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An Optimization of Optical Imaging System using Remote Sensing

AHM Amimul Ahsan, Abduallah Nazib and Md. Kamrul Hasan

***Abstract*—Optical systems are widely used in many applications as the micro and macro world became more sophisticated. The needs of the optical imaging become an obvious solution because of their usefulness in medical science as a light guided and other applications where bright light needs to be shone on a target without a clear line-of-sight path. Optical fiber is used in imaging optics. A coherent bundle of fibers is used, sometimes along with lenses for a long or thin imaging device called an endoscope, which is used to view objects through a small hole in medical application. In other hand, the optical fiber system is used in satellite for imaging as in remote sensing. This paper describes the applications of optical imaging system in medical science as well as optical remote sensing respectively.**

***Index Terms*—Optical System, Line-of-sight, Remote Sensing, Optical Imaging.**

I. INTRODUCTION

Near infrared (NIR) optical imaging is a region of the electromagnetic spectrum (from 800 nm to 2500nm) that lead to a rapid expand techniques that has combined research involving in vivo imaging technologies with research involving imaging probe design to help noninvasively evaluate important molecular events in vivo[1] as well as the optical remote sensing makes use of visible, near infrared (NIR) and short-wave infrared sensors to form images of the Earth surface by detecting the solar radiation reflected from targets on the ground. A different material reflect and absorb differently at different wavelengths Remote Sensing (RS) also called Earth observation, refers to obtaining information about objects or areas at the Earth's surface without being in direct contact with the object or area. Most sensing devices record information about an object by measuring an object's transmission of electromagnetic energy from reflecting and radiating surfaces, here, in this paper we will focus on how to use optical system in imaging.

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II. IMAGE ANALYSIS

A. Imaging in Medical

Near-infrared optical imaging is a newer imaging technique that coupled with sensitive enzymatic alloy specific fluorescent beacons shows much promise for earlier detection of many cancers and their in situ characterization. On the basis of animal studies demonstrating visualization of micro metastasis-sized tumors and the ability to evaluate therapeutic enzyme inhibition real-time, such imaging may be incorporated in the clinical imaging paradigm in the future both to improve cancer screening as well as for monitoring therapy in individual patients. This review details some of the related biology, optical probe design, and required hardware with in vivo cathepsin and matrix metalloproteinase imaging used as examples.

B. Imaging Probes

Overall, there are three general classes of imaging probes that are used to aid in visualization. The most common agents are nonspecific usually smaller molecules which have vascular distribution with leakage into the extra cellular space. These increase contrast of pathology by differential rates of tissue/tumor perfusion or vascular leakage. The problems associated with this approach include the quite limited tumor: background ratio (making visualization more difficult) and the lack of any specific molecular information. Targeted approaches have been developed to increase the localization of image contrast-enhancing molecules in tumors and to reduce their uptake in normal tissues [1]. One potential caveat of using targeted conjugates such as monoclonal antibodies is the fact that target-to-background ratios can be limited by receptor density and/or availability, limited clearance kinetics from the interstitial space, and/or nonspecific cellular uptake or adhesion of certain fluorescent probes. In particular, it may be difficult to differentiate specifically bound from unbound ligands and this is the reason why imaging is usually performed after nonspecifically distributed excess probe has cleared.

C. Smart Probes

The third general classes of imaging contrast agents are smart probes. These agents change their physical properties after specific molecular interaction and are sometimes referred to as molecular beacons. In vivo optical (near-infrared) smart probes that have been developed for the detection of protease activity are based on a quenching-dequenching paradigm as shown in Fig. 1. The

probes are optically silent in their native (quenched) state and become highly fluorescent after enzyme-mediated release of flour chromes resulting in signal amplification of up to several 100-fold depending upon the specific design of note, nonspecific and targeted agents have no amplification and newly developed experimental MRI probes have 3-fold amplification.

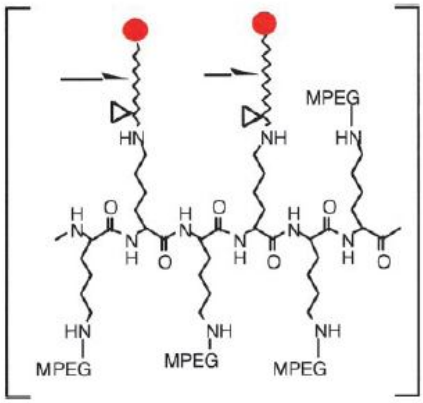

Fig.1. Smart optical probes. Red-filled circles represent fluorochromes,which are spatially near one another initially. Given the close proximity, the fluorochromes are quenched. With specific enzymatic cleavage (arrows) of peptide spacers (undulating lines), fluorochromes are separated from the backbone and each other and markedly increase their fluorescence.

Quenching of fluorescence is secondary to fluorescence resonance energy transfer which is occurred because the fluorochromes on the intact probe are spatially near one another. Enzyme specificity is imparted through the use of enzyme cleavage-specific peptide sequences which can be varied depending upon the desired protease to be visualized. Moreover, other enzymatic pathways are amenable to this activation scheme. This approach has several major advantages over simple targeting: (a) a single enzyme molecule can cleave multiple flour chromes resulting in one form of signal amplification (b) reduction of background signal of several orders of magnitude is possible because the quenched probe is optically silent when injected and remains so until it is activated by its target; and (c) very specific enzyme activities can potentially be interrogated. All of these lead to better visualization of tumors based on their enzyme over expression profile. The probes typically consist of three biocompatible building blocks: (a) a delivery vehicle; (b) near-infrared fluorochromes and (c) enzyme-specific peptide substrates coupling the two. In general, high-affinity ligands have to be able to reach their intended target at sufficient concentrations and for sufficient lengths of time to be detectable in vivo low molecular weight probes are typically subject to fast excretion in vivo, given renal clearance of small molecules and reticuloendothelial system clearance of nonimmunologically.

Shielded compounds .To improve tumoral delivery of the NIRF probes, the delivery vehicles used for all of the probes described in this review are higher molecular weight novel, long-circulating synthetic-protected graft copolymers that have recently been tested in clinical trials. The copolymers accumulate in tumors by extravasation through permeable neovasculature, with uptake of the polymer comparable in magnitude to that of tumor-specific internalizing monoclonal antibodies

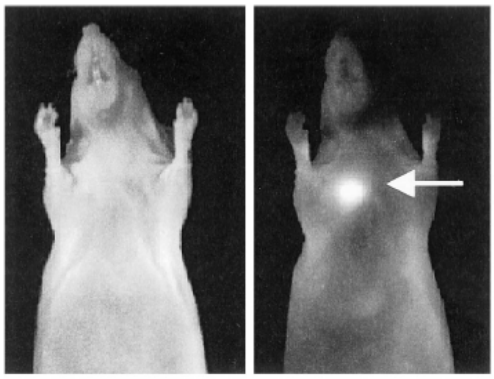

Fig. 2 Near-infrared fluorescence imaging. A micrometastasis-sized tumor brightly fluoresces (right) after i.v. administration of a cathepsin B selective protease probe. White light image (left) for anatomical correlation. Please see text for details.

D. Imaging of Protease

Many tumors have been shown to have elevated levels of proteolytic enzymes, presumably in adaptation to rapid cell cycling and for secretion to sustain invasion, metastasis formation, and angiogenesis. Because they are present at high levels in tumors and are elevated at an early stage, proteolytic enzymes represent an attractive target for antitumor imaging and therapeutic strategies. An additional benefit of targeting proteases for imaging is the relative ease compared with other compartments of probe delivery to the lysosomal and extracellular compartments where pro-tease activity and concentration are the highest. A number of protease sensors that has been summarized. Specific examples, related to tumor aggressiveness and early changes in tumors including cathepsin B, cathepsin D, and MMP-2 imaging are discussed in more detail.

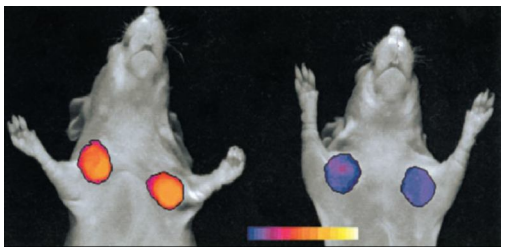

Fig. 3 Real-time imaging of protease inhibition. Control mouse (left) and treated mouse (right), both with two HT- 1080 tumors over expressing MMP-2.

Tumors from the mouse pretreated with an MMP-2 inhibitor show markedly decreased fluorescence compared with untreated tumors.

E. Imaging Cathepsin B

Cathepsin B is a lysosomal cysteine protease involved in cellular protein turnover and degradation [2]. It is over expressed in many tumors as well as over expressed by host cells associated with tumors; its near ubiquity makes it a very attractive target for tumor detection. It has been implicated in tumor progression both metastases formation and in vitro growth decrease in the presence of cathepsin B inhibitors.

Several studies have demonstrated that high levels of cathepsin B expression correlate with aggressive tumor behavior. High levels of cathepsin B expression also correlate inversely with patient survival.

Given cathepsin B's close relationship with early cancers and metastasis with resultant host response, the first optical probes constructed for targeting protease activity were specific for cathepsin B .Fig2 shows a 2-mm xenograft of a LX-1 human lung carcinoma implanted in a nude mouse. In this typical acquisition, 2 nmol of quenched probe was injected i.v. 24 h before near-infrared imaging was performed. The time for imaging after probe administration may be as short as 2 h, depending upon the location of the enzyme being imaged optimal timing after injection depends as well upon the disease imaged,. An image acquisition time on newer systems is in the sub second time frame, allowing real-time visualization of fluorescent anatomical detail. The bright fluorescence, as this example shows, helps locate this micrometastasis-sized tumor, based upon its cathepsin B activity. Other interesting screening and therapy relevant applications of cathepsin B activity are discussed below, with respect to specific diseases.

A probe specific for cathepsin D has also been synthesized and tested in mouse models. The main function of cathepsin D is in protein catabolism. However, a 2–50-fold increase in enzyme levels has been reported in breast Cancers and over expression has been associated with higher metastatic potential. Imaging of cathepsin D was analogous to cathepsin B imaging in Fig. 2. However, these studies additionally demonstrated that it was possible to selectively image tumors based on a difference of a single gene expression.

F. Imaging MMP-2 and Its Inhibition

The level of MMP expression has been shown to be related to tumor stage and metastasis. Among the subtypes, MMP-2 (gelatinase) has been identified as one of the key MMPs. Numerous clinical studies show a clear correlation between MMP-2 expression and poor outcome of disease. A number of MMP inhibitors some of which advanced to Phase III clinical trials have been developed. Given its importance in tumor pathology, a MMP-2-selective probe was constructed. Imaging of MMP-2 activity was demonstrated, starting 2 h after probe administration. Most importantly, a series of experiments showed in parallel cohorts of mice that fluorescent signal intensity after MMP-2 probe administration significantly decreased in tumors from animals that were pretreated with a MMP-2 inhibitor compared with controls, as visualized in Fig. 3. In this figure both mice had two identical tumors known to over express MMP-2 implanted in the anterior chest wall. Thus, essentially real-time protease inhibition may be imaged noninvasively, instead of waiting several months to evaluate anatomical response as is traditionally done in individual patients as well as in vivo animal trials of inhibitor therapy. Such imaging has implications for faster, more accurate titration of inhibitor dosing in human drug trials as well as potentially routine care in the future for individual patients.

G. An Example of Diseases (Breast Cancer)

Breast cancer is the most diagnosed cancer in women in the United States with 190,000 new cases annually and 40,000 deaths. Early detection has been shown to save lives. Optical protease imaging will have several roles in breast cancer evaluation and screening. In a technically elegant study using the nonspecific perfusion fluorochrome ICG, human breast optical fluorescence tomography Although an 8-mm ductal carcinoma was found in this case, the sensitivity and specificity of perfusion imaging may be similar to that of perfusion imaging using other techniques such as MRI, the real strength of optical tomography will be in its combination with molecularly specific probes such as the protease specific probes detailed in this review.

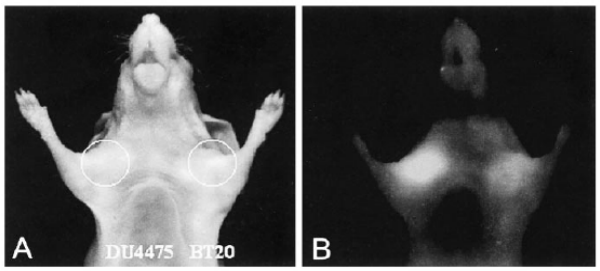

Fig. 4. Aggressiveness of breast cancer revealed with cathepsin B imaging. An aggressive (left) and well-differentiated (right) breast tumor implanted in a nude mouse have different fluorescent signal intensities correlating with their invasiveand metastatic potential

The imparted information is very difficult to obtain otherwise, in some cases, even with biopsy. The technical aspects of optical imaging deep in tissue are briefly discussed below. Another example of an application to breast tissue was reported recently. Using the cathepsin B-sensitive probe, clear differences were seen by NIRF imaging between two models of aggressiveness as visualized in Fig. 4. A well-differentiated human breast cancer (BT20) and highly invasive metastatic human breast cancer (DU4475) were imaged 24 h after i.v. administration of the probe. Both types of breast cancers activated the probe so that both tumors became readily detectable. However, in equalized tumors [3] there was a statistically significant.

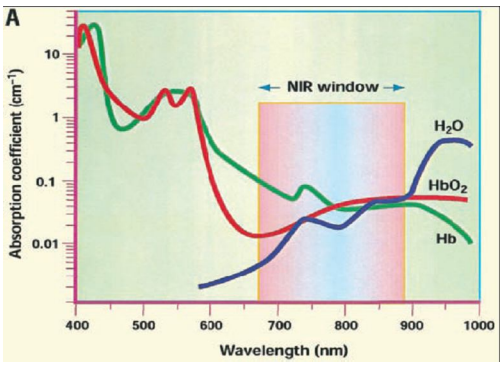

Fig. 5. Absorption of light versus wavelength. Given the decreased absorption of light in the near-infrared (NIR) region compared with visible light (_400–650 nm) and infrared light (_900 nm), tissue penetration of NIR photons may be up to 10–15 cm.

1.5-fold higher fluorescence signal in the highly invasive breast cancer compared with the well-differentiated lesion, which correlated with a 1.4-fold higher cathepsin-B protein content in the aggressive tumors as seen by Western blotting. Thus, important information about likelihood of metastases and the rate of patient survival. Which correlate with cathepsin B expression, may be determined noninvasively in individual patients.

H. Practical Imaging System

This review has focused on the biological targets of protease activated optical probes and the implications for cancer imaging. Excellent reviews on tomographic reconstruction provide detail on the physics and technical aspects of the imaging devices [4]. Here, we provide a very brief review of the technology that allows imaging of a number of different cancers. This can be divided into surface/subsurface imaging and deeper imaging. Fig. 5 shows why deeper imaging is possible using near-infrared probes.

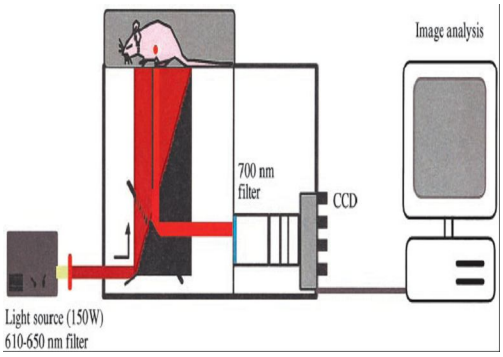

Fig. 6. Schematic of mouse near-infrared reflectance imaging system used to acquire the mouse images in this review. Bandpass light filters remove the excitation light to allow fluorescent imaging of surface and subsurface structures. Optics scheme is analogous to endoscopy.

Light in the visible range is partially absorbed by naturally abundant fluorochromes including hemoglobin. Photons in the infrared region of the electromagnetic spectrum are partially absorbed by water. The near-infrared region of the electromagnetic spectrum provides a window of opportunity with greater tissue penetration. The fluorochromes reported on in this review typically fluoresce in the 700–800-nm range, wavelengths that allow for tissue penetration on the order of 10–15 cm. The technically easiest systems are reflectance systems in which light at one wavelength illuminates a surface and fluorescent photons at a second wavelength are recorded. Such a system for mouse imaging is shown in Fig. 6. Advantages of such devices include ease of use, rapid data acquisition for screening of many animals, and straightforward data analysis. Even early systems could detect subpicomole amounts of fluorochromes, making optical imaging very attractive in terms of sensitivity. Reflectance systems are not intrinsically quantitative for tissue fluorochrome concentration but can provide somewhat quantitative data when imaging of fluorescence is near a surface and are even more accurate when a second imaging channel is also used. Importantly, such reflectance systems for mice are analogous to fluorescent endoscopy for humans .Many epithelial cancers are near surfaces: in addition to the obvious case of examining skin lesions in this fashion, colonoscopy, bronchoscopy, upper gastrointestinal endoscopy, and laparoscopy all provide surface illumination of epithelial tissue at risk for neoplasia. Moreover, near-infrared goggles with appropriate filters are also analogous to the reflectance system and may be used intraoperatively. For example; during neurosurgery, for tumor margin evaluation in real time. Although it is difficult with many imaging modalities including MRI, computed tomography, positron emission tomography, and ultrasound, to interrogate more than one parameter simultaneously, optical imaging lends itself to such multiplexing of even molecular information secondary to the ease of separating wavelengths of light. Thus, as was demonstrated recently, it is possible to use near-infrared fluorescent smart probes to image multiple gene expressions simultaneously and independently.

A second channel allows greater quantitation of concentration based on signal intensity acquired during surface imaging. More importantly, mini arrays of several injected probes for in vivo target assessment may be implemented. For example, a breast lesion may be better characterized with a combination of enzyme activities such as MMP-2 combined with tyrosine kinase evaluation rather than either one alone. It is likely that each group of cancers will have a several targets that would help define the imaging mini array most suited for characterization of that disease. These multichannel techniques are applicable for both subsurface imaging and imaging of deeper tissue. Fluorescence-mediated molecular tomography is a technique that intrinsically provides quantitative Fluor chrome concentration in deep tissue. Although the coefficient of absorption of near-infrared light is on the order of 1 cm through tissue, scattering occurs much more often, approximately every millimeter. Thus, reconstruction must take into account this high scatter, which truly limits deep imaging without advanced reconstruction techniques. As in the reflectance mode, fluorescence-mediated molecular tomography has a detection limit in the range of picomoles, comparing favorably to other modalities such as positron emission tomography [1].

As a simplistic view of the reconstruction, multiple excitation fibers are placed around an object (human breast or whole mouse, for example), and multiple rows of detectors simultaneously record fluorescent signal. This is repeated sequentially for all excitation fibers, and the entire data set is processed using algorithms based upon diffusion-model equations to form images with relatively high resolution (1–3 mm in mice and on the order of 5 mm in human breast). Given the molecular specificity of the probes, this spatial resolution is more than adequate to localize and characterize lesions.

III. OPTICAL REMOTE SENSING

Remote sensing techniques allow taking images of the earth surface in various wavelength region of the electromagnetic spectrum (EMS). One of the major characteristics of a remotely sensed image is the wavelength region it represents in the EMS. Some of the images represent reflected solar radiation in the visible and the near infrared regions of the electromagnetic spectrum, others are the measurements of the energy emitted by the earth surface itself. in the thermal infrared wavelength region. The energy measured in the microwave region is the measure of relative return from the earth's surface [5], where the energy is transmitted from the vehicle itself. This is known as active remote sensing, since the energy source is provided by the remote sensing platform. Whereas the systems where the remote sensing measurements depend upon the external energy source, such as sun are referred to as passive remote sensing systems. Optical remote sensing systems are classified into the following types, depending on the number of spectral bands used in the imaging process.

A. Panchromatic Imaging System

The sensor is a single channel detector sensitive to radiation within a broad wavelength range. If the wavelength range coincides with the visible range, then the resulting image resembles a "black-and-white" photograph taken from space. The physical quantity being measured is the apparent brightness of the targets. The spectral information or "colour" of the targets is lost. Examples of panchromatic imaging systems are: IKONOS PAN SPOT HRV –PAN.

B. Multispectral Imaging System

The sensor is a multichannel detector with a few spectral bands. Each channel is sensitive to radiation within a narrow wavelength band. The resulting image is a multilayer image which contains both the brightness and spectral (colour) information of the targets being observed. Examples of multispectral systems are: LANDSAT MSS, LANDSAT TM, SPOT HRV-XS and IKONOS MS.

Increasing the spatial resolution of imaging sensors is an expensive proposition, both in terms of the sensor and in terms of the amount of sensor data that must subsequently be processed and interpreted. The trained human analyst has traditionally carried the main burden of effective image interpretation, but as technology continues to advance, the volume of high resolution optical and radar imagery has grown at a faster rate than the number of trained analysts. In the 1960s, the remote sensing community, recognizing the staggering cost of putting large passive imaging apertures in space, embraced the concept of exploiting spectral rather than spatial features to identify and classify land cover. This concept relies primarily on spectral signature rather than spatial shape to detect and discriminate among different materials in a scene. Experiments with line-scanning sensors providing up to twenty spectral bands in the visible and infrared were undertaken to prove the concepts [6]. This experimental work helped create interest and support for the deployment of the first space-based Multispectral imager. A Lincoln Laboratory prototype for a multispectral Advanced Land Imager (ALI) was launched in November 2000 aboard the National Aeronautics and Space Administration (NASA) Earth Observing (EO1) satellite. EO-1 also carries a VNIR/SWIR hyper spectral sensor, called Hyperion, with 220 spectral bands and a GSD of thirty meters.

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C. Superspectral Imaging System

A Superspectral imaging sensor has many more spectral channels (typically >10) than a multispectral sensor. The bands have narrower bandwidths, enabling the finer spectral characteristics of the targets to be captured by the sensor. Examples of Superspectral systems are: MODIS, ME

D. Hyperspectral Imaging System

A hyperspectral imaging system is also known as an "imaging spectrometer". it acquires images in about a hundred or more contiguous spectral bands. The precise spectral information contained in a hyperspectral image enables better characterization and identification of targets. Hyperspectral images have potential applications in such fields as precision agriculture (e.g. monitoring the types, health, moisture status and maturity of crops), coastal management (e.g. monitoring of phytoplanktons, pollution, bathymetry changes). An example of a hyperspectral system is: Hyperion on EO1 satellite. On the basis of the success of multispectral sensing, and enabled by advances in focal-plane technology, researchers developed hyperspectral sensors to sample the expanded reflective portion of the electromagnetic spectrum, which extends from the visible region (0.4 to 0.7 □m) through the SWIR (about 2.5 □m) in hundreds of narrow contiguous bands about ten nanometers wide. The majority of hyperspectral sensors operate over the VNIR/SWIR bands, exploiting solar illumination to detect and identify materials on the basis of their reflectance spectra.

If we consider the product of spatial pixels times spectral bands (essentially the number of three-dimensional resolution cells in a hypercube) to be a measure of sensor complexity, then we can preserve the overall complexity in going from a panchromatic sensor (with one broad spectral band) to a hyperspectral sensor (with several hundred narrow spectral bands) by reducing the number of spatial pixels by a factor of several hundred while keeping the field of view constant. In effect, a one-dimensional reduction in spatial resolution by a factor of approximately fifteen (i.e., the square root of K, the number of spectral bands, which is typically about 220) compensates for the increased number of spectral samples and reduces the required aperture diameter by the same factor, thus reducing the potential cost of a sensor. However, while the total number of three-dimensional resolution cells is preserved, the information content of the image is generally not preserved when making such trades in spatial versus spectral resolution

[8].

E. Solar Irradiation

Optical remote sensing depends on the sun as the sole source of illumination. The solar irradiation spectrum above the atmosphere can be modeled by a black body radiation spectrum having a source temperature of 5900 K, with a peak irradiation located at about 500 nm wavelength. Physical measurement of the solar irradiance has also been performed using ground based and space borne sensors [9].

After passing through the atmosphere, the solar irradiation spectrum at the ground is modulated by the atmospheric transmission windows. Significant energy remains only within the wavelength range from about 0.25 to 3 μm see fig 7.

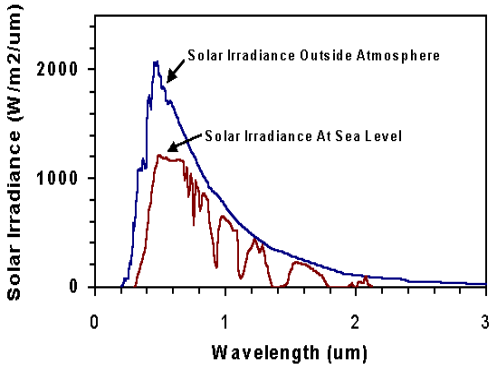

Fig. 7. Solar Irradiation Spectra above the atmosphere and at sea-level.

F. Spectral Reflectance Signature

When solar radiation hits a target surface, it may be transmitted, absorbed or reflected. Different materials reflect and absorb differently at different wavelengths. The reflectance spectrum of a material is a plot of the fraction of radiation reflected as a function of the incident wavelength and serves as a unique signature for the material. In principle, a material can be identified from its spectral reflectance signature if the sensing system has sufficient spectral resolution to distinguish its spectrum from those of other materials. This premise provides the basis for multispectral remote sensing. The following graph in fig.8 shows the typical reflectance spectra of five materials: clear water, turbid water, bare soil and two types of vegetation.

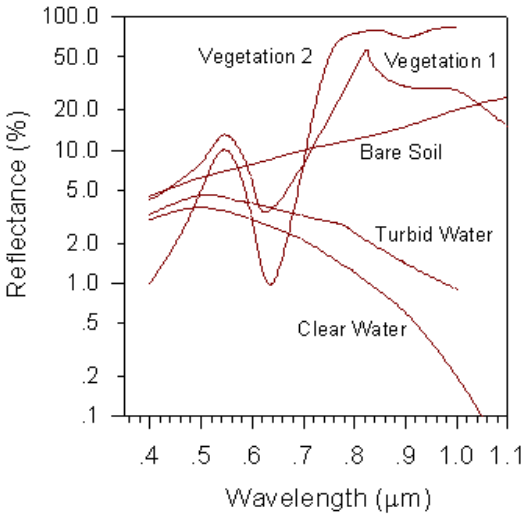

Fig. 8. Reflectance Spectrum of Five Types of Land cover

The reflectance of clear water is generally low. However, the reflectance is maximum at the blue end of the spectrum and decreases as wavelength increases. Hence, clear water appears dark-bluish. Turbid water has some sediment suspension which increases the reflectance in the red end of the spectrum, accounting for its brownish appearance. The reflectance of bare soil generally depends on its composition. In the example shown, the reflectance increases monotonically with increasing wavelength. Hence, it should appear yellowish-red to the eye.

Vegetation has a unique spectral signature which enables it to be distinguished readily from other types of land cover in an optical/near-infrared image. The reflectance is low in both the blue and red regions of the spectrum, due to absorption by chlorophyll for photosynthesis. It has a peak at the green region which gives rise to the green colour of vegetation. In the near infrared (NIR) region, the reflectance is much higher than that in the visible band due to the cellular structure in the leaves. Hence, vegetation can be identified by the high NIR but generally low visible reflectances. This property has been used in early reconnaisance missions during war times for "camouflage detection"[10].

The shape of the reflectance spectrum can be used for identification of vegetation type. For example, the reflectance spectra of vegetation 1 and 2 in the above figures can be distinguished although they exhibit the generally characteristics of high NIR but low visible reflectances. Vegetation 1 has higher reflectance in the visible region but lower reflectance in the NIR region. For the same vegetation type, the reflectance spectrum also depends on other factors such as the leaf moisture content and health of the plants.

The reflectance of vegetation in the SWIR region (e.g. band 5 of Landsat TM and band 4 of SPOT 4 sensors) is more varied, depending on the types of plants and the plant's water content. Water has strong absorption bands around 1.45, 1.95 and 2.50 μm. outside these absorption bands in the SWIR region, reflectance of leaves generally increases when leaf liquid water content decreases fig 9. This property can be used for identifying tree types and plant conditions from

remote sensing images. The SWIR band can be used in detecting plant drought stress and delineating burnt areas and fire-affected vegetation. The SWIR band is also sensitive to the thermal radiation emitted by intense fires, and hence can be used to detect active fires, especially during night-time when the background interference from SWIR in reflected sunlight is absent.

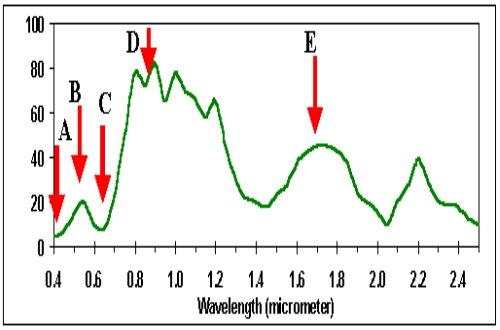

Fig. 9. Typical Reflectance Spectrum of Vegetation.

IV. CONCLUSIONS

The technologies discussed above are just a few of the many promising areas of remote sensing research. Advances in remote sensing will enable quicker and more focused emergency response, more accurate maps, improved navigation, and better geospatial information and derived products for the general public and professionals in a wide variety of fields. Further more the great future for imaging in medical can be promised not only in terms of detecting or observing but the detection of lesions based upon their molecular signatures, and that will help in treatment decisions, and will also help define successful therapeutic drug. The nearinfrared protease imaging technology reviewed here shows examples of molecularly specific probes and some example clinical-use paradigms for their implementation into real life. Treatment and screening approaches of number of cancers may benefit in the near future from these tools. The miniaturization of the components to micrometers size has been gaining significant technological advances recently. The micro-technology demands development and characterization of structures in the micrometer-scale, which would not be possible without efficient developing in optical imaging systems.

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