Terahertz Imaging of *in vivo* Corneal Tissue Hydration

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Abstract

Hydration variations are crucial to understanding the health of biological tissues. Medical imaging using terahertz radiation can detect these variations of water content. Currently, THz medical imaging is challenged by low available signal and limited imaging components in the THz band. Therefore, imaging studies had been limited to *ex vivo*, flattened targets, resulting in distortion of the natural structural and chemical composition of these biological tissues. This study aims to image along the curvature of live human corneal tissues with off-axis parabolic (OAP) mirrors. Uniform strength at a normal incidence was achieved as the THz radiation illuminated on the entire spherical surface of the eye phantoms. The images obtained were successfully used to detect trends in hydration variations of the target. Ultimately, we aim to utilize this imaging modality in a clinical setting in order to deliver fast, accurate pre-surgical images and diagnoses.

Introduction and Background

Eyes are the most immune-privileged carefully regulated organ. Hydration levels of the eye is carefully regulated, especially in the cornea which provides most of it's focusing power and visual acuity. Current methods to measure the hydration levels of the eye include central corneal thickness measurements with ultrasound. However, the level of precision with cornea thickness and hydration is very poor. Clarity and health of the cornea is strongly dependent on its relative hydration levels. Furthermore, disruptions of corneal hydration levels are caused by endothelial pump functions of corneal dystrophies, causing swelling and immune responses of corneal graft rejections, inflammation, and edema.

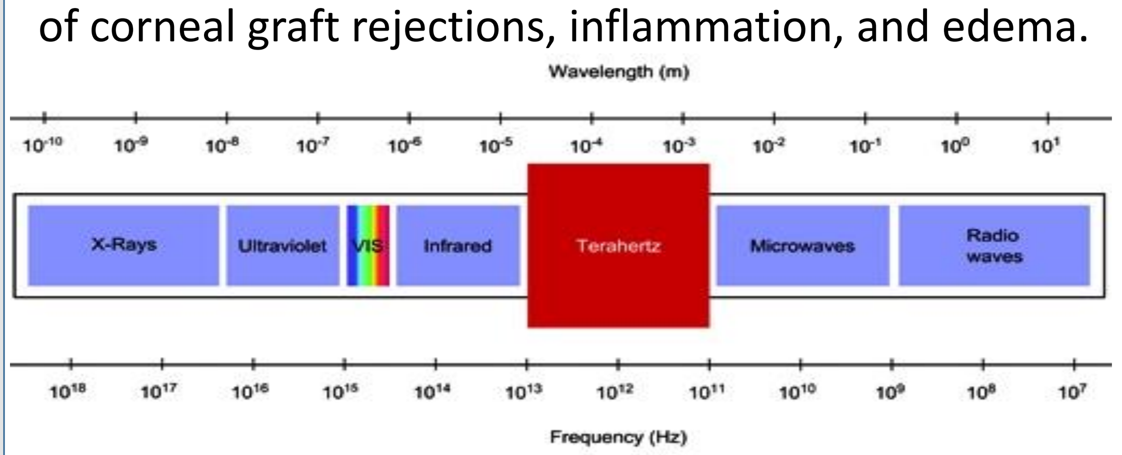

Figure 1. (THz) radiation lies on the electromagnetic spectrum range from 300 GHz to 3 THz. [2]

Because THz radiation is only sensitive to water, it can be used to provide hydration images of tissues. Early detection and intervention is possible by inspecting low hydration is the tissue.

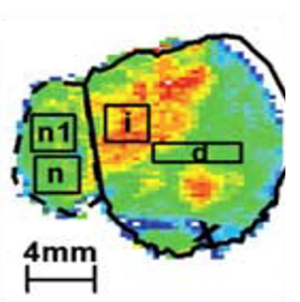

Figure 2. THz image of basal cell carcinoma tissue [3]

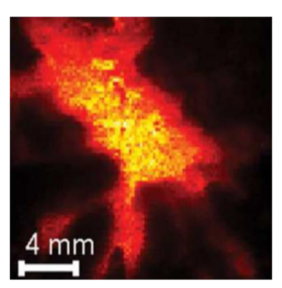

Figure 3. THz image of a breast cancer tumor [4]

Several studies have shown evidence of variations in water content in several diseased tissues including basal cell carcinoma and breast cancer tumors.

Materials and Methods

A THz imaging system for corneal hydration sensing was constructed . Characterization experiments were then performed.

The construction of the THz imaging system employs

- Narrowband solid-state THz source
- Diode-based THz detectors
- Mirror-based THz optics

Optical system calibration and alignment are aided with visible lasers to visually inspect the beam's path and optimize imaging performance.

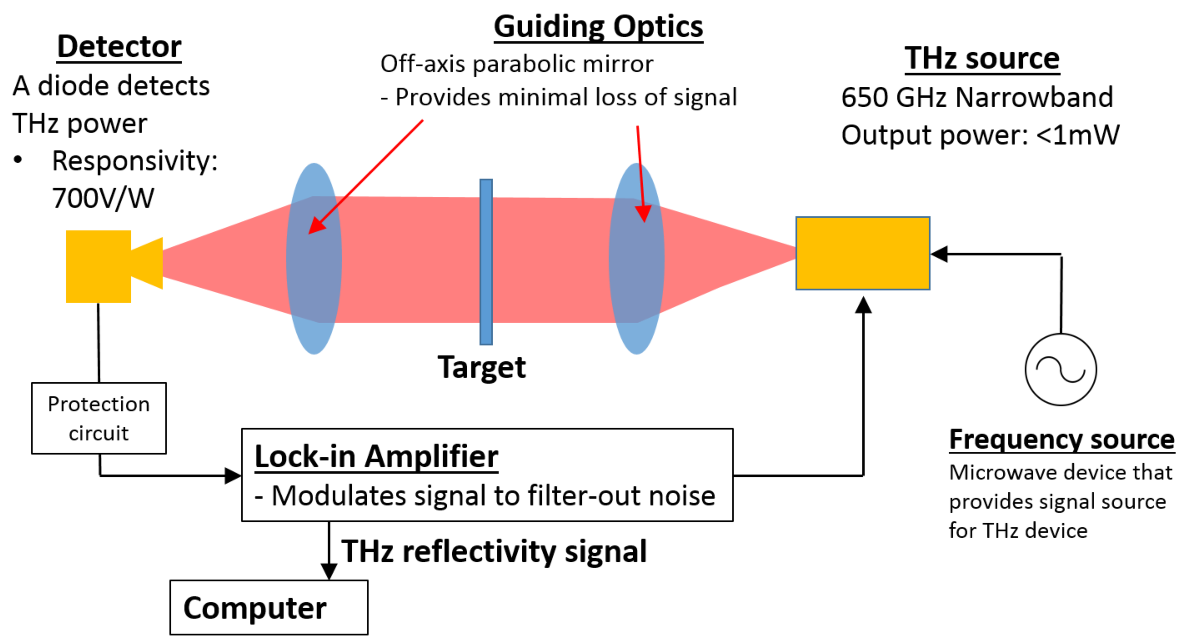

Figure 4. A block diagram of a reflective THz imaging system developed for hydration sensing. Working at a frequency of approximately 650 GHz

The system optics were designed to test a new imaging technique for non-planer surfaces. This technique projects a spherical surface onto a Cartesian plane using off-axis parabolic (OAP) mirrors.

Expected signal strength:
1mW output with:

- mirror reflection loss <2% (x4)
- Signal modulation loss – $2/\pi^2$ x 100 %

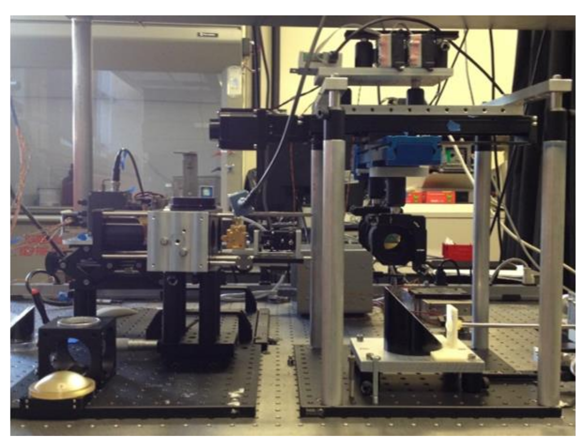

Figure 5. Overall construction of the system and an example of visible laser alignment tool developed. System dimension measures 1ft x 1 ft x 2ft in the prototype stage, and can be further compacted to < 1 ft³

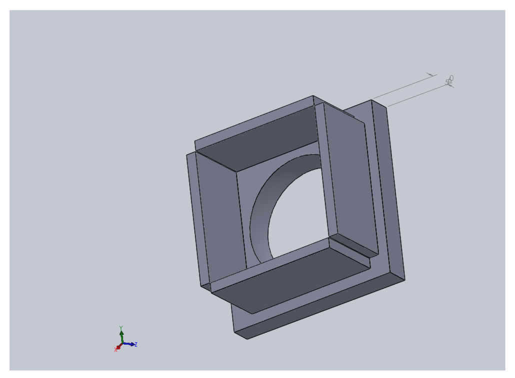

Figure 6. An eye piece designed in SolidWorks to hold the target for imaging. Prototype is fabricated with a 3D printer, and tested in the imaging experiment.

Materials and Methods (cont.)

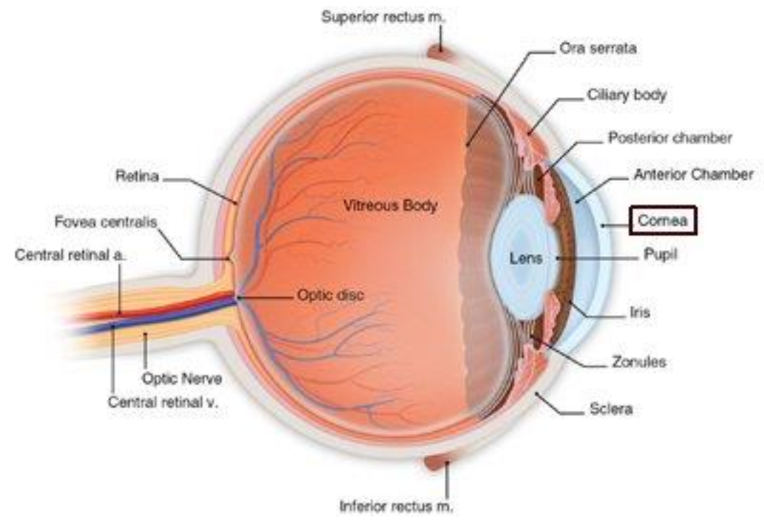

Figure 7 The anatomy of the human eye

Curvature:
Cornea ~ 6.5mm
Sclera ~ 10.8 mm

We obtained images along the curvature of the eye while maximizing the amount of signal strength received.

Results

- A series of calibration and test images were taken to evaluate imaging performance

Illumination Imaging field strength

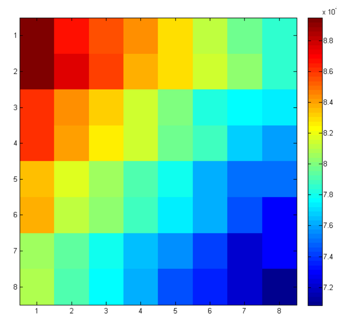

Figure 8.1
Illumination strength variations are computed with MATLAB, with percent error of ~10%

Test images of eye surface using a reflective target, with better optical alignment

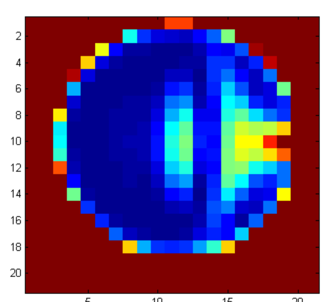

Figure 8.2

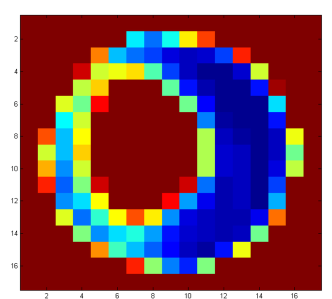

Figure 8.3

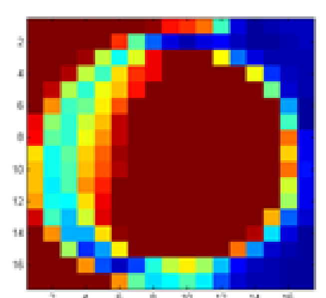

Figure 8.4

Test images of mock eye targets i.e a polypropylene ball with different foil tape patterns . Also shown is an example of an under sampled image.

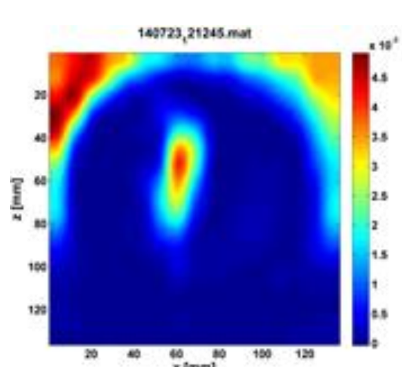

Figure 8.5

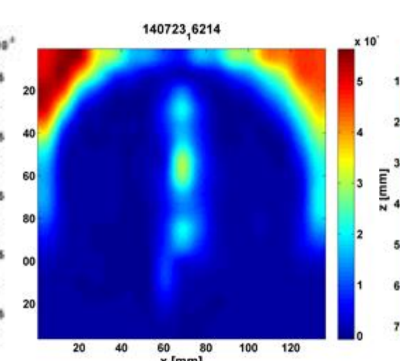

Figure 8.6

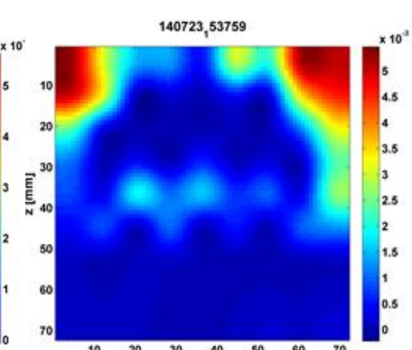

Figure 8.7

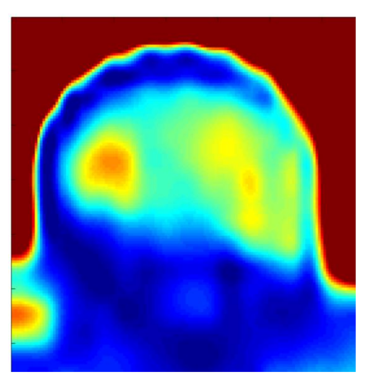

Figure 8.8

Contact lens seen by THz radiation displaying a region in the middle (where the lens was placed) with high signal)

Discussion

The images shown were obtained over an approximate 3-week period. Our objective was to obtain uniform signal strength throughout the entire imaging field while maximizing the amount of signal strength received (Figures 8.1) . Misalignment of the mirrors and calibration often prevented this uniformity. Figures 8.2-8.4 show images of a spherical brass ball. The "hot spots" towards the center of the image indicate a stronger signal strength. After greater uniformity was obtained, patterns of greater specificity were able to be imaged. In figures 8.5-8.7 are images of the brass spherical balls with foil tape attached in a specific pattern. These stripe-like patterns successfully corresponded with the brighter regions of the images. Figure 8.8 is an image of a spherical brass ball with a contact lens attached. The brighter region in the center indicates a greater hydrated region.

Conclusion

THz imaging was successfully used to observe variations in water concentration throughout different eye phantoms. These images confirm the ability of THz radiation to detect solely water content. Monitoring water content and deviations from normal hydration may have significant advantages for diagnosing and disease monitoring in various corneal pathologies including dystrophies, infection, degeneration, inflammation, and graft rejection. Future works include THz imaging for arthritis in bone joints and Traumatic Brain Injury (TBI) detection from corresponding changes in swelling throughout the body.

Future Work

THz device and imaging engineering are continuing field of research. Rigorous imaging optics alignment, optimized signal acquisition methods, and streamlined optical design will improve image quality and acquisition time. This imaging system will be used to image in-vivo ocular tissue in animals and humans. Clinical studies must follow to test the effectiveness of THz hydration imaging of the cornea.

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