage and mammography is the only proven method to reliably detect these tumors.

Risks

- The effective radiation dose from a mammogram is about 0.7 mSv, which is about the same as the average person receives from background radiation in three months.
Federal mammography guidelines require that each unit be checked by a medical physicist every year to ensure that the unit operates correctly.

- Women should always inform their doctor or x-ray technologist if there is any possibility that they are pregnant.
- False Positive Mammograms. Five percent to 15 percent of screening mammograms require more testing such as additional mammograms or ultrasound. Most of these tests turn out to be normal. If there is an abnormal finding a follow-up or biopsy may have to be performed. Most of the biopsies confirm that no cancer was present. It is estimated that a woman who has yearly mammograms between ages 40 and 49 has about a 30 percent chance of having a false-positive mammogram at some point in that decade and about a 7 percent to 8 percent chance of having a breast biopsy within the 10-year period. The estimate for false-positive mammograms is about 25 percent for women ages 50 or older.

What are the limitations of Mammography?

Interpretations of mammograms can be difficult because a normal breast can appear differently for each woman. Also, the appearance of an image may be compromised if there is powder or salve on the breasts or if you have undergone breast surgery. Because some breast cancers are hard to visualize, a radiologist may want to compare the image to views from previous examinations. Not all cancers of the breast can be seen on mammography.

Breast implants can also impede accurate mammogram readings because both silicone and saline implants are not transparent on x-rays and can block a clear view of the tissues behind them, especially if the implant has been placed in front of, rather than beneath, the chest muscles. But the NCI says that experienced technologists and radiologists know how to carefully compress the breasts to improve the view without rupturing the implant. When making an appointment for a mammogram, women with implants should ask if the facility uses special techniques designed to accommodate them. Before the mammogram is taken, they should make sure the technologist is experienced in performing mammography on patients with breast implants.
Conclusion

Medical imaging makes the health care system work more efficiently by fostering greater economy and cost savings. Such savings are often apparent, as when imaging replaces surgery. Other times, savings are harder to see, as when imaging allows a patient to recover in half the time. Imaging's newest frontier, fusing digital imaging with information technology, is introducing savings that stretch throughout the health delivery system.

Medical imaging is extending human vision into the very nature of disease, thus enabling a new and more powerful generation of diagnosis and intervention. Medical imaging is also melding such advances with the productivity-enhancing power of digital and information technology — fostering greater efficiency, quality, and value in health delivery.
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Appendix A: Weekly Reports

Week One:

Met with my advisor and other students on the team.

Created my Web page.

I learnt about the COM block and its components; I read the documentations from the previous team. Also I was able to use the software that allows you to modify the settings. I was introduced to the System View software which aims at personalizing the system in a way that will meet every expectation of the system user and provide the system administrator(s) to manage their own systems with their customized automation software and to solve the problems.

Week 2:

In week 2 of my research project: I got a little bit more of the System View software; i.e. I saw the demo again and worked on some examples. Also we weren't able to establish a connection with the COM blocks TCP/IP #5001 and after some troubleshooting, found out that the router wasn't allowing connection through the wireless LAN lines

Week 3:

I worked on applications to medical imaging.

- Also I learnt about the various processes used in Medical Imaging.

"Medical imaging detects critical illnesses at their most curable stage – and, in many cases, when they are least costly to treat. Medical imaging is center-stage in America's efforts at prevention and early detection". "It remains an important step today in making initial assessments of potential problems, although additional steps are often used to confirm a diagnosis. The primary drawback is that findings are subject to interpretation, and while a recorded image can be produced manually, in practice this is often not done".
Modern imaging technology:

**Radiographs**, more commonly known as x-rays, are often used to determine the type and extent of a fracture. (see Radiography)

**Computed Tomography**, A CT scan, also known as a CAT scan (Computed Axial Tomography scan), traditionally produces a 2D image of the structures in a small section of the body with the use of radiation. (see Computed axial tomography)

**Magnetic Resonance Imaging**, An MRI uses nuclear magnetic resonance spectrometer to produce electronic images of specific atoms and molecular structures in solids, especially human cells, tissues, and organs. Unlike the CT scan it does not use radiation. (see Magnetic resonance imaging)

**Ultrasound**, An imaging technique that uses high frequency sound waves to visualize underwater surfaces, boundaries, objects, and currents. (see Medical ultrasonography)

**Mammography**, a diagnostic procedure to detect breast tumors by the use of X rays, identifies breast cancer one to three years before a lump can be felt, thereby saving lives. (see Mammography)

We have imaging techniques which includes:
- diffuse optical tomography
- elastography
- electrical impedance tomography
- fluoroscopy
- nuclear medicine
- optoacoustic imaging
- ophthalmology

- corneal topography
- Heidelberg retinal tomography
- ocular coherence tomography
- scanning laser ophthalmoscopy

positron emission tomography
Week 4:
I worked on CAT Scan.

The processes involved and how it relates with X-rays. Why is CT scan chosen over x-ray, or why would x-ray be chosen over CT scan. The cost of these procedures and the devices involved.

***CAT Scan (Computed Axial Technology is the process of using computers to generate a three-dimensional image from flat (i.e., two-dimensional) x-ray pictures, one slice at a time... CAT Scanners rather than actually cut people up, they use x-rays to make pictures of the slices to get an overall picture. In the case of x-ray we get the whole picture, but with CAT scan: machines go around in a circle; so they can take x-rays from all sides * CAT scanning adds x-ray images with the aid of a computer to generate cross-sectional views of anatomy. * CAT scanning can identify normal and abnormal structures and be used to guide procedures. * CAT scanning is painless. * Iodine-containing contrast material is sometimes used in CAT scanning. Patients with a history of allergy to iodine or contrast materials should notify their physicians and radiology staff.

Week 5:

Worked on MRI aka magnetic resonance tomography (MRT)

The first MRI exam was performed on July 3, 1977.

To understand how MRI works, let's start by focusing on the "magnetic" in MRI. The biggest and most important component in an
MRI system is the magnet. The magnet in an MRI system is rated using a unit of measure known as a tesla. Another unit of measure commonly used with magnets is the gauss (1 tesla = 10,000 gauss). The magnets in use today in MRI are in the 0.5-tesla to 2.0-tesla range, or 5,000 to 20,000 gauss. Magnetic fields greater than 2 tesla have not been approved for use in medical imaging, though much more powerful magnets -- up to 60 tesla -- are used in research. Compared with the Earth's 0.5-gauss magnetic field, you can see how incredibly powerful these magnets are.

Numbers like that help provide an intellectual understanding of the magnetic strength, but everyday examples are also helpful. The MRI suite can be a very dangerous place if strict precautions are not observed. Metal objects can become dangerous projectiles if they are taken into the scan room. For example, paperclips, pens, keys, scissors, hemostats, stethoscopes and any other small objects can be pulled out of pockets and off the body without warning, at which point they fly toward the opening of the magnet (where the patient is placed) at very high speeds, posing a threat to everyone in the room. Credit cards, bank cards and anything else with magnetic encoding will be erased by most MRI systems.

In this photograph, you can see a fully loaded pallet jack that has been sucked into the bore of an MRI system.

The fact that MRI systems do not use ionizing radiation is a comfort to many patients, as is the fact that MRI contrast materials have a very low incidence of side effects. Another major advantage of MRI is its
ability to image in any plane. CT is limited to one plane, the axial plane (in the loaf-of-bread analogy, the axial plane would be how a loaf of bread is normally sliced). An MRI system can create axial images as well as images in the sagittal plane (slicing the bread side-to-side lengthwise) and coronally (think of the layers of a layer cake) or any degree in between, without the patient ever moving. If you have ever had an X-ray, you know that every time they take a different picture, you have to move. The three gradient magnets discussed earlier allow the MRI system to choose exactly where in the body to acquire an image and how the slices are oriented.

There are many people who cannot safely be scanned with MRI (for example, because they have pacemakers), and also people who are too big to be scanned.

There are many claustrophobic people in the world, and being in an MRI machine can be a very disconcerting experience for them.

The machine makes a tremendous amount of noise during a scan. The noise sounds like a continual, rapid hammering. Patients are given earplugs or stereo headphones to muffle the noise. The noise is due to the rising electrical current in the wires of the gradient magnets being opposed by the main magnetic field. The stronger the main field, the louder the gradient noise.

MRI scans require patients to hold very still for extended periods of time. MRI exams can range in length from 20 minutes to 90 minutes or more. Even very slight movement of the part being scanned can cause much distorted images that will have to be repeated.

Orthopedic hardware (screws, plates, artificial joints) in the area of a scan can cause severe artifacts (distortions) on the images. The hardware causes a significant alteration in the main magnetic field. Remember, a uniform field is critical to good imaging.

MRI systems are very, very expensive to purchase, and therefore the exams are also very expensive.
The basic design used in most is a giant cube.

I learnt about the procedure, the cost of the procedure, the advantages and the disadvantages of having this procedure.

I will be working on Ultrasound next****

Week 6:

I researched Ultrasound.

The uses of Ultrasound.

The dangers involved in the process.

The cost of the procedure.

Ultrasound or ultrasonography is a medical imaging technique that uses high frequency sound waves and their echoes. The technique is similar to the echolocation used by bats, whales and dolphins, as well as SONAR used by submarines. In ultrasound, the following events happen:

1. The ultrasound machine transmits high-frequency (1 to 5 megahertz) sound pulses into
your body using a probe.
2. The sound waves travel into your body and hit a boundary between tissues (e.g.
between fluid and soft tissue, soft tissue and bone).
3. Some of the sound waves get reflected back to the probe, while some travel on further
until they reach another boundary and get reflected.
4. The reflected waves are picked up by the probe and relayed to the machine.
5. The machine calculates the distance from the probe to the tissue or organ (boundaries)
using the speed of sound in tissue (5,005 ft/s or 1,540 m/s) and the time of the each echo's
return (usually on the order of millionths of a second).
6. The machine displays the distances and intensities of the echoes on the screen,
forming a two dimensional image like the one shown below.

Dangers of Ultrasound

There have been many concerns about the safety of ultrasound. Because ultrasound is
energy, the question becomes "What is this energy doing to my tissues or my baby?"
There have been some reports of low birth weight babies being born to mothers who had
frequent ultrasound examinations during pregnancy. The two major possibilities with
ultrasound are as follows:

- development of heat - tissues or water absorb the ultrasound energy which
  increases their temperature locally
- formation of bubbles (cavitations) - when dissolved gases come out of solution
due to local heat caused by ultrasound

However, there have been no substantiated ill-effects of ultrasound documented in
studies in either humans or animals. This being said, ultrasound should still be used only when necessary (i.e. better to be cautious).

Week 7:

***I started out working on Radiology.

***Radiology is a diagnostic specialty within the field of medicine that employs X-Rays and other modalities for diagnostic imaging.

***Radiographs, more commonly known as X-Rays.

Radiography is the creation of radiographs, photographs made by exposing a photographic film or other image receptor to X-rays. Since X-rays penetrate solid objects, but are slightly attenuated by them, the picture resulting from the exposure reveals the internal structure of the object. The most common use of radiography is in the medical field (where it is known as medical imaging).

Another use of radiography is in the examination and analysis of paintings, where studies can reveal such details as the age of a painting and underlying brushstroke techniques that help to identify or verify the artist. X rays are used in several techniques that can provide enlarged images of the structure of opaque objects. These techniques collectively referred to as X-ray microscopy or micro-radiography, can also be used in the quantitative analysis of many materials. One of the dangers in the use of X rays is that they can destroy living tissue and can cause severe skin burns on human flesh exposed for too long a time. This destructive power is used in X-ray therapy to destroy diseased cells.

Week 8:

Worked on Mammography:

- This is a specific type of imaging that uses a low-dose x-ray system for examining the breasts. The images of the breasts can be viewed on film at a view box or as soft copy on a digital mammography work station. Most medical experts agree that successful treatment of breast cancer often is linked to early diagnosis. Mammography plays a central part in early detection of breast cancers because it can show changes in the breast up to two years before a patient or physician can feel them.
Mammography is used to aid in the diagnosis of breast diseases in women. Screening mammography can assist your physician in the detection of disease even if you have no complaints or symptoms.

Initial mammographic images themselves are not always enough to determine the existence of a benign or malignant disease with certainty. If a finding or spot seems suspicious, your radiologist may recommend further diagnostic studies.

Diagnostic mammography is used to evaluate a patient with abnormal clinical findings, such as a breast lump or lumps, which have been found by the woman or her doctor. Diagnostic mammography may also be done after an abnormal screening mammography in order to determine the cause of the area of concern on the screening exam.

Started making the slides for my medical imaging presentation.

Week 9:

Went on a team trip...Cruise. It was fun

Finished with the last sub-topic with Microwave Imaging.

The term microwave imaging covers all processes in which measurements of electromagnetic fields in the microwave region from 300 MHz to 30 GHz are used for creating images.

To create images from microwave measurements, it is necessary to construct a microwave camera, which is able to transmit microwaves and measure the scattered waves at one or more antennas.

Different types of microwave cameras are currently being used for imaging in such areas as ground penetrating radar and remote sensing. Depending on the items to be imaged, different types of microwave cameras are needed. These range from small antennas used for near field measurements in ground penetrating radar to the large airborne systems used in remote sensing. There are two key issues to address when designing a microwave camera. One is the increase of the signal to noise ratio in the system and the other is to assure that the system has a
large dynamic range. The importance of both of these is closely related to the fact that the scattered signal is often very weak in comparison to the transmitted signal. This implies that any noise in the system will have a large impact on the image quality and that the system must be able to distinguish even small differences in the received signals.

- Continued working on my presentation for next week.

**Week 10:**

Worked on my power point presentation.

Did a lot of editing on the slides

**Week 11:**

Presented my slides… Didn’t go as well as i wanted...

Started working on my final report

**Week 12:**

Put my final report together.

Getting ready to leave Hoboken...Started packing ...

I would miss every bit of the last 3 months

Adios amigos!!!